

ALASKA ECONOMIC
TRENDS
JANUARY 2024

Outlook for jobs
in Alaska **2024**

ALSO INSIDE

Job forecasts for Fairbanks,
Anchorage, and Southeast

FROM THE COMMISSIONER

Budget addresses multiple workforce needs in FY 25

By Catherine Muñoz, Acting Commissioner

2024 is ringing in good news for the Alaska economy. This month, *Trends* features our annual employment forecast for the state, with detailed forecasts for Anchorage, Fairbanks, and Southeast. Economists forecast a 1.7 percent job growth rate for the state as a whole this year, which for many industries will mark a full recovery from the pandemic.

Infrastructure money and more oil and gas activity will be economic bright spots this year. This is a welcome shift for the oil industry after a few really tough years, and construction and related services have some growth on the horizon as well. Every Alaska industry this year is forecasted to either grow or hold steady.

Labor shortages continue to be a challenge due to a smaller and older population, but we're targeting our efforts to ease its effects.

In December, Governor Dunleavy unveiled the proposed fiscal year 2025 spending plan, which prioritizes public safety, Alaskan families, and education. The budget funds new public safety officers and salary increases, State Trooper investigators assigned to crimes against children and missing and murdered indigenous Alaskans, acquisition of an all-weather aircraft for public safety operations and response, and a new patrol vessel for Southeast.

Access to affordable housing, food, child care, and energy are essential for a healthy state. The FY 25 budget recognizes the importance of making Alaska an attractive place to live and raise a family.

For example, the budget proposes \$25 million for down payment assistance grants through Alaska Housing Finance Corporation and \$62.6 million for AHFC housing programs.

Funding would also be available for 30 new hires to



expedite application processing for SNAP food benefits, and for food banks and pantries across Alaska. The Governor's Task Force on Child-care is finalizing its' first major report with an extensive list of short-term to long-term recommendations to incentivize and expand availability.

The budget is presented in an informative, interactive infographic: [FY 25 Governor's Proposed Budget At a Glance – Mike Dunleavy \(alaska.gov\)](#). You can click on a department/category or select from the drop-down menu in the upper left corner for a more detailed budget breakdown.

At the Department of Labor, we are pursuing a multi-pronged effort to address Alaska's labor shortages, including greater investments in industry-recognized trainings, targeted media campaigns, and partnerships with industry. The Office of Citizenship Assistance, part of that strategy, is an effort to provide career and training navigation services to legal immigrants and refugees. OCA is funded in the FY 25 budget with three positions to help new citizens navigate employment opportunities and will address common barriers to employment such as language, licensure, and availability of biometric data processing.

The Alaska Legislature will soon reconvene. We wish all legislators and their families safe travels as they prepare for a productive session, and we look forward to many positive outcomes for the Alaskans we serve.

Sincerely,

A handwritten signature in dark ink that reads "Catherine Muñoz".

Contact Acting Commissioner Catherine Muñoz at (907) 465-2700 or commissioner.labor@alaska.gov.



Follow the Alaska Department of Labor and Workforce Development on [X](#) and [Facebook](#).

**JANUARY
2024**

Volume 44 Number 1
ISSN 0160-3345

SARA WHITNEY
Editor

DAN ROBINSON
Chief, Research
and Analysis

Design by Sara Whitney

ON THE COVER:

A winter trail run in Fairbanks
Photo by [Christen Bouffard](#)
Creative Commons [by-nc-sa 2.0](#)

ALASKA
DEPARTMENT of LABOR
and WORKFORCE
DEVELOPMENT

Governor
Mike Dunleavy
Acting Commissioner
Catherine Muñoz

ALASKA ECONOMIC TRENDS

2024 JOBS FORECAST

4 STATEWIDE
10 ANCHORAGE
15 FAIRBANKS
18 SOUTHEAST

22 GAUGING
THE ECONOMY

Trends is a nonpartisan, data-driven magazine that covers a variety of economic topics in Alaska.

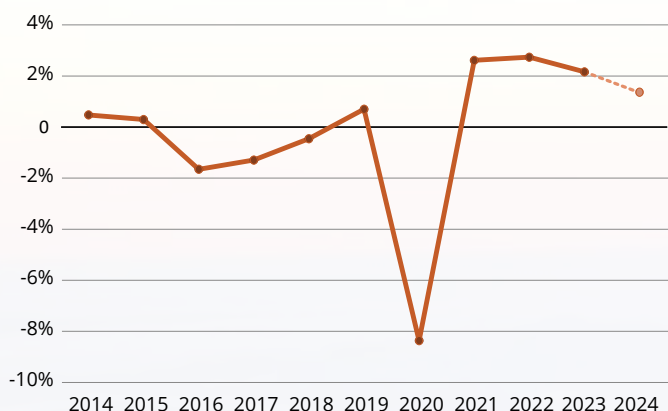
ON THIS SPREAD: The background watermark for 2024 is an aerial view of the mountains around Anchorage.
Photo by Flickr user [Raúl AB](#) under Creative Commons license [by-nc-sa 2.0](#).

If you have questions or comments, contact the authors listed at the end of each article or the editor at sara.whitney@alaska.gov or (907) 465-6561. This material is public information, and with appropriate credit it may be reproduced without permission. To sign up for a free electronic subscription, read past issues, or purchase a print subscription, visit labor.alaska.gov/trends.

Statewide jobs forecast for 2024

Alaska to add 5,400 jobs as all industries grow or stay flat

Jobs forecasted to increase by 1.7%



Note: 2023 is preliminary.

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

By KARINNE WIEBOLD

This year's forecasted growth of 1.7 percent, or 5,400 jobs, will be widespread as all industries either grow or hold steady, bringing Alaska's total job count and many industries above their pre-pandemic levels. Industries that remain significantly below their 2019 levels have either faced big changes in recent years or were already on long-term declines.

Most post-pandemic recovery is behind us. Unlike the last few years' growth, which came from parts of the economy normalizing after COVID disruptions, big projects will be this year's major catalyst. Federal infrastructure projects will start to materialize in 2024, and mining and oil and gas also have big investments on the horizon.

The outlook for statewide jobs, by industry

	Monthly avg, 2022 ¹	Monthly avg, 2023 ¹	Change, 2022-23	Percent change	JOBS FORECAST		
					Monthly avg, 2024	Change, 2023-24	Percent change
Total Nonfarm Employment²	318,800	326,200	7,400	2.3%	331,600	5,400	1.7%
Total Private	241,600	247,800	6,200	2.6%	252,700	4,900	2.0%
Mining and Logging	10,900	11,500	600	5.5%	12,500	1,000	8.7%
Oil and Gas	7,000	7,400	400	5.7%	8,000	600	8.1%
Construction	16,100	16,700	600	3.7%	17,800	1,100	6.6%
Manufacturing	12,100	12,600	500	4.1%	12,600	0	0%
Trade, Transportation, and Utilities	63,800	65,200	1,400	2.2%	66,000	800	1.2%
Wholesale Trade	6,200	6,400	200	3.2%	6,500	100	1.6%
Retail Trade	35,000	35,300	300	0.9%	35,500	200	0.6%
Transportation, Warehousing, and Utilities	22,600	23,500	900	4.0%	24,000	500	2.1%
Information	4,700	4,600	-100	-2.1%	4,600	0	0%
Financial Activities	11,000	10,900	-100	-0.9%	10,900	0	0%
Professional and Business Services	27,300	28,100	800	2.9%	28,600	500	1.8%
Educational (private) and Health Services	50,100	51,300	1,200	2.4%	52,000	700	1.4%
Health Care	38,900	40,000	1,100	2.8%	40,600	600	1.5%
Leisure and Hospitality	34,300	35,600	1,300	3.8%	36,100	500	1.4%
Other Services	11,100	11,400	300	2.7%	11,600	200	1.8%
Total Government	77,200	78,400	1,200	1.6%	78,900	500	0.6%
Federal, except military	15,000	15,400	400	2.7%	15,400	0	0%
State, incl. University of Alaska	22,400	22,800	400	1.8%	23,100	300	1.3%
Local and tribal, incl. public schools	39,800	40,200	400	1.0%	40,400	200	0.5%

¹Preliminary and adjusted estimates. ²Excludes the self-employed, uniformed military, most commercial fishermen, domestic workers, and unpaid family workers.

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Is it finally time to stop focusing on COVID job recovery?

Alaska has been adding back the jobs lost in 2020 for the last few years, but normalizing after COVID will no longer be the main story in 2024 as capital projects and federal investments take center stage.

We would be remiss not to address the recovery once more, however, as our total employment in 2023 still hadn't regained pre-pandemic levels, but probably for the last time.

COVID was the largest shock our economy has ever absorbed, with steeper losses in a shorter time frame than Alaska has weathered before. Alaska lost 27,600 jobs in 2020 as virus mitigation shuttered industries, governments, and schools across the world.

Since then, the state has recovered jobs each year at a fairly consistent rate. In 2021, the growth of 7,900 jobs came from a combination of reopening and huge infusions of federal money in the form of household stimulus checks, enhanced unemployment benefits, and direct support to businesses and state and local governments.

In 2022, Alaska added another 8,500 jobs through the return of cruise ships and the rise in travel, eating out, and recreation.

Recovery to pre-COVID job levels, by industry

	2019 jobs	2024 forecasted	Difference from 2019	
Total Nonfarm Employment	330,000	331,600	0.5%	1,600
Total Private	250,200	252,700	1.0%	2,500
Mining and Logging	13,400	12,500	-6.7%	-900
Oil and Gas	9,900	8,000	-19.2%	-1,900
Construction	16,400	17,800	8.5%	1,400
Manufacturing	13,100	12,600	-3.8%	-500
Transportation, Trade, and Utilities	64,600	66,000	2.2%	1,400
Wholesale Trade	6,600	6,500	-1.5%	-100
Retail Trade	35,600	35,500	-0.3%	-100
Transp, Warehousing, and Utilities	22,500	24,000	6.7%	1,500
Information	5,400	4,600	-14.8%	-800
Financial Activities	11,600	10,900	-6.0%	-700
Professional and Business Services	27,700	28,600	3.2%	900
Educational (private) and Health Svcs	50,800	52,000	2.4%	1,200
Health Care	38,700	40,500	4.7%	1,800
Leisure and Hospitality	36,200	36,100	-0.3%	-100
Other Services	11,000	11,600	5.5%	600
Total Government	79,900	78,900	-1.3%	-1,000
Federal, except military	14,900	15,400	3.4%	500
State, incl. University of Alaska	23,200	23,100	-0.4%	-100
Local and tribal, incl. public schools	41,800	40,400	-3.3%	-1,400

Note: May not sum because of rounding. Excludes the self-employed, uniformed military, most commercial fishermen, domestic workers, and unpaid family workers.
Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Recovery slowed in 2023 with the easiest gains behind us, although nearly every industry grew at least a little. Growth totaled 7,400 jobs, with general recovery bolstered by a record 1.6 million cruise ship visitors. Most industries remained underwater last year, though, with total employment still 3,800 jobs below 2019 levels, or -1.2 percent.

Positives for growth this year

The federal infrastructure bill and the Inflation Reduction Act will route billions of dollars to the state over the next decade. Funds for roads, bridges, ferries, water and sewer facilities, broadband, and other longstanding priorities will make lasting and sometimes overdue improvements. Many of these projects are still in the planning phase, so we might not see significant job growth this year, but they have begun.

The projects will create jobs, at least in the short term, and the results will lay the foundation for further economic growth. For example, port upgrades

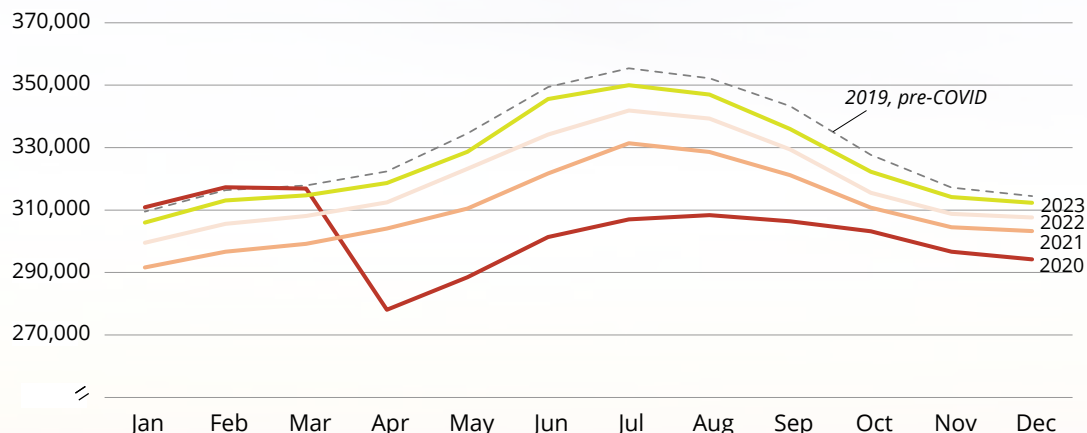
in Anchorage and the development of a far north deep water facility in Nome will raise the state's profile in the global shipping market.

Several large oil and gas projects are anticipated to move forward in 2024, although they won't start producing oil for several more years, even under the most favorable circumstances, and the potential for setbacks will continue until the oil starts to flow.

A new gold mine in the interior is set to begin production this year, spurring new jobs in mining and transportation.

Tourism is an important economic driver for Alaska, and early indicators point to a repeat of last year's

Growth slows each year as Alaska approaches full job recovery



Note: 2023 is preliminary.

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

record visitor season. Alaska's draw is strong, especially for domestic travelers, and trip demand remains high. Cruise visitor numbers are expected to meet or slightly exceed 2023's high water mark of 1.65 million.

The national economy remains strong, with job and wage growth outperforming predictions, although both started to slow in late 2023. While fears of an imminent national recession are receding, some economists are still forecasting a downturn.

What will hold us back in 2024

With pandemic checks over and payment pauses exhausted, people have less income

Households have less disposable income than they had over the last couple of years. Federal stimulus payments have largely been spent, and the Alaska Permanent Dividend was significantly smaller in 2023 than in 2022.

Inflation, which peaked in 2022 at 8.1 percent in Alaska, has slowed but prices remain high, eroding purchasing power. Interest rates shot up in 2022 as the Federal Reserve Board tried to put the brakes on the national economy to curb inflation. Federal student loan repayment, which was paused during the pandemic, resumed in late 2023.

At the same time, wages increased, bolstering some households' ability to withstand higher prices and resumed loan repayments.

Sluggish before COVID; budget woes ongoing

Another factor is hard to quantify, but how Alaska

entered the pandemic will affect how we come out of it, to the degree that the underlying conditions remain the same. Alaska's job growth before COVID was the slowest in the country.

The state continues to struggle with how to pay for services, with the tension between paying out Permanent Fund Dividends and identifying new revenue sources continuing to play out politically and in public opinion. In addition to the state's longstanding budget and revenue problems, the coming years will bring additional pressure for the state to come up with the matching funds required with these recent large federal investments.

Worker shortage is especially acute here, compounded by migration losses, aging

The worker shortage will persist in 2024, particularly for Alaska, and constrain potential growth. We have high job openings and a short supply of workers to fill them; the Bureau of Labor Statistics estimates Alaska has two job openings for every unemployed person seeking work. This makes recruitment and retention a challenge for employers but also gives workers more opportunities than we have seen in decades.

The entire country is grappling with this worker shortage, but Alaska's deficit is stark. In a double blow to worker availability, our population is slightly smaller than it was 10 years ago and is getting older. More Alaskans are aging out of the workforce, and the number in their prime working years (ages 18 to 64) fell by 30,000 from 2013 to 2022.

Alaska has always imported labor, with about 20 percent of our jobs filled by nonresidents in a typical year. Some stay — about 10 percent — but most come to work in our highly seasonal or remote

Statewide Forecast

industries such as seafood processing, tourism, and extraction. With high job openings across the nation, Alaska has less draw for workers, temporary or permanent. Alaska's high wages have given us an edge in the past, but our wage advantage over the rest of the country has narrowed over the last few decades.

Similarly, while Alaska has always seen large numbers of people flowing in and out each year, fewer people have moved here each year over the last decade, and they are not staying as long as they used to. This net migration loss was big enough in several recent years to drive down the population overall.

Movers in both directions tend to be in their 20s and 30s: prime working-age people likely to bring children with them. Losing them and their families, along with the current population aging in place, has exacerbated our labor shortage.

All industries expected to grow or hold steady in 2024

Projects to boost multiple industries, especially oil, construction, linked services

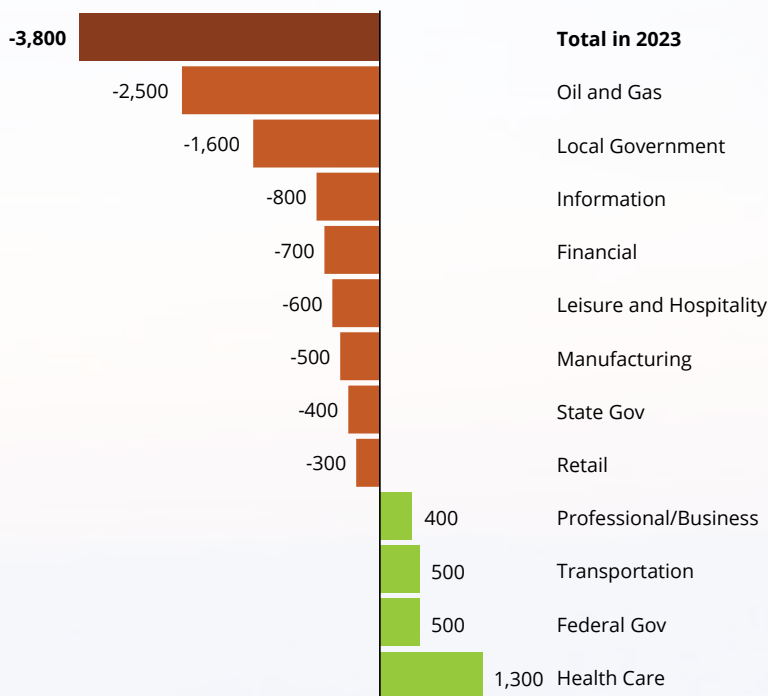
The broader mining sector is forecasted to add 1,000 jobs in 2024, with 600 coming from the oil and gas industry. Hard rock mines tolerated the pandemic downturn well, and their growth this year will come from a new gold mine opening near Tok, about 200 miles southeast of Fairbanks, and small expansions in their workforces across the board.

Oil and gas, on the other hand, was hammered by the pandemic, losing 3,200 jobs in the first two years on top of its declines from the immediately preceding state recession when the industry shed 5,400 jobs.

After those two downturns, oil and gas employment in 2021 was less than half that of 2014. Jobs rebounded somewhat over the last two years, with the industry adding 300 jobs in 2022 and 400 in 2023.

Preparation for the Pikka and Willow projects and

In 2023, many industries were still under water



Note: Preliminary

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

more activity overall will boost oil and gas employment by about 600 this year, although some of the early-phase employment growth will show up in other industries such as construction, transportation, and professional and business services.

Federal infrastructure money will boost construction, although likely by small amounts in 2024 as individual projects take time to fund, bid out, and start. More oil field work, particularly in Willow and Pikka, will also buoy construction.

Construction lost just 600 jobs to COVID and has recovered and grown at an accelerating pace, adding 100 jobs in 2021, 200 in 2022, and 600 in 2023. We expect the industry to add 1,100 jobs in 2024, bringing total employment to 1,400 above 2019's annual average.

Similarly, the professional and business services that support oil and construction work will benefit this year, and we forecast an additional 600 jobs for this industry, pushing it above pre-pandemic levels.

The labor shortage is a big obstacle for the seafood processing industry

Manufacturing lost 1,300 jobs in 2020, mainly in seafood processing, and has added back 800 since. We

Statewide Forecast

don't anticipate job gains this year, and employment will probably remain below pre-pandemic levels.

In late 2023, Trident Seafoods, which has plants across Alaska, announced it plans to sell off several operations including those in Petersburg, Ketchikan, and Kodiak. When those sales take place and who buys will determine the impact in 2024, but this sale will disrupt the processing industry this year.

Finding workers will add an extra obstacle, as most come from outside Alaska and, as mentioned earlier, most of the country will see unusually plentiful job opportunities closer to home.

Manufacturing's job count has been declining over the last decade, although it can be volatile from year to year with wild swings in seafood harvesting around the state and between seasons. Recent years have brought both historically large catches and disaster-level absences. Harvest fluctuations make it hard for processors to anticipate peak labor needs, adding to the difficulty of securing an adequate workforce in remote locations of mainly nonresidents.

Manufacturing covers a variety of other goods, including makers of tents, cookies, boats, alcohol, and cannabis products. Breweries and distilleries have gained traction in recent years, as has the marijuana industry, although data suggest the niche market for cannabis products is approaching its ceiling.

Retail approaches full recovery

Retail lost 2,200 jobs in 2020 as the pandemic prompted closures, shifts in shopping behavior, and a dearth of out-of-state visitors. The industry has regained 1,900 jobs in the years since and we anticipate a small increase of 200 in 2024, bringing retail within 100 jobs of full recovery.

E-commerce continues to eat away at traditional stores' market share, although some of that decrease is simply where the jobs are counted. For example, Amazon is opening a distribution and sorting facility in Anchorage this year, jobs that will be categorized as warehousing rather than retail.

Transportation continues to flourish

Transportation lost 3,400 jobs in 2020 when travel nearly halted, then recovered in the three years that followed with more growth on the horizon in 2024.

According to Alaska Department of Transportation and Public Facilities statistics, international airport passenger numbers for Anchorage and Fairbanks in fiscal year 2023 remained below 2019 levels but cargo numbers soared. Juneau has the state's third-busiest airport, and by late 2023, Juneau's passenger numbers were just 1 percent below its pre-COVID levels.

On the air cargo side, Anchorage moved up a notch in its international ranking to become the third-busiest air cargo airport in the world. The North-Link Aviation project at the Ted Stevens Anchorage

Job opening rates remained high nationwide in 2023



Note: Six-month moving average. Rate is the number of job openings divided by total employment, multiplied by 100.
Source: U.S. Bureau of Labor Statistics

Statewide Forecast

International Airport, worth \$200 million, will increase the airport's traffic capacity with additional plane parking and a 90,000-square-foot warehouse. Construction began in 2023. The parking areas will be completed in late 2024 and the warehouse will be finished by late 2025.

Two industries continue long-term declines

Information is an example of an industry on a long-term decline, with jobs in newspapers, radio stations, and telecommunications peaking more than 20 years ago. In 2000, information had almost 7,500 jobs in Alaska, and by 2023, it was 4,600. We don't forecast any growth for 2024, although the federal infrastructure investments in broadband may stimulate some expansion in the next few years.

Long-term losses have mainly come through technological changes such as print publications and radio news and music moving online. Outsourcing call centers and other support functions has been another factor.

Financial services have faced similar declines, and for similar reasons, although the losses haven't been as dramatic. Online banking and insurance access and working with out-of-state financial managers have lessened the need for local workers, also leading to a flat forecast this year.

Health care to keep growing after new high

Health care will add about 600 jobs in 2024, continuing the long-term trend spurred by the needs of an aging population. Health care has been a mixed bag over the last three years, with ups and downs in hospitals, outpatient services, and nursing homes. Reclassification of some of those jobs further muddied the numbers. Big picture, health care's trajectory has been up, even amid COVID disruptions, with the industry adding 1,300 jobs since 2019 and hitting a high in 2023.

Private social assistance, which includes child care, suffered big losses during the pandemic and is forecasted to add 100 jobs this year, as it did last year.

Leisure and hospitality gets back to normal

Leisure and hospitality, which is strongly linked to tourism as well as local demand, lost over a quarter

of its jobs in 2020 and recovered proportionally, with big gains in the three years that followed. We forecast moderate growth of 500 jobs in 2024, as most of the pandemic losses have already been regained, especially with last year's flood of visitors.

While cruise numbers in 2024 will resemble the previous year's record, no economic changes are on the horizon that would drive up the job count as we saw over the last few years, and a tight labor market will dampen job growth.

State and local governments still struggle to regain ground, meet service demand

About a quarter of Alaska's jobs are in government, with the largest share in local governments (including public schools and tribal governments). State government is second, including the University of Alaska system, and the federal piece, which has been fairly steady in recent years, is smallest.

State government employment has been falling for a decade, and even with the additional pandemic-related hires a few years ago in public health and unemployment services, state government had about 3,700 fewer jobs in 2023 than it had in 2014, right before the statewide recession.

UA sustained similar losses, with 2022 employment, the most recent available, about 2,100 jobs below 2014, a loss of more than a quarter of its jobs.

We forecast the State of Alaska will add 300 jobs in 2024. Some state agencies reported that staffing levels in 2023 left them unable to provide basic services, some of which are statutorily required. These included public defenders, court-appointed guardians, food stamp and Medicaid offices, ferry services, and even the state's own payroll and hiring functions, which have been hobbled by staffing shortages.

Local governments lost 2,800 jobs in 2020, mainly in schools, and gained 1,200 back over the last three years. However, local government still had about 1,600 fewer jobs in 2023 than before COVID.

We forecast 200 more jobs in 2024 as some school districts continue to normalize, but growth will be tempered by the significant budget deficits districts face across the state as well as falling enrollment.

Karinne Wiebold is an economist in Juneau. Reach her at (907) 465-6039 or karinne.wiebold@alaska.gov.

Anchorage jobs forecast for 2024

The largest city is unlikely to reach its 2019 job level this year

By KARINNE WIEBOLD

Anchorage will add an estimated 2,300 jobs in 2024, and while some industries will reach full recovery after their pandemic lows, the city's total employment is unlikely to reach pre-pandemic levels this year.

Unlike Alaska, Anchorage didn't get its head back above water briefly in 2019 after the state-wide recession, so the city has been slower than the rest of the state to claw back its pre-pandemic employment levels.

Anchorage will continue on last year's path of general pandemic recovery, juiced in 2024 by infrastructure projects and supported by strong visitor numbers, a recovering statewide economy, and increased oil activity.

Factors that will boost ongoing recovery in Anchorage in 2024

Oil, construction, and related services to grow; infrastructure funds start flowing

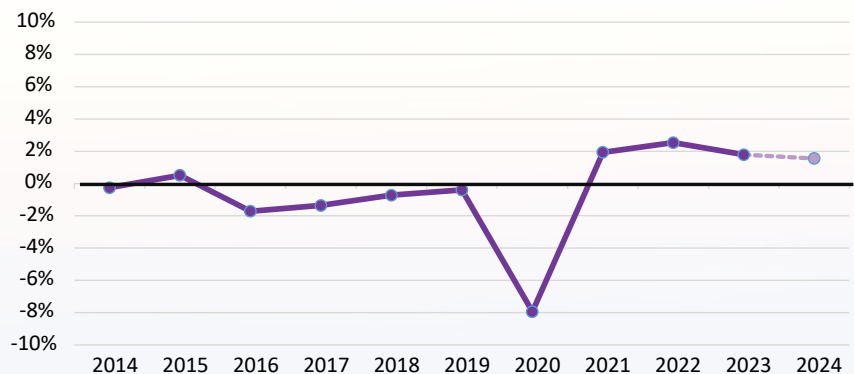
As the state's center for construction and professional and business services, Anchorage will benefit disproportionately from the multi-year infusion of federal infrastructure project funds. We expect an uptick in construction and professional and technical services specifically.

More oil activity will also boost Anchorage employment, both at headquarters and as a major supplier of oil field workers, who then return to Anchorage and spend their earnings in the local economy.

Anchorage airport now third-busiest in the world for cargo; passenger numbers up

Anchorage's transportation industry has been

Forecasted job growth in 2024 will bring Anchorage close to recovery, but not quite there



Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

strong. Airplane passenger numbers reached 95 percent of pre-pandemic levels in fiscal year 2023. Air cargo swelled during the pandemic as online shopping took more of the market share from physical stores, and buyers and sellers sought alternatives to high costs and long waits at backed-up ports across the world.

Air cargo volume dropped in 2023 but remains higher than 2019. Even with the drop, Anchorage's airport jumped up a notch globally, to the third-busiest international cargo airport in the world.

Tourism is a secondary boon for Anchorage

Tourism has been strong, with cruise ship visitors hitting a high of 1.65 million in 2023 and expected to reach that level again in 2024. Independent travelers have also made a strong showing post-pandemic.

While only a handful of cruise ships dock in Anchorage, a meaningful number of tourists make it to Anchorage, either as a destination or along the way to the Interior. Anchorage is a popular in-state destination for locals, too, for pleasure, work, or health care.

Military contributes additional project funds

Joint Base Elmendorf-Richardson is a major

The outlook for Anchorage jobs, by industry

	Monthly avg, 2022 ¹	Monthly avg, 2023 ¹	Change, 2022-23	Percent change	JOBS FORECAST		
					Monthly avg, 2024	Change, 2023-24	Percent change
Total Nonfarm Employment²	145,500	148,100	2,600	1.8%	150,400	2,300	1.6%
Total Private	118,600	121,000	2,400	2.0%	123,200	2,200	1.8%
Mining and Logging	1,800	1,800	0	0%	1,900	100	5.6%
Oil and Gas	1,500	1,500	0	0%	1,600	100	6.7%
Construction	7,200	7,400	200	2.8%	7,900	500	6.8%
Manufacturing	1,900	1,900	0	0%	2,000	100	5.3%
Trade, Transportation, and Utilities	33,300	33,700	400	1.2%	34,100	400	1.2%
Wholesale Trade	4,700	4,800	100	2.1%	4,800	0	0%
Retail Trade	15,700	15,700	0	0%	15,800	100	0.6%
Transportation, Warehousing, and Utilities	12,900	13,200	300	2.3%	13,500	300	2.3%
Information	2,900	2,900	0	0%	2,900	0	0%
Financial Activities	6,900	6,900	0	0%	6,900	0	0%
Professional and Business Services	17,400	17,500	100	0.6%	17,900	400	2.3%
Educational (private) and Health Services	25,800	26,500	700	2.7%	26,900	400	1.5%
Health Care	20,400	20,900	500	2.5%	21,200	300	1.4%
Leisure and Hospitality	16,200	17,000	800	4.9%	17,300	300	1.8%
Other Services	5,400	5,400	0	0%	5,400	0	0%
Total Government	26,900	27,100	200	0.7%	27,200	100	0.4%
Federal, except military	8,500	8,600	100	1.2%	8,600	0	0%
State, incl. University of Alaska	9,400	9,600	200	2.1%	9,700	100	1.0%
Local and tribal, incl. public schools	9,000	8,900	-100	-1.1%	8,900	0	0%

¹Preliminary and adjusted estimates. ²Excludes the self-employed, uniformed military, most commercial fishermen, domestic workers, and unpaid family workers.

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

contributor to the Anchorage economy, and troop numbers have been stable.

The base also brings in additional construction dollars, such as an ongoing runway extension project that was awarded an additional \$107 million in late 2023 as part of the Defense Authorization Bill, which included a 5.2 percent pay raise — dollars that will be at least partially spent in Anchorage.

What will continue to restrain Anchorage job growth this year

Demographic changes complicate problems

A handful of things are working against growth in Anchorage this year. The city has been losing population — in stark contrast to the neighboring Matanuska-Susitna Borough — since hitting a high of 302,127 in 2013.

The population loss is a double-edged sword; the city has fewer workers to fill the large number of job openings, but fewer people also means less demand for local goods and services.

Like the rest of the state, Anchorage is aging, and some of the existing population is aging out of the workforce. They still need things from the Anchorage economy, but they are less likely to be available to work.

The unemployment rate is very low, and the prime working-age population is about 19,000 short of a decade ago, amid increased job openings. This combination has put pressure on wages and given workers more opportunities to change jobs if they want to.

By several metrics (population, jobs, school enrollment, housing construction) Anchorage has been in decline ([see the August 2023 issue](#)) in recent years. While 2024 will bring growth, the city's long-term trajectory is unclear. One of the key questions is quality of life: Do people want to live there, raise families, invest in housing and the community, and make it their home?

While a strong tourism year, increased oil field activity, and federal infrastructure and military projects will heat things up a bit in 2024, it will likely take more than that to turn around a long-lingering stagnation.

Anchorage Forecast

Industry forecasts

Construction, transport, and related growth

Construction, professional and business services, and transportation will all benefit from the infrastructure projects in 2024.

We forecast 500 jobs for construction, growth spurred by a combination of infrastructure and oil field activity.

Professional and business services, which includes architecture and engineering firms, will add an estimated 400 jobs to support these projects. Transportation and warehousing will add a combined 300 jobs.

Growth for the oil industry, finally

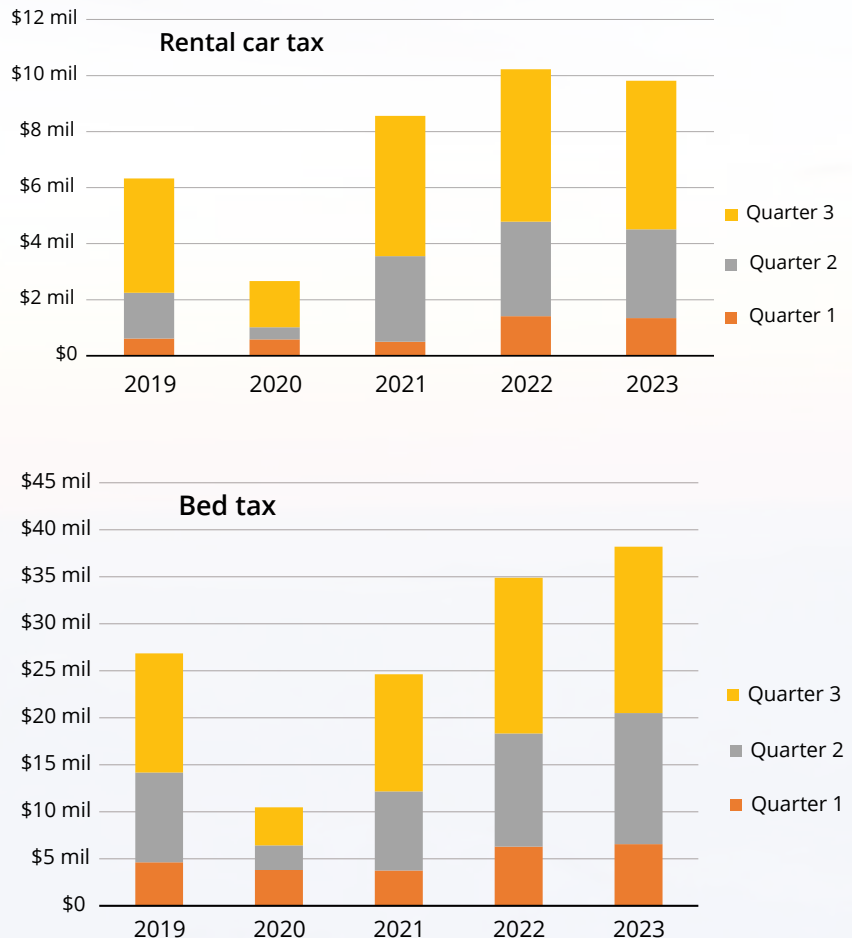
With more happening in the oil fields, we expect Anchorage to add 100 oil jobs in 2024. Anchorage is the in-state corporate headquarters for most oil and gas companies that do business in Alaska, so when the North Slope picks up, some growth in Anchorage becomes likely. That said, the oil company landscape has changed significantly from its heyday.

For example, when BP sold its Alaska interests to Hilcorp, which operates a much leaner workforce and has headquarters in Texas, in 2019, Anchorage lost oil and gas jobs that won't come back. Even with a small amount of growth, Anchorage's oil and gas industry is 40 percent smaller than in 2019 (-1,000 jobs).

Health care's upward trajectory continues

Anchorage health care will keep growing. The industry lost 700 jobs in 2020 when most elective and preventative care was suspended amid COVID. The industry added back a couple hundred jobs in the first two years of recovery, but the biggest jump came in 2023, with 500 jobs.

Anchorage rental car tax, bed tax revenues on the rise after COVID hit



Source: Municipality of Anchorage

We expect 2024 to follow that same long path, adding 300 jobs in a combination of hospitals and ambulatory care, a category that covers doctors' offices and other types of outpatient clinics.

Anchorage is the state hub for health care, providing specialties not available in smaller communities and health facilities such as the Alaska Native Medical Center, whose mission is to deliver care to more than just residents of the city.

Demand for health care has been strong, and the medical needs of our aging population will continue to escalate. Medicaid recertification issues, if they continue, could dampen health care growth, but even in that case, the constraint would be temporary.

Demand for services will stay high

Leisure and hospitality will add 300 jobs, supported

Anchorage Forecast

by local demand and another strong tourism season. Labor constraints will likely temper that growth, however. We expect leisure and hospitality to finish 2024 about 2 percent below pre-pandemic levels.

We forecast slight growth in government in 2024. State government employment in Anchorage peaked at 10,800 in 2014 and has dropped by 1,200 since, between the state recession, pandemic, and revenue woes. We expect the state to add 100 jobs in 2024 as some state functions frayed in 2023 and multiple agencies are seeking additional staff.

Local government has lost jobs most years over the decade, and there is not much to reverse that trend. In general, public education was the reason for the losses.

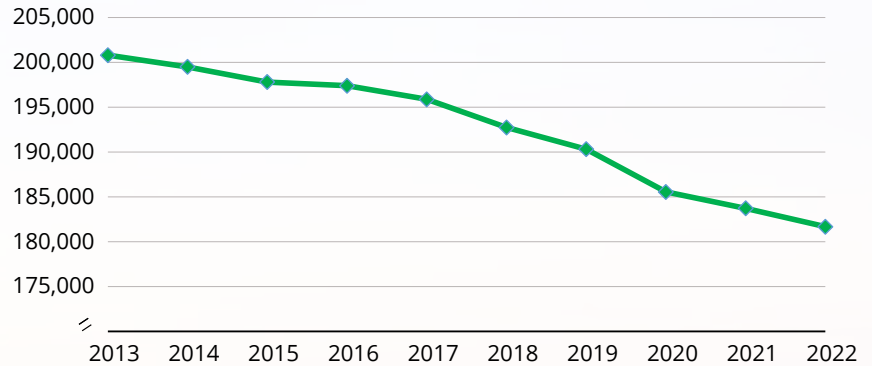
In 2020, local government lost 800 jobs, nearly all from public education. Since then, schools have recovered just a small number of those jobs. In the last couple of years, general local government has also declined by a couple hundred jobs.

While we forecast flat local government employment in 2024, there's no clear turnaround in sight. School enrollment took a blow in 2020 and recovery has been incremental.

During the 2022-2023 school year, the last available, the district remained nearly 1,900 students short of the year before COVID — and that year, the decline had already begun. For example, in 2012-2013, the district had 48,425 students. A decade later, enrollment was 5,100 fewer.

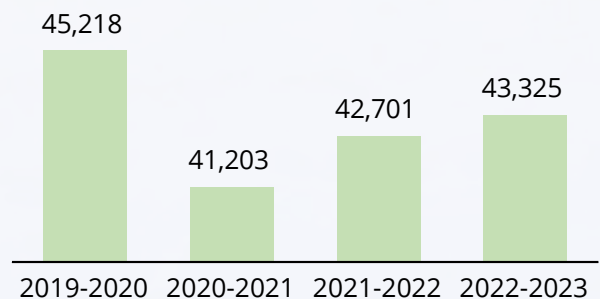
Karinne Wiebold is an economist in Juneau. Reach her at (907) 465-6039 or karinne.wiebold@alaska.gov.

Decline in Anchorage working-age population



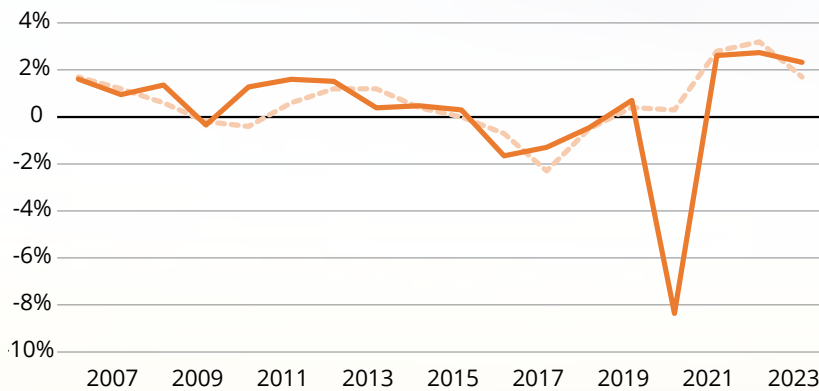
Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Anchorage's public school enrollment still below 2019



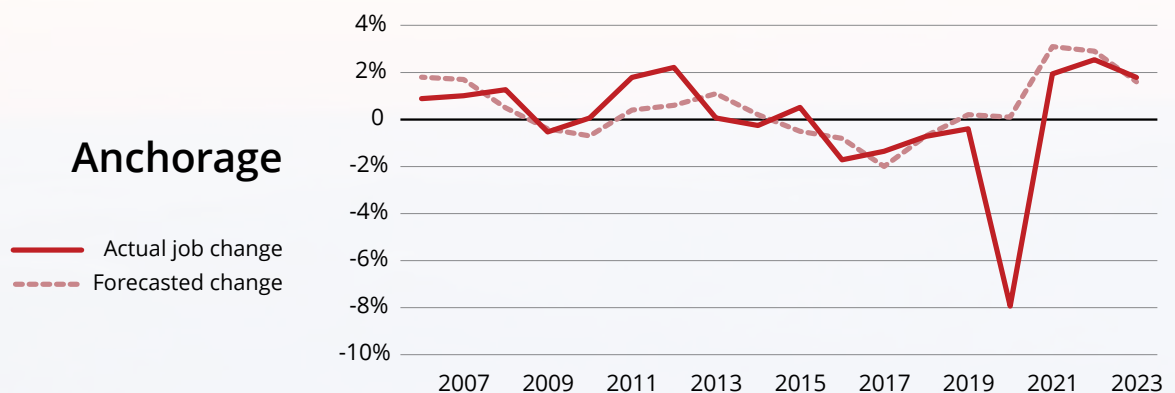
Source: Alaska Department of Education and Early Development

A look at forecasted and actual employment change in recent years



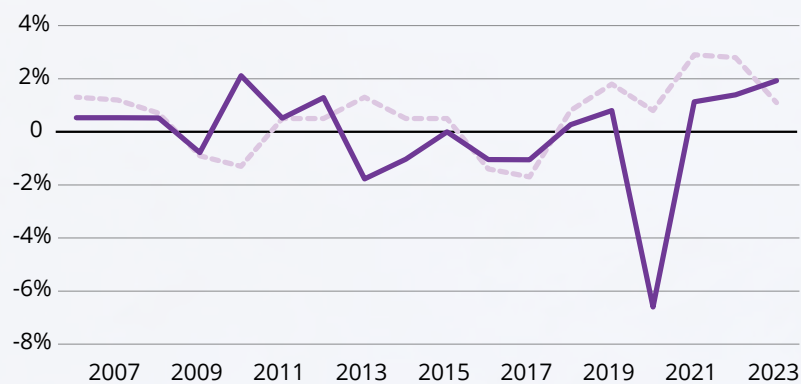
Statewide

— Actual job change
- - - Forecasted change



Anchorage

— Actual job change
- - - Forecasted change

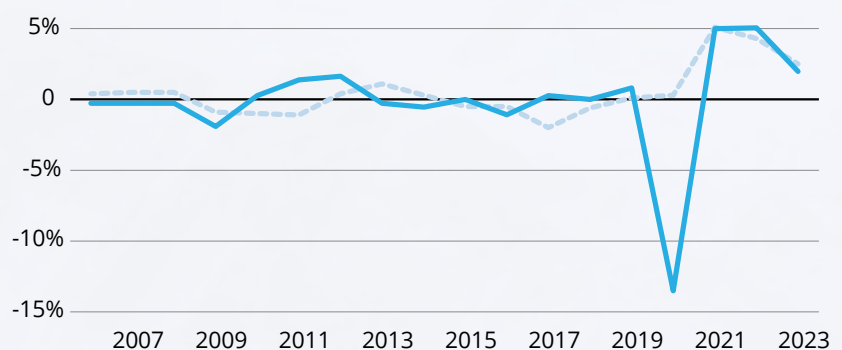


Fairbanks

— Actual job change
- - - Forecasted change

Southeast

— Actual job change
- - - Forecasted change



Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Fairbanks jobs forecast for 2024

Area's milder recovery follows less extreme job losses

By WALTER PROVENZANO

Most of Alaska has been adding jobs at a pace well above pre-pandemic rates, which shows we're still recovering, but that type of growth naturally slows as we approach normalcy.

This is especially true in Fairbanks, where the initial decline caused by the pandemic was less extreme. Fairbanks saw fewer COVID losses because it was more insulated from the types of shocks that hit the rest of Alaska.

The military and the University of Alaska buoy Fairbanks' population and employment. The military especially is a powerful driver, as it creates jobs not just on the bases but through hiring of contractors for special construction projects and by generating secondary activity such as demand for goods and services by service members and their families.

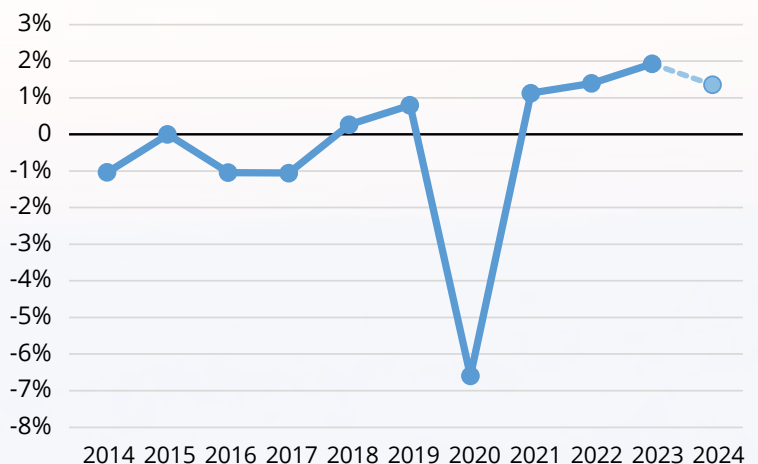
Also, more businesses in Fairbanks were considered essential early in the pandemic and stayed open, and those that did shut down reopened quickly.

These factors protected Fairbanks from steeper pandemic losses, making the corresponding recovery bump smaller — there's been less to recover from. The state lost 8.4 percent of its employment in 2020 while Fairbanks lost 6.6 percent. For 2024, we forecast total job growth of 1.4 percent for Fairbanks, or around 500 jobs, slightly slower growth than the state as a whole.

Mine, federal funds will boost jobs, but labor shortage continues

A handful of new developments will boost the borough's job growth in 2024. The two big ones are the opening of the Manh Choh gold mine near Tok and money from the Infrastructure Investment and

Growth slows as Fairbanks reaches recovery



Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Jobs Act beginning to flow in. We don't yet know what the exact effects will be, but we expect most of the new jobs to be in construction and transportation.

One of the largest constraints on Fairbanks' economy is the broad labor shortage; it doesn't matter how many new jobs open or how much money could be injected into the economy if employers can't find people to fill positions. Fairbanks' labor force has regained ground since 2020 but is significantly smaller than it was in the early 2010s, the result of population loss and aging.

After enjoying a couple of years of population growth in 2020 and 2021 with the installation of the F-35s at Eielson Air Force Base, Fairbanks returned to its long-term trend of population decline in 2022.

A smaller population also puts downward pressure on the economy in that it reduces demand for goods and services, and therefore demand for workers. For 2023 and 2024, however, it appears COVID recovery is still overpowering those effects, so we don't anticipate job loss from those population changes this year.

The outlook for Fairbanks North Star Borough jobs, by industry

	Monthly avg, 2022 ¹	Monthly avg, 2023 ¹	Change, 2022-23	Percent change	JOBS FORECAST		
					Monthly avg, 2024	Change, 2023-24	Percent change
Total Nonfarm Employment²	36,300	37,000	700	1.9%	37,500	500	1.4%
Total Private	26,000	26,700	700	2.7%	27,200	500	1.9%
Mining and Logging	900	900	0	0%	1,000	100	11.1%
Construction	2,500	2,600	100	4.0%	2,800	200	7.7%
Manufacturing	600	600	0	0%	600	0	0%
Trade, Transportation, and Utilities	7,100	7,200	100	1.4%	7,300	100	1.4%
Wholesale Trade	600	600	0	0%	600	0	0%
Retail Trade	4,600	4,600	0	0%	4,600	0	0%
Transportation, Warehousing, and Utilities	2,000	2,000	0	0%	2,100	100	5.0%
Information	300	300	0	0%	300	0	0%
Financial Activities	1,100	1,100	0	0%	1,100	0	0%
Professional and Business Services	2,600	2,500	-100	-3.8%	2,600	100	4.0%
Educational (private) and Health Services	5,400	5,500	100	1.9%	5,600	100	1.8%
Health Care	4,200	4,300	100	2.4%	4,400	100	2.3%
Leisure and Hospitality	4,500	4,500	0	0%	4,600	100	2.2%
Other Services	1,200	1,300	100	8.3%	1,300	0	0%
Total Government	10,300	10,300	0	0%	10,300	0	0%
Federal, except military	3,200	3,300	100	3.1%	3,300	0	0%
State, incl. University of Alaska	4,300	4,400	100	2.3%	4,400	0	0%
Local and tribal, incl. public schools	2,800	2,600	-200	-7.1%	2,600	0	0%

¹Preliminary and adjusted estimates. ²Excludes the self-employed, uniformed military, most commercial fishermen, domestic workers, and unpaid family workers.
Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Construction, health care, and mining lead for growth

With the influx of new federal infrastructure money, we forecast gains for construction of about 200 jobs, or a 7.7 percent increase, in 2024. Construction is one of the few sectors that will regain and surpass its 2019 employment level this year, ending up about 100 jobs above its pre-pandemic level.

According to Sen. Lisa Murkowski’s website, Alaska will receive more than \$6 billion for various infrastructure projects over the next five years, including roads, runways, and broadband internet for rural areas. The growth for 2024 will depend on how much of that money we actually see this year. One of those projects is the Johnson River bridge replacement, with construction anticipated to begin late this year.

Health care is another growing sector in Fairbanks, and it has trended upward for two decades. For 2024, we forecast 100 new jobs, or 2.3 percent growth. This would also put health care over its pre-pandemic levels, by about 200 jobs. As Fairbanks’ population continues to age like the rest of the state, the local demand for health care will grow.

Mining and transportation will also grow this year with the opening of the Manh Choh Mine. To ensure smooth operations, Kinross will need people to operate the mine and drivers to transport the ore back to Fort Knox for processing. By the end of the year when production reaches its full swing, with 60 round trips per day, the mine will support about 700 jobs, 500 in mining and 200 in transportation.

State, federal government and other services to hold steady

Fairbanks’ federal employment has stabilized at around 3,300 jobs after a long decline that began in 2012. Normal federal spending is generally stable, so federal employment will likely remain flat in 2024.

State government is a similar story. Although Fairbanks saw some job growth in state government in 2023, it was out of the ordinary given the long-term downward trend for state government and the flattening-out since 2020. Without any changes in state government spending, its employment in Fairbanks will likely hold steady this year.

The hodgepodge of personal and laundry services,

Fairbanks Forecast

religious organizations, and funeral homes — found in the data as “other services” — lost jobs over the last 20 years, falling from 1,400 in 2004 to 1,000 in 2013 and staying there until the pandemic. These employers have been growing since 2020, with much of the growth in automotive repair and maintenance. We expect that will level out in 2024, leading to a flat forecast.

Leisure and hospitality to recover fully; travel may become bigger

The leisure and hospitality sector suffered the largest pandemic-related drop in employment, and it has also gained the most since businesses reopened and travel picked up. By the end of 2024, leisure and hospitality will add an estimated 100 jobs (2.2 percent), putting it back at its pre-pandemic level.

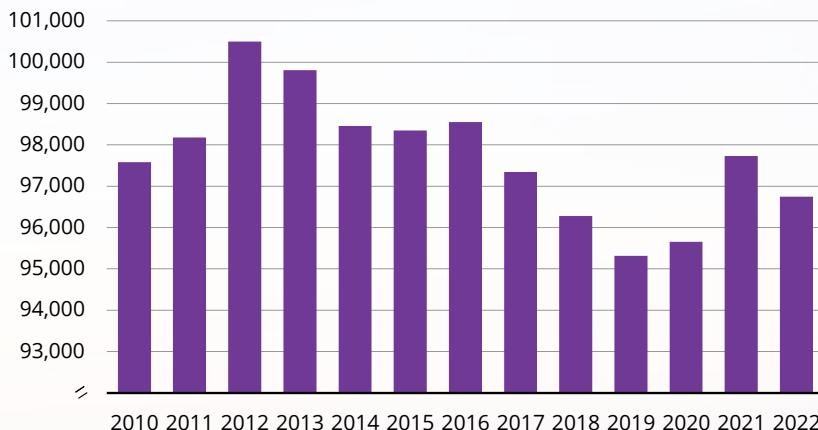
Local demand will drive most of that growth, but some evidence points to travel becoming bigger for Fairbanks. Specifically, bed tax collections are the highest they’ve been since 2018, rising 12.2 percent in 2023. While some of that increase came from high inflation, it’s still a significant jump in revenue.

On the other hand, flights in and out of Fairbanks have only recently reached pre-pandemic levels. No large movement in the number of 2024 flights suggests the sector probably won’t grow much this year.

Local government expected to stay flat after steep declines

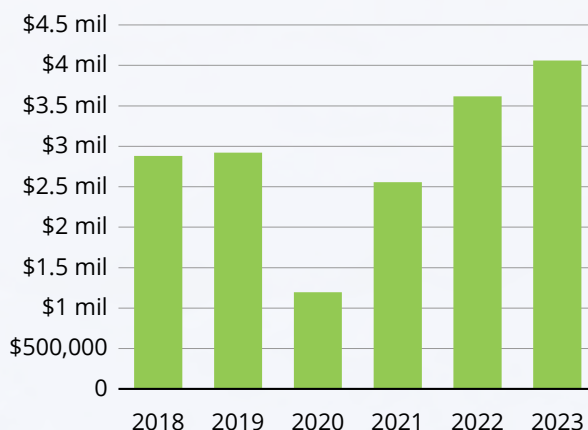
Local governments had a tough year in 2023, and we forecast employment will stay flat in 2024. Most of 2023’s losses were from education, and its challenges remain. Primary school enrollment still trails behind pre-COVID numbers, and recovery in those enrollment numbers has slowed, with the 2022-2023

Eielson build-up briefly broke population loss trend



Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Bed taxes jump, partly with inflation



Note: Reflects the first nine months of the year, to allow comparison with 2023

Source: City of Fairbanks sales tax information

school year’s enrollment increasing just 3.1 percent after jumping 8.8 percent the previous year.

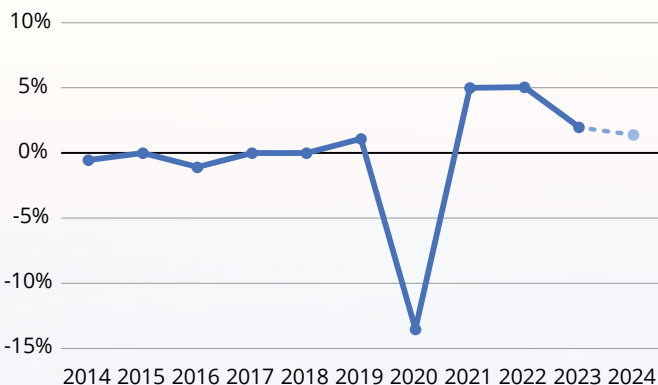
Enrollment appears unlikely to reach its 2019 level any time soon, as it’s been declining since 2012 with population loss and aging. These trends will continue for a while, and if enrollment resumes its downward trend, that will put further pressure on local government jobs, especially in schools.

Walter Provenzano is an economist in Juneau. Reach him at (907) 465-6027 or walter.provenzano@alaska.gov.

Southeast jobs forecast for 2024

More modest growth and the impact of demographics

A fourth year of job recovery on the horizon for Southeast, but smaller



Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

By DAN ROBINSON

Southeast Alaska added 700 jobs in 2023 and is forecasted to add 500 more in 2024. That equates to 1.4 percent growth, a second year of modest gains after the initially strong rebound from pandemic lows.

With the COVID-related disruptions mostly behind us, this year's forecast looks at the region's key economic drivers — the industries that bring money into the region by providing goods and services to people outside of it — and also details the growing importance of demographic trends.

Southeast's economic pillars

Four sectors of Southeast's economy are

The outlook for Southeast Region jobs, by industry

	2022-23				JOBS FORECAST		
	Monthly avg, 2022 ¹	Monthly avg, 2023 ¹	Change, 2022-23	Percent change	Monthly avg, 2024	Change, 2023-24	Percent change
Total Nonfarm Employment²	35,300	36,000	700	2.0%	36,500	500	1.4%
Total Private	23,300	24,000	700	3.0%	24,400	400	1.7%
Mining and Logging	1,100	1,100	0	0%	1,100	0	0%
Construction	1,400	1,500	100	7.1%	1,500	0	0%
Manufacturing	1,700	1,700	0	0%	1,600	-100	-5.9%
Seafood Processing	1,200	1,200	0	0%	1,100	-100	-8.3%
Trade, Transportation, and Utilities	6,900	7,200	300	4.3%	7,300	100	1.4%
Retail Trade	4,000	4,100	100	2.5%	4,200	100	2.4%
Information	400	400	0	0%	400	0	0%
Financial Activities	900	900	0	0%	900	0	0%
Professional and Business Services	1,700	1,700	0	0%	1,800	100	5.9%
Educational (private) and Health Services	4,100	4,200	100	2.4%	4,300	100	2.4%
Health Care	2,700	2,800	100	3.7%	3,000	200	7.1%
Leisure and Hospitality	4,000	4,200	200	5.0%	4,400	200	4.8%
Other Services	1,100	1,100	0	0%	1,100	0	0%
Total Government	12,000	12,000	0	0%	12,100	100	0.8%
Federal, except military	1,400	1,400	0	0%	1,400	0	0%
State, incl. University of Alaska	4,300	4,200	-100	-2.3%	4,300	100	2.4%
Local and tribal, incl. public schools	6,300	6,400	100	1.6%	6,400	0	0%

¹Preliminary and adjusted estimates. ²Excludes the self-employed, uniformed military, most commercial fishermen, domestic workers, and unpaid family workers.

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Southeast Forecast

disproportionately influential in determining whether it will grow or decline in 2024 and beyond: tourism, fishing and seafood, mining, and the combination of state and federal government. All of those inject dollars into the region that circulate in different ways and to varying degrees through other parts of the economy.

That's easy to see with the first three economic drivers — nearly all cruise ship passengers come from outside Southeast, most of our seafood harvest is sold outside, and the gold, silver, and other metals extracted from the Greens Creek and Kensington mines are shipped out of Southeast for further processing and industrial and commercial use around the world.

Thinking of government as an economic driver is less intuitive, but the 5,600 state and federal civilian government jobs plus the significant numbers of U.S. Coast Guard personnel in Sitka and Juneau (uniformed military are not counted in standard government employment numbers) are funded by federal and state revenue, and the services they provide benefit the entire state or nation.

Strong tourism and federal government spending in 2024

Southeast set cruise ship passenger records in 2023 — 1.65 million arrived in Juneau, all of whom made additional stops throughout the region — and the numbers are expected to hit 1.7 million in 2024.

For context, the 2023 numbers are 23 percent above the previous high set in 2019 before the pandemic halted cruise ship tourism, which returned in smaller amounts over the two years that followed.

The ships have also been arriving earlier and continuing to come until later. The first 2024 cruise ship will arrive in early April and the last ship is scheduled for late October. Historically, almost all of the ships came between mid-May and mid-September.

Growth of that magnitude will add revenue and create or stabilize jobs in a variety of industries, including leisure and hospitality, retail trade, transportation, and local government.

Another robust contributor to 2024 jobs will be federal money from the 2021 Infrastructure

Loss of working-age population by area in Southeast, 2013-2022

	2013	2022	Change	% Change
Haines	1,625	1,432	-193	-11.9%
Hoonah-Angoon	1,454	1,257	-197	-13.5%
Juneau	22,351	20,285	-2,066	-9.2%
Ketchikan	8,962	8,270	-692	-7.7%
Petersburg	2,007	1,822	-185	-9.2%
Prince of Wales-Hyder	4,027	3,265	-762	-18.9%
Sitka	5,770	5,076	-694	-12.0%
Skagway	738	716	-22	-3.0%
Wrangell	1,446	1,080	-366	-25.3%
Yakutat	420	396	-24	-5.7%
Total Southeast	48,800	43,599	-5,201	-10.7%

Note: Working age is 18 to 64.

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section

Investment and Jobs Act, which will include billions in new investments nationwide covering energy and power, broadband, and traditional land and water transportation infrastructure.

Alaska will receive more per capita than any other state, and in Southeast Alaska, hundreds of millions of dollars will be dedicated to the Alaska Marine Highway System — the state's ferries. The money will help AMHS acquire new ferries, build and repair shore-based infrastructure, and improve operations.

State ferries have long provided critical connections within the region, to the Lower 48, and to the rest of coastal Alaska, but the system has struggled with declining service levels for years for a variety of reasons, including significant budget cuts.

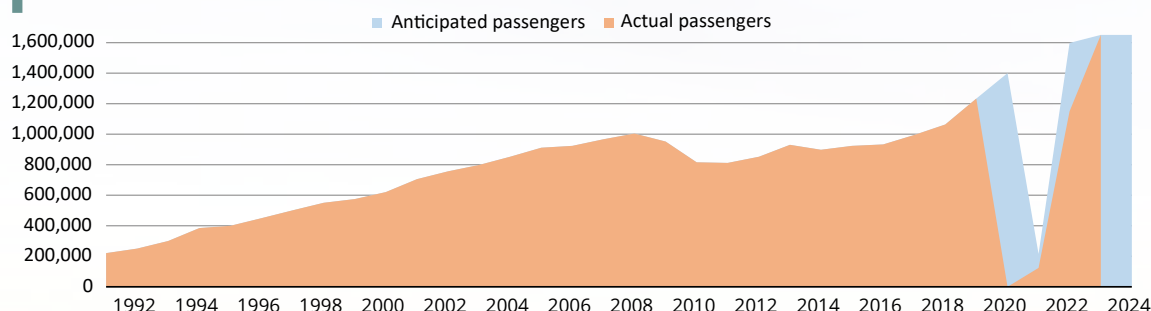
As recently as 2012, the ferries transported about 263,000 Southeast riders a year, but ridership has steadily fallen over the last decade and totaled just 152,000 by 2019. For context, ferry traffic declined 57 percent in the region over a period when the region's population fell about 3 percent.

Following the COVID-related disruptions of 2020, traffic has climbed over the last few years and reached about 114,000 in 2022, a big jump from 2021 but still less than half the ridership of 10 years earlier.

Stability in mining and state government jobs

Mining's nearly 1,000 jobs — almost all at the two

Cruise ship passenger numbers hit a new high in 2023



Sources: Cruise Industry News, 2022 Annual Report; 2021 Rain Coast data; and Cruise Lines International Association, 2022-2023

Juneau-area mines, Greens Creek and Kensington — pay well over \$100 million a year in wages and are often the largest sources of property tax revenue for the City and Borough of Juneau. Employment has been stable at that level for a decade now and no big changes are expected in 2024.

State government has had a very different decade. Since 2012, the total number of state government jobs in Southeast — including University of Alaska campuses in the region — has fallen from 5,600 to 4,300, a drop of 23 percent.

Since 2020, though, state government's job counts have been almost flat, with some of the declines attributable to the state's inability to fill an unusually large number of open positions. Significant budget cuts aren't anticipated in 2024, either to state agencies or the University of Alaska.

Disruptions in Southeast's critical fisheries in 2024

More workers harvest fish and seafood in Southeast Alaska than anywhere in the state besides Southwest. The most recent estimates show average monthly employment of more than 1,700 in 2022, with the summer peak topping 3,500. ([See the November 2023 issue.](#)) An additional 1,200 work in seafood processing jobs, a number that hit around 2,500 at the season's peak in recent years.

After high prices and big harvests in 2022, prices for salmon fell hard in 2023, making it a tough year for fish harvesters in the region. The latest news is that Trident Seafoods, Alaska's largest processor, plans to sell a third of its Alaska plants, including facilities in Ketchikan and Petersburg.

It's too soon to tell what the attempts to sell the plants will mean for the 2024 salmon season, but

the market for salmon has been up and down dramatically in recent years. Although harvests are generally strong — boding well for the longer term — the next few years will probably be chaotic for prices and processing capacity.

Long-term demographic trends present additional challenges

If demographics weren't a factor, the substantial influx of federal dollars and tourism-related spending in 2024 would likely generate strong job growth for the region. But Southeast's working-age population — people between 18 and 64 — has declined and will likely continue to decrease for at least a few more years.

Although the region's total population of 72,218 is about a thousand people below its 2000 level, the region's working-age population fell by only 6,500 over that period. It's difficult to produce job growth without growth in the working-age population.

Negative net migration — more people moving out of the region than moving into it — over the last decade or so is the main reason for those losses. That mirrors the pattern in most of the state, with the Matanuska-Susitna Borough being the most notable exception. ([See the March 2023 issue.](#))

The other major driver is that baby boomers — the especially large cohort born from 1946 to 1964 — are aging out of their prime working years.

All 10 boroughs/census areas have lost working-age people

Skagway's working-age decline from 2013 to 2022 was smallest in Southeast at just 3 percent and

Southeast Forecast

Wrangell's was largest at 25 percent, but there were no exceptions to the region-wide downward trend. (See the table on the previous page.)

One of the challenges ahead is that a smaller percentage of the total population is working-aged. Because the overall population is nearly stable in the region, that means the number of people who need goods and services hasn't changed dramatically but the number of people available to do the work to provide them has.

Understanding how all this will affect the region's ability to add jobs is a new challenge for economists. Typically, growth in a region's basic sectors consistently produces employment and population growth.

Job openings reflect these shifts

One of the early signs that something big changed in recent years was a large increase in job openings. There have been roughly two open jobs in Alaska for every person actively looking for a job for over a year now. These numbers aren't available for Southeast but are probably similar. It's far more normal for the relationship to be reversed: up to twice as many job seekers as open positions.

Employers will navigate this much more competitive market for workers with different degrees of success, but overall there just won't be enough bodies to fill all of the positions employers would like to fill. It's one of the reasons migration and considerations about the quality of life have become increasingly important to an area's ability to compete with other places for workers.

Migration and quality of life key to staying competitive

Residents' overall assessment of the quality of life in their communities is a more nebulous economic

Places where more people are moving in than out tend to be places with strong and growing economies.

driver but a critical contributor to a region's economic health. What makes a place somewhere people want to live is partly subjective, but data suggest that the strength of the job market, housing availability and affordability, the quality of K-12 schools, the climate, recreational and entertainment options, and health care cost and access all play important roles. Being a place where people want to live also brings money into an economy and keeps it circulating once it's there.

Quality of life is a hard thing to measure. The clearest way to assess whether a community has the combination of things people are looking for is to determine whether more people are moving in than out. By that measure, South-

east and Alaska as a whole have struggled over the last decade.

From 2012 to 2022, Southeast had a net migration loss of 4,610 people, a hit of 6.2 percent. (The region's total population didn't fall that much, though, because the other factor that drives population change is births minus deaths, and that number was positive over the decade.)

Among the region's 10 boroughs and census areas, the biggest percentage losses to migration were in the Prince of Wales/Hyder Census Area (-12.6 percent), Wrangell (-12.1 percent), and Sitka (-9.4 percent).

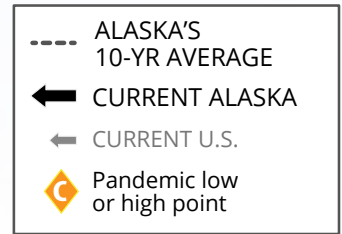
Petersburg eked out a small 0.3 percent gain while the Hoonah-Angoon Census Area added 2.8 percent and Skagway a robust 13.8 percent.

Juneau and Haines had migration-related population losses of 6.3 percent over the 2012-2022 period, Ketchikan's were slightly lower at 4.7 percent, and Yakutat was nearly flat with a loss of just 0.6 percent.

More than ever, communities that can attract people to live there and retain their existing populations will have an advantage in the competition for workers.

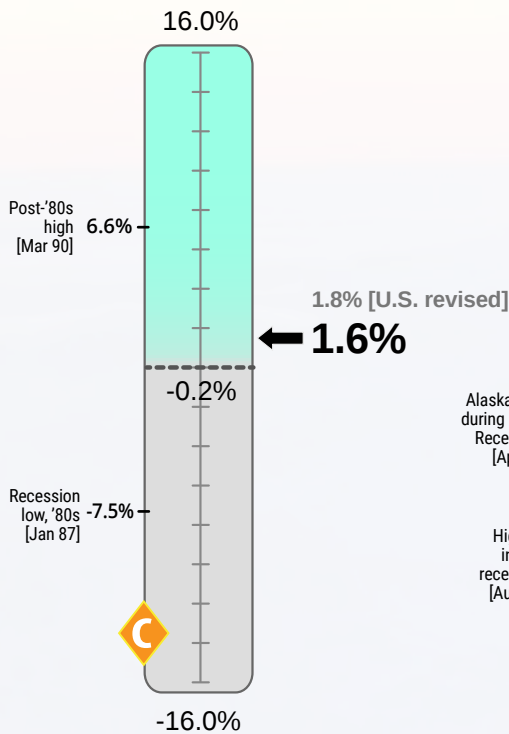
Dan Robinson is chief of the Research and Analysis Section. Reach him at (907) 465-6040 or dan.robinson@alaska.gov.

Gauging The Economy



Job Growth

November 2023
Over-the-year percent change

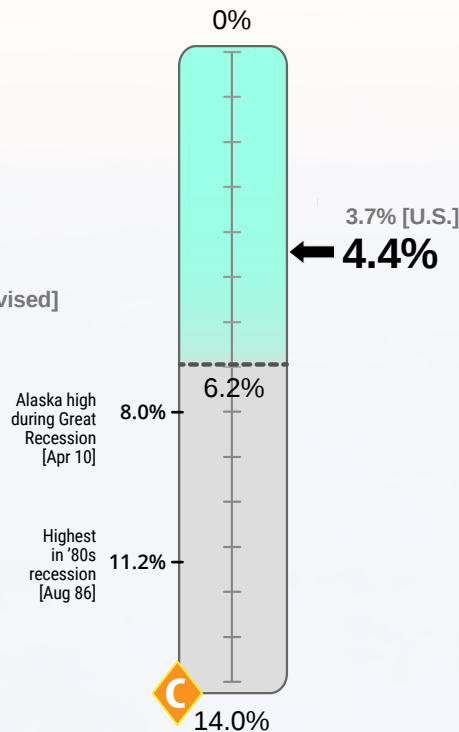


Alaska's November employment was 2.1 percent above last November but still 1.0 percent below 2019, an important reference point because that was a pre-pandemic employment level.

National employment, which was up 1.8 percent from November 2022, was 3.5 percent above its 2019 level.

Unemployment Rate

November 2023
Seasonally adjusted

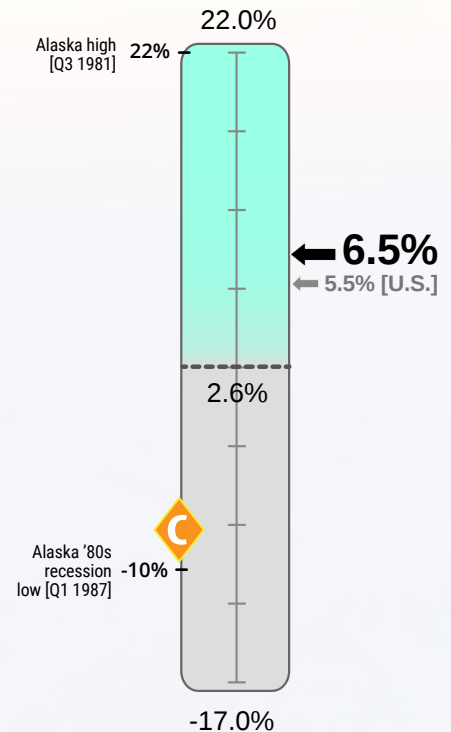


Alaska's unemployment rate has been less useful as an economic measure during the pandemic and its aftermath because of data collection difficulties.

It's clear, however, that unemployment rates in Alaska and the U.S. are historically low and that the shortage of workers is a bigger economic challenge than unemployment.

Wage Growth

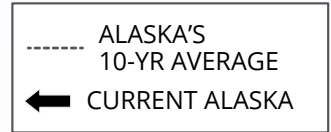
2nd Quarter 2023
Over-the-year percent change



After falling hard during the pandemic, total wages paid by Alaska employers have bounced back and show strong growth.

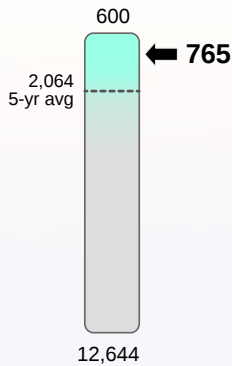
Wages were up 6.5 percent from year-ago levels in the second quarter of 2023 and 19.0 percent above first quarter 2019.

Gauging The Economy



Initial Claims

Unemployment, week ending Dec. 16, 2023*

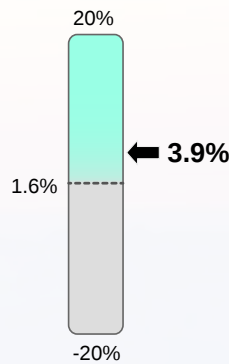


Unemployment claims jumped during the pandemic as many businesses shut down or limited services. Pandemic-driven claims loads have fallen, and new claims for benefits are well below their long-term average.

*Four-week moving average ending with specified week

GDP Growth

3rd Quarter 2023
Over-the-year percent change*

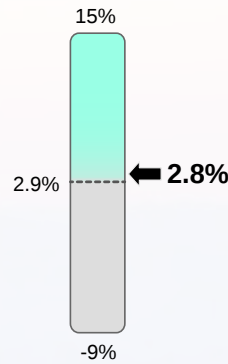


Gross domestic product is the value of the goods and services a state produces. It's an important economic measure but also a volatile one for Alaska because commodity prices influence the numbers so much — especially oil prices.

*In current dollars

Personal Income Growth

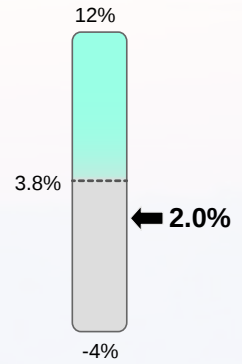
3rd Quarter 2023
Over-the-year percent change



Personal income consists of three main parts: 1) wages and salaries; 2) dividends, interest, and rents; and 3) transfer payments (payments from governments to individuals).

Change in Home Prices

Single-family, percent change from prior year, Q2 2023



Home prices shown include only those for which a commercial loan was used. This indicator tends to be volatile from quarter to quarter.

Population Growth

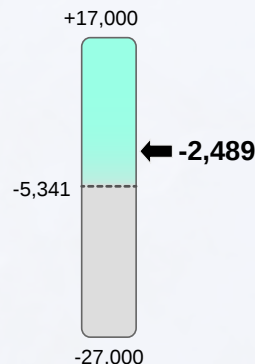
2021 to 2022



After four years of decline, Alaska's population grew slightly in 2021 and 2022, as natural increase (births minus deaths) slightly exceeded losses from migration.

Net Migration

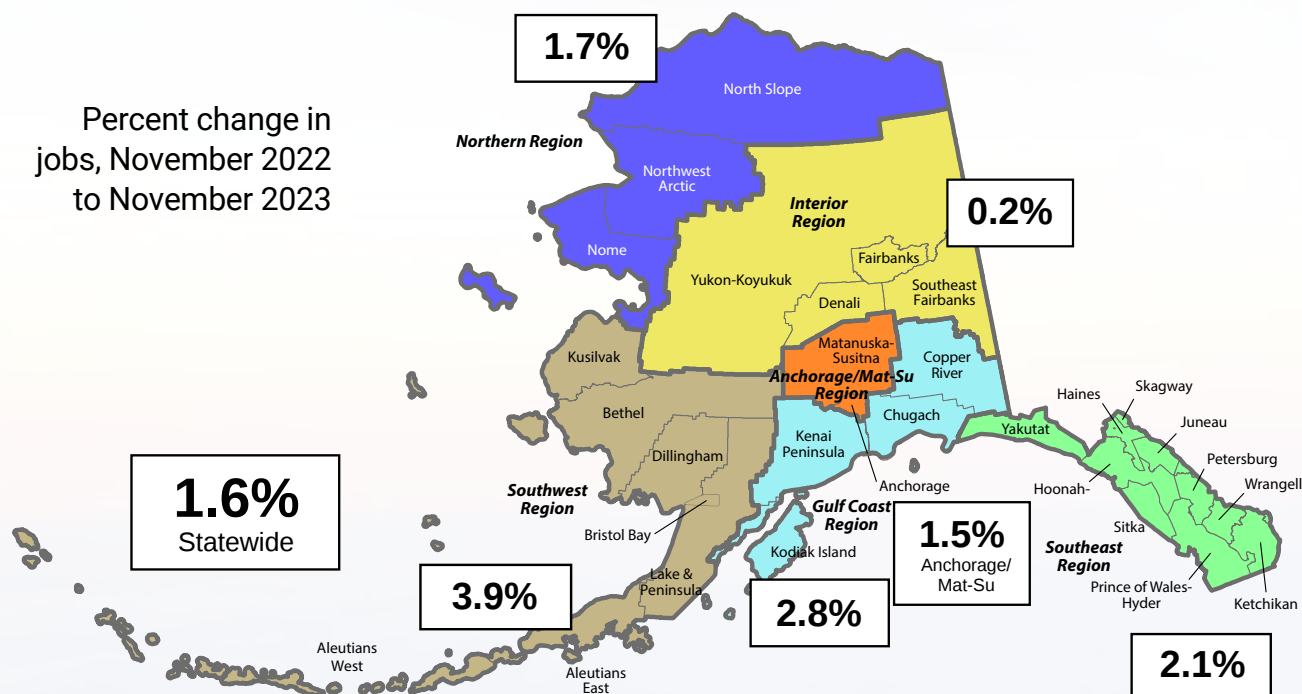
2021 to 2022



The state had net migration losses for the tenth consecutive year in 2022, although the losses have become smaller. Net migration is the number who moved to Alaska minus the number who left.

Employment by Region

Percent change in
jobs, November 2022
to November 2023



Unemployment Rates

Seasonally adjusted

	Prelim.	Revised	
	11/23	10/23	11/22
United States	3.7	3.9	3.6
Alaska	4.4	4.3	3.7

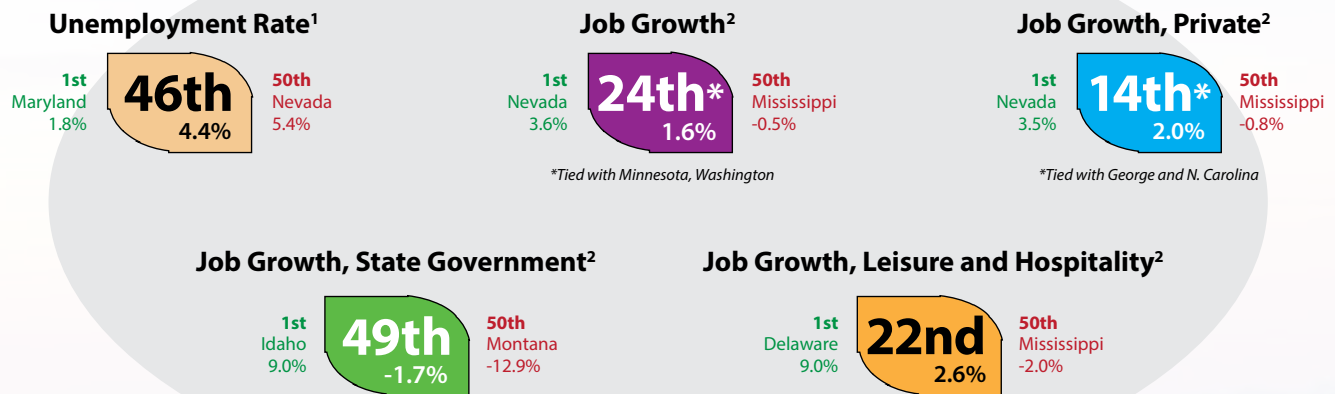
Not seasonally adjusted

	Prelim.	Revised	
	11/23	10/23	11/22
United States	3.5	3.6	3.4
Alaska	4.4	4.1	3.7

Regional, not seasonally adjusted

	Prelim.	Revised			Prelim.	Revised			Prelim.	Revised	
	11/23	10/23	11/22		11/23	10/23	11/22		11/23	10/23	11/22
Interior Region	4.5	4.0	3.8	Southwest Region	8.8	7.9	6.9	Southeast Region	4.0	3.6	3.5
Denali Borough	12.2	9.9	11.8	Aleutians East Borough	4.2	2.3	3.4	Haines Borough	8.0	6.3	6.9
Fairbanks N Star Borough	4.0	3.6	3.4	Aleutians West	4.7	3.9	4.1	Hoonah-Angoon	5.9	4.1	6.8
Southeast Fairbanks	5.6	5.3	4.5	Census Area				Census Area			
Census Area				Bethel Census Area	9.5	9.5	7.6	Juneau, City and Borough	3.2	2.9	2.6
Yukon-Koyukuk	9.4	9.2	7.2	Bristol Bay Borough	4.7	4.8	6.4	Ketchikan Gateway	3.8	3.3	3.7
Census Area				Dillingham Census Area	7.8	7.3	5.5	Borough			
				Kusilvak Census Area	14.7	14.1	11.7	Petersburg Borough	5.3	4.8	5.7
Northern Region	7.3	7.0	6.2	Lake and Peninsula	7.4	6.0	6.6	Prince of Wales-Hyder	6.1	6.3	4.8
Nome Census Area	7.5	7.1	5.6	Borough				Census Area			
North Slope Borough	5.1	5.0	4.4					Sitka, City and Borough	3.1	3.0	2.5
Northwest Arctic Borough	9.6	8.9	8.9	Gulf Coast Region	5.6	4.6	4.7	Skagway, Municipality	11.1	4.5	10.0
				Kenai Peninsula Borough	5.0	4.4	4.4	Wrangell, City and Borough	5.8	4.6	5.0
Anchorage/Mat-Su Region	3.8	3.6	3.2	Kodiak Island Borough	6.8	4.2	5.1	Yakutat, City and Borough	5.9	5.4	7.0
Anchorage, Municipality	3.5	3.4	2.9	Chugach Census Area	6.9	6.1	3.4				
Mat-Su Borough	4.8	4.3	4.0	Copper River Census Area	9.0	7.4	12.4				

How Alaska Ranks



Note: Government employment includes federal, state, and local government plus public schools and universities.

¹November seasonally adjusted unemployment rates

²November employment, over-the-year percent change

Sources: U.S. Bureau of Labor Statistics; and Alaska Department of Labor and Workforce Development, Research and Analysis Section

Other Economic Indicators

	Current		Year ago	Change
Urban Alaska Consumer Price Index (CPI-U, base yr 1982=100)	257.938	1st half 2023	252.271	+2.2%
Commodity prices				
Crude oil, Alaska North Slope,* per barrel	\$84.39	Nov 2023	\$92.58	-8.8%
Natural gas, Henry Hub, per thousand cubic feet (mcf)	\$3.06	Nov 2023	\$6.43	-52.4%
Gold, per oz. COMEX	\$2,069.10	12/22/2023	\$1,795.30	+15.3%
Silver, per oz. COMEX	\$24.57	12/22/2023	\$23.62	+4.0%
Copper, per lb. COMEX	\$3.91	12/22/2023	\$3.76	+3.9%
Zinc, per lb.	\$1.15	11/23/2023	\$1.32	-12.9%
Lead, per lb.	\$1.00	11/23/2023	\$0.96	+4.2%
Bankruptcies				
	48	Q3 2023	54	-11.1%
Business	7	Q3 2023	3	+133.3%
Personal	41	Q3 2023	51	-19.6%
Unemployment insurance claims				
Initial filings	4,665	Nov 2023	5,236	-10.91%
Continued filings	24,560	Nov 2023	24,485	0.31%
Claimant count	6,449	Nov 2023	6,303	2.32%

*Department of Revenue estimate

Sources for this page and the preceding three pages include Alaska Department of Labor and Workforce Development, Research and Analysis Section; U.S. Bureau of Labor Statistics; U.S. Bureau of Economic Analysis; U.S. Energy Information Administration; Kitco; U.S. Census Bureau; COMEX; NASDAQ; Alaska Department of Revenue; and U.S. Courts, 9th Circuit

EMPLOYER RESOURCES

Key changes to foreign labor certification program

Changes to Alaska's Foreign Labor Certification processes offer improved, streamlined service to H-2A and H-2B employers.

These programs allow U.S. employers to bring foreign nationals to the United States to fill temporary agricultural and nonagricultural jobs. The H-2A program serves agricultural employers while most H-2B jobs in Alaska are in the seafood processing industry and in seasonal retail and tourism. Both programs require Alaska employers to recruit for U.S. workers via their state workforce agency in AlaskaJobs for their positions to be certified for visa application.

Instead of emailing job order requests, employers will work directly with their local Alaska job center or Seafood Office staff to set up accounts in AlaskaJobs and enter their H-2A and H-2B job orders, or do both via self-service. Staff will provide an array of services in addition to ensuring that job orders meet Alaska standards and are ready to open for recruitment.

The FLC program will review for further

program-specific compliance, arrange for timely H-2A housing inspections, and open the job order at the appropriate time for the employer's application for certification. Employers can also use AlaskaJobs to check the status of their job orders, view applicants, and even recruit.

[Click here](#) for new information, updated instructions, and links to all of the resources employers need for this process.

Employers with questions can contact Alaska's Foreign Labor Certification program at (907) 465-6471 or dol.flc@alaska.gov. For information about Foreign Labor Certification from the U.S. Department of Labor's Office of Foreign Labor Certification, see <https://www.dol.gov/agencies/eta/foreign-labor> or contact the Chicago National Processing Center at tlc.chicago@dol.gov.

Employer Resources is written by the Employment and Training Services Division of the Alaska Department of Labor and Workforce Development.

SAFETY MINUTE

Reducing carbon monoxide risks in cold weather

The cold weather in our great state doesn't stop us from working or enjoying the outdoors. We have adapted, gotten the right gear, determined our limits, and found ways to keep warm. We enclose buildings under construction with plastic sheeting, reduce drafts, and minimize working outdoors, and all of these things affect access to fresh air and air movement.

Using fuel-burning equipment can generate carbon monoxide, a simple asphyxiant that displaces oxygen in a worker's blood and can build up in these tightly sealed buildings. According to OSHA, carbon monoxide is the No. 1 cause of death from breathing in harmful chemicals. It is so dangerous because people can't smell, see, or taste it but it can kill within minutes.

In addition to an employer's responsibility for ensuring adequate available oxygen (at least 19.5%) in the ambient air, OSHA and Alaska standards provide exposure limits for carbon monoxide and other air contaminants. Listed below are some standards that apply to fuel-burning equipment.

- [Alaska's additional air contaminants table Z-1-A](#), Limits for air contaminants.

- [29 CFR 1910.1000](#), Air contaminants, [TABLE Z-1](#) Limits for air contaminants.
- [29 CFR 1926.55](#), OSHA's Gases, vapors, fumes, dusts, and mists standard.
- [29 CFR 1926.154](#), Temporary heating devices.

Employers can use alternatives to fuel-burning heaters, equipment, and tools in enclosed areas; operate fuel-burning devices consistent with manufacturers' instructions; use carbon monoxide detectors or alarms; and train workers about these hazards to reduce the potential for carbon monoxide poisoning and as part of their cold weather safety program. A simple toolbox talk from the OSHA alliance with the Center for Construction Research and Training can help inform workers and is available [here](#).

For more information about cold weather safety or to assess potential air contaminants in the workplace, please contact AKOSH Consultation and Training at (907) 269-4950 or [submit a consultation request here](#).

Safety Minute is provided by the Alaska Occupational Safety and Health Consultation and Training Section of the Alaska Department of Labor and Workforce Development.

Relevance and Need

For the

Tongass Old-Growth Conservation Strategy

A Forest Plan Revision Pre-assessment



Review Team:

Elizabeth Berkley, U. S. Forest Service, Alaska Region, Anchorage, AK

Steve Brockmann, New Solutions Inc., Juneau, AK

Philip Manlick, U. S. Forest Service, Forestry Sciences Laboratory, Juneau, AK

Sarah Markegard, U. S. Fish and Wildlife Service, Anchorage, AK

Myrnie Mayville, U. S. Forest Service, Pacific Planning Service Group, Yreka, CA

August, 2023

Revised January 2024

U.S. Forest Service
Tongass National Forest

Executive Summary

As part of the Pre-assessment phase of an impending Tongass National Forest Plan revision, the Forest Service convened a Review Team to evaluate the need for and relevance of the existing Tongass Old-Growth Conservation Strategy (Conservation Strategy or Strategy) under a new Forest Plan. The objective of this review was to evaluate three potential options: (1) maintaining the Strategy as is, modified only as necessary to comply with the 2012 Planning Rule; (2) eliminating the Strategy in favor of more general, ecosystem-level guidance less focused on old-growth forest; and (3) updating or otherwise modifying the Strategy to improve its functionality.

The Conservation Strategy was developed in the 1990s and adopted as an integral part of the 1997 Forest Plan, to ensure continued existence of viable populations of old-growth dependent and old-growth associated wildlife, well-distributed across the Tongass. The Strategy includes a system of Large, Medium, and Small old-growth reserves, a network of old-growth corridors connecting the Medium and Large reserves, and a series of Standards and Guidelines that provide additional protection for species and species groups with conservation needs not fully addressed by the reserve system alone.

The Review Team considered the original purpose and subsequent evolution of the Conservation Strategy, and reviewed recently published scientific information on old-growth-associated species for which the Strategy was developed, additional species for which conservation concerns have been identified, landscape-scale conservation, and reserve design. This information was evaluated in the context of the 2012 Planning Rule's direction on conservation of ecosystem integrity and diversity, species viability, and climate change resilience. The report evaluates how each of the three options (i.e., keep, eliminate, or modify the Strategy) could work to protect the unique wildlife diversity of the Tongass National Forest, which is characterized by many endemic subspecies and genetic lineages.

The Review Team concluded that the structure and content of the existing Conservation Strategy appears to be largely consistent with the 2012 Planning Rule and that the Strategy continues to be relevant and necessary. Although the existing Strategy provides a solid basis for conservation of old-growth dependent species, the Team identified several potential modifications that would help address additional requirements of the 2012 Planning Rule, particularly those associated with ecosystem diversity and climate change resilience. The Team also recommends modifications to a few of the existing Standards and Guidelines to improve protection for vulnerable species. Ultimately, the Team recommends Option #3 – updating the Strategy to improve its functionality (i.e., keep, but modify).

The following recommendations, supported by analysis and citations in the main text, are provided:

- Update the existing Strategy to include explicit consideration of ecosystem diversity and climate resilience (Option #3 – keep, but modify).
- Update existing Standards and Guidelines addressing species-specific needs by:
 - Developing guidance on management of “post fledging areas” around each 100-acre goshawk nest buffer, to protect adequate habitat for fledglings learning to fly and hunt.
 - Increasing seasonal buffers around known wolf dens to reduce disturbance during pup-rearing, and maintain adequate forest cover for wolves and their prey species.
 - Improving connectivity of Small Old-Growth Reserves (through corridor protection and forest restoration) for flying squirrels and other wildlife.

- Protecting old-growth stands occupied by marbled murrelets, rather than only known nests (which are not routinely searched for, difficult to find, and rarely discovered).
- Consider additional conservation measures for species with emerging conservation concerns (marbled murrelet, little brown bat, western screech owl, and yellow-cedar).
- Develop monitoring programs for vulnerable species to inform adaptive management.
- Develop a GIS database of existing old-growth corridors that connect designated reserves.
- Identify and retain existing “Very Large” old growth reserves in each biogeographic province.
- Include ADF&G, USFWS, and Tribes in discussions related to modification of the Strategy.
- Retain the Interagency Review Process for OGR modifications (Appendix K).
- Compile all elements of the Conservation Strategy into a discrete, stand-alone document.
- Appendix C lists additional evaluations recommended by the Team to inform the Assessment and Plan Development phases of the revision.

Table of Contents

Executive Summary.....	2
Table of Contents	4
Introduction	6
Report Organization	6
Purpose and Evolution of the Tongass Old-Growth Conservation Strategy.....	7
1997 Revised Forest Plan	7
2008 Forest Plan Amendment	9
2016 Forest Plan Amendment	10
Land Transfers	10
New Information on Conservation Strategy Design Species.....	11
Queen Charlotte Goshawk	12
Alexander Archipelago Wolf.....	12
Northern Flying Squirrel.....	13
American Marten and Pacific Marten.....	14
Prince of Wales River Otter	14
Brown Bear.....	15
Mountain Goat.....	15
Pacific Great Blue Heron	15
Species with Emerging Conservation Concerns	15
Marbled Murrelet	16
Little Brown Bat.....	16
Western Screech-Owl.....	16
Yellow-Cedar	17
Recent Developments in Conservation Reserve Design and Management.....	17
Climate Change Considerations	20
Ecosystem Integrity and Diversity	21
Species Viability and Distribution	23
Endemism	23
Best Available Scientific Information	26
Executive Order 14072 – Strengthening the Nation’s Forests, Communities, and Local Economies	27
Conservation Strategy Options	28
Option #1 - Retain the Conservation Strategy As Is	28

Option #2 - Eliminate the Conservation Strategy	29
Option #3 - Modify/Update the Conservation Strategy.....	32
Recommendations	34
Conclusions	36
Literature Cited	37
Appendix A – Summary and new information on original Conservation Strategy design species	54
Appendix B - Species with Emerging Conservation Concerns.....	62
Appendix C. Suggested Evaluations for the Forest Plan Assessment.....	67

Relevance and Need for the Tongass Old-Growth Conservation Strategy

Introduction

In 1997, the U.S. Forest Service adopted an updated Land and Resources Management Plan (Forest Plan) for the Tongass National Forest (Tongass) in Southeast Alaska that included a comprehensive strategy intended to provide for long-term viability of wildlife species associated with or dependent on old-growth forest (USFS 1997 ROD). This strategy, referred to as the Tongass Old-Growth Conservation Strategy (Conservation Strategy or Strategy), was retained with minor modifications through 2008 and 2016 amendments of the Forest Plan (USFS 2016 ROD, 2008 ROD). The Forest Service is now initiating a comprehensive Tongass Forest Plan revision under planning rules adopted in 2012 (2012 Planning Rule). The process of revising a Forest Plan begins with an Assessment to evaluate existing information relevant to the plan area within the broader landscape, prior to development of a proposed plan for analysis and public comment. This report is intended to inform the Assessment and aid in development of a revised Forest Plan.

Forest Service planners are currently considering evaluation of three options for the Conservation Strategy during the Forest Plan revision: (1) maintaining the Strategy as is, modified only as necessary to comply with the 2012 Planning Rule; (2) eliminating the Strategy in favor of more general, ecosystem-level guidance that includes old-growth forest with other ecosystems; and (3) updating or otherwise revising the Strategy to improve its functionality. This report provides background to inform development and evaluation of these three options.

Report Organization

In this report, we review the purpose and evolution of the Conservation Strategy and describe relevant new science available on species for which the Strategy was designed, as well as literature for species for which there are emerging conservation concerns. We also discuss recent developments and reviews of conservation strategy design that may be useful to the Assessment. Following this review of new science, we address several relevant aspects of both the 2012 Planning Rule, which will guide the Forest Plan revision process, and Executive Order 14072, which addresses management of federal forest lands, with focus on mature and old-growth forests. With this background, we describe and evaluate the three options listed above (i.e., retain, eliminate, or modify the Strategy). The main text concludes with a list of our recommendations for the Conservation Strategy. Appendices A and B, which follow our bibliography of cited literature, provide additional background and summarizes scientific information that has become available since the last comprehensive review of the Conservation Strategy in 2007, for each of the original eight species for which the Strategy was developed, and for four species with emerging conservation concerns. Appendix C offers an annotated list of evaluations that we believe would help inform the Assessment and Development phases of the Forest Plan revision.

Purpose and Evolution of the Tongass Old-Growth Conservation Strategy

1997 Revised Forest Plan

The Conservation Strategy was initially developed by a team of nine wildlife biologists representing three agencies (U.S. Forest Service, Alaska Department of Fish and Game, and U.S. Fish and Wildlife Service) in the 1990s. This interagency team, known as the “Interagency Viable Population Committee” or “VPOP”, was tasked by the Forest Service with developing a strategy for maintaining viable populations of native wildlife, well-distributed across Southeast Alaska. The committee screened 356 vertebrate species that occur in Southeast Alaska and identified eight species associated with old-growth forest habitats for which there were viability and/or distribution concerns. These species, which served as “design species” for the strategy, included northern goshawk (*Accipiter gentilis laingi*), great blue heron (*Ardea herodias fannini*), Alexander Archipelago wolf (*Canis lupus ligoni*), brown bear (*Ursus arctos*), American marten (*Martes americana*), river otter (*Lutra canadensis mira*), mountain goat (*Oreamnos americanus*), and northern flying squirrel (*Glaucomys sabrinus*). The proposed strategy ultimately included a network of protected habitat patches (“reserves”) connected by forested corridors (primarily marine beach fringe and freshwater riparian buffers), and species-specific management standards deemed important for maintaining viability and distribution (Suring et al. 1993).

The reserve system was developed as a “coarse filter” element to meet the needs of species requiring forested tracts of various sizes and was intended to provide “umbrella” habitat protection for a broad diversity of species beyond the eight old-growth associated species that were used to guide design of the system. Species-specific standards were added as “fine-filter” elements to provide additional protections in the managed “matrix” lands outside the reserves, for species whose needs would not be fully met by the reserve system alone.

The draft strategy was peer-reviewed by 18 research scientists from across the country, with expertise in conservation biology (Kiestler and Eckhardt 1994). This review, which was coordinated by the Forest Service’s Pacific Northwest Research Station, led to modifications of the proposed strategy (Suring et al. 1994), particularly with respect to reserve sizes and corridor widths.

Various versions of the individual Conservation Strategy elements (i.e., reserves, beach buffers, riparian buffers, species-specific standards, etc.) were included in different combinations across 10 different action alternatives evaluated in the 1997 Forest Plan amendment environmental impact statement. Risk assessment panels composed of species experts rated relative risk of each Forest Plan alternative to continued persistence of each of the design species (Shaw 1999). The findings of these panels were described in Appendix N of the 1997 Forest Plan Final Environmental Impact Statement (USFS 1997 FEIS, App N) and by Shaw (1999).

A revised version of the Strategy was ultimately adopted as an integral part of the 1997 Forest Plan (USFS 1997 ROD, pp. 6-7). Elements of the Strategy were dispersed throughout the plan, and included mapped reserves, Standards and Guidelines, and Appendices. The Forest Plan designated a system of Large, Medium, and Small Old-Growth Reserves (OGRs) that met specified minimum size, composition, and spacing criteria (USFS 1997 Forest Plan, App. K). The reserve system included all “non-development” Land Use Designations (LUDs) that were already in protected status, such as congressionally designated Wilderness, National Monument, and LUD II Roadless Areas, and Forest Service-designated LUDs such as Remote Recreation or Municipal Watershed that did not allow timber harvest (USFS 1997 ROD p. 7).

Where necessary to meet the size and spacing criteria of the Conservation Strategy, a new Old-Growth Habitat LUD was applied to dedicated OGRs. Small OGR locations were considered draft and were to be reviewed by interagency teams during project-level analyses (USFS 1997 Forest Plan, OG Management Prescription WILD122, p. 3-80 to 3-82; and App. K). Additional guidance on interagency review of Small OGRs was provided by the Tongass Plan Implementation Team (TPIT) (1998, p. 1).

At least one “very large” OGR (>120,000 acres) was identified in each biogeographic province where possible (USFS 1997 FEIS App N, p. 21 and ROD, p.7), to address concerns expressed during the peer review for conservation of brown bear and wolf, which have large home ranges and are sensitive to human interactions (Keister and Ekhardt 1994). These reserves were not formally designated as “Very Large”, but were included within the “Large” reserve category (all of which were to exceed 40,000 acres). Specific criteria requiring very large reserves in each province were also not included in the Forest Plan’s Appendix K reserve criteria. (We recommend that proposals to adjust large reserves should account for, and maintain, these very large reserves, which are not explicitly described in the Forest Plan.)

Connectivity between OGRs was provided by 1,000-foot-wide, protected buffers along all marine and estuary shorelines, and riparian buffers of variable widths. The original VPOP proposal had called for riparian buffers of at least 100 feet on each side of streams (200+ feet total buffer width) to provide corridors for animals moving through managed matrix lands (Suring et al. 1993). This criterion matched riparian buffers required at the time by the Tongass Timber Reform Act (TTRA, P.L. 101-626) to protect anadromous fish habitat. The 1997 Forest Plan substantially increased riparian protections, particularly for headwaters and other non-fish-bearing streams, with adoption of stream protection measures recommended by the Anadromous Fish Habitat Assessment (AFHA 1995). New standards and guidelines required identification and delineation of Riparian Management Areas for each project where land disturbance would occur. Buffer widths varied with stream gradient and channel type. These enhanced riparian buffers were to be integrated into the Conservation Strategy as they were identified for each project (USFS 1997 FEIS, p. N-23; ROD, p. 7; Plan, pp. 4-52 to 4-55).

The network of marine shoreline and freshwater riparian buffers was intended to provide landscape linkages between Large and Medium OGRs. Where these buffers failed to provide continuous, forested connectivity between reserves, additional corridors were to be designated during project-level analyses (USFS 1997, Plan, p. 4-118). Additional guidance on evaluation and designation of old-growth corridors was provided by TPIT (1998, pp. 14-15). Their preliminary review of existing corridors identified several old-growth reserves with inadequate connectivity due to previous harvest and isolation.

No connectivity was required among Small OGRs. Instead, Small OGRs were intended to serve as temporary habitat for animals moving between the larger reserves, and as longer-term habitat for species with smaller home ranges (e.g., 20 to 40 flying squirrels per reserve) (Suring 1993; USFS 1997, Plan, App. K). Acres allocated to Small OGRs could also be used to protect corridors between Medium and Large OGRs where necessary (USFS 1997, Plan, p. 4-118).

Beach, estuary, and riparian buffers were expected to provide adequate habitat for river otters, without additional fine-filter, species-specific standards (Suring et al., p. 35). Forest-wide standards and guidelines were included for each of the other design species (USFS 1997 Plan, pp. 4-111 to 4-117). Standards and guidelines that applied only in areas that had been most impacted by timber harvest (not Forest-wide) required retention of legacy forest structure in timber harvest units larger than two acres to provide habitat for goshawks and marten.

Timber harvest was prohibited on all islands smaller than 1,000 acres to protect endemic terrestrial species (USFS 1997 ROD, p.7 and 36). Surveys for endemic terrestrial mammals were required prior to any project proposing to substantially alter vegetative cover (e.g., road construction, timber harvest, etc.) on islands smaller than 50,000 acres, and projects were to be designed to provide for long-term persistence of any distinctive taxa present (USFS 1997 Plan, p. 4-117).

Additional Standards and Guidelines were included in the Forest Plan for several other species (e.g., marine mammals, seabirds, shorebirds, moose, waterfowl, other raptors, etc.) not directly addressed by VPOP, peer reviews, or risk assessment panels. We consider these plan components important but outside the scope of the Conservation Strategy and this report.

2008 Forest Plan Amendment

In preparation for a Forest Plan amendment, the Forest Service hosted an interagency workshop with invited scientists in April 2006 to review new scientific information relevant to the Conservation Strategy (USFS 2008 Workshop Proceedings). The Forest Service also commissioned a comprehensive review of scientific information on conservation strategies, conservation planning, population and species viability, and landscape ecology produced since the Conservation Strategy was originally developed (Haufler 2006). The presentations, discussions, and literature review all suggested that the design of the Conservation Strategy structure (i.e., “coarse filter” system of connected reserves supplemented by a “fine filter” set of species-specific management standards and guidelines to protect vulnerable species in the matrix outside reserves) remained well-supported by current science.

Several modifications (termed “Considerations” in the language of the workshop) were recommended to improve effectiveness of the reserve system and management standards, based on research from Southeast Alaska on goshawks, wolves, marten, brown bears, forest birds, endemic small mammals, and other species. The findings and recommendations shared at the workshop, and subsequent discussions among panelists, were summarized in workshop proceedings (USFS 2008 Workshop Proceedings) and in a comprehensive review and analysis of the Conservation Strategy included in the 2008 Forest Plan FEIS (USFS 2008 FEIS App. D).

Haufler’s (2006) review recommended several modifications, including finer-scale viability analyses for endemic and isolated populations of vulnerable species to determine adequacy of the Conservation Strategy for endemic species and an evaluation of plant association representation in the reserve system to ensure comprehensive conservation of ecosystem biodiversity.

The 2008 Forest Plan revision adopted final locations for all but a few of the Small OGRs, eliminating the need for most project-level OGR reviews. It also combined and replaced goshawk and marten Standards and Guidelines describing legacy forest structure requirements with a simplified and less restrictive Legacy Forest Structure Standard and Guideline that applied only to harvest units larger than 20 acres (rather than two acres as required in the 1997 Forest Plan) over a larger portion of the Forest. A new guideline was included that allowed harvest of probable goshawk nesting habitat if no evidence of nesting was observed in two consecutive years. These changes to goshawk and marten standards effectively weakened habitat protections within the matrix. The endemic terrestrial mammal standard was modified to allow the use of existing inventory data, rather than project area surveys, where existing information was considered adequate to assess project-level effects on endemic mammal distribution. Guidance on project-level analyses of wolf mortality was modified to require consideration of human

access to the project area via all roads, not just roads open to vehicular traffic. Other improvements recommended during the 2006 Interagency Conservation Strategy Review workshop were not adopted.

2016 Forest Plan Amendment

In 2016, the Forest Plan was amended to expedite transition away from old-growth timber harvesting and towards a forest products industry that uses predominantly young-growth forests (USFS 2016, Forest Plan ROD, p. 5). Additional Forest Plan components were developed to facilitate development of renewable energy sources and manage the Forest's transportation system corridors.

Under the amended 2016 Forest Plan, young-growth may now be harvested within the Old-growth Habitat LUD, and in beach and estuary fringe and Riparian Management Areas (stream buffers), with certain restrictions, during the 15 years following adoption of the amended plan. The net effect of such harvest in reserves and corridors on wildlife was expected to vary depending on the type of treatment, condition of surrounding forest stands, size of created openings, species being considered, and extent of harvest (Bennetsen and Jacobson 2016). Little or no young-growth has been harvested on these conservation lands to date, so the impacts are believed to be negligible at this time.

Old-growth harvest was further restricted, but young-growth harvest was allowed, within development LUDs located in watersheds identified as high conservation priority by Trout Unlimited ("T77 watersheds") (Trout Unlimited undated) or as "Conservation Priority Watersheds" by The Nature Conservancy and Audubon Alaska in their 2007 conservation assessment of Southeast Alaska (Albert and Schoen 2007, pp. 34-43) (USFS 2016, ROD pp. 7-8 and 37). This additional protection potentially reduces risks to old-growth-dependent and -associated species in those areas. The ROD commits the Forest Service to a review of the environmental effects of young-growth harvest in these conservation priority areas after five years of Forest Plan implementation. This review is in progress with a draft completed by the Interdisciplinary Team in collaboration with the Tongass Transition Collaborative.

Land Transfers

Modifications to the Conservation Strategy reserve system have occurred as a result of two major land transfers. The National Defense Authorization Act for Fiscal Year 2015 authorized conveyance of 18 parcels of Tongass National Forest land totaling 69,585 acres to Sealaska, the Alaska Native regional corporation for Southeast Alaska (USFS 2016 Forest Plan ROD, p. 21). Substantial portions of the conveyed lands were formerly Medium or Small OGRs that may now be logged under the less-restrictive forestry regulations of the State of Alaska. To compensate for loss of the conservation lands, Congress designated approximately 152,000 acres of new LUD II Roadless Areas, providing more protection to undeveloped areas remaining in the vicinity of several of the land conveyances.

Following completion of the conveyances, an interagency review team evaluated the remaining protected areas for compliance with the OGR size, spacing, and composition criteria of the 2008 Forest Plan's Appendix K. The team recommended several OGR modifications that were adopted as part of the 2016 Forest Plan amendment, resulting in a net increase of 6,171 acres of OGR and 7,148 acres of productive old-growth forest in the reserve system from post-conveyance levels (USFS 2016 Forest Plan ROD, p. 21).

A 2018 interagency team reviewed one of the small OGRs affected by the Trust land exchange and recommended modifications to compensate for the impacts to habitat connectivity, as part of the Interagency Review Process initiated for the POW Landscape Level Analysis (POW LLA) (IRT 2018). The

recommendation was not implemented because the proposed modification would not have overlapped activities proposed by the POW LLA (USFS 2019, pp. 19-20).

In 2022, the Forest Service completed a land exchange with the Alaska Mental Health Trust (Trust). Approximately 21,000 acres of National Forest System lands (including 10,200 acres suitable for timber production and 1,300 acres of Old-Growth Habitat LUD) were conveyed to the Trust. These lands are expected to be logged, to provide income for the Trust. The Forest Service acquired approximately 18,000 acres, all of which will be managed for natural conditions and recreation (as required by enabling legislation). Approximately 1,950 acres of acquired lands will be managed as old-growth habitat.

No comprehensive interagency review was done specifically for the land exchange, as specified by Appendix K of the 2016 Forest Plan. Instead, an internal review concluded that “Requirements of the Old-Growth Conservation Strategy continue to be met in areas where old-growth habitat was conveyed” (Stewart 2022 Correspondence with enclosure, dated April 26, 2022).

Implementation of specified interagency OGR review procedures following land conveyances was identified as a chronic issue at the 2006 Conservation Strategy review workshop (USFS 2008 Workshop Proceedings. Pp. 102-103). We recommend that guidance on the Interagency Review Process be included in Forest Plan components or as an appendix addressing land conveyances, to alert lands staff to the procedural requirements similar to that of Appendix K. Such guidance should point out that transfer of any lands from non-development LUDs could affect functioning of the reserve system and should trigger a review process.

New Information on Conservation Strategy Design Species

The 2012 Planning Rule requires the Forest Service to use the best available science and document how that information was used to inform development of Forest Plans. The original Conservation Strategy was developed using the best available scientific information and expertise available at that time on the ecology of select focal species and methods for conserving important elements of their habitat (USFS 2008 FEIS App. D). Modifications to the Conservation Strategy should likewise reflect the latest scientific findings on landscape-scale conservation of the species for which the Conservation Strategy was designed, or other species as indicated by the best available science.

In Appendix A, we provide brief synopses of each of the eight original design species, summarize vulnerabilities and conservation status of each, and offer examples of information published since the last comprehensive review in 2007, as part of the 2008 Forest Plan amendment process (USFS 2008 Workshop Proceedings, USFS 2008 FEIS App D). (A brief review was conducted for the 2016 Forest Plan amendment (USFS 2016 FEIS, App. D) to evaluate potential impacts to the “integrity” of the Strategy. This review did not include species-specific accounts beyond discussions related to proposed modification of individual Standards and Guides.)

Below we highlight some of the relevant new information on the original design species. Our discussions here are cursory and intended to be introductory. We recommend more thorough investigation of these species during the Forest Plan revision if substantial modifications to the Strategy are considered. See Appendix A for additional information on each of these species.

Queen Charlotte Goshawk

Recently available literature on the Queen Charlotte goshawk subspecies (*A. G. laingi*) includes comprehensive reviews of species ecology and habitat management needs (Boyer 2020, Parks Canada Agency 2018, Vennesland 2018, McClaren et al. 2015, Smith 2013, CFCI 2012, USFWS 2007), foraging ecology and diet (Case 2021), and genetic diversity and differentiation (Kunz et al. 2019, Geraldtes et al. 2019, Bayard de Volo 2013, Sonsthagen et al. 2012). The Northern Goshawk Habitat Recovery Implementation Group in British Columbia has produced a habitat and territory model for the subspecies in Canada that offers good insight into habitat needs (Smith and Sutherland 2008) that could be adapted as a method of monitoring habitat capability for goshawks in managed portions of the Tongass.

One shortcoming of the Tongass' Conservation Strategy is insufficient conservation of suitable habitat to create "post-fledging areas" surrounding more rigidly protected nest stands, to provide adequate forested habitat for fledgling goshawks learning to fly and hunt, as recommended by Smith and Flaherty (2023), Parks Canada Agency (2018), McClaren et al. (2015), Smith (2013), CFCI (2012), and USFWS (2007). Smith (2013) evaluated foraging habitat around 136 known goshawk nests across Southeast Alaska and found that most were in areas with inadequate protection of suitable foraging habitat, for either fledglings or resident adult females. Smith and Flaherty (2023) concluded that the Conservation Strategy "is not contributing sufficient secure habitat to sustain breeding pairs of the northern goshawk across southeast Alaska".

The VOP committee recommended that no timber harvest be allowed within a core area of about 1,600 acres surrounding each goshawk nest, no roading or recreational development within ¼ mile (126 acres) of each nest, and harvest of no more than 5 percent of the productive old growth per decade in the remainder of the (approximately 5,000-acre) home range outside the core area (Suring et al. 1993). These recommendations were not implemented in the 1997 Forest Plan.

The current Forest Plan provides for 100-acre buffers of unharvested productive old-growth around confirmed goshawk nests. (This protection lasts only two years around probable but unconfirmed goshawk nests, which is inconsistent with known goshawk nesting behavior). This buffer is intended to minimize disturbance to nesting goshawks and presumably provide habitat for fledglings near the nest, but is well below standards recommended by goshawk specialists. Boyer (2020) and Doyle (2006) provided examples of treatments to improve second-growth in post fledging areas. We note that timber harvest need not be prohibited in the post fledging area (outside core nest stand areas which are currently protected by 100-acre nest buffers on the Tongass). Instead, most management guidelines recommend restrictions on timing, extent, and methods of timber harvest in the post fledging area.

Alexander Archipelago Wolf

New information on Alexander Archipelago wolves includes analyses of diet (Roffler et al. 2021), habitat and den site selection (Roffler et al. 2018, Roffler and Gregovich 2018, Person and Brinkman 2013, Person and Russell 2009), and wolf harvest vulnerability (Gilbert et al. 2022, Gilbert et al. 2016, Wolf Technical Committee (WTC) 2017, Person and Brinkman 2013, Person and Logan 2012, Person and Russell 2008). Management of deer habitat is tightly connected to wolf management and has been addressed by WTC (2017), Gilbert (2015), Brinkman et al. (2011), Person et al. (2009), Nelson et al. (2008), Farmer and Kirchoff (2007), Farmer et al. (2006), and Schoen and Kirchoff (2007). Bennetsen (2020) provided a recent literature review of young growth management for both wolves and deer. Additional information on deer foraging ecology can be found in Hanley et al. (2014, 2012) and Shanley

et al. (2021). Genetic evaluations of wolf taxonomy and evolutionary history have been published by Pacheco et al. (2022), Zarn et al. (2019), Hendricks et al. (2019, 2018), Schweizer et al. (2016), Weckworth et al. (2015), Cronin et al. (2014), and Weckworth et al. (2011). Each of these topics are reviewed in USFWS (2015).

Recommendations specifically addressing management of denning habitat on the Tongass are provided by Roffler and Gregovich (2018), who recommended expanding seasonal den site buffers to at least 734 m (approximately ½ mile), including as much flat, low-elevation old-growth near freshwater as possible, and retaining productive old-growth forest on at least 61 percent of each core denning area. Additional habitat recommendations are provided by WTC (2017).

The U.S. Fish and Wildlife Service is currently evaluating a 2020 petition to list the subspecies as threatened or endangered (the fourth such petition since 1993). The petition was prompted primarily by harvest mortality from trapping and hunting on POW that has exceeded the State of Alaska's guideline harvest level of 30 percent of the estimated fall wolf population several times in recent years. Road systems built largely in support of timber harvest on the island have been implicated as increasing wolf vulnerability to harvest. The importance of large reserves in minimizing overharvest of wolves, and the impacts associated with higher road densities, are highlighted by Person and Logan (2012), Person and Russell (2008), and WTC (2017).

Northern Flying Squirrel

Although Forest Plan Standards and Guidelines refer to northern flying squirrels generally, conservation concerns on the Tongass have focused on the POW flying squirrel (*G. S. griseifrons*), a subspecies restricted to several islands in the POW complex. Recent research on the species includes work on home range size, fine-scale movements, dispersal, foraging, and energetic costs of traversing fragmented forest on POW (Flaherty et al. 2010, Flaherty et al. 2008). Pyare et al. (2010) studied den site selection in fragmented landscapes while Shanley et al. (2013) looked at local and landscape scale habitat selection based on composition and structure. Several authors (including Smith and Flaherty 2023, Trapp et al. 2019, Smith 2012, Smith et al. 2011, and Smith and Person 2007) evaluated flying squirrel dispersal and landscape connectivity.

Smith and Person (2007) studied demographic viability of flying squirrels in small reserves of various composition, with different levels of landscape connectivity versus isolation. They concluded that small OGRs do not have a high probability of supporting flying squirrel populations in isolation for long periods. The contribution of small OGRs to conservation of flying squirrels depends on the degree of isolation and functional connectivity with other large, medium, or small reserves. Smith and Person (2007) suggested that conservation planning that explicitly considers quality and configuration of OGRs in a modified landscape is essential to ensure functional metapopulations of flying squirrels. Additional research suggested that local extirpations are likely, especially in smaller reserves (Smith et al. 2011).

Small OGRs across the POW complex currently provide an average of about 1,300 acres of productive old-growth, ranging from about 300 to over 3,500 acres per small OGR (Tongass OGR Tracking Table 2013). This suggests that most small OGRs would require immigration on the lower end of Smith et al.'s (2011) estimates, to maintain viable flying squirrel populations. These findings, though, underscore the importance of habitat connectivity between small OGRs, which is currently not required by the Forest Plan. (The original VPOP recommendations (Suring et al. 1993, pp. 29-30) included connecting corridors

of old growth forest between all reserves, including small reserves, with gaps no greater than 65 feet to allow flying squirrels to glide across openings). Additionally, Smith et al. (2011) recommended spacing reserves no more than 1 km (0.6 miles) apart to facilitate successful dispersal between reserves and increasing the amount of productive old-growth in small OGRs.

This work on the inadequacy of small OGRs to provide for persistence and dispersal of flying squirrel populations was later cited by Smith and Flaherty (2023) in their critique of the existing Conservation Strategy. These studies of flying squirrel demographics and dispersal through forested and harvested landscapes are directly relevant to an update of the Forest Plan and its Conservation Strategy.

American Marten and Pacific Marten

Recent literature on marten includes research on habitat selection (Flynn and Schumacher 2016), dispersal distances (Pauli et al 2012), foraging ecology (Manlick et al. 2019), population dynamics (Flynn and Schumacher 2009), genetics and endemism (Collela et al. 2018, Collela et al. 2019, Collela et al. 2021, Dawson et al. 2017), and colonization history and distribution (Pauli et al. 2015, Dawson et al. 2017).

Concerns have emerged for isolated populations of Pacific marten (*M. caurina*), now considered a distinct species limited, in Southeast Alaska, to Kuiu Island (where it hybridizes with American marten) and Admiralty Island (where genetic diversity is low) (Collela et al. 2021, Collela et al. 2019, Collela et al. 2018, Dawson et al. 2017, Cook and MacDonald 2013, MacDonald and Cook 2007). Genetic evidence suggests that where the two marten species hybridize, as documented on Kuiu Island, asymmetrical gene flow can result in slow removal of Pacific marten genetics, ultimately leading to genetic swamping and extirpation of Pacific marten (Collela et al. 2021, Collela et al. 2019, Dawson et al. 2017). Some authors suggest that this may have occurred on POW and other islands in Southeast Alaska (Collela et al. 2019, Dawson et al. 2017, Pauli et al. 2015).

A habitat selection study on Chichagof Island (using data from the 1990s) confirmed selection for structurally complex, old-growth forest habitats (Flynn and Schumacher 2016). On Kuiu Island, important predictors of marten habitat at landscape scales included lower elevation, closed canopy old-growth forest in areas with higher densities of salmon streams near the coast (Koch 2016). The predictor variables of marten habitat from Koch (2016) confirm the continuing need for old-growth forest and riparian zone protections in lower elevation areas, and provide support for potential modifications where such habitat protection is lacking.

An apparent emerging threat to American marten is recent fisher (*Pekania pennanti*) colonization along mainland rivers (especially the Taku River) in Southeast Alaska (Kupferman et al. 2022). Where there is range overlap, fishers are a dominant competitor that suppress marten populations (Pauli et al. 2022, Manlick et al. 2017).

Prince of Wales River Otter

We found no new science on the POW river otter subspecies. However, during NEPA analyses, wildlife and subsistence biologists often cite the Conservation Strategy or Forest Plan standards and guidelines as sufficient to protect river otter habitat, highlighting the ongoing importance of beach and estuary fringe buffers and riparian management areas for this species.

Brown Bear

New findings on brown bears include studies related to resource and habitat selection, spatial use, movement patterns, and home range sizes (Crupi et al. 2014, Flynn et al. 2007); diet and the role of bears in the food web (Harrer and Levi 2018, Shakeri et al. 2018); and impacts of humans on bear foraging (Wheat and Wilmers 2016). The most relevant findings from Flynn et al. (2007) documented differences in habitat selection by male and female brown bears in altered versus less altered watersheds on Chichagof Island. They found that bears, especially females, spent more time farther from salmon spawning streams, and female bears were more abundant and consumed more salmon in less altered watersheds. Based on spatial use patterns adjacent to salmon streams, Flynn et al. (2007) recommended retention of at least 500 ft no-cut buffers along streams with spawning salmon and larger buffers and/or increased habitat protections where bear populations are a management objective. This recommendation was effectively incorporated into a guideline in the current Forest Plan (pg. 4-88).

Mountain Goat

Recent literature on mountain goats confirm that they are sensitive to climatic variables including amount of snowfall in winter and heat stress in summer, both of which can reduce mountain goat survival (White et al. 2018, White et al. 2011). White et al. (2018) predicted that projected increases in summer temperature would have stronger negative effects on mountain goat populations than the potential positive effects of reduced winter snowfall, prompting concerns over species persistence.

Other research focused on colonization history, phylogenetics, habitat selection and genetic isolation of Southeast Alaska populations (Shafer et al. 2012, Shafer et al. 2010). Shakeri et al. (2021) demonstrated that mountain goats exhibited a strong degree of seasonal range fidelity, with space use expanding in the summer and constricting during the winter. Continuing to emphasize protection of critical winter habitat, which is often old or mature forests in lower elevation areas near cliffs, may be an important consideration in the Conservation Strategy and in light of future climate scenarios.

Pacific Great Blue Heron

Recent research on Pacific great blue heron (*A. h. fannini*) in British Columbia demonstrated that colonies close to bald eagle nests experience higher reproductive success than those far from bald eagle nests (Jones et al. 2013). Breeding colonies close to bald eagle nests were large enough that the occasional losses of chicks to the resident pair were outweighed by higher reproductive success. Relevant implications to the Conservation Strategy of this study are limited, other than the importance of protecting both known roosting/colony sites of herons and bald eagle nests (requirement under law (Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act)).

Additional background on each of these original design species is provided in Appendix A.

Species with Emerging Conservation Concerns

Recent information suggests that several old-growth-associated species that were not part of the original design of the Conservation Strategy may need further consideration. Here we review four such species, including marbled murrelet (*Brachyramphus marmoratus*), little brown bat (*Myotis lucifugus*), western screech-owl (*Megascops kennicottii*), and one plant, yellow-cedar (*Callitropsis nootkatensis*).

Marbled Murrelet

The marbled murrelet was considered abundant and well distributed in Southeast Alaska in the 1990s, when the Conservation Strategy was developed. Since then, substantial and potentially alarming population declines have been reported across Alaska, including an estimated 79 percent decline in marbled murrelet numbers in Southeast Alaska between 1994 and 2006 (Piatt et al. 2007). Declines were more recently documented in 2016 by ADF&G in Tracy and Endicott Arms of Southeast Alaska: about half as many marbled murrelets were recorded in July 2016 (Nesvacil et al. 2018) as in July 2002 (Kissling et al. 2011). Causes of the observed population declines have not been explicitly investigated in Southeast Alaska.

Other recent studies of marbled murrelets in Alaska have focused on marine space use, movements, foraging behaviors, and disturbance by vessels (Barbaree et al. 2015, Bertram et al. 2016, Haynes et al. 2008, 2010; Haynes and Nelson 2011, Pontius and Kirchhoff 2009, Schoen et al. 2013). One recent study investigated the nesting ecology of marbled murrelets in Southeast Alaska (Barbaree et al. 2014).

Little Brown Bat

Populations of the little brown bat have been declining across North America, primarily due to mortality caused by white-nose syndrome, a fungal disease that has spread rapidly since it was first detected in New York in 2006. The disease was detected in British Columbia in 2023, and is expected in Southeast Alaska in the near future. The U.S. Fish and Wildlife Service is currently evaluating whether to list the species range-wide.

Research on the Tongass has documented that little brown bats near Juneau hibernate in dispersed sites, close to summering areas, which may slow the spread of white-nose syndrome and reduce impacts to Southeast Alaska populations should it arrive in Alaska (Blejwas et al., 2021).

Western Screech-Owl

Recent research in Southeast Alaska has confirmed that the species is found primarily at lower elevations and is often associated with riparian habitats (Lewis and Kissling 2009). Concerns over impacts to screech-owls due to habitat loss and competitive exclusion by barred owls (*Strix varia*) have led to federal listing of the western screech-owl as “Threatened” under the Species at Risk Act in adjacent British Columbia (COSEWIC 2012, Elliot 2006). Similar concerns for habitat impacts and competitive displacement by barred owls have been raised for (unlisted) populations elsewhere (Acker 2012, Cannings and Angell 2001, Hardy et al. 1999).

Competition from barred owls for prey and nest sites, and suspected direct predation have also been implicated in declines of spotted owls (*Strix occidentalis*), screech-owls, and other species in the Pacific northwest, as barred owls have expanded their range across the region (Acker 2012, Olson et al. 2005, Kelly et al. 2003, Pearson and Livezey 2003, Cannings and Angell 2001). Similar dynamics may be occurring as the barred owl expands its range northerly into Southeast Alaska. Kissling et al. (2009b) documented apparent displacement of western screech-owls in southern Southeast Alaska by barred owls, as the distribution and occupancy rate of barred owls expanded, particularly on the mainland, and distribution of screech-owls narrowed between historic (1986-1992) and recent (2005-2008) surveys.

Lewis and Kissling (2009) and Kissling and Lewis (2009) recommended continued or expanded protection of valley-bottom forests and riparian zones to assure presence of large snags with natural cavities, given

the paucity of primary cavity excavators (woodpeckers) in Southeast Alaska, to provide adequate nest sites. Kissling and Lewis (2009) also recommended retention of patches of legacy forest structure in timber harvest units to provide nesting and roosting structure for owls, and more intensive investigation of genetic structure among owl populations across Southeast Alaska. They also recommended further evaluation of diet and habitat use by barred owls in Southeast Alaska, as potential competitors of screech-owls and other raptors, including goshawks.

Yellow-Cedar

Although not a wildlife species, yellow-cedar is a common tree across much of Southeast Alaska that has been in decline as a result of its vulnerability to climate change. The U.S. Fish and Wildlife Service recently produced a status assessment for the species (USFWS 2018) as part of its evaluation of a petition to list the species as threatened or endangered. Listing was ultimately found to be not warranted, due to the expected widespread distribution of the species in spite of acknowledged declines in the core of its range (Fed. Reg. 84(194):53342-53343, 10/7/2019).

Special consideration may be warranted on the Tongass because mortality of the tree is most common in the southern portion of Southeast Alaska. An updated Conservation Strategy that more fully addresses conservation of biodiversity could include protection of existing stands in areas expected to offer climate refugia (such as higher-elevation, north-facing stands less prone to thaw-freeze cycles during snow-free periods), dispersal corridors to sites expected to offer suitable habitat over several generations (measured in centuries), and perhaps assisted migration efforts.

Additional information on each of these species with emerging conservation concerns is provided in Appendix B.

Recent Developments in Conservation Reserve Design and Management

In its review of the Conservation Strategy, the 2016 Forest Plan FEIS pointed out that the basic structure of a connected reserve network with constraints on management in the matrix outside the reserves remained well supported by scientific literature (USFS 2016 FEIS App D). The review noted the importance of freshwater systems as nutrient sources and movement corridors for a variety of organisms within ecosystems, supporting inclusion of riparian buffers as part of the Conservation Strategy. The review highlighted the importance of managing human uses outside the reserves to help support wildlife populations, regulate movement of organisms, buffer sensitive areas, and maintain integrity of aquatic systems.

The 2016 review also discussed a “reverse-matrix” model of conservation design in which conservation lands serve as the matrix within which development activities are carefully managed to maintain healthy environmental conditions across the plan area. More intensive activities would occur on “islands” within the “sea” of conservation land (Schmiegelow et al. 2006). This approach was also recommended by peer reviewers of the original strategy developed by VPOP in 1993 (Keister and Eckhardt 1994, p. 16 and pp. 146-147). Such a scheme could be a good fit for the Tongass, where much of the landscape remains undeveloped, but would require substantial planning and consideration to ensure that specific resources are conserved in spatial arrangements that protect a broad range of values and ecosystem services (including many beyond those considered by the existing Conservation Strategy alone).

Lertzman and MacKinnon (2013) recommended a watershed approach to reserve design, particularly along the North Pacific coast of Southeast Alaska and British Columbia, where opportunities to protect undeveloped watersheds, from headwaters to saltwater, still exist. Schoen and Albert (2007) developed an example of how such an approach could work on the Tongass by integrating Albert and Schoen's (2007) "Conservation Priority Watersheds" where ecological values were highest, and "Timber Production Watersheds", where ecological values were lower and timber harvest could be concentrated within the smallest land base and fewest miles of roads with the least cumulative impact on intact habitat values. The strategy was specifically designed to maintain biodiversity and ecological integrity of the Southeast Alaska rainforest ecosystem while also providing for a sustainable timber industry within the region. (Old-growth forest in Albert and Schoen's (2007) Conservation Priority Watersheds were designated as unsuitable for harvest in the 2016 Tongass Forest Plan.)

A watershed approach allows for effective conservation of representative ecosystem and species diversity, and continuation of ecological processes and natural disturbance regimes. Protection of adjacent watersheds can be particularly good for providing connectivity to surrounding lands (Lertzman and MacKinnon 2013). Many of the reserves in the Tongass' Conservation Strategy currently cover complete watersheds. A review of Large and Medium OGRs may reveal opportunities to extend such protection and improve reserve functionality where existing boundaries exclude portions of undeveloped watersheds. We do not recommend proposals that would reduce conservation of entire watersheds where such protection currently exists.

Much research and analysis has been devoted to evaluation of the Northwest Forest Plan (NWFP), a 1994 strategy that amended 19 National Forest plans and seven Bureau of Land Management resource management plans in western Washington, Oregon, and California (Davis et al. 2022). Like the Tongass Conservation Strategy, the NWFP protected a network of habitat reserves and established management constraints across the federal lands to conserve old-growth-dependent and endemic species. Full attainment of the objectives of the plan were expected to take one to two centuries (Davis et al. 2022, DellaSala et al. 2015).

Periodic reviews have established that the NWFP has successfully protected late successional and old-growth forests within the plan area in spite of large wildfires (Davis et al. 2022, Davis et al. 2015), although increases in wildfires, invasive competitors, and forest pathogens (all facilitated by climate change) have potential to compromise long-term attainment of the plan's objectives (Spies et al. 2019, DellaSala 2015).

Inadequate consideration of climate change during development of the NWFP has been identified as a potential weakness of the NWFP (Spies et al. 2019, Spies et al 2018, DellaSala et al. 2015). Because the effects of climate change are expected to be pervasive, rather than localized like most stochastic stressors, there is concern that persistence of even widely dispersed species could be compromised in spite of the redundancy provided by many widespread local populations (DellaSala et al. 2015).

Spies et al. (2019, 2018) and DellaSala et al. (2015) asserted that the NWFP has made substantial progress toward meeting many of its goals, with some cautionary notes. For example, while old-growth forest declines have been dramatically reduced, populations of both northern spotted owls (*Strix occidentalis caurina*) and marbled murrelets (two of the flagship species for which the plan was established) continued to decline, but at slower rates of decline (of either populations or habitat) on federal lands compared to adjacent, non-federal lands. These declines have been attributed primarily to

biotic factors, including competition from invasive barred owls suppressing recruitment and survival of spotted owls and nest predation on murrelets by abundant jays and other corvids. Improvements were also reported for several of the aquatic habitat conditions monitored across the plan area, although the number of salmonid species and population units listed under the Endangered Species Act increased (Spies et al. 2019).

Smith and Flaherty (2023) recently issued similar cautionary notes about species conservation on the Tongass. For example, small OGRs were originally intended to serve the dual purposes of providing temporary habitat for animals dispersing through the managed matrix and supporting resident species with smaller home ranges (specifically, 1 female marten and 20 to 40 flying squirrels in each small OGR) (Suring et al. 1993). Research on population demographics and dispersal capability of flying squirrels on POW, however, suggests that many small OGRs are too small to reliably support populations of flying squirrels over the long term, and are too isolated to allow for adequate immigration from source populations (Smith and Flaherty 2023, Smith et al. 2011).

Additional examples from Smith and Flaherty (2023) include inadequate conservation of foraging habitat surrounding identified goshawk nests on the Tongass, and competitive displacement of an endemic old-growth specialist, the Wrangell Island vole (*Myodes gapperi wrangeli*), by the more widespread habitat generalist, Keen's mouse (*Peromyscus keeni macrorhinus*) following clearcut logging.

Wildlife conservation within the NWFP area (and on the Tongass) is complicated by many forces beyond the control of the Forest Service. Some of these factors have compromised progress toward the NWFP's goals (Spies et al. 2019). Nevertheless, there are actions that the Forest Service can take to address perceived deficiencies. DellaSala et al. (2015) recommended a variety of improvements to the NWFP, including enhanced forest reserve protections, carbon storage capacity, aquatic conservation, and at-risk species recovery. Spies et al (2019) recommended collaboration with stakeholders to restore ecosystem dynamics and structural diversity at multiple scales using local workers as a way to simultaneously promote climate change resilience, economic opportunities, and public support for agency management. Many of these recommendations could likely be adapted to the Tongass, to address or avoid analogous issues.

Given the inherent uncertainty associated with viability and fate of affected species and the roles of various taxa in ecosystem function, monitoring and adaptive management will remain crucial to maintaining the effectiveness of both the NWFP (Spies et al. 2019, Spies et al. 2018, DellaSala et al. 2015) and the Tongass' Conservation Strategy (Smith and Flaherty 2023, Marcot 2013, USFS 2008 Workshop Proceedings, Haufler 2006). Statistically defensible monitoring programs can often be resource intensive, but creative approaches that rely on emerging technologies to document species presence (e.g., acoustic monitoring, environmental DNA, etc.) and habitat distribution (e.g., habitat capability modeling based on remote sensing) may allow for increased efficiencies.

Novel modeling approaches have been developed to incorporate habitat needs of target species into evaluations of reserve effectiveness (e.g., Burns et al. 2013, Suring 2012, Haight and Travis 2008). Some combination or variation of these methods could prove useful in an evaluation and potential update of the reserve system on the Tongass. Such models rely on data that may not exist for many of the species in Southeast Alaska, however.

Climate Change Considerations

Like the NWFP, the Tongass' Conservation Strategy was developed without explicit consideration of climate change. The Tongass, however, has been recognized as an important contributor to global climate mitigation due to its ability to sequester and store substantial quantities of carbon. The rate of carbon sequestration and the amount of carbon stored is well understood to vary across forest stand ages, with younger stands (approximately 30-120 years) sequestering carbon at the fastest rate and older (120+ years) storing the greatest amount of carbon (Pregitzer and Euskirchen 2004). The extensive areas of mature and old-growth forest within the Tongass has prompted many to regard the Tongass as globally significant with regard to the carbon stored within its forest ecosystems. Despite not considering climate change or its stronghold of carbon stores in the development of the Conservation Strategy, there is evidence that climate change is impacting the Tongass. However, as a largely intact temperate rainforest, the Forest may be relatively stable compared to other ecosystems to the south.

Several regions of the Tongass are likely to offer relatively stable vegetative conditions through at least year 2080 in comparison to other areas of the North Pacific rainforest (which extends from northern California to the Kodiak archipelago) (DellaSala et al. 2018). These recent findings support DellaSala's (2015) earlier recommendation to consider more and larger reserves on the Tongass, particularly on north-facing slopes as potential climate micro-refugia. Areas identified as likely to provide greater stability in a changing climate should also be considered for reserves, if not already protected (DellaSala et al. 2018).

As vegetation responds to climate change, we can expect broad shifts in habitat conditions and distributions (DellaSala et al. 2018, Buma and Barrett 2015, Shanley et al. 2015). Along with these changes in habitat, we can expect some species to move into Southeast Alaska from the south and east. There are currently many "peripheral" species that occur in the southern portion of Southeast Alaska (e.g., Revillagigedo and Prince of Wales, Misty Fjords National Monument, and vicinity) but not northern Southeast Alaska. Many of these have distributions that extend far to the south, and southern Southeast Alaska represents the northern limit of their range. Plants such as Pacific silver fir (*Abies amabilis*), western red cedar (*Thuja plicata*), and Pacific yew (*Taxus brevifolia*), for example, are all projected to expand their ranges further into Southeast Alaska (Case et al. 2017, Coop and Waring 2011). Animals such as band-tailed pigeon (*Patagioenas fasciata*) and purple shore crab (*Hemigrapsus nudus*), which are largely restricted to southern Southeast Alaska, could extend their ranges northward (limited, in some cases by their dispersal abilities among the islands of the Archipelago). Some species are likely to migrate upslope where higher elevations will provide suitable conditions in the future.

Movement of species from the east, down mainland river corridors, may also be facilitated by receding glaciers and reduced snowpack in the Coast Mountains. Fishers, for example, have recently been documented in the Taku River drainage (Kupferman et al. 2022), where they are likely to impact porcupine and marten populations (Pauli et al. 2022, Manlick et al. 2017). Moose and brown bears have also recently colonized portions of Southeast Alaska via mainland river corridors.

Building climate change resilience into Forest Plans is a focus of the 2012 Planning Rule. The Forest Service is currently evaluating several aspects of climate change and how it may affect management of the Tongass. A thorough review of the topic is beyond the scope of this report, but it is clear that many elements of the current Conservation Strategy, such as protected reserves and connecting corridors, will remain important as the Forest Service endeavors to provide for biodiversity in a changing environment.

It is likely that some aspects of the Conservation Strategy could be expanded or otherwise modified to serve broader purposes than originally envisioned.

We recommend, for example, a spatially explicit evaluation of the connecting corridors designated in the current Conservation Strategy to ensure their adequacy to support movement (including upslope and northerly migration) and maintenance of species expected to be affected by climate change. Nuñez et al. (2013), demonstrated a methodology for identifying broad corridors for movement of organisms between areas where human influence was low while simultaneously routing the corridors along present-day spatial gradients of temperature to facilitate climate resilience in the Pacific Northwest. Such an approach may be useful on the Tongass. Carroll et al. (2010) used climate change projections to model resiliency of conservation reserve systems in the Pacific Northwest for northern spotted owls and 130 other species. They recommended including climate refugia, and incorporating core habitats of diverse taxa in addition to biodiversity hotspots, to maximize reserve system resilience.

Climate change is likely to trigger or facilitate many other impacts to species and habitats across the Tongass. With continued warming, hydrologic changes related to more rapidly melting glaciers and rising elevation of the winter snowline will alter discharge in many rivers and streams across Southeast Alaska, which will have important consequences for terrestrial ecosystems (Wolken et al. 2011). Effects of climate change on salmon, and the many species that rely on nutrients provided by them, are likely to vary depending on location and extent of temperature changes, and could include accelerated or depressed growth rates, or elevated mortality (Zhang et al. 2019). Invasive competitors, novel pathogens and forest pests, increased occurrence of fire, more frequent and significant droughts and floods, loss of alpine habitats to forest encroachment, accelerated primary succession of deglaciated areas, and shifts in plant and insect phenology are all likely to occur (Buma and Barrett 2015, Shanley et al. 2015, Marcot 2013, Wolken et al. 2011, Gayton 2008, Haufler 2006). Increases in vapor pressure deficits could reduce growth of trees (Lopez et al. 2021, Grossiord et al. 2020), impacting timber harvest and forest restoration programs. These changes are likely to interact in unpredictable ways that could create additional unforeseen impacts.

In addition to providing for climate-induced migration, Gayton (2008) recommended reducing non-climate-related stressors to minimize impacts to climate-vulnerable species. We recommend a review of each species expected to be vulnerable to climate change, to consider what threats might be within the Forest Service's ability to reduce. Haufler (2006, p. 25) suggested that such a review could be informed by viability analyses at the scale of individual islands or island groups, for endemics and other species perceived as sensitive to climate change or other habitat impacts on the Tongass.

Ecosystem Integrity and Diversity

Ecosystem Integrity and Diversity are two focuses of the 2012 Planning Rule. The existing Conservation Strategy was designed specifically to conserve integrity of old-growth forest ecosystems across the Tongass, to ensure viability of old-growth associated species. Elements of ecosystem integrity identified in the 2012 Planning Rule include ecosystem structure, function, composition, and connectivity. While the reserve system does appear to provide good representation of functional old-growth forest communities, with many forest types included in the reserve system (Haufler 2006), it was not designed to conserve ecosystem diversity beyond old-growth forests.

The full range of Non-Development LUDs on the Tongass (which are formally included in the Conservation Strategy's reserve system) protect a broad diversity of plant communities and ecosystems beyond old-growth forest. It is not clear, however, how comprehensive this protection is for plant communities other than forested habitats (e.g., muskeg, meadows, etc.) The 2012 Planning Rule requires maintenance or restoration of "the diversity of ecosystems and habitat types throughout the plan area."

Haufler (2006, p. 22) specifically recommended an evaluation of whether all 57 of the plant associations identified on the Tongass are sufficiently represented in the reserve network. There may be other ecosystem or habitat classification schemes in use that would provide additional insight into the range of diversity represented or lacking in the reserves. Such an evaluation now seems particularly warranted, if it has not already been done, given the Planning Rule's requirements related to conservation of ecosystem diversity.

Expansion of the scope of the Conservation Strategy to embrace the full diversity of habitats on the Tongass could help ensure conservation of species not directly associated with old-growth forests. Several amphibians, for example, are found on the mainland and many of the islands of Southeast Alaska (MacDonald and Cook 2007). All are tied to freshwater ponds, streams, or rivers for breeding, but the adults use a variety of habitats. Conservation concerns include habitat fragmentation and disease, with anecdotal reports of local population declines and extirpations (Olson 2009). Documentation of amphibian pathogens in Southeast Alaska, including chytrid fungus (*Batrachochytrium dendrobatidis*) (Hossack et al. 2020) has prompted concerns for some populations. A Conservation Strategy that addresses biodiversity beyond old-growth forest systems could help provide for the needs of amphibians and other species that are less dependent on old-growth forests.

The concepts of resilience, representation, and redundancy (Shaffer and Stein 2000) are widely recognized in the field of conservation biology as critical to effective habitat conservation, and are referred to in the directives of the Forest Service Handbook (Land Management Planning Handbook, 2015, Sec. 1909.12 Chapters 10 and 20). Collectively, the "3Rs" are key to implementation of the Agency's vision for ecosystem integrity, providing a basis for maintaining adaptive capacity to withstand stressors, diversity of plant and animal communities, and persistence of native species.

Resilience refers to the ability of a species or population to withstand perturbations, and relies largely on provision of adequate amounts of functional habitat. This is analogous to the integrity element required by the Planning Rule. Representation acknowledges that organisms exist across a spectrum of natural habitats and conditions, and that this diversity should be maintained to preserve the adaptive potential and range of natural ecosystem processes that have developed through periods of environmental volatility and stability over eons. The Planning Rule's ecosystem diversity requirements directly address representation. The third element, redundancy, recognizes that functional protection must be provided in multiple locations at appropriate scales to ensure that all populations of any species will not be impacted by a major perturbation event. We recommend that each of the plant associations (or other categories of ecosystems/habitats if alternative classification systems are used) on the Tongass be protected in multiple locations where possible and appropriate. This redundancy is especially important for rare communities, which may be particularly vulnerable to stochastic stressors.

Species Viability and Distribution

Language from the 1982 Planning Rule that required “viable” wildlife populations be “well-distributed” across the plan area was the basis for selection of the design species identified by the VPOP committee as they developed the Conservation Strategy in the 1990s. Some of the species were facing viability threats while others were not believed to be well distributed (Suring 1993).

The 2012 Planning Rule does not include the term “well-distributed” to define species vulnerability. Instead, it defines viable populations as those that “persist over the long term with sufficient distribution to be resilient and adaptable to stressors and likely future environments” (emphasis added).

Persistence is mandated for all native species in the plan area under the 2012 Planning Rule. Ecosystem-level plan components are expected to provide for that persistence, for most species. Species-specific plan components are required where ecosystem-level components alone are determined to be inadequate to maintain viability of federally listed endangered, threatened, proposed, or candidate species, and species with recognized viability issues (i.e., designated Species of Conservation Concern). In some cases, species-level plan components may also be necessary for species that are not federally listed or designated by the Forest Service as Species of Conservation Concern.

Persistence implies (or requires) resilience and adaptability, both of which rely on adequate distribution of populations. Species-level plan components may be necessary, in some cases, to provide for that distribution. Nothing in the 2012 Planning Rule precludes including such components for species that are not federally listed or designated as a Species of Conservation Concern to continue to persist over the long term with sufficient distribution.

In the case of the Tongass, which is naturally fragmented by its island archipelago geography (which naturally impacts species’ movements and distributions), ecosystem-level plan components may be adequate to provide for resilience and adaptability of the full range of biodiversity present on individual islands or island complexes. In some cases, however, species-level plan components may be necessary to conserve (for example) endemic forms, unique genetic lineages, or isolated populations, even if those subspecies, lineages, or populations are not facing eminent viability threats. The goal of these species-specific plan components would be to prevent stressors from rising to a level at which viability would become a concern. Where logging or other human-induced habitat alteration will be ongoing, species-level standards or guidelines may be particularly critical, and could explicitly address species distribution necessary to provide resilience and adaptability.

Endemism

Island ecosystems are well known for their incomplete faunas and high levels of endemism (Sawyer et al. 2018, Cook and MacDonald 2013, Losos and Ricklefs 2009, Quammen 1997). Both of these conditions are apparent on the Tongass, where the northern islands, for example, support brown bears but no black bears or wolves while the southern islands have both black bears and wolves; brown bears have only recently been expanding their distribution into the middle and southern islands. All three species are found along the full length of the immediately adjacent mainland (Cook and MacDonald 2013). As another example, both red squirrels (*Tamiasciurus hudsonicus*) and sooty grouse (*Dendragapus fuliginosus*), which are common across much of the Forest, are missing from POW. There are many other known examples of incomplete and uneven faunas across the islands of the Tongass. Continued field

work to document species occurrence across the archipelago remains important, as systematic surveys of biodiversity have occurred on only a small minority of the thousands of islands of Southeast Alaska (Cook and MacDonald 2013, Cook et al. 2006).

Long-term isolation of animal populations in Southeast Alaska, likely established by glacial refugia and post-glacial migrations, and now enforced by the presence of deep saltwater fjords, has led to development of many unique genetic lineages, subspecies, and species (e.g., Sawyer et al. 2019; Dawson et al. 2017, 2014, 2007; Cook and MacDonald 2013, Weckworth et al. 2011, Cook et al. 2006). Even among birds, which are generally less restricted by saltwater channels, endemic forms such as the POW spruce grouse have evolved (Dickerman and Gustafson 1996). This fine-scale genetic diversity on the Tongass is unique among the National Forests, and iconic on a global scale.

The unique biodiversity present on the Tongass requires careful management consideration. Risk assessment panels reviewing the draft Conservation Strategy prior to its adoption in the 1997 Forest Plan, determined that endemic mammals were the most sensitive of all wildlife species to landscape disturbances such as timber harvest (Swanston et al. 1996, p. 11). Protection of unique, isolated, or otherwise sensitive wildlife populations from threats such as logging, mining, human sprawl, tourism, hunting and trapping, and introductions of exotic and domesticated species will remain important (Cook and MacDonald 2013). Because species assemblages and genetic diversity within those assemblages vary across the many islands of Southeast Alaska, Cook et al. (2006) recommended that each island be considered an independent biological unit until managers develop a better understanding of connectivity among the many divergent populations. Smith and Flaherty (2023) reiterated this concern and recommendation. This suggests that persistence of many wildlife populations on the Tongass should be assessed and managed at the scale of islands and island groups, rather than at the scale of the entire Forest as envisioned by the 2012 Planning Rule due to the uniqueness of the Tongass with respect to the level of endemism supported across its many islands. No other National Forest in the system is comprised of an island archipelago at this scale with associated biodiversity and endemism. As a result, additional consideration may be needed to meet objectives for biodiversity in the 2012 Planning Rule and maintain distinct populations across the Tongass compared to other National Forests.

Smith and Flaherty (2023) provided an example of differential impacts of clearcut logging on two superficially similar species with limited dispersal capabilities - Wrangell Island vole (*Myodes gapperi wrangeli*), an endemic habitat specialist adapted to old-growth forest, and Keen's mouse (*Peromyscus keeni macrorhinus*), a widespread habitat generalist that competes directly with the vole and displaces the vole following logging. Management intended to protect the endemic vole, which is known only from Wrangell and Etolin islands, might avoid clearcuts on these two islands, for example, in favor of partial harvests or other logging systems that could maintain suitable habitat for the unique vole.

Even species with good dispersal capabilities may require special consideration where island biogeography limits availability or diversity of prey. Goshawks on POW, for example, have comparatively larger home ranges, higher adult mortality, and lower fledgling production than goshawks elsewhere in Southeast Alaska (Flatten et al. 2002, Titus et al. 2002), presumably because key prey species such as red squirrels, and sooty grouse are absent from POW and surrounding islands but common elsewhere in the region (Lewis et al. 2006, Lewis 2001). Forest management to address such circumstances could, for example, use timber harvest methods and young growth treatments on POW that favor POW spruce grouse and ptarmigan (two key prey species present on the island) while producing habitats that

goshawks can successfully hunt (i.e., forest with open mid-story with small openings to allow for flight). Logging prescriptions might be different on islands where prey communities are more diverse. Similar situations may also exist for other predators, such as wolves.

Conservation of genetic diversity is complicated by incomplete information. Advances in molecular genetics have improved our understanding of the origins and current distribution of genetic diversity across several taxa in Southeast Alaska, yet many taxa have not been investigated. Among those that have, our knowledge of distribution among the thousands of islands of the archipelago remains incomplete. Much of the genetic diversity within the endemic subspecies and lineages remains hidden. A robust reserve system, offering secure habitat distributed across all the islands of the archipelago, remains our best bet for conserving this hidden diversity. Any replacement or modification of the Strategy should recognize this diversity and seek to conserve it.

The existing reserve system was designed specifically to provide undisturbed old-growth habitat on every island of the Tongass. Currently-available information suggests that additional protection and restoration of old-growth connectivity between small OGRs, among other adjustments, may be required to assure that the reserves function as intended (Smith and Flaherty 2023, Smith et al. 2011). But the reserve system provides a solid foundation intended to provide for a broad spectrum of biodiversity.

In addition to conservation of large blocks of suitable habitat linked by terrestrial corridors, Cook and MacDonald (2013) recommended identification and protection of sites that may facilitate connectivity between islands, reiterating a recommendation by Cook et al. (2006) that management plans should prioritize protection of sites that may facilitate connectivity among islands (not just within islands) by establishing logging (and other disturbance) buffers for suspected linkages and wildlife corridors for natural movement of organisms between islands. This approach could, for example, protect natural habitat conditions along both sides of narrow reaches of saltwater between islands, so that animals making the crossing reach suitable habitat rather than lands impacted by logging and roads. Opportunities to conserve suitable habitat, in addition to existing beach buffers, along narrow saltwater reaches could be identified as part of connectivity reviews done for climate change resilience or other goals.

We support Haufler's (2006) recommendation to develop population viability assessments conducted at the scale of individual islands or island groups, within identified endemism zones on the Tongass. For example, such assessments could be done for vulnerable endemics such as the POW flying squirrel within the POW island complex and Pacific marten on Kuiu Island, to ensure that habitat needs and anthropogenic threats are adequately addressed.

Monitoring of select endemic or isolated populations expected to be vulnerable to anthropogenic or climate-induced habitat modification, competition from invasive competitors, or novel pathogens should ideally be included as part of any updated Conservation Strategy, to assess attainment of goals related to maintenance of biological diversity (Cook and MacDonald 2013). There are currently few or no data available to establish baseline population levels (in absolute numbers or as relative index values) or population trends for wildlife on the Tongass, with few exceptions (wolves on POW are one such exception). A statistically-defensible monitoring program focused on endemic taxa potentially impacted by human-induced habitat modification or climate change could fulfill multiple needs, including informing an adaptive management program that seeks to address uncertainty.

We note that monitoring is a mandatory element of forest plans under the 2012 Planning Rule with emphasis on plan-level and broad-scale monitoring to inform adaptive management of ecological and watershed conditions and focal species (i.e., species with viability challenges). Although focal species have yet to be determined for the new Forest Plan, the 2012 Planning Rule does not preclude monitoring other species if they can serve as ‘indicators’ of ecosystem composition, structure, function and connectivity or a measure of biodiversity. For example, the northern flying squirrel may serve as a good indicator of landscape connectivity (Smith 2012).

There is a great deal of new scientific information available on the phylogenetics of many species across the Tongass. A current, comprehensive review of available literature and data on endemism and genetic diversity in Southeast Alaska would help frame the issues more clearly. Knowledge of where unique forms currently occur is useful for Forest planning. Analyses of where those unique populations may be most vulnerable would require additional data on threats, distribution, and (ideally) population demographics, but would be particularly relevant to development of an updated Conservation Strategy tailored to the unique conditions of the Tongass. A comprehensive review of the available genetics literature and synthesis of that information to evaluate vulnerability of specific populations is beyond the scope of this report, but we see this task as useful in development of a strategy for conserving the full range of biodiversity across the Tongass.

Best Available Scientific Information

The 2012 Planning Rule requires the Forest Service to use the “best available scientific information to inform the planning process” and to document how the information was used to inform the assessment, the plan decision, and the required monitoring program. The last comprehensive review of available scientific information relevant to the Conservation Strategy was done in 2006 (USFS 2008 Workshop Proceedings, Haufler 2006). The 2016 Forest Plan amendment was focused specifically on young-growth transition, and was prefaced by an expressed intent to maintain the integrity of the existing Conservation Strategy. Therefore, there was no comprehensive review of recent science related to the Conservation Strategy or its design species.

Relevant new information has been published on conservation planning and the biology of several species that inhabit the Tongass since the last comprehensive review in 2006. Some of this information is highlighted in our discussions above, and in the attached appendices. Much work has been done, for example, on genetic diversity for a variety of taxa, including several not discussed here. Important work on habitat use and dispersal capability has been published for a few key species, including wolves, flying squirrels, and marten. Work to document distribution and abundance of various species has continued, but likely at lower levels than in the recent past. We lack data that might be useful for detecting population trends or changes in distribution for all but a few species (e.g., wolves, mountain goats, and some waterfowl, marine mammals, and seabirds). Recent data on population demographics are particularly scarce or nonexistent for most species. Consequently, we are limited in our ability to detect wildlife population responses to management actions or environmental change.

We encourage interagency efforts to establish statistically defensible monitoring programs for species expected to be vulnerable to Forest management and climate change. If possible, monitoring should be designed to allow evaluation of population-level responses to a wide range of management activities, including habitat restoration efforts, commercial timber harvest, changes in human access (especially via

roads), and game harvests, as well as long-term changes in climate. Strategic monitoring and associated research could establish baseline population indices useful for evaluating performance of the Forest Plan and the Conservation Strategy, and for providing essential feedback on adaptive management and responses to climate change.

The existing Conservation Strategy is based on a considerable foundation of scientific information and expertise, some of which may not be apparent from a reading of the various elements of the Strategy, which are spread throughout the Forest Plan. Modifications to the Strategy should only be considered if they are similarly supported by science.

Our review found scientific support for a few changes to Forest Plan Standards and Guidelines (see **New Information on Conservation Strategy Design Species**). We also found scientific support for a few potential alternatives to the basic structure of the Strategy that might be feasible for the Tongass, including reverse matrix designs (Schmiegelow et al. 2006) and watershed-based approaches (Lertzman and MacKinnon 2013, Schoen and Albert 2007).

Proposed changes to the basic structure of the Conservation Strategy should only be developed with a thorough understanding of accepted principles of conservation biology. Implementation of an alternative structure, such as a reverse matrix or watershed-based design, would require a great deal of analysis and review to ensure that it would accomplish the ambitious goals of conserving old-growth dependent and old-growth associated species, along with the full range of biodiversity required by the 2012 Planning Rule. Building in climate change resilience would require additional consideration. It is likely, though, that pieces of these scientifically-supported alternative designs could be used to strengthen specific elements of the existing Strategy without a major restructuring.

Substantial changes to the structure of the Conservation Strategy should not be considered without additional review of relevant science. Haufler's (2006) review could serve as a template to be updated, for example. We also recommend independent expert review of any substantial modification proposals. The 1997 Strategy was adopted after expert panels on several topics provided useful insight that improved the Strategy. Alternatives to the existing Strategy should be held to a similar level of scientific rigor and scrutiny. Such an effort would require substantial investments of time and funding by both the Forest Service and their agency and tribal partners. Retention of the basic structure of the existing Strategy, with updates to improve consistency with current scientific information and address specific vulnerabilities for identified species and populations, would likely require more modest investments.

Presentations at a scientific workshop, similar to the one held in 2006 (USFS 2008 Workshop Proceedings) focused on recent findings, could provide additional insight on conditions and processes specific to the Tongass, from people who have spent time in this unique place. Such settings tend to generate practical recommendations better suited to Southeast Alaska conditions than more conceptual information available from peer-reviewed, international journals. Both formats, though, have merit and neither is likely to provide a complete picture on its own.

Executive Order 14072 – Strengthening the Nation's Forests, Communities, and Local Economies

On April 22, 2022, President Biden signed Executive Order 14072, declaring it a policy of his administration to pursue science-based, sustainable forest and land management, and “conserve

America's mature and old-growth forests on Federal lands". The Tongass's existing Conservation Strategy might well serve as a national example of how such conservation can be accomplished.

The order directs executive branch agencies to "manage forests on Federal lands, which include many mature and old-growth forests, to promote their continued health and resilience; retain and enhance carbon storage; conserve biodiversity; mitigate the risk of wildfires; enhance climate resilience; enable subsistence and cultural uses; provide outdoor recreational opportunities; and promote sustainable local economic development." The Secretary of Agriculture, working through the U.S. Forest Service, is directed to "analyze the threats to mature and old-growth forests on Federal lands" and develop "conservation strategies that address threats to mature and old-growth forests on Federal Lands." Again, the Tongass is currently well-positioned to provide a longstanding example of a successful conservation strategy (potentially in need of updating to more explicitly address climate resilience or other emerging issues).

Conservation Strategy Options

Revision of the Forest Plan offers an opportunity to evaluate and adjust the Conservation Strategy to reflect current conditions, emerging issues, projections of future conditions, improved understanding of wildlife needs, and current Federal direction on conservation of biodiversity and other forest resources.

The Forest planning process is likely to evaluate a range of management alternatives, from forest-wide prohibitions on old-growth logging to increased intensity and extent of logging and other forms of resource development stimulated, in part, by relaxation of existing management constraints.

Maintaining viability of the many unique wildlife populations across the islands of the Tongass would depend largely on how this development is managed. Here we discuss 3 options for the Conservation Strategy that could be considered: (1) maintenance of the existing Conservation Strategy, updated only as necessary to meet the requirements of the 2012 Planning Rule, (2) elimination of the Conservation Strategy (including old-growth reserves and associated, wildlife-related standards and guidelines), and (3) modification and update of the Conservation Strategy to address current, emerging, and anticipated future conditions.

A broad range of elements could be incorporated into any of these three options. The adequacy of any alternative strategy will depend largely on how resource development such as logging and road construction is managed. Forest Plan alternatives that propose to increase logging or road development, for example, will require higher levels of conservation protection than alternatives that propose to curtail logging of old-growth forest and limit development of new roads. Our recommendations reflect this relationship.

Option #1 - Retain the Conservation Strategy As Is

Although we lack population monitoring data for most species (wolves on Prince of Wales Island are a notable exception), the existing Conservation Strategy appears to be protecting the vulnerable species for which it was designed. The U.S. Fish and Wildlife Service, for example, cited the Conservation Strategy as a factor mitigating threats to three of the design species: Queen Charlotte goshawk (72 FedReg 63123, see pp. 63130-63134), Alexander Archipelago wolf (81 FedReg 435, see pp. 449-450), POW flying squirrel (77 FedReg 52301, see pp 52304-52305) and one non-design, endemic subspecies, the POW spruce grouse (USFWS 2010, see p. 19) in their findings that listing as threatened or

endangered was not warranted for any of the four species. It is likely that at least some of these petition findings would have been different, and that a list of “At Risk Species” for the Tongass would look very different today if the Conservation Strategy had never been implemented. We note that the U.S. Fish and Wildlife Service is currently evaluating a 2020 petition to list the Alexander Archipelago wolf as threatened or endangered with outcome pending.

Many aspects of the existing Conservation Strategy match up well with requirements of the 2012 Planning Rule for ecosystem-level and species-specific plan components. The Conservation Strategy, as is, also addresses key elements of Executive Order 14072 on Strengthening Our Nation’s Forests, which emphasizes protection of mature and old-growth forests. Retaining the structure and content of the Conservation Strategy with updates only as necessary to match current formatting and content requirements would likely maximize efficiency while providing reasonable assurance that old-growth forest ecosystems, including their dependent and associated wildlife, will be conserved across the Tongass. The existing strategy would be part of a “no action” alternative evaluated during the Forest Plan revision. It could also be a logical element of one or more action alternatives.

There are some aspects of the Conservation Strategy, however, that could be enhanced to provide more holistic compliance with the 2012 Planning Rule and current scientific information. Perhaps most notably, the Strategy was not intended to provide for climate resilience. It is likely that the Tongass’ OGR system, as currently configured, provides good climate resilience in many areas of the Forest. Confirming this will require additional assessment. Some key additions (discussed below, under **Modify/Update the Conservation Strategy**) would likely enhance climate resilience.

The Conservation Strategy was designed specifically to maintain the integrity of productive old-growth forest ecosystems. It was not designed to address the full diversity of ecosystems across the Tongass. It is likely that most and perhaps all plant associations (or other appropriate ecosystem classification categories) identified on the Tongass are well represented in the Conservation Strategy’s reserve system. If analysis reveals that some ecosystems are not well represented at multiple locations in the reserve system, the Forest Plan revision process could likely address this to comply with 2012 Planning Rule requirements related to maintenance of ecosystem diversity.

Scientific studies from Southeast Alaska and adjacent coastal British Columbia have identified several potential modifications to species-specific Standards and Guidelines that could reduce impacts of human activity on old-growth-dependent species. These are discussed above (see **New Information on Conservation Strategy Design Species**) and in Appendix A.

Retaining the Conservation Strategy as is, without incorporating the latest scientific information, would be a missed opportunity unless factors such as climate resilience, ecosystem diversity, and updated species-specific protections are incorporated into the revised plan in other ways. At a minimum, the 2012 Planning Rule requires explanation of how the best available scientific information was used to inform the plan revision process.

Option #2 - Eliminate the Conservation Strategy

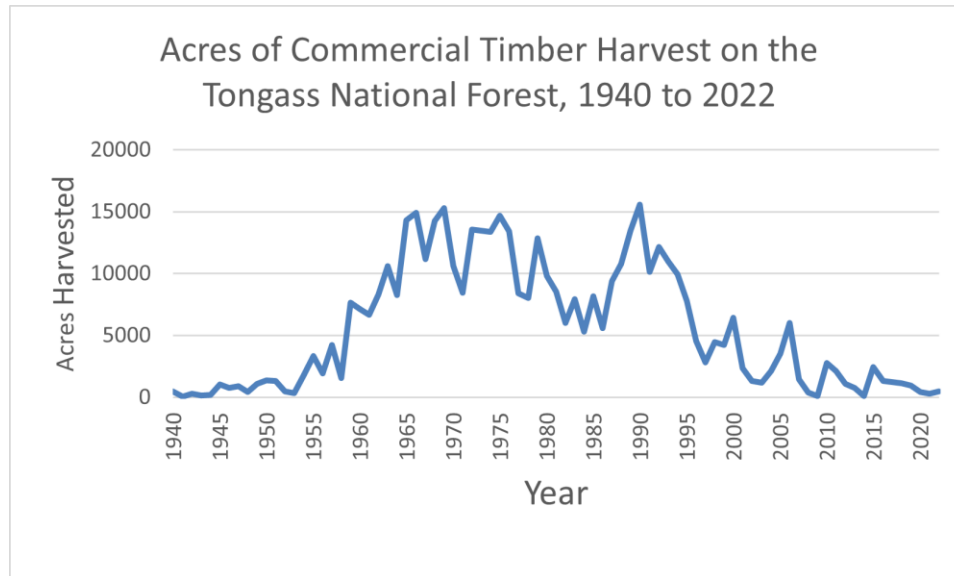
A second option is elimination of a discrete Conservation Strategy, presumably in favor of more general guidance on how and where resource development could occur. Many Forest Plan variations could potentially be formulated with varying levels of restrictions on how programs and activities (e.g., timber, recreation, transportation, mining, hydropower, etc.) would operate, but there would presumably be no

discrete reserves intended specifically for conservation of old-growth-dependent wildlife. Elimination of the Conservation Strategy also implies elimination of standards and guidelines intended to reduce impacts on the old-growth-dependent species that the Conservation Strategy was designed to protect.

Several developments in recent years have resulted in lower impacts to old-growth-associated wildlife than were anticipated when the Conservation Strategy was originally developed, which might be used to justify elimination or relaxation of the Conservation Strategy. For example:

- Old-growth logging on the Tongass has declined substantially over the last several decades, due to a combination of economic and regulatory constraints. Industrial logging increased rapidly between the mid 1950s and 60s, to supply newly-built pulp and sawmills in the region. Harvests were variable but comparatively high through the mid 1990s, averaging over 400 million board feet from nearly 11,000 acres clearcut per year between 1965 and 1995. Since then, harvests have declined, averaging only 47 million board feet from less than 2,000 acres per year since the last pulp mill in the region closed in 1997 (internal Tongass data, see spreadsheet “TNF Timber Volume Harvest”). This history of high harvest levels between the 1960s and 1990s, followed by a decline to present conditions is illustrated in Figure 1, which shows acres logged on the Tongass since 1940, before industrial-scale logging began in the 1950s.
- The 2016 Forest Plan amendment focused on accelerating the transition to harvest of young-growth forests (i.e., stands that have regenerated following past logging or other disturbance) to supplement and ultimately replace harvest of old-growth forest. Restrictions on young-growth harvest in otherwise protected Old-Growth Reserves, Beach and Estuary Buffers, and Riparian Management Areas were relaxed and harvest of old-growth forest in watersheds identified as high priority for conservation was restricted (USFS 2016, ROD). The intent of these changes was to reduce harvest of old-growth forest.
- On July 15, 2021, the U.S. Department of Agriculture (USDA) announced a new Southeast Alaska Sustainability Strategy (SASS) to help support a diverse economy, enhance community resilience, and conserve natural resources. One of the four primary components of the strategy is ending large-scale, old-growth timber harvest on the Tongass and focusing resources to support forest restoration, recreation, climate resilience, and sustainable young-growth forest management. The other 3 components of SASS include restoring the 2001 Roadless Rule protections (see bullet below), engaging with tribal nations, and identifying short- and long-term opportunities for investments.
- The 2001 Roadless Rule has also limited timber harvest on the Tongass, although application of this rule has fluctuated between presidential administrations through a series of Federal rulemakings, court rulings, and executive actions. Most recently, on January 27, 2023, the Forest Service adopted a final rule reinstating the 2001 Roadless Rule, prohibiting timber harvest and road construction in Inventoried Roadless Areas on the Tongass (88 FR 5252, pp. 5252-5272). With the 2001 Roadless Rule in place, over 9.3 million acres of the 17-million-acre Tongass are off limits to timber harvest due to their location within Inventoried Roadless Areas.

Figure 1. Acres of commercial timber harvest on the Tongass National Forest between 1940 and 2022.



Despite recent declines in timber harvest, interest in developing Southeast Alaska’s natural resources is likely to remain. We expect political pressure to vary as successive administrations focus on different programs and priorities. Current efforts, for example, include improving the economics of young-growth timber harvest, stimulating processing and secondary manufacturing, developing renewable energy sources, and expanding recreational opportunities. Future administrations could focus on expanding transportation options, mineral development, and timber harvest (including old-growth). Elimination of the Conservation Strategy now could leave many wildlife populations vulnerable to extirpation if old-growth harvests resume without an adequate strategy in place.

Depending on how resource development and other activities are constrained or otherwise managed, a Forest Plan without dedicated Old-Growth Reserves and species-level standards and guidelines may or may not adequately provide for ecosystem integrity and long-term persistence of the full range of biodiversity across the Tongass.

Extraction of natural resources such as timber and minerals, and development of infrastructure such as roads, buildings, and transmission lines have potential to put some wildlife populations at risk, especially populations with restricted distributions and limited ability to move between islands (Cook and MacDonald 2013). Species that require large tracts of habitat with minimal human disturbance are also particularly vulnerable.

The greatest impacts to wildlife habitat in Southeast Alaska since the arrival of Europeans have been from industrial-scale logging of old-growth forests. If old-growth logging continues, it must be managed to ensure that ecosystem integrity and diversity are conserved and persistence of the full diversity of native wildlife is maintained. Alternative strategies are certainly conceivable, but some combination of Forest Plan components (i.e., a “strategy”) will be required to mitigate potential impacts to forest ecosystems and the native species they support.

Risks to old-growth-dependent wildlife will be dramatically reduced if harvest of old-growth forest is prohibited. Forest Plan alternatives that limit logging to existing second-growth stands will be more likely

to provide for ecological sustainability. Large tracts of undisturbed habitat will, by default, remain intact if future logging is restricted to existing second-growth. The need for specifically-designated Old-Growth Reserves will be reduced. Management constraints for road construction, mining, and other human development will be required to maintain the integrity of specific resources such as remaining large patches of old-growth forest and landscape linkages, but this could potentially be handled through ecosystem-level plan components other than strict delineation of reserve boundaries.

Management of timber harvest to allow for wildlife occupancy and movement through the managed portion of the Forest will remain important, even if logging is restricted to second-growth forests. Some elements of the current Strategy intended to reduce impacts to wildlife, which are typical elements of modern forestry in many places, should be encouraged or required through Forest Plan guidance. For example, restrictions on harvest unit sizes, retention of forest structure within and between harvest units, and protection of sensitive sites such as nest stands, denning habitats, communal roosts, wintering areas, seasonal migration corridors, beach and estuary buffers, freshwater riparian zones, and brood-rearing habitats should be implemented where appropriate. Incorporation of plan components to provide such protection will likely be necessary to meet desired conditions, with or without a dedicated old-growth Conservation Strategy.

Given the political volatility of Tongass logging over the last few decades, any old-growth harvest prohibition might best be considered a temporary condition. Reestablishment of an adequate conservation strategy upon resumption of old-growth logging may not be feasible, given political and budget realities. Retention of a suitable strategy, therefore, may be a more prudent course to provide for long-term conservation of old-growth dependent wildlife, even if timber harvest is restricted to existing second-growth in the next Forest Plan.

Option #3 - Modify/Update the Conservation Strategy

There are many possible ways to incorporate enhancements into an updated Conservation Strategy. The scope of the Strategy could certainly be expanded to more fully embrace requirements of the 2012 Planning Rule. For example, ecosystem diversity and climate resilience could both be explicitly addressed, and likely accommodated with some key modifications. Species-specific plan components could also be updated to better reflect current science. In any case, the existing Strategy provides a solid basis from which to begin as it is foundationally consistent with the 2012 Planning Rule in content, structure, and intent.

Expansion of the Strategy's scope carries a potential downside of diluting focus on (and protection of) productive old-growth forests. Risks associated with this dilution of focus depend largely on how timber harvest and other forms of resource development are managed. If old-growth logging is anticipated to continue or increase or uncertainties exist, continued focus on old-growth forest conservation is warranted. Forest Plan alternatives that prohibit or substantially curtail old-growth logging would likely be strengthened by a Conservation Strategy that addresses a broader suite of resources and ecosystem functions rather than focusing exclusively on old-growth forest.

A Strategy that conserves the complete range of ecosystem diversity will help ensure that all the necessary parts of this complex "machine" remain intact. Haufler (2006) recommended using plant associations to verify that ecosystem diversity is comprehensively represented within the reserve system. There may be other ecosystem classifications in use that would offer better resolution for the

purposes of evaluating representation of ecosystem diversity. We stress that regardless of which ecosystem classification system is used, representation should be redundant (where possible), to account for stochastic disturbances, and forward-focused to account for projected changes attributable to climate change and natural succession.

The existing Conservation Strategy endeavors to address the needs of Southeast Alaska's unique diversity of endemic species and subspecies, genetic lineages, and isolated wildlife and plant populations through coarse filter protection of reserves connected by forested corridors. Timber harvest has been and remains prohibited on all islands smaller than 1,000 acres to protect vulnerable endemics that may be present (USFS 1997, ROD and Forest Plan).

An enhanced Strategy to address genetic diversity within native taxa could include identification and protection of potential movement corridors between islands (Cook and MacDonald 2013). Cooperative, interagency monitoring programs for vulnerable populations of endemic wildlife in places where threats are known or suspected could also be incorporated (Cook and MacDonald 2013) to ensure that goals for maintenance of biodiversity are achieved.

The Tongass has been identified as a globally important storehouse for sequestered carbon, an ecosystem service that could be enhanced by reducing harvest of mature and old-growth forest stands in the region (DellaSala et al. 2022, Leighty et al. 2006). Downscaled climate models have shown that forest communities in some areas of the Tongass are likely to remain relatively stable, in comparison to surrounding lands (DellaSala et al. 2018). Climate resilience could be enhanced through protection of these climate-stable areas and landscape linkages to facilitate climate-induced range shifts of plants and animals.

Recent research has identified a small number of potential improvements that could be made to species-specific elements of the existing Conservation Strategy. These are described above, with author citations, under **“New Information on Conservation Strategy Design Species”** and below in Appendix A. We recommend that these modifications be incorporated during the Forest Plan revision.

Queen Charlotte goshawk – Develop guidelines for management of post-fledging areas, to ensure adequate habitat around nest stands for young birds learning to fly and hunt.

Alexander Archipelago wolf - Expand protection of den sites and associated habitat to improve security and reduce disturbance of denning wolves. Manage surrounding forest to retain adequate old-growth in core denning areas.

Northern flying squirrel – Identify and protect corridors of productive mature or old-growth forest between each Small OGR and its neighboring OGRs and old-growth patches in adjacent non-development LUDs. This will facilitate immigration and improve the likelihood of persistence of flying squirrels in, and recolonization in the event of extirpation from, individual Small OGRs.

Marbled murrelet – Protect old-growth stands occupied by marbled murrelets, rather than only known nests (which are not routinely searched for, difficult to find, and rarely discovered).

An alternative to the current Conservation Strategy is implementation of a “reverse matrix” design, as described in Schmiegelow et al. (2006) and Pletscher (1994). With this design, lands in conservation status serve as the matrix. Management Areas (to use the language of the 2012 Planning Rule) that allow

resource development would be carefully located and appropriately sized to avoid sensitive areas and maintain adequate landscape linkages. Protection of landscape-level habitat features such as remaining large patches of high-volume old-growth, connecting corridors, deer and mountain goat wintering areas, and seasonal migration corridors, for example, might be accomplished through placement of Management Areas away from such features. Finer-scale elements, such as nests, dens, and roosts would likely require establishment of plan components (Standards and Guidelines) that apply within the management areas. Such an approach may be worth considering, as an alternative to the existing Conservation Strategy.

Several elements of Schoen and Albert's (2007) Conservation Strategy for Southeast Alaska could be adapted to improve aspects of the existing Strategy. Old-growth stands within Albert and Schoen's (2007) Conservation Priority Watersheds are already explicitly protected from timber harvest in the 2016 Forest Plan (USFS 2016 ROD). Inclusion of these stands, or the entire watersheds in which they occur, where feasible, could add substantial ecological value to the Conservation Strategy. Second-growth stands in these watersheds could be identified as high priority for restoration work to re-establish uneven age distribution and other old-growth characteristics. Timber Production Watersheds might be useful for identifying suitable old-growth for harvest during transition to primarily or exclusively second-growth harvest. Management Areas for harvest of second-growth after full transition could also be located within Albert and Schoen's (2007) Timber Production Watersheds.

Recommendations

During the Forest Planning Process, several alternatives will likely be considered, potentially ranging from prohibiting all old-growth harvest to continuing old-growth harvest at various levels. Given this range of alternatives, our recommendations below are based on 1) an assumption that some level of management activities may affect old-growth forests and associated species, 2) our understanding of emerging stressors, and 3) consideration of scientific information produced since the last comprehensive review of the Conservation Strategy.

We recommend that the revised Forest Plan include a modified version of the existing Conservation Strategy that explicitly addresses the ecosystem diversity and climate resilience elements of the 2012 Planning Rule (Option #3 - Modify/Update the Conservation Strategy), as discussed above.

Modifications to address ecosystem diversity, for example, could include designation of additional reserves to ensure representation of each plant association (or other categories of ecosystems/habitats if alternative classification systems are used) in multiple locations where possible and appropriate. This redundancy is especially important for rare communities, which may be particularly vulnerable to stochastic stressors. Climate resilience could be incorporated by adding protection for lands projected to offer comparatively stable conditions (e.g., north-facing slopes) and elevational corridors to facilitate climate-induced migration of plants and animals. This expansion of scope should not come at the expense of old-growth conservation.

Species-specific plan components will likely be required in the revised Forest Plan, regardless of whether any Species of Conservation Concern or Focal Species are officially designated, to ensure viability and long-term persistence of all native wildlife. We recommend careful consideration of the existing Standards and Guidelines, which address species-specific needs that are not sufficiently covered by the existing reserve system and connecting corridors. Some of the existing standards and guidelines (i.e.,

those for goshawk, wolf, flying squirrel, and marbled murrelet) should be updated, as described elsewhere in this report, to reflect current science.

We recommend additional consideration of species for which conservation concerns have recently been identified (i.e., marbled murrelet, little brown bat, western screech-owl, and yellow-cedar) as well as select endemic and isolated populations expected to be vulnerable to climate-induced or other anthropogenic habitat modification, competition from invasive competitors, or novel pathogens. Additional evaluations and potential adjustments to the existing Strategy may be warranted to provide for conservation of these species.

Monitoring and adaptive management will be crucial, especially for species, lineages, and populations known or suspected to be sensitive to human-induced habitat alteration or climate change, and for species for which other conservation concerns have emerged. Uncertainty will remain an inherent element of species viability, especially in a changing environment. Monitoring will allow for informed evaluation of how well the revised Forest Plan provides for that viability. Adaptive management will allow managers to adjust as necessary to respond to new information. We recommend working closely with PNW Research Station scientists and other partners to develop statistically defensible monitoring programs to evaluate the effectiveness of the Conservation Strategy in achieving Forest Plan objectives and attaining desired conditions.

We recommend identification and protection of old-growth corridors between Small OGRs and adjacent reserves. (Current guidance requires connectivity only between adjacent Large and Medium OGRs.) Recent studies on the Tongass have identified issues with dispersal and metapopulation functionality for flying squirrels (a primary design species for Small OGRs). Habitat restoration may be required in some areas. We expect that protecting and improving connectivity for flying squirrels would provide habitat benefits for a variety of other species (including marten) that also use forest habitats within the managed matrix.

We recommend that all connecting corridors specified by the Conservation Strategy (i.e., beach, estuary, and riparian buffers, plus additional corridors identified in project-level connectivity analyses) be compiled and formally documented in a Forest-wide GIS layer. This database would be useful for evaluation of Forest Plan alternatives, and during project-level planning and analysis of future timber sales, transportation system additions, and other projects that propose to modify forest vegetation.

We recommend that criteria defining “Very Large” reserves, which are explained in the 1997 Forest Plan ROD but not explicitly described or required in the Forest Plan itself, be included in the revised Forest Plan. (We believe that this omission was an oversight.) Any proposals that would affect land designations should account for, and maintain, the “Very Large” reserves.

We encourage inclusion of the U.S. Fish and Wildlife Service and Alaska Department of Fish and Game (original partners in development of the Conservation Strategy) in discussions related to modification of the Strategy. Both agencies were involved in development of the Strategy and currently rely on it to conserve species for which they have responsibilities. Tribes also have an interest in conservation of wildlife associated with old-growth forest, and should be included in these discussions. (We note that Native corporations have fiduciary interests in maintaining profitability and do not generally speak for the tribes on matters related to wildlife conservation.)

We recommend retention of the Interagency Process (Appendix K of the Forest Plan) for projects with potential to affect the size or configuration of reserves (including any non-development LUDs). Plan components addressing land transfers/conveyances should include guidance alerting lands staff to procedural requirements (Appendix K) and offer an opportunity for interagency review/comment.

Lastly, we recommend compiling all elements of the Conservation Strategy into a discrete, stand-alone document. All relevant standards, guidelines, and direction, along with maps of the full reserve system, should be available in one focused document. Currently this information is dispersed throughout the Forest Plan and the corporate GIS database. In some cases, it is not clear which standards and guidelines are part of the Strategy and which are not. Similarly, it is not well known that non-development LUDs beyond Old-Growth Habitat are formally part of the reserve system. A complete compilation of the Strategy will be particularly useful for development, analysis, and comparison of Forest Plan alternatives during the revision process. This will also help with consistency and communications both with employees and partners.

Appendix C describes several additional evaluations that we believe will help clarify various issues during Assessment and Development phases of the Forest Plan revision.

Conclusions

The existing Conservation Strategy appears to be largely consistent with the 2012 Planning Rule. The Strategy includes both ecosystem-level and species-specific approaches that work in tandem: a reserve network linked by corridors that also provide important habitat (i.e., riparian, beach fringe, and estuary buffers) offers a broad approach to meet the habitat needs of most species. Fine-scale Standards and Guidelines address needs of species unmet by the reserve system alone. We conclude that the basic foundation of the Conservation Strategy is sound, and that the constituent elements of the Strategy will remain relevant for as long as human uses of the Tongass continue. With some modification to address climate change projections and new science related to conservation of affected species, we expect that the Conservation Strategy will continue to maintain the ecological integrity of the diverse natural communities of the Forest. We believe that the Strategy should be maintained (with minor modification) as the backbone of wildlife conservation on the Tongass, to provide for ecosystem diversity and allow for natural processes and disturbances in a manner that allows for sustainable human development.

Literature Cited

- Acker, J. 2012. Recent trends in western screech-owl and barred owl abundances on Bainbridge Island, Washington. *Northwestern Naturalist*, 93:133-137.
- ADF&G Website - [Mountain Goat Species Profile, Alaska Department of Fish and Game](#)
- Alaska Center for Conservation Science. 2017. Alaska Species Ranking System—Little brown myotis (*Myotis lucifugus*). Alaska Natural Heritage Program, University of Alaska Anchorage.
- Albert, D. and J. Schoen. 2007. A Conservation Assessment for the Coastal Forests and Mountains Ecoregion of Southeastern Alaska and the Tongass National Forest. Ch. 2 in A Conservation Assessment and Resource Synthesis for The Coastal Forests and Mountains Ecoregion in the Tongass National Forest and Southeast Alaska. The Nature Conservancy. ([Coastal Forests & Mountains Ecoregion Assessment](#) [\(conservationgateway.org\)](#))
- Andrén, H. 1994. Effects of Habitat Fragmentation on Birds and Mammals in Landscapes with Different Proportions of Suitable Habitat: A Review. *Oikos*, 71(3), 355–366. <https://doi.org/10.2307/3545823>
- Barbaree, B. A., Nelson, S. K., & Dugger, B. D. 2015. Marine space use by marbled murrelets (*Brachyramphus marmoratus*) at a mainland fjord system in Southeast Alaska.
- Barbaree, B. A., Nelson, S. K., Dugger, B. D., Roby, D. D., Carter, H. R., Whitworth, D. L., & Newman, S. H. 2014. Nesting ecology of Marbled Murrelets at a remote mainland fjord in Southeast Alaska. *The Condor*, 116(2), 173–184. <https://doi.org/10.1650/CONDOR-13-116.1>
- Bayard de Volo, S. R. T. Reynolds, S. A. Sonsthagen, S. L. Talbot, and M. F. Antolin. 2013. Phylogeography, postglacial gene flow, and population history of North American northern goshawks (*Accipiter gentilis*). *The Auk* 130(2):342-354.
- Bat Conservation International. 2018. Little Brown Bat (*Myotis lucifugus*). [NABat] North American Bat Monitoring Program. <https://www.nabatmonitoring.org/bats-we-monitor/little-brown-bat>
- Ben-David, M., E. A. Flaherty, and C. A. Eckrich. 2014. Implementation and effectiveness monitoring of small mammal response to biodiversity wildlife thinning. Final report. 10 pages.
- Bennetsen, Bonnie M. B. and Sheila Jacobson. 2016. “Biological Evaluation for Wildlife and Fish for Tongass National Forest Plan Amendment”.
- Bennetsen, Bonnie M. B. 2020. Tongass National Forest young-growth management guidelines for stands with a wildlife management objective. Exhibit 3 of the Tongass Young-Growth Management Strategy, USDA Forest Service, Tongass National Forest, Juneau, Alaska. 86 pages.
- Bertram, D. F., MacDonald, C. A., O’Hara, P. D., Cragg, J. L., Janssen, M. H., McAdie, M., & Boyd, W. S. 2016. Marbled murrelet (*Brachyramphus marmoratus*) movements and marine habitat use near proposed tanker routes to Kitimat, BC, Canada.
- Bidlack, A. L. and J. A. Cook. 2001. Reduced genetic variation in insular northern flying squirrels (*Glaucomys sabrinus*) along the North Pacific Coast. *Animal Conservation* 4:283-290

BirdLife International. 2023. *Species factsheet: Brachyramphus marmoratus*.

<http://datazone.birdlife.org/species/factsheet/marbled-murrelet-brachyramphus-marmoratus>

Blejwas, K. M., Pendleton, G. W., Kohan, M. L., & Beard, L. O. 2021. The Milieu Souterrain Superficiel as hibernation habitat for bats: Implications for white-nose syndrome. *Journal of Mammalogy*, 102(4), 1110–1127. <https://doi.org/10.1093/jmammal/gyab050>

Boland, J., Smith, W., & Hayes, J. 2009. Survey of Bats in Southeast Alaska with Emphasis on Keen's Myotis (*Myotis keenii*). *Northwest Science*, 83, 169–179. <https://doi.org/10.3955/046.083.0301>

Boyer, Christophe. 2020. "Forest Restoration on Haida Gwaii: Implications for Goshawk Habitat". University of Victoria, Restoration of Natural Systems Diploma Program ER 390

Brinkman T. J., D. K. Person, F.S. Chapin III, W. Smith, K. J. Hundertmark. 2011. Estimating abundance of Sitka black-tailed deer using DNA from fecal pellets. *Journal of Wildlife Management* 75(1):232-242

Buma, B. and T. Barrett. 2015. Spatial and topographic trends in forest expansion and biomass change, from regional to local scales. *Global Change Biology* 2015:1-10. doi: 10.1111/gcb.12915

Buma, B., P. E. Hennon, C. A. Harrington, J. R. Popkin, J. Krapek, M. S. Lamb, L. E. Oakes, S. Saunders and S. Zeglen. 2017 Emerging climate-driven disturbance processes: widespread mortality associated with snow-to-rain transitions across 10° of latitude and half the range of a climate-threatened conifer. *Glob Chang Biol* 23:2903–2914. <https://doi.org/10.1111/gcb.13555>

Burger, A. E. 2004. Marbled murrelet (*Brachyramphus marmoratus*), In *Accounts and Measures for Managing Identified Wildlife. Ministry of Environment, Victoria B.C., Canada.*

Burns, E. S., S. F. Tóth, and R. G. Haight. 2013. A modeling framework for life history-based conservation planning. *Biological Conservation* 158:14-25.

Cannings, R. J., and T. Angell. 2001. Western Screech-Owl (*Otus kennicottii*). In *The Birds of North America*, No. 597 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Carroll, C, J. R Dunk, and Moilanen, A. 2010. Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA. *Global Change Biology*. 16(3):891-904.

Carter, H. R., McAllister, M. L. C., & Isleib, M. E. P. 1995. Chapter 27: Mortality of Marbled Murrelets in Gill Nets in North America. In: *Ralph, C. John; Hunt, George L., Jr.; Raphael, Martin G.; Piatt, John F., Technical Editors. 1995. Ecology and Conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; p. 271-284, 152.* <https://www.fs.usda.gov/research/treesearch/27909>

Case, G.. 2013. "Foraging Ecology of the Northern Goshawk in Coastal British Columbia". M.S. Thesis, Oregon State University.

Case, M. J. and J. J. Lawler. 2017. Integrating mechanistic and empirical model projections to assess climate impacts on tree species distributions in northwestern North America. *Global Change Biology*, 23(5), 2005–2015. doi:10.1111/gcb.13570

Coast Forest Conservation Initiative (CFCI). 2012. Maintaining the Integrity of Northern Goshawk Nesting and Post-fledging Areas in the Ecosystem Based Management Plan Area of Coastal British Columbia: Guidance for Forest Professionals.

Colella, J. P., E. J. Johnson, and J. A. Cook. 2018. Reconciling molecules and morphology in North American Martes. *Journal of Mammalogy* 99:1323-1335.

Colella, J. P., R. E. Wilson, S. L. Talbot, J. A. Cook. 2019. Implications of introgression for wildlife translocations: the case of North American martens. *Conservation Genetics* 20:153-166.

Colella, J. P., T. Lan, S. L. Talbot, C. Lindqvist, J. A. Cook. 2021. Whole-genome resequencing reveals persistence of forest-associated mammals in Late Pleistocene refugia along North America's North Pacific Coast. *Journal of Biogeography* 48:1153–1169.

Comeau, V. M. and L. D. Daniels 2022 Multiple divergent patterns in yellow-cedar growth driven by anthropogenic climate change. *Climatic Change* 170: 22

Cook, J. A. and S. O. MacDonald 2013. Island Life - Coming to grips with the insular nature of Southeast Alaska and adjoining coastal British Columbia. Ch 2, pp. 19-42 in G. H. Orians and J. W. Schoen. 2013. North Pacific temperate rainforests – ecology and conservation. Audubon Alaska and the Nature Conservancy of Alaska in association with University of Washington Press. Published by Univ. Washington Press.

Cook, J. A., N. G. Dawson, and S. O. MacDonald. 2006. Conservation of highly fragmented systems: the north temperate Alexander Archipelago. *Biological Conservation*. 133: 1-15.
doi:10.1016/j.biocon.2006.05.026

Coops, N. C. and R. H. Waring. 2011. Estimating the vulnerability of fifteen tree species under changing climate in Northwest North America. *Ecological Modelling* 222 (2011) 2119–2129.

COSEWIC. 2008. COSEWIC assessment and update status report on the Great Blue Heron fannini subspecies *Ardea herodias fannini* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 39 pp.). (link: Species at Risk Status Reports)

COSEWIC. 2012. COSEWIC assessment and status report on the Western Screech-Owl kennicottii subspecies (*Megascops kennicottii kennicottii*) and the Western Screech-Owl macfarlanei subspecies (*Megascops kennicottii macfarlanei*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 30 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

Cronin M. A., A. Canovas, D. L. Bannasch, A. M. Oberbauer, and J. F. Medrano. 2014. Single nucleotide polymorphism (SNP) variation of wolves (*Canis lupus*) in Southeast Alaska and comparison with wolves, dogs, and coyotes in North America. *Journal of Heredity* doi:10.1093/jhered/esu075

Crupi, A. P., R. W. Flynn, L. R. Beier, D. P. Gregovich, and J. N. Waite. 2014. Movement patterns, home range size, and resource selection of brown bears near the Malaspina Glacier, Southeast Alaska. Alaska Department of Fish and Game, Final Wildlife Research Report. ADF&G/DWC/WRR-2014-2, Juneau.

Davis, R. J., D. M. Bell, M. J. Gregory, Z. Yang, A. N. Gray, S. P. Healey, and A. E. Stratton. 2022. Northwest Forest Plan—The First 25 Years (1994–2018): Status and Trends of Late-Successional and Old-Growth

Forests. Gen. Tech. Rep. PNW-GTR-1004. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 82 p. <https://doi.org/10.2737/PNW-GTR-1004>.

Davis, R. J., J. L. Ohmann, R.E. Kennedy, W. B. Cohen, M. J. Gregory, Z. Yang, H. M. Roberts, A. N. Gray, and T. A. Spies. 2015. Northwest Forest Plan—the first 20 years (1994–2013): status and trends of late successional and old-growth forests. Gen. Tech. Rep. PNW-GTR-911. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 112 p. <https://doi.org/10.2737/PNW-GTR-911>.

Davy, C. M., von Zuben, V., Kukka, P. M., Gerber, B. D., Slough, B. G., & Jung, T. S. 2022. Rapidly declining body size in an insectivorous bat is associated with increased precipitation and decreased survival. *Ecological Applications: A Publication of the Ecological Society of America*, 32(7), e2639. <https://doi.org/10.1002/eap.2639>

Dawson, N. G., A. G. Hope, S. L. Talbot, and J. A. Cook. 2014. A multilocus evaluation of ermine (*Mustela erminea*) across the Holarctic, testing hypotheses of Pleistocene diversification in response to climate change. *Journal of Biogeography*, 41: 464–475.

Dawson, N., S. O. MacDonald, and J. A. Cook. 2007. Endemic Mammals of the Alexander Archipelago. Southeast Alaska Conservation Assessment, Chapter 6.7 Available online: https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/alaska/seak/era/cfm/Documents/6.7_EndemicMammals.pdf

Dawson, N. G., J. P. Colella, M. P. Small, K. D. Stone, S. L. Talbot, and J. A. Cook. 2017. Historical biogeography sets the foundation for contemporary conservation of martens (genus *Martes*) in northwestern North America. *Journal of Mammalogy* 98:715–730.

DellaSala, D. A., R. Baker, D. Heiken, C. A. Frissell, J. R. Karr, S. K. Nelson, B. R. Noon, D. Olson and J. Strittholt. 2015. Building on Two Decades of Ecosystem Management and Biodiversity Conservation under the Northwest Forest Plan, USA. *Forests* 2015, 6:3326–3352; doi:10.3390/f6093326

DellaSala, D. A., P. Brandt, M. Koopman, J. Leonard, C. Meisch, P. Herzog, P. Alaback, M. Goldstein, S. Jovan, A. MacKinnon, and H. von Wehrden. 2018. Climate Change May Trigger Broad Shifts in North America's Pacific Coastal Rainforests. *Encyclopedia of the Anthropocene*, pp. 233–244. <https://doi.org/10.1016/B978-0-12-809665-9.09367-8>

DeGange, A. R. 1996. A conservation assessment for the marbled murrelet in Southeast Alaska. *Gen. Tech. Rep. PNW-GTR-388*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p. (Shaw, Charles G., III, Tech. Coord.; *Conservation and Resource Assessments for the Tongass Land Management Plan Revision*), 388. <https://doi.org/10.2737/PNW-GTR-388>

Dickerman, R. W., and J. Gustafson. 1996. The Prince of Wales spruce grouse: a new subspecies from southeastern Alaska. *Western Birds* 27:41–47.

Elliott, K. 2006. Declining numbers of Western Screech-Owl in the lower mainland of British Columbia. *British Columbia Birds* 14:2–11.

Environment Canada. 2016. Management Plan for the Great Blue Heron *fannini* subspecies (*Ardea herodias fannini*) in Canada [Proposed]. *Species at Risk Act Management Plan Series*. Environment Canada, Ottawa. iii + 26 pp.

- Farmer, C. J., D. K. Person, and R. T. Bowyer. 2006. Risk factors and mortality of black-tailed deer in a managed forest landscape. *Journal of Wildlife Management* 70:1403-1415.
- Farmer, C. J. and M. D. Kirchhoff. 2007. Ecological classification of deer habitat in the Tongass National Forest, Alaska. *Northwestern Naturalist* 88:73-84
- Flaherty, E. A., W. P. Smith, S. Pyare, and M. Ben-David. 2008. Experimental trials of the northern flying squirrel (*Glaucomys sabrinus*) traversing managed rainforest landscapes: perceptual range and fine scale movements. *Canadian Journal of Zoology* 86:1050-1058.
- Flaherty, E. A., B. D. Merav, and W. P. Smith. 2010. Diet and food availability: implications for foraging and dispersal of Prince of Wales northern flying squirrels across managed landscapes. *Journal of Mammalogy* 91:79-91.
- Flatten, C., K. Titus, and S. Lewis. 2002. Technical assistance, analysis and dissemination of results from an interagency northern goshawk study on the Tongass National Forest. Alaska Department of Fish and Game.
- Flynn, R. W., T. V. Schumacher, and M. Ben-David. 2004. Abundance, prey availability and diets of American martens: implications for the design of old-growth reserves in Southeast Alaska. Final Wildlife Research Report, U.S. Fish and Wildlife Service Grant DCN 70181-1-G133. Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 43 pages.
- Flynn, R.W., S. B. Lewis, L. R. Beier, G. W. Pendleton. 2007. Brown bear use of riparian and beach zones on northeast Chichagof Island: Implications for streamside management in coastal Alaska. Alaska Department of Fish and Game, Wildlife Research Report. 98 pages.
- Flynn, R. W. and T. V. Schumacher. 2009. Temporal changes in population dynamics of American martens. *Journal of Wildlife Management* 73:1269-1281.
- Flynn, R.W. and T.V. Schumacher. 2016. Habitat selection of American martens on northeast Chichagof Island, Southeast Alaska, 1991-1997. Alaska Department of Fish and Game, Wildlife Research Report ADF&G/DWC/ WRR-2016-6, Juneau. 31 pages.
- Garroway, C. J., J. Bowman, T. J. Cascaden, G. L. Holoway, C. G. Mahan, J. R. Malcolm, M. A. Steele, G. Turner, and P. J. Wilsom. 2010. Climate change induced hybridization in flying squirrels. *Global Change Biology* 16:113-121.
- Gayton, D. V. 2008. Impacts of climate change on British Columbia's biodiversity: A literature review. Extended Abstract. *BC Journal of Ecosystems and Management* 9(2):26-30.
http://www.forrex.org/publications/jem/ISS48/vol9_no2_art4.pdf
- Geraldes, A., K. K. Askelson, E. Nikelski, F. I. Doyle, W. L. Harrower, K. Winker, D. E. Irwin. 2019. Population genomic analysis reveal a highly differentiated and endangered genetic cluster of northern goshawks (*Accipiter gentilis laingi*) in Haida Gwaii. *Evolutionary Applications*. 12:757-772.
- Gilbert, Sophie L. 2015. Environmental Drivers of Deer Population Dynamics and Spatial Selection in Southeast Alaska. PhD Dissertation. ProQuest Number: 3722586

- Gilbert, S. L., T. Haynes, M. S. Lindberg, D. Albert, M. Kissling, and D. K. Person. 2016. Future population trends and drivers of change for Alexander Archipelago wolves on and near Prince of Wales Island, Alaska. *PeerJ Preprints* 4:e1934v1 <https://doi.org/10.7287/peerj.preprints.1934v1>
- Gilbert, S. L., T. Haynes, M. S. Lindberg, D. Albert, M. Kissling, L. Lynch L and and D. K. Person. 2022. Potential Futures for Coastal Wolves and Their Ecosystem Services in Alaska, With Implications for Management of a Social-Ecological System. *Front. Ecol. Evol.* 10:809371. doi: 10.3389/fevo.2022.809371
- Grossiord, C., T. N. Buckley, L. A. Cernusak, K. A. Novick, B. Poulter, R. T. W. Siegwolf, J. S. Sperry and N. G. McDowell. 2020. Plant responses to rising vapor pressure deficit. *New Phytologist* 226:1550–1566. doi: 10.1111/nph.16485
- Haight and Travis 2008. Reserve design to maximize species persistence. *Environ Model Assess* 13:243–253. DOI 10.1007/s10666-007-9088-4
- Hamer, T. E., & Nelson, S. K. 1995. Chapter 6: Characteristics of Marbled Murrelet Nest Trees and Nesting Stands. In: *Ralph, C. John; Hunt, George L., Jr.; Raphael, Martin G.; Piatt, John F., Technical Editors. 1995. Ecology and Conservation of the Marbled Murrelet. Gen. Tech. Rep. PSW-GTR-152. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; p. 69-82, 152.* <https://www.fs.usda.gov/research/treesearch/27888>
- Hanley, Thomas A.; Spalinger, Donald E.; Mock, Kenrick J.; Weaver, Oran L.; Harris, Grant M. 2012. Forage resource evaluation system for habitat—deer: an interactive deer habitat model. Gen. Tech. Rep. PNW-GTR-858. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 64 p
- Hanley, Thomas A.; Gillingham, Michael P.; Parker, Katherine L. 2014. Composition of diets selected by Sitka black-tailed deer on Channel Island, central Southeast Alaska. PNW-RN-570. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p
- Hannah, K. 2009. Call Playbacks Increase Detection Rates of Northern Hawk Owls in Recent Burns. *J. of Raptor Research*, 43(3):241-244. <https://doi.org/10.3356/JRR-08-49.1>
- Hardy, P. C., M. L. Morrison, and R. X. Barry. 1999. Abundance and habitat associations of elf owls and western screech-owls in the Sonoran Desert. *Southwestern Naturalist* 44:311-323.
- Harrer, L. E. F., and T. Levi. 2018. The primacy of bears as seed dispersers in salmon-bearing ecosystems. *Ecosphere* 9(1):e02076. 10.1002/ecs2.2076
- Haufler, J. 2006. Review of Conservation Science Produced Since 1997 and Its Relationship to the Tongass National Forest Land and Resource Management Plan. Report Prepared For Tetra Tech and the Tongass National Forest. Ecosystem Management Research Institute, Seeley Lake, MT. 36pp.
- Hausleitner, D, J. Dulisse, and I. Manley. 2015. Seasonal and sex-biased survival of adult interior western screech-owls (*Megascops kennicottii macfarlanei*) in southeast British Columbia. *Northwestern Naturalist*. 96:205-211.
- Haynes, T. B., & Nelson, S. K. 2011. Dynamics of multi-species feeding associations in marine waters near Juneau, Alaska.

Haynes, T. B., Nelson, S. K., & Newman, S. H. 2010. Diel Shifts in the Marine Distribution of Marbled Murrelets Near Port Snettisham, Southeast Alaska. *Waterbirds*, 33(4), 471–478.

<https://doi.org/10.1675/063.033.0406>

Haynes, T. B., Nelson, S. K., Poulsen, F., & Padula, V. M. 2008. At-sea Habitat Use and Patterns in Spatial Distribution of Marbled Murrelets in Port Snettisham, SE Alaska.

Heinl, S. 2010. Birds of Southeast Alaska – an annotated list from Icy Bay south to Dixon Entrance. Alaska Geographic, Anchorage, AK.

Hendricks, S. A., R. M. Schweizer, R. J. Harrigan, J. P. Pollinger, P. C. Paquet, C. T. Darimont, J. R. Adams, L. P. Waits, B. M. vonHoldt, P. A. Hohenlohe, and R. K. Wayne. 2019. Natural re-colonization and admixture of wolves (*Canis lupus*) in the US Pacific Northwest: challenges for the protection and management of rare and endangered taxa. *Heredity* 122:133–149.

Hendricks, S. A., R. M. Schweizer, and R. K. Wayne. 2018. Conservation genomics illuminates the adaptive uniqueness of North American gray wolves. *Conservation Genetics* 20:29–43.

Hennon PE, D'Amore DV, Schaberg PG, Wittwer DT, Shanley CS. 2012. Shifting climate, altered niche, and a dynamic conservation strategy for yellow-cedar in the North Pacific coastal rainforest. *BioScience*, 62, 147–158.

Hennon, P. E.; C. M. McKenzie, Carol M.; D'Amore, David V.; Wittwer, Dustin T.; Mulvey, Robin L.; Lamb, Melinda S.; Biles, Frances E.; Cronn, Rich C. 2016. A climate adaptation strategy for conservation and management of yellow-cedar in Alaska. Gen. Tech. Rep. PNW-GTR-917. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 382 p.

Hoekman, S. T. 2019. *Kittlitz's Murrelet Monitoring in Glacier Bay National Park and Preserve 2010–2018*. National Park Service, Department of the Interior.

Hossack, Blake R; Adams, Michael J; Honeycutt, R Ken; Belt, Jami J; Pyare, Sanjay. 2020. Amphibian chytrid prevalence on boreal toads in SE Alaska and NW British Columbia: tests of habitat, life stages, and temporal trends. *Diseases of aquatic organisms*. 137(2):159-165.

Hranac, C. R., Haase, C. G., Fuller, N. W., McClure, M. L., Marshall, J. C., Lausen, C. L., McGuire, L. P., Olson, S. H., & Hayman, D. T. S. 2021. What is winter? Modeling spatial variation in bat host traits and hibernation and their implications for overwintering energetics. *Ecology and Evolution*, 11(17), 11604–11614. <https://doi.org/10.1002/ece3.7641>

Hupp, J. W., Hodges, J. I., Jr., Conant, B. P., Meixell, B. W. and Groves, D.J. 2010. Winter Distribution, Movements, and Annual Survival of Radiomarked Vancouver Canada Geese in Southeast Alaska. *The Journal of Wildlife Management*, 74: 274-284. <https://doi.org/10.2193/2009-057>

Hutto, R. L., C. J. Conway, V. A. Saab, and J. R. Walters. 2008. What constitutes a natural fire regime Insight from the ecology and distribution of coniferous forest birds in North America. *Fire Ecology*. 4(2): 115-132.

Interagency Review Team (IRT). 2018. Language for OGR POW LLA. Draft internal report, Tongass National Forest. 23 pp.

Iverson, G. C. 1993. Conservation of the Vancouver Canada goose in southeast Alaska. Pages 91-98 in L. H. Suring, D. C. Crocker-Bedford, R. W. Flynn, C. L. Hale, G. C. Iverson, M. D. Kirchhoff, T. E. Schenck, L. C. Shea, and K. Titus. 1993. A strategy for maintaining well-distributed, viable populations of wildlife associated with old-growth forests in southeast Alaska. S. Dep. Agric. For. Serv. and Dep. Fish and Game, Juneau, Alaska.

Jochum, K., Savory, G., & Reimer, J. 2021. Inventory of Threatened Bat Species on Fort Wainwright, Alaska.

Jones, I. M., Butler, R. W. and Ydenberg, R. C. 2013. Recent switch by the great blue heron *Ardea herodias fannini* in the Pacific northwest to associative nesting with bald eagles (*Haliaeetus leucocephalus*) to gain predator protection. *Canadian Journal of Zoology*, 91(7), pp.489-495.

Kaupas, L. A., & Barclay, R. M. R. 2018. Temperature-dependent consumption of spiders by little brown bats (*Myotis lucifugus*), but not northern long-eared bats (*Myotis septentrionalis*), in northern Canada. *Canadian Journal of Zoology*, 96(3), 261–268. <https://doi.org/10.1139/cjz-2017-0123>

Kelly, E. G., E. D. Forsman, and R. G. Anthony. 2003. Are Barred Owls displacing spotted owls? *Condor*, 105:45-53.

Kiester, A. R. and C. Eckhardt. 1994. Review of Wildlife Management and Conservation Biology on the Tongass National Forest: A Synthesis with Recommendations. Pacific Northwest Research Station, USDA Forest Service.

Kirchhoff, M., and V. M. Padula. 2010. Alaska WatchList: Highlighting Declining and Vulnerable Bird Species in Alaska. *Audubon Alaska, Anchorage, AK*.

Kissling, M. L, and S. B. Lewis. 2009. Overall Recommendations, pp. 156-161 in Kissling, M. L. and S. B. Lewis, 2009. Distribution, abundance, and ecology of forest owls in Southeast Alaska. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska, and Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 215pp.

Kissling, M. L., S. B. Lewis, and D. Cushing. 2009a. Diet of the western screech-owl (*Megascops kennicottii*) in Southeast Alaska. Ch. 5, pp. 119-131 in Kissling, M. L, and S. B. Lewis. 2009. Distribution, abundance, and ecology of forest owls in Southeast Alaska. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska, and Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 215pp.

Kissling, M. L., S. B. Lewis, and G. Pendleton. 2009b. Factors influencing forest owl detectability in Southeast Alaska. Ch. 1, pp. 20-20 in Kissling, M. L, and S. B. Lewis. 2009. Distribution, abundance, and ecology of forest owls in Southeast Alaska. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska, and Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 215pp.

Kissling, M. L., S. B. Lewis, L. Suring, and G. Pendleton. 2009c. Decadal changes in occupancy of forest owls in Southeast Alaska, 1986-2008. Ch 2, pp. 51-83 in Kissling, M. L, and S. B. Lewis. 2009. Distribution, abundance, and ecology of forest owls in Southeast Alaska. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska, and Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 215pp.

- Kissling, M. L., S. B. Lewis, and D. A. Cushing. 2010a, Diet of the western screech-owl in Southeast Alaska. *Western Birds* 41:247-255.
- Kissling, M. L., S. B. Lewis, and G. Pendleton. 2010b. Factors influencing the detectability of forest owls in southeastern Alaska. *Condor*, 112(3):539-548.
- Kissling, M. L., P. Lukacs, S. B. Lewis, S. Gende, K. Kuletz, N. Hatch, S. Schoen, and S. Oehlers. 2011. Distribution and Abundance of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Selected Areas of Southeastern Alaska. *Marine Ornithology*, 39(1), 3–11.
- Koch, C. H. 2016. Effects of demography on resource selection by martens on Kuiu Island, Alaska. University of Wyoming Thesis. 45 pages.
- Koopman, M. E., Hayward, G. D., McDonald, D. B. 2007. High Connectivity and Minimal Genetic Structure Among North American Boreal Owl (*Aegolius funereus*) Populations, Regardless of Habitat Matrix, *The Auk*, Volume 124, Issue 2, 1 April 2007, Pages 690–704. <https://doi.org/10.1093/auk/124.2.690>
- Kunz, F., A. Gamauf, F. E. Zachos, E. Haring. 2019. Mitochondrial phylogenetics of the goshawk *Accipiter gentilis* superspecies. *Journal of Zoological Systematics and Evolutionary Research*. 57:942-958.
- Kupferman, C. A., A. P. Crupi, L. P. Waits, S. L. Gilbert. 2022. Spatial and temporal partitioning of mustelids in Southeast Alaska. *Ecosphere* Volume 12(11) Article e03827
- Lebeda, C. S. and Ratti, J. T., 1983. Reproductive biology of Vancouver Canada geese on Admiralty Island, Alaska. *The Journal of Wildlife Management*, pp.297-306.
- Leighty, Wayne W.; Hamburg, Steven P.; Caouette, John. 2006. Effects of Management on Carbon Sequestration in Forest Biomass in Southeast Alaska. *Ecosystems* 9:(7)1051-1065. DOI: 10.1007/s10021-005-0028-3.
- Lertzman, K. and A. MacKinnon. 2013. Why watersheds-evaluating the protection of undeveloped watersheds as a conservation strategy in northwestern North America. Ch 8, pp. 189-226 in G. H. Orians and J. W. Schoen. 2013. North Pacific temperate rainforests – ecology and conservation. Audubon Alaska and the Nature Conservancy of Alaska in association with University of Washington Press. Published by Univ. Washington Press.
- Lewis, S. B. 2001. Breeding season diet of northern goshawks in southeast Alaska with a comparison of techniques used to examine raptor diet. MS Thesis, Boise State University, Boise, Idaho.
- Lewis, S. B., K. Titus, and M. R. Fuller. 2006. Northern Goshawk Diet During the Nesting Season in Southeast Alaska. *Journal of Wildlife Management*. 70(4):1151-1160.
- Lewis, S. B., and M. L. Kissling. 2009. Habitat range, habitat use, and movements of Western Screech-Owls (*Megascops kennicottii*) in central Southeast Alaska. Ch 3, pp. 84-106 in Kissling, M. L., and S. B. Lewis. 2009. Distribution, abundance, and ecology of forest owls in Southeast Alaska. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska, and Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 215pp.
- Lopez, J., D. A. Way, and W. Sadok. 2021. Systemic effects of rising atmospheric vapor pressure deficit on plant physiology and productivity. *Global Change Biol*. 27:1704-1720.

Losos, J. B., and R. E. Ricklefs. 2009. Adaptation and diversification on islands. *Nature*. 457(12 Feb): 830-836.

MacDonald, S. O. and J. O. Cook. 2007. Mammals and amphibians of Southeast Alaska. Special Publication Number 8, The Museum of Southwestern Biology, University of New Mexico, Albuquerque, New Mexico.

Manlick, P. J., J. E. Woodford, B. Zuckerberg, J. N. Pauli. 2017. Niche compression intensifies competition between reintroduced American martens (*Martes americana*) and fishers (*Pekania pennanti*). *Journal of Mammalogy*, 98(3):690–702.

Manlick, P. J., S. M. Petersen, K. M. Moriarty, J. N. Pauli. 2019. Stable isotopes reveal limited Eltonian niche conservatism across carnivore populations. *Functional Ecology* 33:335–345.

Marcot, B. 2013. Concepts of conservation biology applied to wildlife in old-forest ecosystems, with special reference to Southeast Alaska and northern coastal British Columbia. Ch 7, pp. 168-188 in G. H. Orians and J. W. Schoen. 2013. North Pacific temperate rainforests – ecology and conservation. Audubon Alaska and the Nature Conservancy of Alaska in association with University of Washington Press. Published by Univ. Washington Press.

McClaren, E. L., Mahon, T., Doyle, F. I., & Harrower, W. L. 2015. Science-Based Guidelines for Managing Northern Goshawk Breeding Areas in Coastal British Columbia. *Journal of Ecosystems and Management*, 15(2), 1-91.

Neraas, L., D. Tallmon, M.L. Kissling, and S. B. Lewis. 2009. Genetic variation and sex identification of western screech-owls (*Megascops kennicottii*) in Southeast Alaska. Ch. 6, pp. 132-150 in Kissling, M. L, and S. B. Lewis. 2009. Distribution, abundance, and ecology of forest owls in Southeast Alaska. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska, and Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas, Alaska. 215pp.

Nelson, S. K. 1997. Marbled Murrelet (*Brachyramphus marmoratus*), version 2.0. *Birds of North America*. <https://doi.org/10.2173/bna.276>

Nelson, S. K., & Newman, S. 2009. *Marbled Murrelet Activity Patterns and Health at Port Snettisham, Alaska*. Alaska Department of Fish and Game, Juneau, AK.

Nelson, J., D. Cottam, E. W. Holman, D. J. Lancaster, S. McCorquodale, and D. K. Person. 2008. Habitat guidelines for black-tailed deer: Coastal Rainforest Ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies. 49 pages

Nesvaci, K. A., P.G. W. Pendleton, M. Kissling, M. Spathelf, and Lukacs. 2018. *Assessing Kittlitz's and Marbled Murrelet Abundance at Sites in Southeast Alaska, and their Applicability for Long-term Monitoring* (p. 12).

Nikolov, B. P., Zlatanov, T, Groen, T., Stoyanov, S., Hristova-Nikolova, I., Lexer, M. J. 2022. Habitat requirements of Boreal Owl (*Aegolius funereus*) and Pygmy Owl (*Glaucidium passerinum*) in rear edge montane populations on the Balkan Peninsula. *Avian Research*, Volume 13, 2022. <https://doi.org/10.1016/j.avrs.2022.100020>

- Norris, R., Arcese, P., Preikshot, D., & Bertram, D. 2007. Diet reconstruction and historic population dynamics in a threatened seabird. *Journal of Applied Ecology*, 44, 875–884.
<https://doi.org/10.1111/j.1365-2664.2007.01329.x>
- Núñez, T. A., J. J. Lawler, B. H. McRae, D. J. Pierce, M. B. Krosby, D. M. Kavanagh, P. H. Singleton, and J. J. Tewksbury. 2013. Connectivity Planning to Address Climate Change. *Conservation Biology*, Volume 00, No. 0, 1–10 DOI: 10.1111/cobi.12014
- Oakes L. E., Hennon P.E., Ardoin N.M. et al. 2015 Conservation in a social-ecological system experiencing climate-induced tree mortality. *Biological Conservation*, 192, 276–285.
- Olson, G. S., R. G. Anthony, E. D. Forsman, S. H. Ackers, P. J. Loschl, J. A. Reid, K. M. Dugger, E. M. Glenn, and W. J. Ripple. 2005. Modeling of site occupancy dynamics for Northern Spotted Owls, with emphasis on the effects of Barred Owls. *Journal of Wildlife Management* 69:918-932.
- Olson, D. 2009. Herpetological conservation in northwestern North America. *Northwestern Naturalist*, 90:61-96.
- Pacheco, C., A. V. Stronen, B. Jędrzejewska, K. Plis, I. M. Okhlopkov, N. V. Mamaev, S. V. Drovetski, and R. Godinho. 2022. Demography and evolutionary history of grey wolf populations around the Bering Strait. *Molecular Ecology* 31:4851–4865.
- Parker, D. I., Cook, J. A., & Lewis, S. W. 1996. Effects of timber harvest on bat activity in Southeastern Alaska's temperate rainforests. *Bats and Forests Symposium*.
- Parks Canada Agency. 2018. Recovery Strategy for the Northern Goshawk *laingi* subspecies (*Accipiter gentilis laingi*) in Canada. Species at Risk Act Recovery Strategy Series. Parks Canada Agency, Ottawa. 2 parts, 34 pp. + Appendices + 56 pp.
- Patriquin, K. J., & Barclay, R. M. R. 2003. Foraging by Bats in Cleared, Thinned and Unharvested Boreal Forest. *Journal of Applied Ecology*, 40(4), 646–657.
- Pauli, J. N., W. P. Smith, M. Ben-David. 2012. Quantifying dispersal rates and distances in North American martens: a test of enriched isotope labeling. *Journal of Mammalogy*, 93(2):390–398.
- Pauli, J. N., W. E. Moss, P. J. Manlick, E. D. Fountain, R. Kirby, S. M. Sultaire, P. L. Perrig, J. E. Mendoza, J. W. Pokallus, and T. H. Heaton. 2015. Examining the uncertain origin and management role of martens on Prince of Wales Island, Alaska. *Conservation Biology*, Volume 29, No. 5, 1257–1267
- Pauli, Jonathan N., Ecological studies of the American marten (*Martes americana*): quantifying cryptic processes in an elusive species, Ph.D., Program in Ecology, May, 2010.
- Pauli, J. N., P.J. Manlick, J. M. Tucker, G. Bradley Smith, P.G. Jensen, J.T. Fisher. 2022. Competitive overlap between martens *Martes americana* and *Martes caurina* and fishers *Pekania pennanti*: a rangewide perspective and synthesis. *Mammal Review* ISSN 0305-1838.
- Pearson, R. R., and K. B. Livezey. 2003. Distribution, numbers and site characteristics of Spotted Owls and Barred Owls in the Cascade Mountains of Washington. *Journal of Raptor Research* 37:265-276.
- Person, David K; Ingle, Moira A.; Kirchhoff, Matthew; Bowyer, Terry R. 1996. The Status and Conservation of the Alexander Archipelago Wolf in Southeastern Alaska. *Wolves of America Conference Proceedings* 1996. Albany, NY

- Person, D. K. and A. L. Russell. 2008. Correlates of mortality in an exploited wolf population. *The Journal of Wildlife Management*. 72(7):1540-1549
- Person, D. K. and A. L. Russell. 2009. Reproduction and den site selection by wolves in a disturbed landscape. *Northwest Science* 83:211-224.
- Person, D., C. Farmer, P. O'Connor, and J. Doerr. 2009. Habitat use and survivorship of Sitka black-tailed deer in Southeast Alaska: a regional meta-analysis and synthesis. Alaska Department of Fish and Game Federal Aid Annual Research Performance Report. 13 pages
- Person, D. K. and B. D. Logan. 2012. A spatial analysis of wolf harvest and harvest risk on Prince of Wales and associated islands, Southeast Alaska. Final Wildlife Research Report, ADF&G/DWC/WRR-2012-06, Alaska Department of Fish and Game, Juneau, Alaska. 29 pages.
- Person, D. K. and Brinkman, T. J. 2013. Succession debt and roads. In: G. H. Orians and J. W. Schoen (eds), *North Pacific temperate rainforests*. Univ. of Washington Press, pp. 143– 167.
- Piatt, J. F., Kuletz, K., Burger, A. E., Hatch, S., Friesen, V., Birt, T., Arimitsu, M., Drew, G., Harding, A., & Bixler, K. (2007). *Status Review of the Marbled Murrelet (Brachyramphus marmoratus) in Alaska and British Columbia*. Open-File Report 2006–1387. US Geological Survey.
- Pontius, K. E., & Kirchhoff, M. D. 2009. Prey-Capture by Marbled Murrelets in Southeast Alaska. *Northwestern Naturalist*, 90(2), 151–155.
- Pregitzer, K.S.; Euskirchen, E.S. 2004. Carbon cycling and storage in world forests: biome patterns related to forest age. *Global Change Biology*. 10: 2052–2077
- Proudfoot, G. A., F. R. Gehlbach, and R. L. Honeycutt. Mitochondrial DNA variation and phylogeography of the eastern and western screech-owls. *Condor*, 109:617-627.
- Pyare, S. and W. S. Longland. 2002 Interrelationships among northern flying squirrels, truffles, and microhabitat structure in Sierra Nevada old-growth habitat. *Canadian Journal of Forest Research* (32): 1016-1024.
- Pyare, S., W. P. Smith, C. S. Shanely. 2010. Den use and selection by northern flying squirrels in fragmented landscapes. *Journal of Mammalogy*, 91(4):886-896.
- Quammen, D. 1997. *The Song of the Dodo: Island Biogeography in an Age of Extinction*. Scribner Book Co. ISBN: 9780684827124.
- Roffler, G. H. and D. P. Gregovich. 2018. Wolf space use during denning season on Prince of Wales Island Alaska. Nordic Board for Wildlife Research. *Wildlife Biology*. <https://bioone.org/journals/Wildlife-Biology> on 25 Jan 2021
- Roffler, G. H., D. P. Gregovich, and K. R. Larson. 2018. Resource selection by coastal wolves reveals the seasonal importance of seral forest and suitable prey habitat. *Forest Ecology and Management* 409:190-201.
- Roffler, G. H., J. M. Allen, A. Massey, and T. Levi. 2021. Metabarcoding of fecal DNA shows dietary diversification in wolves substitutes for ungulates in an island archipelago. *Ecosphere* 12(1):e03297.10.1002/ecs2.3297

Sawyer, Y. E., S. O. MacDonald, E. P. Lessa, and J. A. Cook. 2019. Living on the edge: Exploring the role of coastal refugia in the Alexander Archipelago of Alaska. *Ecology and Evolution* 9:1777–1797.

Schoen, J. and D. Albert. 2007. Southeastern Alaska Conservation Strategy: A Conceptual Approach. Ch. 10 in *A Conservation Assessment and Resource Synthesis for The Coastal Forests and Mountains Ecoregion in the Tongass National Forest and Southeast Alaska*. The Nature Conservancy and Audubon Alaska. ([Ch10 SE AK Conserv Strategy Conceptual Approach-conservationgateway.org](#))

Schoen, J. and M. Kirchhoff. 2007. Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). Chapter 6.1 (17 pages) in Schoen, J. W. and E. Dovichin (editors): *The coastal forests and mountains ecoregion of southeastern Alaska and the Tongass National Forest: a conservation assessment and resource synthesis*. Audubon Alaska and The Nature Conservancy, Anchorage, Alaska.

Schoen, S. K., Kissling, M. L., Hatch, N. R., Shanley, C. S., Stephensen, S. W., Jansen, J. K., Catterson, N. T., & Oehlers, S. A. 2013. Marine birds of Yakutat Bay, Alaska: Evaluating summer distribution, abundance, and threats at sea.

Schmiegelow, F. K. A., S. G. Cumming, S. Harrison, S. Leroux, K. Lisgo, R. Noss, and B. Olson. 2006. Conservation beyond crisis management: a reverse-matrix model – A discussion paper for the Canadian BEACONS project. 18pp.

Schweizer, R. M., B. M. vonHoldt, R. Harrigan, J. C. Knowles, M. Musiani, D. Coltman, J. Novembre, and R. K. Wayne. 2016. Genetic subdivision and candidate genes under selection in North American grey wolves. *Molecular Ecology* 25:380–402.

Shaffer, M. L. and B. A. Stein. 2000. Safeguarding Our Precious Heritage. Pages 301-321 in B.A. Stein, L.S. Kutner and J.S. Adams (eds.), *Precious Heritage: The Status of Biodiversity in the United States*. Oxford University Press, New York.

Shakeri, Y. N., K. S. White, and T. Levi. 2018. Salmon-supported bears, seed dispersal, and extensive resource subsidies to granivores. *Ecosphere* 9(6):e02297. [10.1002/ecs2.2297](#)

Shanley, C. S., S. Pyare, and W. P. Smith. 2013. Response of an ecological indicator to landscape composition and structure: implications for functional units of temperate rainforest ecosystems. *Ecological Indicators* 24:68– 74.

Shanely, C. S., D. R. Eacker, C. P. Reynolds, B. M. Bennetsen. 2021. Using LiDAR and random forest to improve deer habitat models in a managed forest landscape. *Forest Ecology and Management* 499.

Shaw, C. G. 1999. Use of Risk Assessment Panels During Revision of the Tongass Land and Resource Management Plan. USDA Forest Service, Pacific Northwest Research Station. PNW-GTR-460.

Shively, R., & Barboza, P. 2017. Range and Roosting Ecology of the Little Brown Bat, *Myotis Lucifugus*, in Interior and Northern Alaska. *Northwestern Naturalist*, 98(2), 122–131.

Slough, B., Lausen, C., Paterson, B., Hansen, I., Thomas, J., Kukka, P., Jung, T., Rae, J., & Wetering, D. 2022. New records about the diversity, distribution, and seasonal activity patterns by bats in Yukon and northwestern British Columbia. *Northwestern Naturalist*, 103, 162–182.

<https://doi.org/10.1898/NWN21-10>

- Smith, A. B., Kissling, M., Capuano, A. M., Lewis, S. B., & Mooney, T. A..2023. Aerial hearing thresholds and ecoacoustics of a threatened pursuit-diving seabird, the marbled murrelet *Brachyramphus marmoratus*. *Endangered Species Research*, 50, 167–179. <https://doi.org/10.3354/esr01234>
- Smith, J. R. and G. Sutherland. 2008. (DRAFT) “Northern Goshawk (*Accipiter gentilis laingi*) Habitat and Territory Models”. Coastal British Columbia, Cortex Consultants prepared for: The Northern Goshawk Habitat Recovery Implementation Group.
- Smith, W. P. 2012. Sentinels of ecological processes: the case of the northern flying squirrel. *BioScience* 62:950- 961.
- Smith, W. P. 2013. Spatially explicit analysis of contributions of a regional conservation strategy toward sustaining northern goshawk habitat. *Wildlife Society Bulletin* 37(3)649-658.
- Smith, W. P., and E. A. Flaherty. 2023. Wildlife studies on the Tongass National Forest challenge essential assumptions of its wildlife conservation strategy. *J. Wildlife Management*. DOI: 10.1002/jwmg.22450
- Smith, W. P., S. M. Gende, and J. V. Nichols. 2005. The northern flying squirrel as an indicator species of temperate rain forest: test of an hypothesis. *Ecological Applications* 15:689-700.
- Smith, W. P. and D. K. Person. 2007. Estimated persistence of northern flying squirrel populations in temperate rain forest fragments of Southeast Alaska. *Biological Conservation* 37:626-636.
- Smith, W. P, D. K. Person, and S. Pyare. 2011. Source–sinks, metapopulations, and forest reserves: conserving northern flying squirrels in the temperate rainforests of Southeast Alaska. Pages 399–422 in J. Liu, V. Hull, A. T. Morzillo, and J. Wiens, editors. *Sources, sinks, and sustainability across landscapes*. Cambridge University Press, New York, New York, USA.
- Snively, M. L., G. W. Pendleton. K. S. Christie. And K. M. Blejwas. 2021. Little brown myotis activity patterns in South-Central Alaska. *Northwestern Naturalist*, 102(3), 216–231. <https://doi.org/10.1898/1051-1733-102.3.216>
- Sonsthagen, S. A., E. L. McClaren, F. I. Doyal, K. Titus, G. K. Sage, R. E. Wilson, J. R. Gust, and S. L. Talbot. 2012. Identification of metapopulation dynamics among Northern Goshawks of the Alexander Archipelago, Alaska, and Coastal British Columbia. *Conservation Genetics* 13:1045–1057.
- Spies, T. A., J. W. Long, S. Charnley, P. F. Hessburg, B. G. Marcot, G. H. Reeves, D. B. Lesmeister, M. J. Reilly, L. K. Cerveney, P. A. Stine, and M. G. Raphael. 2019. Twenty-five years of the Northwest Forest Plan: what have we learned? *Front Ecol Environ* 2019; doi:10.1002/fee.2101.
- Spies, T. A., P. A. Stine, R. Gravenmier, J. W. Long, and M. J. Reilly. 2018. Synthesis of science to inform land management within the Northwest Forest Plan area. Portland, OR: USFS, Pacific Northwest Research Station. Gen Tech Rep PNW-GTR-966.
- Stewart, M. E. 2022 Correspondence concerning Administrative Change 2 to 2016 Forest Plan due to Mental Health Trust Land Exchange, with enclosure, dated April 26, 2022. File Code: 1920. USDA Forest Service, Tongass National Forest, Ketchikan, AK.
- Suring, L. H., D. C. Crocker-Bedford, R. W. Flynn, C. S. Hale, G. C. Iverson, M. D. Kirchhoff, T. E. Schenck, L. C. Shea, and K. Titus. 1993. A Proposed Strategy for Maintaining Well-distributed Viable Populations of

Wildlife Associated with Old-growth Forests in Southeast Alaska. U.S. Department of Agriculture, Forest Service, Alaska Region; report of the interagency committee, Tongass Land Management Planning Team. Final Review Draft.

Suring, L. 2012. Modeling the Habitat Relationships of Species of Conservation Concern in Old Forests of Southeast Alaska, USA. Prepared for the USDA Forest Service Alaska Region and Tongass National Forest, Juneau, Alaska. Northern Ecologic L.L.C., Suring, Wisconsin. Technical Bulletin 2012–1.

Swanston, D. N., C. G. Shaw III, W. P. Smith, K. R. Julin, G. A. Cellier, and F. H. Everest. 1996. Scientific Information and the Tongass Land Management Plan: Key Findings from the Scientific Literature, Species Assessments, Resource Analyses, Workshops, and Risk Assessment Panels. USDA Forest Service General Technical Report PNW-GTR-386

Tessler, D., M. Snively, and T. Gotthardt. 2014. New Insights on the Distribution, Ecology, and Overwintering Behavior of the Little Brown Myotis (*Myotis lucifugus*) in Alaska. *Northwestern Naturalist*, 95. <https://doi.org/10.1898/13-12.1>

Thomas, J. P., & Jung, T. S. 2019. Life in a northern town: Rural villages in the boreal forest are islands of habitat for an endangered bat. *Ecosphere*, 10(1), e02563. <https://doi.org/10.1002/ecs2.2563>

Thomas, J. P., Kukka, P. M., Benjamin, J. E., Barclay, R. M. R., Johnson, C. J., Schmiegelow, F. K. A., & Jung, T. S. 2021. Foraging habitat drives the distribution of an endangered bat in an urbanizing boreal landscape. *Ecosphere*, 12(3), e03457. <https://doi.org/10.1002/ecs2.3457>

Thomas, J. P., Reid, M. L., Jung, T. S., & Barclay, R. M. R. 2019. Site occupancy of little brown bats (*Myotis lucifugus*) in response to salvage logging in the boreal forest. *Forest Ecology and Management*, 451, 117501. <https://doi.org/10.1016/j.foreco.2019.117501>

Titus, K., C. Flatten, G. W. Pendleton, R. Lowell, and S. Lewis. 2002. Northern goshawk survival rates -- Tongass National Forest, Alaska (Poster presentation). 3rd North American Ornithological Conference. New Orleans, LA.

Tongass Plan Implementation Team (TPIT). 1998. Tongass National Forest Land and Resources Management Plan Implementation Policy Clarification. USDA Forest Service, Alaska Region, Tongass National Forest, August 1998.

Trapp, S. E., C. C. Day, E. A. Flaherty, P. A. Zollner, and W. P. Smith. 2019. Modeling impacts of landscape connectivity on dispersal movements of northern flying squirrels (*Glaucomys sabrinus griseifrons*). *Ecological Modelling* 394:44-52.

Trout Unlimited. Undated. The Tongass 77: a closer look. Trout Unlimited, Alaska Program. Available online at [The Tongass 77 - America's Salmon Forest \(americansalmonforest.org\)](https://americansalmonforest.org). 23pp.

United States Fish and Wildlife Service (USFWS). 2007. Queen Charlotte goshawk status review. USFWS Alaska Region, Juneau Fish and Wildlife Field Office. 169 pp.

USFWS. 2010. Species assessment and listing priority assignment form, Prince of Wales spruce grouse. USFWS, Alaska Region, Anchorage Field Office. 28 pp.

USFWS. 2015. Species status assessment for the Alexander Archipelago wolf (*Canis lupus ligoni*). Version 1.0, December 2015. USDI Fish and Wildlife Service Alaska Region, Anchorage, Alaska. 162 pages.

United States Forest Service (USFS). 1997. (“ROD/FEIS”) Tongass Land Management Plan Revision, Record of Decision, Final Environmental Impact Statement, Appendices; Vols 1-4, and Errata). USDA Forest Service, Alaska Region, Tongass National Forest. R10-MB-338dd.

USFS. 1997. (“Forest Plan”) Tongass National Forest Land and Resources Management Plan. USDA Forest Service, Alaska Region, Tongass National Forest. R10-MB-338dd.

USFS. 2008. (“ROD/FEIS”) Tongass Land and Resource Management Plan Final Environmental Impact Statement Plan Amendment Record of Decision. USDA Forest Service. R10-MB-603a.

USFS. 2008. (“Forest Plan”) Tongass National Forest Land and Resource Management Plan. USDA Forest Service R10-MB-603b.

USFS. 2008. (“Workshop proceedings”) Interagency Conservation Strategy Review: An Assessment of New Information Since 1997, Workshop Summary Report with Considerations Resolution Matrix. April 10-14, 2006, Ketchikan, Alaska. USDA Forest Service. 169pp.

USFS. 2016. (“ROD”) Tongass National Forest Land and Resources Management Plan – Record of Decision. Forest Service Alaska Region, Tongass National Forest. R10-MB-769l.

USFS. 2016. (“Forest Plan”) Tongass National Forest Land and Resource Management Plan. USDSA Forest Service Alaska Region, Tongass National Forest. R10-MB-769j

USFS. 2019. Prince of Wales Landscape Level Analysis Project - Record of Decision and Appendices 1 – 4. USDA Forest Service, Alaska Region, Tongass National Forest Thorne Bay Ranger District and Craig Ranger District. R10-MB-833m. March 2019.

Vennesland, R. G. 2018. Analysis of studies on the availability of northern goshawk foraging habitat in known versus randomly generated home ranges on the coast of British Columbia. Parks Canada Agency.

Weckworth, B. V., N. G. Dawson, S. L. Talbot, M. J. Flamme, J. A. Cook. 2011. Going Coastal: Shared Evolutionary History between Coastal British Columbia and Southeast Alaska Wolves (*Canis lupus*). PLoS ONE 6(5): e19582. doi:10.1371/journal.pone.0019582

Weckworth, B. V, N. G. Dawson, S. L. Talbot, J. A. Cook. 2015. Genetic distinctiveness of Alexander Archipelago wolves (*Canis lupus ligoni*): Reply to Cronin et al. (2015). Journal of Heredity, 2015 1-3 (Letter to the Editor)

Weigl, P. D. 2007. The northern flying squirrel (*Glaucomys sabrinus*): a conservation challenge. Journal of Mammalogy, 88(4):897-907.

Wheat, R. E., and C. C. Wilmers. 2016. Habituation reverses fear-based ecological effects in brown bears (*Ursus arctos*). Ecosphere 7(7):e01408. 10.1002/ecs2.1408

Whitman, Jackson S. 2009. Diet and prey consumption rates of nesting Boreal Owls, *Aegolius funereus*, in Alaska. Canadian Field-Naturalist 123(2): 112-116.

Wolf Technical Committee. 2017. Interagency Wolf Habitat Management Program: recommendations for Game Management Unit 2. USDA Forest Service, USDI Fish and Wildlife Service, and Alaska Department of Fish and Game, Management Bulletin R10-MB-822. 38 pages.

Wolken, J. M., T. N. Hollingsworth, T. S. Rupp, F. S. Chapin, S. F. Trainor, T. M. Barrett, P. F. Sullivan, A. D. McGuire, E. S. Euskirchen, P. E. Hennon, E. A. Beever, J. S. Conn, L. K. Crone, D. V. D'Amore, N. Fresco, T. A. Hanley, K. Kielland, J. J. Kruse, T. Patterson, E. A. G. Schuur, D. L. Verbyla, and J. Yarie. 2011. Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. *Ecosphere* 2(11):124. doi:10.1890/ES11-00288.1

Woodford, R. 2022. Good News for Alaska Bats. Alaska Fish & Wildlife News.
http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=1032

Woolington, J. D. 1984. Habitat use and movements of river otters at Kelp Bay, Baranof Island, Alaska. Thesis, University of Alaska, Fairbanks, Alaska. 147 pages.

Zarn, K. E. 2019. Genomic Inference of Inbreeding in Alexander Archipelago Wolves (*Canis lupus ligoni*) on Prince of Wales Island, Southeast Alaska. Graduate Student Theses, Dissertations, & Professional Papers. 11497. <https://scholarworks.umt.edu/etd/11497>

Zhang, X., H-Y Li, Z.D. Deng, L. R. Leung, J. R. Skalski, and S. J. Cooke. 2019. On the variable effects of climate change on Pacific salmon. *Ecological Modelling*. 397:95-106.

Appendix A – Summary and new information on original Conservation Strategy design species

Queen Charlotte Goshawk (*Accipiter gentilis laingi*)

The Queen Charlotte goshawk is a subspecies of the northern goshawk that nests and hunts in the mature and old-growth forests of coastal British Columbia and Southeast Alaska. Primary prey includes a variety of birds and small mammals, including grouse, ptarmigan, squirrels, hares, jays, thrushes, woodpeckers, crows, and similar-sized animals. Prey availability, and therefore diet, varies from island to island and along the mainland, across the range of the subspecies. Mature and old-growth forest are critical for supporting adequate populations of forest-dwelling prey in habitat that goshawks can effectively hunt (i.e., productive understory with open mid-story), with well-developed crown layers to support and shelter their large nests. Nesting pairs are territorial, with nest stands spaced somewhat uniformly across available habitat.

In 1994, the U.S. Fish and Wildlife Service was petitioned to list the subspecies under the *Endangered Species Act*. Following a series of petition findings and court actions, the bird was listed as Threatened in British Columbia (Fed. Reg. 77(148):45870-45893; Aug 1, 2012). Listing was deemed not warranted in Southeast Alaska due primarily to the comparatively greater habitat protections provided by the Conservation Strategy, which was explicitly cited and described in the Fish and Wildlife Service's findings (Fed. Reg. 72(216):63123-63140; November 8, 2007). The subspecies is also listed as Threatened under Canada's federal *Species at Risk Act*, Red-listed by the British Columbia Conservation Data Centre, and is an Identified Wildlife Species under the Forest and Range Practices Act (COSEWIC 2013). NatureServe lists the subspecies as 'Imperiled' (T2) rangewide and in Alaska (S2). There is no ranking for the Queen Charlotte goshawk with the International Union for Conservation of Nature (IUCN).

Recently available literature on the Queen Charlotte goshawk subspecies includes comprehensive reviews of species ecology and habitat management needs (Boyer 2020, Parks Canada Agency 2018, Vennesland 2018, McClaren et al. 2015, Smith 2013, CFCI 2012, USFWS 2007), foraging ecology and diet (Case 2021), and genetic diversity and differentiation (Kunz et al. 2019, Geraldo et al. 2019, Bayard de Volo 2013). The Northern Goshawk Habitat Recovery Implementation Group in British Columbia has produced a habitat and territory model for the subspecies in Canada that offers good insight into habitat needs (Smith and Sutherland 2008).

We note that many of these authors (including Parks Canada Agency 2018, McClaren et al. 2015, Smith 2013, CFCI 2012, USFWS 2007) recommend protection of "post fledging areas" of several hundred acres surrounding more rigorously protected nest stands, to provide forested habitat adjacent to the nest stand for fledgling goshawks learning to fly and hunt. Smith (2013) specifically evaluated post-fledging habitat on the Tongass and recommended modifications to existing standards and guidelines. Most authors suggest that logging may be allowed in post fledging areas, but must be designed to protect foraging habitat by, for example, limiting the timing of operations, size of openings, and methods of treatment. Currently there is no such guidance on the Tongass. Boyer (2020) and Doyle (2006) provided examples of treatments to improve second-growth in post fledging areas.

Alexander Archipelago Wolf (*Canis lupus ligoni*)

The Alexander Archipelago wolf (AA wolf) is a subspecies endemic to Southeast Alaska and coastal British Columbia. Sitka black-tailed deer are the wolf's primary prey across much of their range on the Tongass, where they inhabit the mainland and many but not all of the major island groups. On the mainland and some of the islands, alternative ungulate prey such as moose, mountain goat, or elk occur. Where ungulate diversity or populations are low, alternative prey species may include beaver, salmon, seals, sea lions, black bears, sea otters, and a variety of birds and other mammals (Roffler et al. 2021, USFWS 2015). The AA wolf is a habitat generalist although it avoids second-growth in the stem exclusion phase (i.e., greater than about 30 years old) (Roffler et al. 2018, Person and Brinkman 2013). Because of its reliance on Sitka black-tailed deer in many areas of Southeast Alaska, and the deer's reliance on old-growth forest during severe winter weather, conservation of old-growth is considered critical to maintenance of viable wolf populations (USFWS 2015, Person 2001). Harvest of wolves by trapping and hunting can also affect wolf populations. Where road densities are high, harvest mortality can reach unsustainable levels as trappers and hunters use roads to access many of an island's wolf pack territories (WTC 2017, USFWS 2015, Person and Brinkman 2013, Person and Logan 2012, Person and Russell 2008, Person et al. 1996).

The AA wolf has been the subject of 4 listing petitions to date, in 1993, 2011, 2015, and 2020. Threats identified by the petitioners have included loss of winter habitat (low elevation, old-growth forest) for their primary prey, Sitka black-tailed deer, and excessive harvest mortality facilitated by road systems built largely in support of timber harvest. The Fish and Wildlife Service determined that listing was not warranted for the 1993, 2011, and 2015 petitions citing, among other factors, habitat protections provided by the Tongass Forest Plan. Analyses for the 2020 petition are currently underway. NatureServe lists the subspecies as 'Vulnerable' (T3) and there is no ranking of this subspecies on IUCN.

Scientific information available since the last Forest Plan revision includes focused work on wolf diets (Roffler et al. 2021), habitat and den site selection (Roffler et al. 2018, Roffler and Gregovich 2018, Person and Brinkman 2013, Person and Russell 2009), and wolf harvest vulnerability (Wolf Technical Committee (WTC) 2017, Person and Brinkman 2013, Person and Logan 2012, Person and Russell 2008). Management of deer habitat has been addressed by WTC (2017), Gilbert (2015), Brinkman et al. (2011), Person et al. (2009), Nelson et al. (2008), Farmer and Kirchoff (2007), Farmer et al. (2006), and Schoen and Kirchoff (2007). Bennetsen (2020) provided a recent literature review for both wolves and deer related to young-growth management, and additional information on deer foraging ecology and models can be found in Hanley et al. (2012, 2014) and Shanley et al. (2021). Gilbert et al. (2022) developed a model to describe interactions among deer and wolf populations, habitat, climate, and humans. Genetic evaluations of wolf taxonomy and evolutionary history have been published by Pacheco et al. (2022), Zarn et al. (2019), Hendricks et al. (2019, 2018), Schweizer et al. (2016), Weckworth et al. (2015), Cronin et al. (2014), and Weckworth et al. (2011). Each of these topics are reviewed in USFWS (2015).

Recommendations provided in both Roffler and Gregovich (2018), WTC (2017), and Person and Russell (2009) are directly relevant to improving existing Standards and Guidelines intended to buffer denning wolves from human disturbance during sensitive pup-rearing periods, and to better conserve critical denning habitat on the Tongass. The importance of large reserves to minimize overharvest of wolves is highlighted by Person and Logan (2012), Person and Russell (2008), and Wolf Technical Committee (WTC, 2017).

Northern flying squirrel (*Glaucomys sabrinus*)

There are two subspecies of northern flying squirrels in Southeast Alaska: the Alaska Coast flying squirrel (*G. s. zaphaeus*) of the mainland and adjacent islands (such as Mitkof, Etolin, Wrangell, and Revillagigedo islands) and the Prince of Wales (POW) flying squirrel (*G. s. griseifrons*) from 11 islands within the POW Complex (Bidlack and Cook 2001). Flying squirrels are known to associate with several elements of old-growth forest habitat and play a key ecological role in the forest ecosystem as a prey species and dispersal vector for mycorrhizal fungi which have a symbiotic relationship with dominant conifers and are essential for forest development (Flaherty et al. 2010). Flying squirrels rely on large trees and snags for denning, multilayered forest canopies, and prefer a well-developed shrub layer for protection while foraging on the ground. Flying squirrels in Southeast Alaska tend to exhibit more of a generalist lifestyle, occupying a variety of forested habitats with densities often increasing with forest complexity (Smith et al. 2005). Although they were identified as a MIS, it has been argued that they are not an ideal indicator for old-growth habitat, but rather an indicator of landscape connectivity (Smith 2012, Shanley et al. 2013). Their diet consists of vegetation, truffles and other fungi, lichens, and insects (Pyare et al. 2002, Flaherty et al. 2010).

In 2011 there was a petition to list the POW flying squirrel as threatened or endangered. The subsequent 90 day finding concluded that there was not substantial information indicating that listing may be warranted. This finding largely relied on the protections in place under the Conservation Strategy (Fed.Reg 77(168):52301-52308, August 29, 2012). IUCN status of the northern flying squirrel is listed as 'Least Concern' and stable with no ranking for the POW subspecies. Similarly, NatureServe lists the northern flying squirrel as globally 'Secure' (G5), the POW subspecies as 'Apparently Secure' (T4), and does not have a ranking for the Alaska Coast flying squirrel, which is presumably secure.

Most of the new information since the last Conservation Strategy review is from research on POW. This includes work on home range size, fine-scale movements, dispersal, foraging, and energetic costs in a fragmented forest (Flaherty et al. 2008, Flaherty et al. 2010). Flaherty's research suggests that there are increased energetic demands associated with traversing clearcuts and squirrels are not likely to venture into these areas. In addition, they found that food resources for squirrels were more prevalent in old-growth forests compared to second-growth and clearcuts. Limited food resources for squirrels in managed habitats may influence foraging success and dispersal. Pyare et al. (2010) studied den use and selection in fragmented landscapes and found dens in both snags and live trees. Flying squirrels selected for the largest diameter trees (mostly western hemlock) in higher-volume forests with lower levels of fragmentation. Shanley et al. (2013) looked at local and landscape scale habitat selection based on composition and structure and found that flying squirrels selected for large old-growth patches and higher structural connectivity at a local scale but not at the landscape scale. However, Trapp et al. (2019) found that landscapes with greater connectivity exhibited longer flying squirrel dispersal distances, more sinuous dispersal paths, and a greater total area of landscape utilization. Landscape connectivity is a critical feature that largely determines distribution and persistence of flying squirrels (Smith 2012). Smith and Person (2007) estimated persistence of flying squirrel populations in small, isolated habitat reserves composed of old-growth upland rainforest and mixed-conifer peatlands on the Tongass. Their results indicated that mixed-conifer peatland habitat was unlikely to sustain populations and that viability of flying squirrel populations in small habitat reserves depended on the amount of upland old-growth within that reserve. Moreover, they concluded that small isolated reserves would not likely support a persistent population in the absence of immigration and emphasized the importance of dispersal between small reserves to ensure persistence of metapopulations of flying squirrels (Smith and Person

2007). The contribution of small OGRs in the conservation of flying squirrels depends on the degree of isolation and functional connectivity with other large, medium, or small reserves. Smith and Person (2007) suggest that conservation planning that explicitly considers quality and configuration of OGRs in a modified landscape is essential to ensure functional metapopulations of flying squirrels.

Smith et al. (2011) combined empirical data on movement of dispersing juvenile flying squirrels through various habitats on POW with population modeling of flying squirrels in Southeast Alaska to estimate the number of immigrants required for populations to persist for 25 and 100 years in hypothetical small OGRs with 400 to 1600 acres of productive old-growth forest habitat. (Small OGRs across the POW complex currently provide about 300 to over 3,500 acres of productive old-growth according to the Tongass' internal OGR Tracking Table.) They found that small reserves would likely sustain populations of flying squirrels for at least 25 years with immigration of 1 disperser every 1 to 5 years, depending on the amount of productive old growth habitat available. Persistence over 100 years would require much greater rates of immigration, ranging from 10 to 162 dispersers per year, suggesting that extirpations are likely, especially in smaller reserves. Successful recolonization would likely require arrival of at least 6 immigrants per year to insure reestablishment of a breeding population.

Local extirpations followed by recolonization by dispersers are a defining feature of functional metapopulations. Habitat connectivity that provides for immigration and recolonization from source populations is critical. Smith et al.'s (2011) modeling suggested that less than half of the small OGRs on POW are close enough together to allow for successful dispersal through managed matrix lands. They recommended spacing reserves no more than about 1 km (0.6 miles) apart to facilitate successful dispersal between reserves, increasing the amount of productive old-growth in small OGRs to reduce reliance on immigration, protection of designated corridors of suitable old-growth forest habitat where such opportunities remain, and treatment of young-growth to accelerate development important old-growth characteristics (greater height and open mid-story to allow gliding).

The range of the southern flying squirrel (*Glaucomys volans*) has been expanding northward likely due to changes in climate. This species is an intense competitor of northern flying squirrels and vector of a pathological nematode (Weigl 2007). In areas where this expansion has happened there are subsequent declines of northern flying squirrels as well as hybridization (Weigl 2007, Garraway et al. 2010).

Marten (*Martes americana* and *Martes caurina*)

American marten (*M. americana*) and Pacific marten (*M. caurina*) are both native to Southeast Alaska. American marten were introduced to some islands in the 1930-1950's (POW, Chichagof, and Baranof). The Pacific marten only occurs on Kuiu and Admiralty Islands though historically occurred more broadly across Southeast Alaska and may have been negatively impacted by the American marten introductions (Dawson et al. 2017). Marten were identified as MIS due to their close association with old forests, vulnerability to logging activities and habitat fragmentation, and their importance as a furbearer. Mature and structurally complex coniferous forests provide optimal habitat for marten with important components being those that often occur in old-growth habitat such as overstory canopy cover, snags, fallen logs, stumps, and abundant large trees for denning and resting. The diet of marten varies seasonally but they mostly rely on small rodents (voles, squirrels, mice), berries, and intertidal resources (e.g., salmon, bivalves). Areas with high canopy cover connecting mature forests increase the likelihood of dispersal and connection between metapopulations (Flynn et al. 2004).

NatureServe lists Pacific marten as 'Apparently Secure' (G4) globally with no status in Alaska, and no ranking on IUCN. American marten is listed as 'Least Concern' but decreasing on IUCN and a NatureServe ranking of globally 'Secure' (G5) and 'Secure' (S5) in Alaska. Pacific marten populations in the southern portion of their range are federally listed as threatened in Oregon and California (*M. caurina humboldtensis*, Coastal Distinct Population Segment).

Recent literature on marten includes research on habitat selection (Flynn and Schumacher 2016), dispersal distances using non-invasive isotopic labeling (Pauli et al 2012), foraging ecology (Manlick et al. 2019), population dynamics (Flynn and Schumacher 2009), genetics and endemism (Collela et al. 2018, Collela et al. 2019, Collela et al. 2021), colonization history and distribution (Pauli et al. 2015 and Dawson et al. 2017). A habitat selection study on Chichagof Island from, validated selection for structurally complex, old-growth forest habitats (Flynn and Schumacher 2016). Marten showed greatest affinity for old-growth in the winter and summer. During the fall, habitat use varied, but the study confirmed general avoidance of non-forested or open habitat (Flynn and Schumacher 2016). On Kuiu Island, important predictors of marten habitat at landscape scales included lower elevation, closed canopy old-growth forest in areas with higher densities of salmon streams near the coast (Koch 2016). On POW, Pauli (2010 thesis) indicated that marten populations were large and well-connected despite substantial fragmentation of habitat and trapping. Juveniles dispersed from areas with fewer marten and limited suitable habitat to areas with higher marten densities and more contiguous forest. Pauli (2010) found that proximity of high-volume forest patches was positively correlated with connectivity of marten populations and even small, fragmented patches of forest may have conservation value for forest carnivores. Martens were most abundant in old-growth stands compared to managed stands (Ben-David et al. 2014).

Concerns have emerged for isolated populations of Pacific marten, now considered a distinct species limited, in Southeast Alaska, to Kuiu Island (where it hybridizes with American marten) and Admiralty Island (where genetic diversity is low) (Collella et al. 2021, Collela et al. 2019, Collela et al. 2018, Dawson et al. 2017, Cook and MacDonald 2013, MacDonald and Cook 2007). Genetic evidence suggests that where the two marten species hybridize, as shown on Kuiu Island, asymmetrical gene flow results in slow removal of Pacific marten genetics, ultimately leading to genetic swamping and extirpation of Pacific marten (Collela et al. 2021, Collela et al. 2019, Dawson et al. 2017).

A likely emerging threat to marten is the recent fisher colonization in Southeast Alaska (Kupferman et al. 2022). Where there is range overlap, fishers are a dominant competitor that suppress marten populations (Pauli et al. 2022 and Manlick et al. 2017).

Prince of Wales River Otter (*Lutra canadensis mira*)

POW River otter is a subspecies of the northern river otter found only on the islands and mainland throughout Southeast Alaska and western British Columbia. The river otter was selected as an MIS because of its association with coastal and freshwater aquatic environments and adjacent upland habitats. They use forested habitat on the Tongass for resting and pupping averaging 0.5 miles from beach shorelines. Predominant vegetation at den sites in Southeast Alaska is uneven-aged old-growth forest on well drained sites near streams (Woolington 1984). Burrows often consist of roots of large conifer trees and decaying snags. POW river otters tend to use streams as travel corridors between den sites and foraging areas on the coast. Their diet mainly consists of fish and other aquatic animals in intertidal areas. NatureServe lists the POW river otter as a 'Vulnerable' (T3) subspecies. POW river otters

do not have a listed IUCN status. We found no new science on this subspecies. During NEPA analysis, wildlife and subsistence biologists often cite the Conservation Strategy or Forest Plan standards and guidelines as sufficient to protect river otter habitat with important elements being beach and estuary fringe buffers and riparian management areas.

Brown Bear (*Ursus arctos*)

Brown bears are an iconic species in Southeast Alaska, where they play an important role in maintaining the ecological balance of the region. The species was selected as an MIS on the Tongass and occurs on Admiralty, Baranof, and Chichagof Islands and on the coastal mainland. Populations of brown bears on northern islands of Southeast Alaska are effectively isolated from the mainland. Inter-island movement is limited although it likely occurs between Baranof and Chichagof islands. Brown bears use a variety of habitat types but tend to concentrate along salmon streams and associated riparian forest in the summer (Suring et al. 1993). They often select for habitat mosaics that contain riparian old-growth forests. Denning habitat includes both low elevation old-growth forest where they use large tree roots for den sites and cave dens in alpine or subalpine settings. Riparian old-growth forest was found to have the highest habitat capability for supporting brown bear populations (selection relative to availability) (Suring et al. 1993). Brown bears are omnivorous but predominantly rely on salmon, berries, grasses, sedges, cow parsnip, ground squirrels, carrion, and roots.

Alaska remains the last stronghold of brown bears in North America with an IUCN ranking of 'Least Concern' and NatureServe status of 'Apparently Secure' (G4) globally and 'Apparently Secure' (S4) in the State. Southeast Alaska has some of the highest brown bear densities in the world. However, brown bears can be vulnerable due to their low reproductive rates, sensitivity to human disturbance and development (i.e., roads providing access for hunting), and high reliance on salmon in coastal areas.

Recently available information on brown bears is from the Alaska Department of Fish and Game and include collaring studies related to resource and habitat selection, spatial use and movement patterns, home range sizes, and population estimation in Yakutat. Additional bear research focused on diet and the role of bears in the food web (Shakeri et al. 2018, Harrer and Levi 2018) and impacts of humans on bear foraging (Wheat and Wilmers 2016). Flynn et al. (2007) studied the differences in habitat selection of male and female brown bears in altered versus less altered watersheds on Chichagof Island. They found that bears, especially females, spent more time farther from salmon spawning streams; and female bears were more abundant and consumed more salmon in less altered watersheds. Based on spatial use patterns adjacent to salmon streams, Flynn et al. (2007) recommended retention of at least 500 ft no-cut buffers along streams with spawning salmon and larger buffers and/or increased habitat protections where bear populations are a management objective.

Mountain Goat (*Oreamnos americanus*)

Mountain goats naturally occur only on the mainland in Southeast Alaska and possibly Baranof Island, with an augmentation transplant of additional goats to Baranof in 1923. They have been introduced to Revillagigedo Island and Chichagof, but the Chichagof population died off. Goats in coastal areas exhibit altitudinal migrations from alpine summer ranges to winter ranges at or below tree line, typically in old-growth forest habitats (ADF&G website). Key forest habitat characteristics for mountain goats include structurally complex mature forests near steep terrain, as well as travel corridors between seasonal sites.

Mountain goat diet consists of conifers, lichen, moss, and shrubs in forested habitat and forbs and graminoids in alpine/subalpine areas (Bennetsen 2020).

The mountain goat population in Southeast Alaska is fairly robust, with an IUCN ranking of 'Least Concern' and NatureServe ranking of 'Apparently Secure' (S4) in the State. Mountain goat populations in other areas of North America are either imperiled or vulnerable except in Alberta and Montana.

Recent literature on mountain goats is predominantly from ADF&G's collaring studies that provided data on movement patterns, habitat use, environmental stressors, reproduction and survival (White et al. 2011, 2012, 2017, 2018), genetics and colonization history (Shafer et al. 2010, 2011, 2012), space use and range fidelity (Shakeri et al. 2021) and environmental and human stressors on goats (Martchenko et al. 2021). Mountain goats are sensitive to climate variables including amount of snowfall in winter and heat stress in the summer, both of which can reduce mountain goat survival (White et al. 2011). White et al. (2018) predicted that projected increases in summer temperature had stronger negative effects on mountain goat populations than the potential positive effects of reduced winter snowfall, with implications of concerns over species persistence in the future. Shakeri et al. 2021 demonstrated mountain goats exhibited a strong degree of seasonal range fidelity, with space use expanding in the summer and constricted during the winter.

Pacific Great Blue Heron (*Ardea herodias fannini*) (note that the Pacific Great Blue Heron is referred to as the Northwestern Great Blue Heron in Suring 1993).

The Pacific great blue heron is a regional endemic subspecies with low population numbers (Campbell et al 1990). Total population size is unknown, however. The subspecies is listed as 'Apparently Secure' (T4), The NatureServe Global Status was last reviewed 4/6/2016. There is not an IUCN ranking of Pacific Great Blue Heron. The subspecies is vulnerable to disturbance from land management activities, that include logging and mining (Schenck and Suring 1993). It resides along the Pacific coast from southeastern Alaska (Yakutat Bay) south to Washington state. Non-breeders range north to Cook Inlet, Alaska and east to the interior of central and southern British Columbia (Gabrielson and Lincoln 1959, Tobis pers. com. 1992). (NatureServe). The subspecies nests colonially in tall Sitka spruce, western red cedar, western hemlock, pine, red alder and black cottonwood (Campbell et al. 1990). Isolation from disturbance appears to be an important factor in nest site selection. In Alaska, Northwestern great blue herons (same subspecies (*A.h.fannini*)) may be particularly sensitive to disturbance because of heightened susceptibility to weather and predation losses (Schenck and Suring 1993). Globally, the herons are also susceptible to pollution of foraging areas, particularly estuaries, and exclusion from wetland areas by development. An increase in bald eagles (*Haliaeetus leucocephalus*) since the 1980's has increased predation at rookeries.

The Pacific great blue heron was assessed as Special Concern in 1997 and again in 2008 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) due to a small population size, declining productivity, and threats related to bald eagle predation, habitat loss, and human disturbance. The species was listed on Schedule 1 of the *Species at Risk Act* (SARA) in 2010. In Canada, this subspecies is distributed along the coast of British Columbia with a relatively small population that is concentrated at a few breeding colonies in southern British Columbia. There is evidence of declines in productivity and it is unclear whether the population is stable or declining. Threats from eagle predation, habitat loss and human disturbance are ongoing, particularly in the southern part of the range where concentrations of birds are highest (Environment Canada, 2016).

In Canada, this subspecies is distributed along the coast of British Columbia with a relatively small population that is concentrated at a few breeding colonies in southern British Columbia. There is evidence of declines in productivity and it is unclear whether the population is stable or declining. Threats from eagle predation, habitat loss and human disturbance are ongoing, particularly in the southern part of the range where concentrations of birds are highest. The Pacific great blue heron is darker plumaged, smaller in size and has a smaller clutch size than continental herons (relevant to reproductive rate). Declines and other issues with productivity and population size are thought to primarily be due to bald eagle predation, human disturbance and destruction of nesting and foraging habitat. The species is listed as Special Concern (a wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats) in BC, Canada.

Although predation by a strongly recovering bald eagle population was thought to have contributed to the decline of great blue herons, Jones et al., 2013, found that, in their study area in British Columbia, Pacific great blue herons in colonies close to a bald eagle nest experienced higher reproductive success than those far from bald eagle nests. Breeding colonies close to bald eagle nests were large enough that the occasional losses of chicks to the resident pair were outweighed by the higher reproductive success. They hypothesized that *A. h. fannini* in the Pacific northwest changed their nesting habits during the 1990s in response to the continued growth of the bald eagle population. Breeding colonies, even large long-established colonies and even in the midst of chick-rearing, began to be abandoned in the face of persistent predatory behavior by bald eagles. Initially, it appeared that great blue herons took up nesting individually or in small groups, but by the time of their study (2005, 2006), most pairs in the study area nested in just a few large colonies, each of which was co-located (<200 m) with a resident pair of bald eagles (COSEWIC 2008).

Appendix B - Species with Emerging Conservation Concerns

Marbled Murrelet (*Brachyramphus marmoratus*)

The marbled murrelet is a small seabird that typically nests on moss-covered boughs in the canopy of large-diameter trees within low-elevation (<800 m) stands of structurally complex, coastal old-growth forest (Burger 2004, DeGange 1996, Hamer & Nelson 1995, Nelson & Newman 2009). Marbled murrelets spend most of their lives at sea but travel inland up to 50 miles to nest (Nelson & Newman 2009, Piatt et al. 2007). Because of this nesting preference, the species range largely parallels that of the north temperate rainforest, from northern California, through Oregon, Washington, and British Columbia, to Southeast and Southcentral Alaska (Nelson 1997). In Southeast Alaska, marbled murrelets appear to use a wider range of habitat types for nesting than in the Pacific Northwest and British Columbia. On some treeless islands in Southeast Alaska marbled murrelets lay eggs on bare talus slopes in mountainous areas (Nelson & Newman 2009, Piatt et al. 2007). Marbled Murrelets often forage in pairs within a mile of the shore; the joint effort appears to help with safety from predators and efficiency in catching prey.

Because of its unique association with old-growth forests, and declining population trend, the marbled murrelet is a species of conservation concern at statewide, national, and international levels (BirdLife International 2023, Kirchhoff & Padula 2010). The marbled murrelet is currently listed in the Lower 48 states as a threatened species under the Endangered Species Act, IUCN rank is 'Endangered' and is ranked by NatureServe as 'Vulnerable' both globally and in Alaska (G3, S3). Southern populations appear to be declining primarily because of diminishing old-growth nesting habitat and increased predation on eggs and chicks due to logging (Peery and Henry 2010, Peery et al 2004, Andr  n 1994). Marbled murrelets also experience direct mortality as by-catch in nearshore drift gill nets (Carter et al. 1995) and reduced survival and productivity from declines in key forage fish species from ocean warming and acidification (Peery et al 2004). Similar pressures exist in Southeast Alaska, although old-growth forest in Southeast Alaska is still relatively abundant, and marbled murrelets in Alaska may have a lesser dependence on old-growth trees for nesting than birds in the Lower 48 (Barbaree et al. 2014).

Repeated surveys have established that Southeast Alaska provides important habitat for marbled murrelets. Roughly half of all marbled murrelets in Alaska in 2006 lived in Southeast (Piatt et al. 2007). Annual abundance surveys in Glacier Bay National Park indicate that dense concentrations of marbled murrelets (~63,000 birds) during early July constitute a significant fraction of the global population (Hoekman 2019).

Despite the relatively high density of marbled murrelets in Southeast Alaska compared to other parts of the range, a 2007 status review of marbled murrelets in Alaska and British Columbia found that marbled murrelet numbers in Southeast Alaska declined from approximately 687,000 birds in 1994 to 144,000 in 2006, a 79 percent decline. The decline was steeper in Southeast than in other parts of Alaska, but declines were noted across the state (Piatt et al. 2007, pp. 46). Population declines were attributed to combined and cumulative effects of human activities (including logging, gillnet bycatch, oil pollution) and natural factors such as ocean regime shifts or predation. Declines were also recorded in 2016 by ADF&G in Tracy and Endicott Arms of Southeast Alaska: about half as many marbled murrelets were recorded in July 2016 (Nesvacil et al. 2018) as in July 2002 (Kissling et al. 2011), although annual variation in bias

arising from uncertain identification may contribute to variability in abundance estimates from year to year.

Other recent studies of marbled murrelets in Alaska have focused primarily on marine space use, movements, foraging behaviors, and disturbance by vessels (Barbaree et al., 2015; Bertram et al., 2016; Haynes et al., 2008, 2010; Haynes & Nelson, 2011; Pontius & Kirchhoff, 2009; Schoen et al., 2013); however, one recent study investigated the nesting ecology of marbled murrelets in Southeast Alaska (Barbaree et al., 2014). Conservation needs for marbled murrelets include protection of important nesting habitat from clearcut logging, and increased monitoring of population trends, especially in southern Southeast Alaska where clearcut logging is more intensive. Tongass Forest Plan standards and guidelines pertaining to marbled murrelets currently include a 600-foot radius no-cut buffer zone around identified nests (USFS 2016), although scientists recommended that this standard be modified to protect occupied stands rather than identified nests, which are rarely discovered (USFS 2008 Workshop Proceedings). Gaining a better understanding of prey fish response to warming oceans could also allow managers to better prepare for marbled murrelet conservation needs in a changing climate (Norris et al. 2007).

Little Brown Bat (*Myotis lucifugus*)

The little brown bat is one of seven species of bats that has been documented in Southeast Alaska. It has a widespread range in North America from Alaska-Canada boreal forests south through most of the contiguous United States into central Mexico. It is suspected that little brown bats in Southeast Alaska hibernate in caves associated with karst systems, rootwad cavities, and rock crevices in the winter, and they roost and form maternity colonies (made up of 2 - 100+ individuals) in trees, artificial structures, under rocks, and in piles of wood in the summer and fall. Little brown bats tend to select for mature forested habitats compared to second-growth forest (Parker et al. 1996, Tessler et al. 2014, Alaska Center for Conservation Science 2017). Little brown bats emerge from hibernation in the spring and summer, and individuals may swarm around caves before mating in the fall. Foraging activities vary depending on vegetation density, and studies have found higher foraging activity from bats in intact forest patches and along the patch edges, with less activity in clear-cut areas (Patriquin & Barclay 2003) or young-growth forests (see Bennetsen 2020). The diet consists of a wide variety of insects, which may have allowed the broad geographic distribution of the species (Kaupas & Barclay 2018).

The little brown bat is currently being considered for listing as a threatened or endangered species across its range under the Endangered Species Act. The US Fish and Wildlife Service is currently conducting a status assessment to inform the listing determination. The finding is expected in 2024. This species was once very abundant but has experienced severe declines due to white-nose syndrome (WNS), a novel fungal disease. It is listed as 'Endangered' by the IUCN and 'Vulnerable' (G3) globally and 'Vulnerable' in the State (S3). Little brown bats have experienced more than a 90% decline in population numbers where WNS has been detected (Bat Conservation International 2018). The fungus responsible for WNS, *Pseudogymnoascus destructans*, arrived in New York in 2006 and has spread from this epicenter each year, with WNS now confirmed in 38 states and eight Canadian provinces. As of 3 April 2023, white-nose syndrome was confirmed in British Columbia. WNS is moving rapidly, and while it has not yet been detected in Alaska, its arrival in the state seems likely in the near future.

Recent studies of little brown bat in Alaska and Canada have focused primarily in boreal forest habitats (Shively & Barboza 2017, Thomas & Jung 2019, Thomas et al. 2019, Jochum et al. 2021, Snively et al.

2021, Thomas et al. 2021, Slough et al. 2022). Comparatively little research has occurred in the temperate rainforests of Southeast Alaska, coastal British Columbia, and the Pacific Northwest. However, ADF&G has established a network of year-round acoustic monitoring stations across Southeast Alaska to learn more about their seasonal activity patterns across the region (Woodford, 2022). The Forest Service has collaborated on this effort since 2015. These acoustic monitoring data along with radiotelemetry data revealed that little brown bats near Juneau hibernate in a dispersed manner, close to summering areas, which may slow the spread of WNS and reduce impacts in Southeast Alaska populations should it arrive in Alaska (Blejwas et al. 2021). Two recent studies have also documented cumulative impacts of climate (temperature and precipitation), disease, and nutritional stress on little brown bats in the northwestern portion of their range (Hranac et al. 2021, Davy et al. 2022). Further research is needed to better understand little brown bat populations in Southeast Alaska and how they respond to habitat loss and other factors (Boland et al. 2009).

Western Screech-owl (*Megascops kennicottii kennicottii*)

The western screech-owl is a small, nocturnal owl of coniferous and deciduous forests and woodlands. In Southeast Alaska, where it is a rare year-round resident (Heinl 2010), it is found primarily at lower elevations and is often associated with riparian habitats, especially along larger streams.

Lewis and Kissling (2009) tracked 10 radio-tagged screech-owls on Mitkof Island in central Southeast Alaska during 2005 – 2006 to evaluate habitat use and home range. They found that roosts and nests were closer to large streams than random points, suggesting preferential use of riparian and floodplain habitats, likely due to more abundant prey and nesting cavities along streams. Nests were in natural cavities of dead snags or dead portions of live trees, often surrounded by dense patches of smaller trees. Lewis and Kissling (2009) and Kissling and Lewis (2009) recommended continued protection of valley-bottom forests and riparian zones to assure presence of large snags with natural cavities, given the paucity of primary cavity excavators (woodpeckers) in Southeast Alaska, to provide adequate nest sites.

Diet in Southeast Alaska includes primarily small mammals (shrews, lemmings, voles, and mice) and invertebrates (beetles, caterpillars, other insects, worms, and spiders) (Kissling et al. 2010a, 2009a). Birds are rarely taken (Kissling et al. 2010a, 2009a).

Concerns over impacts to screech-owls due to habitat loss and competitive exclusion by barred owls (*Strix varia*) have led to federal listing of the western screech-owls as “Threatened” in adjacent British Columbia under the Species at Risk Act (COSEWIC 2012, Elliot 2006). Similar concerns have been noted for populations elsewhere (Acker 2012, Cannings and Angell 2001, Hardy et al. 1999). Kissling et al. (2009c) documented apparent displacement of western screech-owls in southern Southeast Alaska by barred owls (*Strix varia*), as the distribution and occupancy rate of barred owls expanded, particularly on the mainland, and distribution of screech-owls narrowed between historic (1986-1992) and recent (2005-2008) surveys.

Competition from barred owls for prey and nest sites, hybridization, and suspected direct predation have been implicated in declines of spotted owls (*Strix occidentalis*), screech-owls, and other species in the Pacific northwest, as barred owls have expanded their range across the region (Hausleitner 2015, Acker 2012, Kelly et al. 2003, Pearson and Livezey 2003, Olson et al. 2005). Similar dynamics are apparently occurring in Southeast Alaska as the barred owl expands its range northerly (Kissling et al. 2009c).

Vehicle strikes have been identified as a potentially significant mortality source, as screech-owls apparently forage along the forest edges provided by roads (Hausleitner et al. 2015, Kissling and Lewis 2009). Kissling and Lewis (2009) suggested that evaluation of owl use along busy roads in select towns might identify areas where motorists could be alerted to the presence of owls with signs and reduced speed limits to minimize vehicle strikes.

Kissling et al. (2010, 2009b) and Kissling and Lewis (2009) developed survey techniques for owls in Southeast Alaska that may be useful for a monitoring program designed to evaluate population trends and distributional shifts in response to environmental changes and management activities.

Proudfoot et al (2007) evaluated phylogenetic relationships among four related species of owls, and found strong support for differentiation of western screech-owls from eastern (*M. otus*) and whiskered (*M. Trichopsis*) screech-owls and flammulated owls (*Otus flammeolus*). Their evaluation of purported western screech-owl subspecies supported differentiation of coastal *M. k. kennicotti* from the more interior *M. k. mcfarlanei* of southern British Columbia, Idaho, and Montana, likely due to geographic separation provided by the Cascade Mountains. Neraas et al. (2009) evaluated genetic divergence of western screech-owls from Southeast Alaska using markers from two mitochondrial DNA sites. They found no evidence of geographic structuring, as birds from Southeast Alaska shared haplotypes with birds from California and Washington. Efforts to distinguish gender from nuclear DNA were unsuccessful.

Management actions suggested by Kissling and Lewis (2009) included expansion of riparian zone protections to provide nesting and foraging habitat. They also recommended retention of patches of legacy forest structure in timber harvest units to provide nesting and roosting structure for owls and a more intensive investigation of genetic structure among owl populations across Southeast Alaska.

Yellow-Cedar (*Callitropsis nootkatesis*)

Yellow-cedar is a slow-growing, long-lived tree that occurs from Prince William Sound in southern Alaska to northern California. Isolated populations occur in Eastern Oregon and the Selkirk Mountains of southeastern British Columbia. The species reaches its greatest density and largest size in the coastal temperate rainforests of Southeast Alaska and British Columbia, where it is valued as a commercial timber species because its wood is strong and rot resistant. Growth is more shrub-like near alpine timberline and in boggy sites at lower elevations (Hennon et al. 2016). IUCN lists this species as 'Least Concern', with a NatureServe ranking of 'Apparently Secure' both globally and in Alaska (G4, S4).

Dead and dying stands have been documented throughout Southeast Alaska and in the northern portion of coastal British Columbia. This phenomenon is termed "yellow-cedar decline". The primary cause of death has been identified as freeze injury to the roots, which occurs when hard freezes coincide with periods of no snow cover (which would otherwise insulate the ground). Freeze damage can accumulate over years, weakening individual trees and eventually causing mortality. Freeze-weakened trees may also have elevated susceptibility to pathogens and insect infestations (Hennon et al. 2016, Hennon et al 2012).

Hard freeze events during periods with no snow have become increasingly common at lower elevations in Southeast Alaska and at various elevations in British Columbia as mean winter temperatures shift to above Buma et al.'s (2017) "snow-rain threshold", which they defined as >0 °C mean winter temperature. These freeze events cause the highest levels of mortality among trees growing in wet, poorly drained sites, where the trees typically have shallow roots. Stands on better-drained sites, where trees grow

deeper roots, and on higher or north-facing sites that retain more snow through the winter, are less affected (Hennon et al. 2016, D'Amore and Hennon 2006). On Haida Gwaii, an island group off the northern coast of British Columbia, though, Comeau and Davis (2022) documented divergent responses among trees at each of their 15 study sites (all of which had wet soils). Some trees at each of the sites had increased growth rates as others declined. The authors suggested that in addition to climate, poorly understood factors such as microsite conditions, pathogens, and genetics may drive vulnerability at the level of individual trees.

In their 2016 climate adaptation strategy for yellow-cedar, Hennon et al. (2016) suggested that some northern populations are currently maladapted to their local environment because of climate change. Buma et al. (2017) produced high-resolution projections of suitable yellow-cedar habitat through the end of the 21st century and concluded that approximately 50% of areas with currently suitable climate are expected to warm beyond the snow-rain threshold that appears to trigger decline. Hennon et al. (2016) suggested that harvest of dead and dying yellow-cedar in areas now considered unsuitable would be preferable to harvest of healthy trees in areas expected to provide more stable or otherwise suitable conditions in the future. This suggests that conservation of sites projected to remain or become suitable habitat may be warranted.

Buma et al (2017) pointed out that very little (<1–9%, depending on latitude) of the area expected to remain suitable in the future (i.e., climatic refugia) is in currently protected landscapes. Several authors have suggested that adjustments may be needed to improve conservation of areas likely to provide suitable habitat for yellow-cedar (e.g., DellaSala et al. 2018, Buma et al. 2017, Hennon et al 2017, Oakes et al. 2015).

Active management to favor yellow-cedar on suitable sites in the managed matrix, through planting, thinning, and selective harvest of competing species, is expected to help conserve yellow-cedar in some areas (Hennon et al. 2017). Forest planners considering how to address climate change resilience on the Tongass should also consider how protected areas could contribute to yellow-cedar conservation. We suggest that protected area designations (e.g., OGRs) could be extended or otherwise modified to increase representation of climate refugia, as modeled by DellaSala et al. (2018), Buma et al. (2017), and likely others.

Appendix C. Suggested Evaluations for the Forest Plan Assessment

Our review has identified knowledge gaps about implementation and effectiveness of several aspects of the existing and prior Forest Plans, and how well the Conservation Strategy is positioned to support climate change resilience. As part of the analyses that will be conducted during the upcoming Forest Plan revision, we recommend the following evaluations, most of which are discussed in the body of this document. Many of these evaluations could inform implementation of actions recommended above, in our “Recommendations” section.

Implementation of the forest legacy structure standards, 1997 to present. The 1997 Forest Plan established standards and guidelines for retaining forest structure within some harvest units to help maintain goshawk and marten habitat in the matrix between reserves. These standards and guidelines were replaced in 2008 and modified in 2016. It would be useful to know how these standards have been interpreted and implemented, and their efficacy of meeting desired conditions before duplicating or modifying them in a revised Forest Plan.

Review of endemism and genetic diversity. We recommend conducting a more comprehensive review of available literature and data on endemism and genetic diversity across Southeast Alaska for as many taxa as possible. Knowledge of where unique forms currently occur, and where they may be vulnerable, would directly inform development of an updated Conservation Strategy tailored to the unique conditions of the Tongass.

Evaluate adequacy of corridors for metapopulation functions and climate-induced migrations. Conduct a spatially explicit evaluation of connecting corridors between existing OGRs and old-growth forest patches within other non-development LUDS as designated in the current Conservation Strategy, and consider their adequacy to support wildlife dispersal and climate-induced migrations (including upslope and northerly migration) and maintenance of species expected to be affected by climate change (e.g. mountain goats).

Assess the potential for climate refugia. Identify locations likely to provide suitable habitats to replace those projected to be impacted by climate change. Consider protection for areas likely to offer comparatively greater habitat stability. Incorporate core habitats of diverse taxa in addition to biodiversity hotspots, to maximize reserve system resilience.

Evaluate representation of ecosystem diversity within the reserve system (Haufler 2006, p. 22). Use plant associations or other classification schemes to evaluate whether the existing reserves protect the full diversity of ecosystems across the Tongass. Such an evaluation now seems particularly warranted, if it has not already been done, given the Planning Rule’s requirements related to conservation of ecosystem diversity. We recommended that regardless of which ecosystem classification system is used, representation should be redundant (where possible), to account for stochastic disturbances, and forward-focused to account for projected changes attributable to climate change and natural succession. (We note that plant associations don’t always translate to habitat types for wildlife.)

Develop population viability assessments for discrete, vulnerable populations. Consider Haufler’s (2006) recommendation to develop population viability assessments at the scale of individual islands or island groups, within identified endemism zones on the Tongass. For example, such assessments could be done for endemics (similar to Smith and Person’s (2007) assessment of POW flying squirrel) or other species

with identified conservation challenges (e.g. Pacific marten on Kuiu Island), to ensure that habitat needs and anthropogenic threats are adequately addressed.

Identify key areas for young-growth transition. If the Forest Plan Revision process considers continued transition from old-growth harvest to young-growth, we recommend identifying key areas to support future old-growth harvest. Criteria could include:

- Least important for maintaining ecosystem integrity and diversity (broadly represented, abundant redundancy, etc.). “Timber Production Watersheds” identified by Albert and Schoen (2007) meet this standard.
- Not critical for climate adaptation/species migration
- Potentially at risk of loss to climate change or other factors, regardless of management efforts
- Outside existing Small OGRs and OGR corridors
- Outside “Conservation Priority Watersheds” identified by Albert and Schoen (2007)

Forest Restoration on Haida Gwaii: Implications for Goshawk Habitat

University of Victoria
Restoration of Natural Systems Diploma Program
ER 390



Christophe Boyer
December 2020

Abstract

Haida Gwaii, a remote group of islands off the northwest coast of British Columbia, is home to an endemic species of Northern Goshawks (*Accipiter gentilis laingi*), at imminent risk of extirpation. The loss of old growth habitat due to industrial logging is the principal reason for the decline of goshawk populations on Haida Gwaii. The survival of the raptor is dependent on the abundance and accessibility of prey (such as red squirrels (*Sciurus vulgaris*) and red-breasted sapsuckers (*Sphyrapicus ruber*)) which are closely tied to the composition of the forest. Structurally complex forests with widely spaced trees and variable canopy heights, critical attributes for goshawk foraging, have been replaced by monocrop, over-dense conifer plantations that are not accessible to goshawks. In the spring of 2020, a silvicultural thinning treatment was completed to improve the accessibility of second growth stands along the Yakoun River for goshawk foraging. The treatment, part of a multi-year project, reduced the stand density of a 70.6-hectare area from 905 to 531 stems per hectare, while retaining standing dead trees for wildlife habitat. Plot data was collected to quantify the effectiveness of silvicultural treatments in mimicking the conditions of the forest structure and prey resource availability that support existing goshawk forage territory. Results from the 2020 treatment showed that the stand density was successfully reduced to the specifications outlined in the project prescription and that red squirrels were preferentially feeding around large diameter Sitka spruce trees. Results from the old growth control sites showed a lower stem density than the 2020 and 2019 treatment sites and a relatively higher abundance of red squirrels than red-breasted sapsuckers. Plot data from the 2019 treatment site showed a relatively higher abundance of red-breasted-sapsucker compared to red-squirrels. Goshawk prey are present in the 2019 and 2020 treatment areas, and by improving the accessibility of the stand through thinning treatments, these forests may develop the necessary conditions for goshawk foraging. This initial field study has highlighted the need for rigorous scientific monitoring before and after thinning treatments to inform the location and implementation of future restoration projects, and to evaluate whether silvicultural treatments are effective in recruiting new goshawk foraging territory.

Table of Contents

Abstract.....	2
Introduction.....	5
1.0 Background.....	5
1.1 Weather and climate	5
1.2 History	6
1.3 Haida Gwaii Goshawks.....	6
2.0 Site Description.....	8
3.0 Objectives.....	9
3.1 Quillicum Environmental Services.....	9
3.2 UVic ER390 project.....	10
4.0 Methodology.....	10
4.1 Stand management prescription	10
4.2 Project stages and timeline.....	12
4.3 Layout – stage 1.....	13
4.4 Falling – stage 2	13
4.5 Operations – stage 3	14
4.6 2020 Treatment area quality plots.....	15
4.7 Old growth control plots.....	16
4.8 2019 Treatment area quality plots.....	17
5.0 Results.....	18
5.1 2020 treatment area.....	18
5.2 Old growth control plots	19
5.3 2019 treatment area.....	21
6.0 Discussion.....	22
7.0 Recommendations and Conclusion	25
8.0 Acknowledgements.....	24
9.0 References.....	26

List of Figures

Figure 1 – 2020 Treatment polygons and road access.....	9
Figure 2 – South Graham Island, Haida Gwaii.....	10
Figure 3 – Polygon B, pre-treatment stand.....	12
Figure 4 – Operational planning map.....	13
Figure 5 – Cat-facing and girdling.....	15

Figure 6 – Red-breasted sapsucker and red squirrel feed signs.....	17
Figure 7 – 2020 post-treatment diameter class and species composition.....	19
Figure 8 – Old growth control site: diameter class and species composition.....	20
Figure 9 – 2019 treatment area quality plots: diameter class and species composition.....	22

List of Tables

Table 1 – Stand management prescription.....	11
Table 2 – Restoration project timeline.....	12
Table 3 – Location of control sites	16
Table 4 – Location of 2019 treatment areas.....	17
Table 5 – 2020 treatment results: stems per hectare.....	18
Table 6 – 2020 old growth control sites: stems per hectare.....	19
Table 7 – 2019 treatment area quality plots: stems per hectare.....	21

Introduction

The Haida Gwaii Northern Goshawk (*Accipiter gentilis laingi*) is a genetically distinct subspecies of forest raptor endemic to Haida Gwaii, and at extreme risk of extirpation (Geraldes et al. 2018). Goshawks rely on mature, spaced forest stands for nesting and foraging, and much of their habitat has been lost to industrial logging (B.C. MOFML, 2010). Silvicultural thinning treatments in over-dense second growth stands offer a substantial opportunity to recruit new foraging habitat for Haida Gwaii goshawks (Doyle, 2004; McClaren et al. 2015). Quillicum Environmental Services, who have demonstrated expertise in riparian forest management, have partnered with Taan Forest Products, the Council of the Haida Nation and Old Massett Village Council to complete a multi-year forest restoration project in the Yakoun watershed. This report will combine a technical description of the 2020 project with a data analysis comparing prey abundance and forest structure in the 2019 and 2020 treatment sites with old growth control sites that currently support goshawk foraging on Haida Gwaii.

1.0 Background

1.1 Weather and climate

Haida Gwaii is an archipelago located between 50-130km off the mainland coast of British Columbia, north of Vancouver Island and south of the Alaskan panhandle. Comprising two large Islands, Graham and Moresby, and over 200 smaller islets, the archipelago remained ice free during the last ice age. As a result, endemic species of flora and fauna survived in a glacial refuge made possible by the relatively temperate maritime influence of the Pacific Ocean (Banner et al., 2014).

Located within the coastal western hemlock (CWH) biogeoclimatic zone, the climate of Haida Gwaii is characterized by cool summers and mild winters with an annual average precipitation ranging from over 3000mm along the windward west coast to less than 1500mm along the leeward side of Graham Island (Banner et al., 2014). The disturbance regime on Haida Gwaii is dominated by frequent, intense windstorms which result in small canopy gaps where individual or a few large trees fall to the forest floor (Banner et al., 2014). The Islands experience the highest winds in the winter and fall where damaging winds primarily come from the south east. Windthrow in riparian reserves is a common occurrence where trees retained in narrow buffer zones are unable to withstand the wind forces funneling through watershed corridors (Holt, 2005).

1.2 History

The Yakoun River, known to the Haida as the Yaaguun, is an important fishing river for the Haida Nation (pers comm., Humphries, 2020). However, intensive logging has severely degraded freshwater habitat and has resulted in a steep decline of salmon populations (Pacific Salmon Commission, 2019). In the heart of the Skidegate plateau, which includes the Yakoun watershed, what was once 90% old growth forest (trees over 250 years old), has been converted to 90% young forest (less than 50 years old) (Pojar, 2008). Young second growth stands are missing the old growth forest characteristics that provide functional habitat for all organisms, such as varied age classes, layered vertical structures and flora species diversity (Pojar, 2008). Young stands have been further simplified from the intensive browsing by invasive black tailed deer, which is depleting the forest understory and inhibiting the regeneration of western redcedar (*Thuja plicata*) and yellow cedar (*Cupressus nootkatensis*) in particular (Pojar, 2008).

Historically, the impact of clearcutting was exacerbated in riparian areas, where the largest, most easily accessed trees could be harvested and transported downriver. The majority of the mainstem and tributary systems on Haida Gwaii not logged before the Second World War were harvested right up to the edge of both banks between 1960 to the late 1980's (Holt, 2005). Before the enactment of the BC Forest Practices Code in 1995, there were no regulations in place to protect riparian forests along fish bearing streams from being logged (Holt, 2005). The practice of logging to the edge of watercourses prior to 1995 resulted in a significant decline in riparian ecosystem function. Riverbanks stripped of the ancient root systems of old forests became destabilized, leading to increased levels of erosion and turbidity and decreasing channel complexity (Holt, 2005).

1.3 Haida Gwaii Goshawks

A recent study by Geraldine et al. (2018) has confirmed the long-suspected fact that the Haida Gwaii Goshawk is a genetically distinct subspecies. The research team, from the University of British Columbia, has called on the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) to upgrade the raptor's official listing from threatened, to endangered, given that their population is estimated to be a mere 48-57 individuals (COSEWIC, 2013).

Loss of mature forest habitat due to logging is primarily responsible for the precipitous decline of goshawk populations in coastal British Columbia (B.C. MOFML., 2010). Goshawk nest density is directly linked to the abundance and availability of prey on the landscape and clear-cut harvesting of mature forests is removing high quality foraging habitat (Mahon and Doyle, 2003). Goshawks, who favor mature, structured forests with closed canopy cover, large diameter trees and open understory (McClaren et al. 2015), require a stand density between 400-500 stems per hectare (sph) to locate their prey and fly freely through the understory to hunt (Mahon and

Doyle, 2003). In particular, Goshawks favor forest habitats with complex vertical structures where different age classes and tree species make up multiple layers of tree height (McClaren et al. 2015; Reynolds, pers comm, 2020). In this environment, the birds have a multitude of perches from which to ambush their prey on the forest floor, in trees or in flight (Mahon and Doyle, 2003). The homogenous second growth forests (less than 50 years), which now dominate Graham Island, do not contribute to the foraging territory of Goshawks on Haida Gwaii (CFCI, 2012; Mahon and Doyle, 2003).

Meanwhile, the conservation of the species remains a high priority for the Haida Nation. Effective as of 2010, the Haida Gwaii Land Use Objectives Order (HGLUOO), works to protect Haida cultural values and maintain the ecological integrity of important wildlife habitats (CHN. and B.C., 2014). The order created twelve goshawk reserve zones across Graham Island to protect nest sites and foraging habitat from human disturbance (CHN and BC, 2014). Further, the order explicitly calls for the recruitment of mature forest through voluntary management intervention in Goshawk nesting areas that have been previously altered or harvested (CHN. and BC, 2014).

Frank Doyle conducted 183 habitat suitability transects on Haida Gwaii in 2003-2004 to assess the abundance and availability of Goshawk prey. His results (Doyle, 2004) indicate that the introduced red squirrel is the leading prey species for Goshawks (43%), followed by red-breasted sapsucker (11.3%) and hairy woodpecker (4.5%). Other studies found that preferred goshawk prey species in coastal BC include red squirrel, passerines (thrushes and jays), woodpeckers and grouse (CFCI, 2012; McClaren et al. 2015; B.C. MOFML, 2010)

Doyle's transects (2004) spanned varying age classes and site series in second growth stands and his results indicated that goshawk forage potential was highest in 30-39-year spruce leading floodplain sites and stands with a combination of hemlock and spruce. Spacing projects within this age class may accelerate the suitability of second growth stands for Goshawk forage up to a decade earlier (Doyle, 2004) than if the stand were left to succeed naturally. Other studies have also identified silvicultural treatments such as pruning or thinning of younger second growth stands (45-60 years) as a way to improve breeding habitat (including foraging) characteristics for Goshawks (McClaren et al. 2015).

Science based guidelines can inform silvicultural treatments and help forest managers make decisions that balance ecological objectives with forest harvesting. The HGLUOO has established conservation reserves along with baseline practices that address the need for conservation and restoration initiatives on Haida Gwaii. In response, Taan Forest Products, the Haida-owned forestry company who hold the largest single land tenure on the Islands, has begun to take an active role in funding and supporting forest restoration projects on Graham Island. Since 2018, Taan Forest Products, Quillicum Environmental services, the council of the Haida Nation and Old Massett Village council have come together to support annual forest restoration

treatments along the Yakoun River. The success of the 2019 pilot project, led by Quillicum Environmental Services, led to the expansion of the treatment area and project scope in 2020.

2.0 Site description of 2020 treatment area

The 2020 project site is located in the riparian areas along the north and south bank of the Yakoun River, at longitude 132°17'52"W and latitude 53°26'51"N (Taan, 2019). Our treatment area is an over dense conifer stand totaling 70.6 hectares (Taan, 2019) with a species composition of 80% Sitka spruce (*Picea sitchensis*), 10% western hemlock (*Tsuga heterophylla*) and 10% red Alder (*Alnus rubra*). The average age of the stand is approximately 30 years old and has a stand density of 905 stems per hectare (sph). The site is within the CWHwh1 biogeoclimatic zone has a medium to rich soil nutrient regime and a mesic-sub mesic soil moisture regime (Taan, 2019), which results in a principal site series classification of western hemlock-Sitka spruce (HwSs) – Lanky moss (101) and a lesser component of western redcedar/Sitka spruce (CwSs) – Sword fern (105) (Banner et al., 2014). At 35m above sea level, the site is situated in the lower elevations of the Yakoun watershed (Esri, 2019), which experience mean annual temperatures of 7.5 degrees Celsius and mean annual precipitation levels of 1878mm per year (UBC, 2020), primarily falling as rainfall.

13.3 hectares of our treatment area overlap with the lower HUGLOO designated lower Yakoun Goshawk reserve zone, and the entirety of our treatment area (70.6 ha) is within the foraging territory (5.2km radius) of three confirmed and documented Goshawk nests (Figure 1) (Taan, 2019). The treatment area also lies within the HUGLOO protected area for fish habitat and 100-year floodplain (Taan, 2019). The proximity to HUGLOO Goshawk reserves was one of the principal reasons that this site was chosen for treatment (Taan, 2019). It is also one of the largest riparian areas along the lower Yakoun impacted by past logging activity and as a result has good road access for the safety of the crew (Taan, 2019).

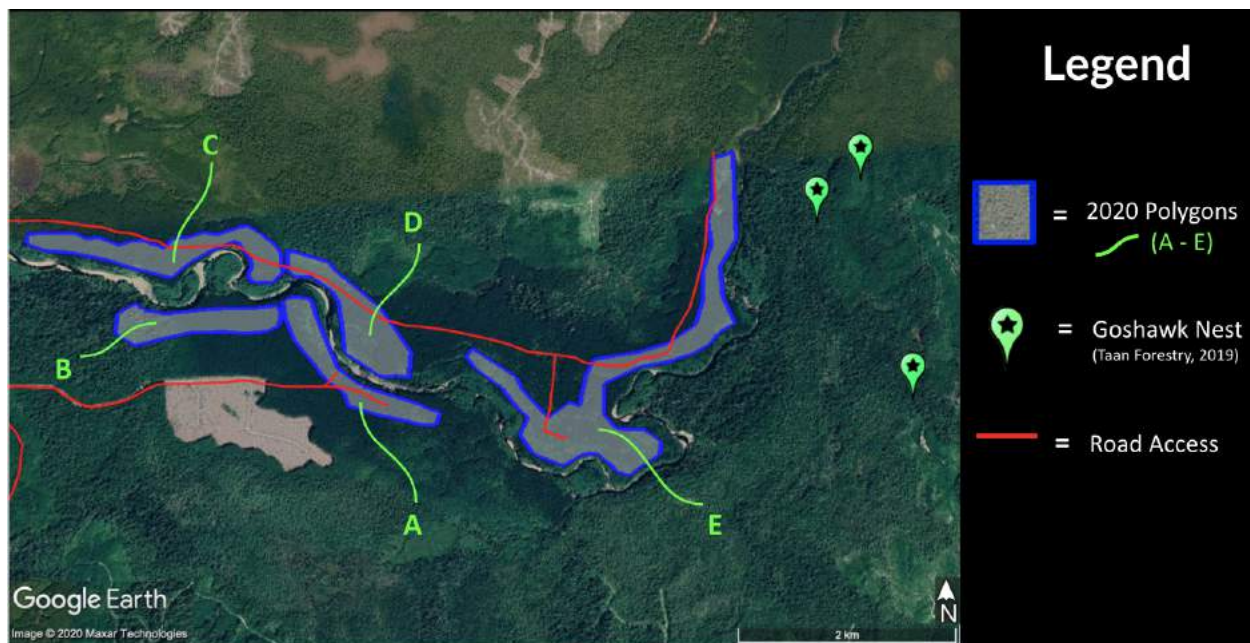


Figure 1 - 2020 treatment polygons and road access (within 5.2km foraging radius of goshawk nests) (Ta'an, 2019). Plot centre: 53°30'32"N, 132° 9'55"W. (WGS84)

3.0 Objectives

3.1 Work completed by Quillicum Environmental Services:

1. To decrease the density of second growth stands, in order to accelerate forest succession and the development of riparian old growth characteristics.
 - i) To recruit additional foraging habitat for the Haida Gwaii Goshawk within 5-10 years
 - ii) To increase root development to improve bank stability and reduce erosion (20-30 years)
 - iii) To increase stand tree size for the recruitment of large woody debris for terrestrial and aquatic inputs over the long term (60-80 years)
2. To use silvicultural techniques to enhance the wildlife value of standing dead and live trees
 - i) To increase insect colonization potential in standing dead trees
 - ii) To increase cone production in standing live trees

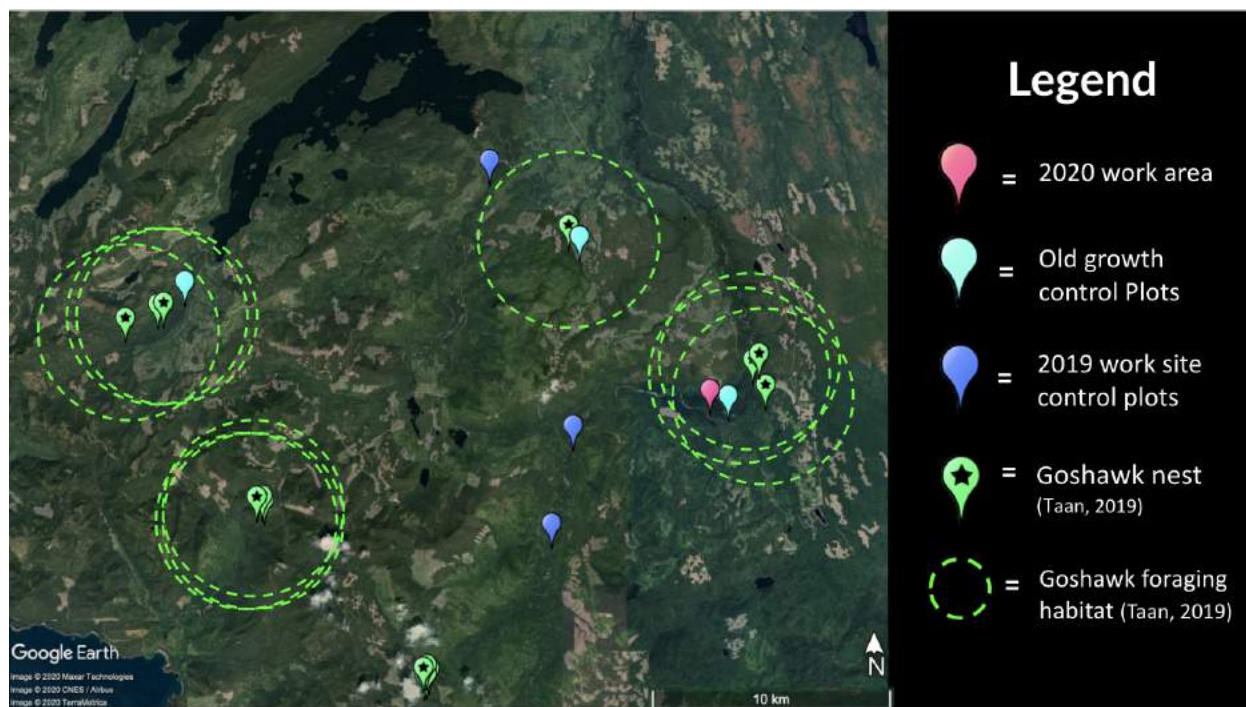


Figure 2 - South Graham Island, Haida Gwaii. Map centre: 53°31'8.00" N, 132°20'21.00"W (WGS84)

3.2 Work completed for UVic ER390 final project:

1. To measure the efficacy of silvicultural treatments in mimicking the conditions of the forest structure and prey resource availability that support existing goshawk forage territory
 - i) To quantify the reference (control) conditions of stand density and prey availability in mature forest stands within goshawk foraging habitat
 - ii) To quantify the conditions of stand density and prey availability in the 2020 and the 2019 treatment sites (Figure 2)

4.0 Methodology

4.1 Stand Management Prescription

The stand management prescription for the 2020 treatment area was finalized in December 2019. The work was approved by the council of the Haida Nation in January 2020 and work began in February 2020.

Table 1 - Current and Post Treatment Stand Conditions. Hw = western hemlock, Ss = Sitka spruce, Dr = red alder, Snag = dead standing tree. From 2020 SMP (Taan Forest).

CURRENT / POST TREATMENT STAND CONDITIONS											
Polygon	DBH Class	Hw		Ss		Dr		Total		Snag	
		Current Density (sph)	Target Density (sph)	Current Density (sph)	Target Density (sph)	Current Density (sph)	Target Density (sph)	Current Density (sph)	Target Density (sph)	Current Density (sph)	Target Density (sph)
YAKR01 – unit 1	0 -10	20	0	0	0	0	0	20	0	N/A	0
	10.1 – 20	28	0	28	0	75	0	130	0	N/A	65
	20.1 – 40	45	20	308	200	10	10	363	230	N/A	133
	40.1 - 60	0	0	328	250	5	5	333	255	N/A	78
	60>	0	0	60	60	0	0	60	60	0	0
	Total	93	20	723	510	90	15	905	545	N/A	275

Polygons A-E, represented by YAKR01 in Figure 1, total 70.6 hectares, and were surveyed by employees of Taan Forest in the fall of 2019 to determine stand density (current density in Table 1) prior to treatment. The target density of the treatment area was 545 stems per hectare (sph), and the target species composition was 94% Sitka spruce, 4% western hemlock and 2% red alder. Post treatment stand density (target density in Table 1) was surveyed by employees of Quillicum environmental in the spring of 2020 (see results).

The treatment prioritizes the retention of the largest diameter trees. No trees above 60cm in diameter, measured at breast height (dbh) were targeted for treatment regardless of species. Trees were retained in smaller diameter classes (0-10cm and 10.1- 20cm) if they were necessary to make up the target density of 545 sph. If larger trees were present, then only trees above 20cm dbh were retained, and trees below 20cm were either girdled (>15cm) or felled (<15cm), regardless of species type.

Girdling and cat-facing are chainsaw techniques to kill a tree without having to cut it down (more details in section 5.3). The prescription calls for cat-facing 20 sph of the approximate 340 sph of trees targeted for girdling (Taan, 2019). Girdled trees were only chosen within the 40.1 - 60cm dbh class. The prescription targets the retention of snags (dead standing trees) at a density of 275 sph. Snags include girdled trees, cat-faced trees or existing dead trees present on site not deemed safe by the falling crew.



Figure 3 - Polygon B, pre-treatment stand with a density of 905 sph (majority spruce and hemlock) Deteriorating western redcedar stump (foreground) shows size of previous old growth stand.

4.2 Project stages and timeline

This following section explains the methodology for the six stages of the project in sequential order: Layout, snag falling, operations, 2020 treatment area quality plots, old growth control plots and 2019 treatment area quality plots.

Table 2 - Restoration project timeline

Stage/Task	February	March	April	May
Stage 1/ Layout				
Stage 2/ Falling				
Stage 3 / Operations				
Stage 4/ Quality Plots				
Stage 5,6/ Control Plots				

4.3 Layout – Stage 1

Three employees from Quillicum Environmental completed the site preparation for the 2020 treatment area (70.6 hectares). The layout crew split up according to falling corners as outlined in the maps provided by Taan forestry and loaded into Avenza maps (example on Figure 4). The team flagged all treatment trees (Girdles, Cat-faces, wildlife trees, danger trees) and delineated work boundaries for tree falling (stage 2) and operations (stage 3). The layout team conducted regular plots of 5.64m radius (1/100th of a hectare) to double check their own work and their colleagues' work for quality assurance.

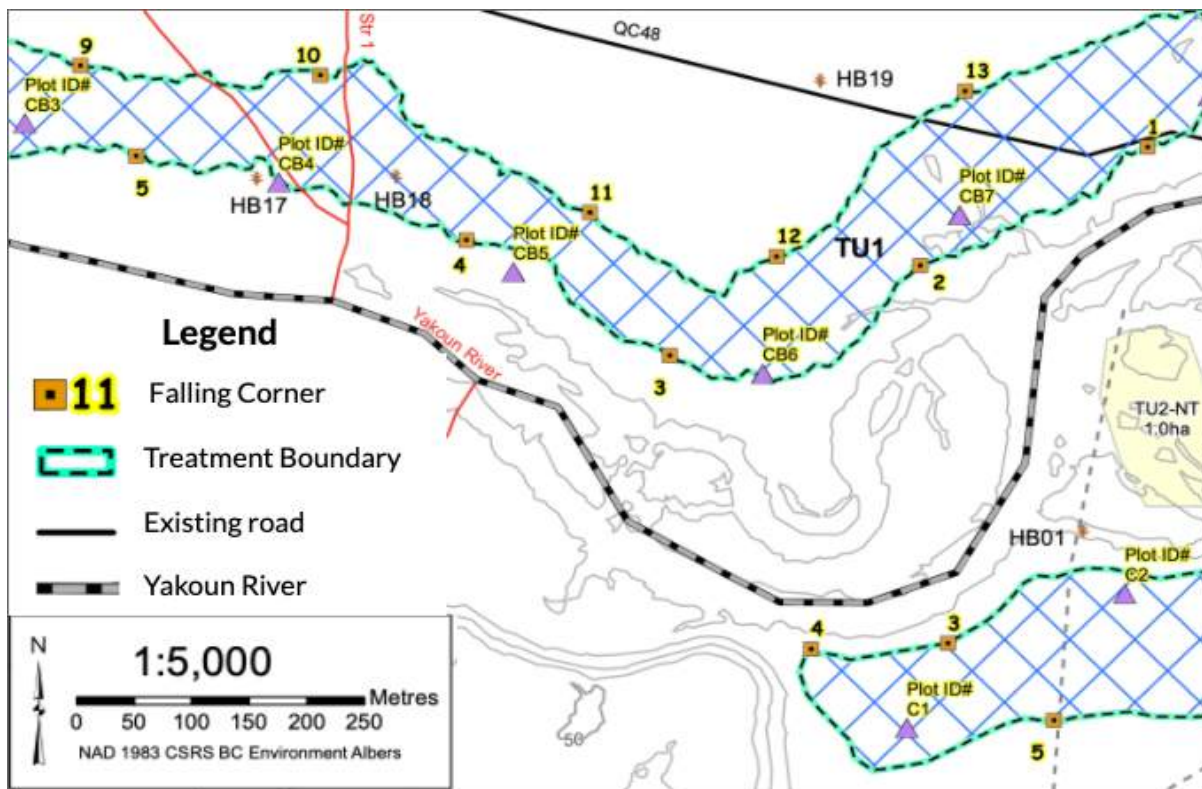


Figure 4 - Operational planning map, Taan Forestry Stand Management Prescription (2020). Sub-section view of polygon C (north side of Yakoun) and polygon B (south side of Yakoun River) treatment area.

4.4 Falling – Stage 2

Once the layout was underway, a crew of four professional fallers began cutting down dangerous trees that could potentially pose a risk to the crew in the operations stage. Danger trees included rotten trees susceptible to blow-down, leaning trees with unstable root systems and fallen trees that were suspended horizontally above the forest floor. Any dead trees flagged by the layout crew that were deemed safe and stable by the fallers were left standing as potential wildlife habitat.

4.5 Operations – Stage 3

Full crew operations began on March 9th, 2020 and included seven Haida from Old Masset and three supervisors from Quillicum Environmental services. Using chainsaws, the crew cut down any live trees less than 15cm dbh. Professional certification is needed to cut down any tree above 15cm dbh, and as a result, any species above 15cm dbh was either girdled or cat-faced.

To girdle trees, the crew used chainsaws to remove the bark and cambium layers around the entire circumference of selected trees at approximately waist height (Figure 5). Girdling removes the phloem, cambial and xylem tissue, which rapidly kills the tree and is a cost-effective technique for selectively thinning forests and plantations (Moore, 2013). Girdled trees remain as standing snags that may provide wildlife value for insects and birds, which in turn may provide prey for Goshawks (Taan, 2019).

Cat-facing is a technique in which a strip of bark and cambium is cut away from the tree in a 1m by 20cm vertical strip (Figure 5). This technique is designed to mimic a natural wind disturbance in which a falling tree strikes another tree and injures it by removing the bark and cambium and exposing the heart wood to disease. Cat-facing will trigger a stress response by the tree by which it will produce more cones, which may provide feed for migratory birds and squirrels and in turn provide feed for Goshawks within 1-3 years (Taan, 2019). Eventually, cat-facing will likely kill the tree, but it will persist much longer than a girdled tree, and after producing the desired cone stock, will remain as standing snag that may provide wildlife value (pers comm, Simmons, 2019).



Figure 5 - Cat-face (left) and Girdle (right) on Sitka spruce (Ss) trees identified for treatment

4.6 2020 Treatment area quality plots – Stage 4

A total of 83 quality plots were conducted in polygons A to E of the 2020 treatment area by myself and one of my co-workers. Quality plots were taken to quantify the post-treatment density of live trees and standing snags. The data was relayed to Taan Forest Products, the tenure license holder, to ensure the project was following the objectives of the stand management prescription.

The team followed the standard methods for the collection of forest inventory data as outlined in the BC field manual for describing terrestrial ecosystems (B.C. M.F.R., 2010). Quality plots were randomly identified on the smartphone application ‘Avenza Maps’ prior to entering the polygon. The assessor used a 5.64m length plot cord to measure plot circles that represented 1/100th of a hectare. The species composition and diameter at breast height was recorded for each tree in the plot. A tally of live and dead trees (girdled, cat-face, natural snag) was taken to determine post-treatment stand density (sph) as well as snag density (sph). In addition, I collected data on the presence or absence of squirrel feeding in 11 of the 83 plots, all of which were located in polygon E (Figure 1). The GPS location of each plot was recorded using the smartphone application ‘maps.me’.

4.7 Old growth control plots – stage 5

With the help of Nick Reynolds of Sangan Environmental Services (pers comm, 2020), Ben Levesque of Taan Forest Products (pers comm, 2020) and Bart Simmons of Quillicum Environmental Services (pers comm, 2020), I was able to identify three different mature forest stands on Graham Island that would act as control sites for this study.

Each control site is located in old growth forest stands that are within the 5.2km foraging habitat radius (Taan, 2019) of documented goshawk nests (Figure 2). The sites were chosen to represent a reference control to evaluate the differences in forest structure and prey availability between the 2020 post-treatment work area and the mature forest stands within goshawk foraging territory.

I recruited one of my co-workers to help me collect data in 15 control plots (Datleman= 5, Yakoun= 6, Florence= 4) at three different locations in the spring of 2020. The GPS locations of each plot were recorded using the smartphone application ‘maps.me’. Table 3 shows the coordinates of the first plot taken at each location.

Table 3 – Location of control sites

Date of field visit	Location	GPS coordinates (WGS84)
05/10/2020	Yakoun River	53°30'9.04"N, 132° 08'54"W
05/27/2020	Datleman Creek	53°32'47.53"N, 132° 30'11"W
06/26/2020	Florence Creek	53°33'51.36"N, 132°14'43"W

At each control site, I used a 11.3m length plot cord to measure plot circles that represented 1/25th of a hectare. I used a longer plot cord in order to get a more accurate average density given the age structure and large diameter class of trees in old growth stands (pers comm, Simmons, 2020). Although the treatment area quality plots (stage 4) used a 5.64m plot cord, I am confident that given the relatively high number of quality plots (n=83) that we can safely make tree density comparisons across sites.

For each plot, I recorded the species and diameter at breast height of all living and dead standing trees. Next, I recorded the presence or absence of red-breasted sapsucker signs by examining all the trees in the plot for evidence of vertical grid-like bore holes (Figure 6) that are characteristic of sapsuckers (Davidson et al. 2015; BC, 1999). I also recorded the presence or absence of red-squirrel activity including cone shavings from feeding or potential dens around the trunks of trees (Figure 6). For both species, I recorded live sightings and audible animal calls in each plot.



Figure 6 – Sapsucker bore holes (left) and Sitka spruce cone shavings (right) from red squirrel feed site

4.8 2019 Treatment area quality plots – stage 6

As part of my project, I also collected data of the stand density and species composition in the 2019 work areas that were completed by Quillicum environmental services and the crew from Old Masset Village. I worked for Quillicum Environmental in the spring of 2019 and was well acquainted with the layout and location of each polygon (poly).

The 2019 work areas consisted of three different polygons (54, 38 and 42), totaling 27 hectares. The stand management prescription for 2019 targeted the retention of 500 stems per hectare (instead of 545 sph in 2020) but had the same principal objectives as the 2020 project (Quillicum, 2019). The thinning process was designed to reduce the stand density to create additional foraging territory for the Haida Gwaii Goshawk (Quillicum, 2019).

In the spring of 2020, I recruited the help of one of my co-workers to aid in recording data for a total of 16 plots (Poly 54 = 7 plots, Poly 42 = 3 plots, Poly 38 = 6 plots) across three different sites on Graham Island. Table 4 shows the coordinates of the first plot taken at each location.

Table 4 – Location of 2019 Treatment areas

Date of field visit	Location	GPS coordinates (WGS84)
05/10/2020	Polygon 54	53°35'38"N, 132°18'15"W
05/27/2020	Polygon 42	53°29'27 "N, 132°14'58"W
06/26/2020	Polygon 38	53°27'10.61"N, 132°15'48.72"W

In each polygon I used an 11.3m plot cord to measure plot circles that represented 1/25th of a hectare. As in my quality plots and old growth control plots, I recorded the species and diameter at breast height of all living and dead standing trees in each plot. Again, I used the same methods from stage 4 and 5 to detect the presence or absence of red-breasted sapsucker sign and red-squirrel sign, both of which are goshawk prey.

5.0 Results

5.1 2020 Treatment area

The operational stage of the project, with the crew from Old Masset village, was completed on May 29th, 2020. Our quality plots within the treatment area (n=83) indicated that after the completion of the project, we achieved a stem density of 531 stems per hectare, and a standing dead trees (snag) density of 255 stems per hectare. Five out of 11 (45%) plots in polygon E had evidence of red-squirrel sign in the form of cone shavings or dens, and all of the evidence was concentrated around larger diameter Sitka spruce trees. The standing snags recorded within the quality plots included girdled, cat-faced and wildlife trees left standing by the falling crew.

Table 5 – 2020 treatment results: stems per hectare

	Live trees (sph)	Standing snags (sph)	Tree species composition
Pre-treatment	905	N/A	80% spruce, 10% hemlock, 10% red alder
Target	545	275	94% spruce, 4% hemlock and 2% alder
Post-treatment result	531	255	97% spruce, 2% hemlock and 1% alder

The post-treatment species composition and the average diameter class (dbh) across 83 quality plots are indicated in Figure 7. The forest stand is approximately 30 years old and is dominated by Sitka spruce. There was no red cedar detected in the treatment area, and there was a minimal component of western hemlock and red alder.



Figure 7 – 2020 post-treatment diameter class and species composition

5.2 Old growth control plots

The old growth control plots are located on the south side of Graham Island (Table 3) and represent a reference condition for existing goshawk foraging territory. Live and dead tree densities are shown in Table 6, as well as the species composition at each site. The Datleman Creek is a low floodplain zone dominated by Sitka spruce, and most closely resembles the species composition of our 2020 treatment area. Out of a total of 15 control plots taken across three sites, 13 plots (87%) had evidence of red squirrel feeding activity and 9 plots (60%) showed evidence of sapsucker feeding. A total of 12 standing snags were detected across 15 plots. Three out of 15 snags were over 100cm dbh and one snag along the Datleman had a dbh of 254cm.

Table 6 – 2020 old growth control sites: stems per hectare

	Live trees (sph)	Standing snags (sph)	Tree species composition
Yakoun River	237.5	12.5	21% spruce, 41% hemlock, 34% alder, 4% cedar
Datleman Creek	205	25	78% spruce, 20% hemlock and

			2% alder
Florence Creek	319	25	15% spruce, 77% hemlock and 8% cedar
Average across sites	254	21	34% spruce, 48% hemlock, 13% alder, 5% cedar

The species composition and diameter class (dbh) across 15 plots is shown in Figure 8. The y-axis shows the relative percentage of species detected in the plots across three control sites. Western hemlock makes up the largest proportion of tree species followed by Sitka spruce. The majority of the red alder detected was below 50cm dbh and was concentrated in plots dominated by recent disturbance. Western redcedar, though only consisting of 5% of the trees detected in the control plots, made up a relatively significant proportion of the oldest and largest biomass trees (>70cm dbh).

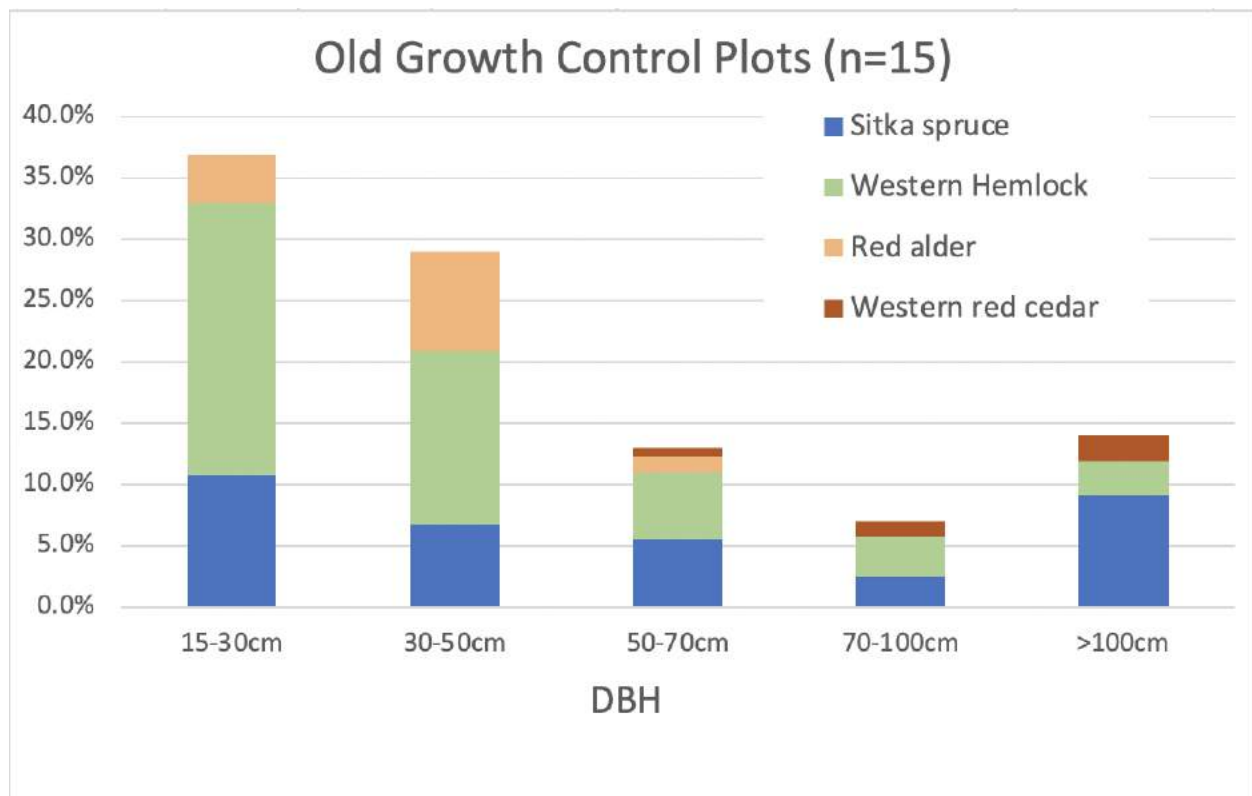


Figure 8 – Old growth control site: diameter class and species composition

5.3 2019 treatment area

Table 7 – 2019 treatment area quality plots: stems per hectare

	Live trees (sph)	Standing snags (sph)	Tree species composition
Polygon 38	458	333	56% spruce, 24% hemlock, 20% alder
Polygon 42	546	225	40% spruce, 59% hemlock, 1% alder
Polygon 54	496	114	25% spruce, 47% hemlock, 1% alder, 28% cedar
Average across sites	500	224	40% spruce, 43% hemlock, 7% alder, 10% cedar

Results combining data across 16 plots within the 2019 treatment area (Table 7) indicate a live tree density of 500 sph and a standing snag density of 224 sph. The 2019 polygons had a higher proportion of smaller diameter trees (<15cm) than the 2020 polygons, and as a result, there were more trees cut down by the operations crew and less trees retained as standing snags in the form of girdles or cat-faces. This is particularly evident in polygon 54, with a standing snag density of 114 sph. Across the three polygons, 14 out of 16 plots (88%) had evidence of red-breasted sapsucker bore holes and 9 out of 16 plots (56%) had spruce cone shavings from red squirrel activity.

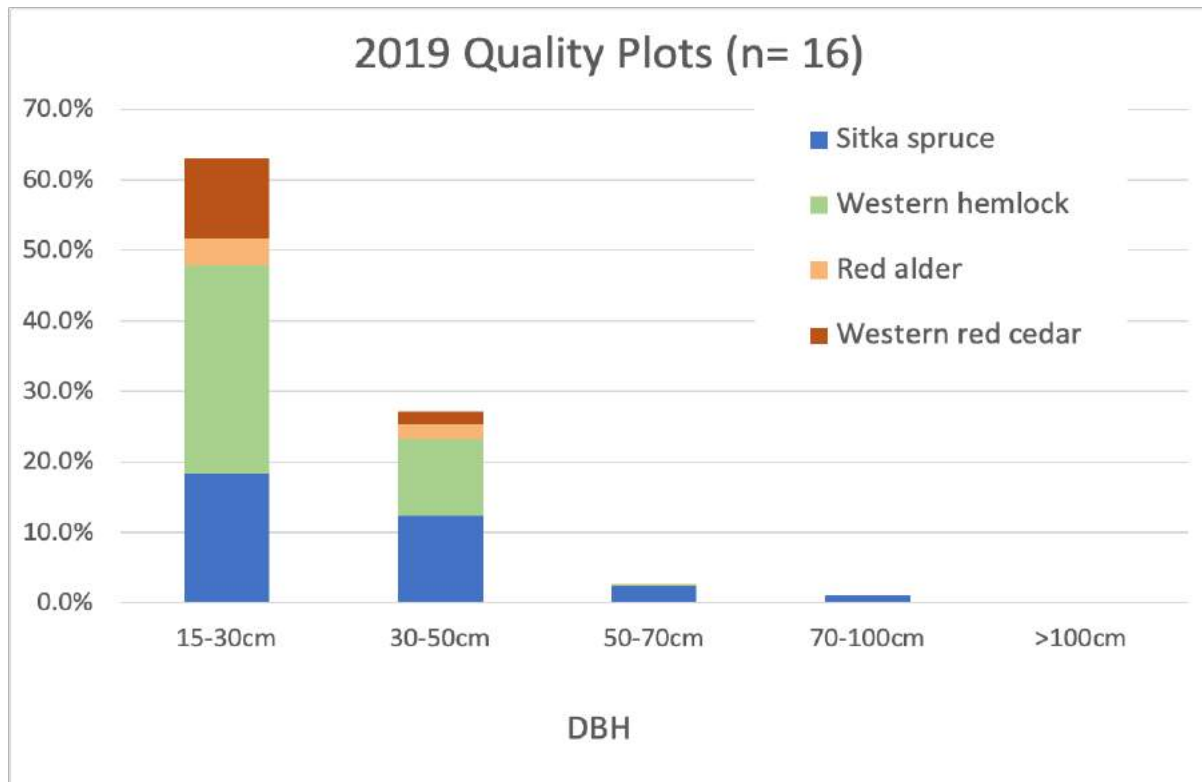


Figure 9 – 2019 treatment area quality plots: diameter class and species composition

As seen in Figure 9, the majority of trees in the 2019 polygons were below 50cm dbh even though the forest stands in polygon 42 and 38 are approximately 55 years old (Quillicum, 2019). Western hemlock is the dominant species across the three sites, followed by Sitka spruce. The majority of the redcedar was found in polygon 54, which had a pre-treatment density of approximately 4000 sph (Quillicum, 2019).

6.0 Discussion

The presence and availability of prey are key drivers in the viability of goshawk populations in coastal British Columbia (CFCI, 2012; Doyle, 2004; McClaren et al. 2015). In an effort to increase the availability of goshawk prey, the 2020 riparian restoration project led by Quillicum Environmental Services reduced the density of live trees in the treatment area from 905 sph to 531 sph. The majority of the trees were either girdled or cat-faced, which contributed to a post treatment snag density of 255 sph.

Though the density of live trees was reduced, the majority of treatment trees (girdles, cat-faces) still remained standing as dead trees. The result will be a delayed and incremental decrease in stand density as the standing snags fall to the forest floor over the next 5-10 years (Taan, 2019),

or longer. The majority of the treatment area will not immediately become suitable goshawk foraging territory, as the raptors will likely still have difficulty flying freely through the stand where the majority of treated trees remain as obstacles for attacking and detecting prey. However, the treatment will serve to accelerate the natural thinning process, and, as the remaining live trees express their dominance, the forest will continue to develop characteristics typical of old growth forests, such as multilayered canopies and a stand density closer to 400-500 sph, the ideal forest structure for goshawk nesting and foraging (Doyle, 2004).

In the 2020 treatment area, snag falling and microsite specific treatment selections by the layout crew have created variability in the forest stand, which may accelerate the development of sub-canopy gaps and flyways suitable for goshawk foraging (McClaren et al. 2015). Dense concentrations of dangerous trees were cut down by the falling crew before the operations stage, which resulted in clearings in the canopy and areas with very low density throughout the treatment area. It is not possible to quantify the total change in density of live and dead trees before and after treatment as we do not have data on the density of pre-treatment snags. However, we do know there has been a net decrease in the number of standing stems within the treatment area. The quality plots indicate a live tree density of 531 sph and a snag density of 255 sph, though there is a considerable degree of variability in stand density throughout the treatment site depending on microsites and topography. The prescription took into account this variability by specifying that the target stem density could fluctuate from 500-650 sph depending on specific conditions. This gave the operations crew considerable discretion to retain high value trees (larger dbh or crown) in denser clusters immediately adjacent to forest clearings. Resulting pockets of open forest have created a mosaic of tree densities that more closely resemble the natural windfall disturbance regime on Haida Gwaii. Variable spacing treatments will help develop the stand from a homogenous plantation into a structurally complex forest that is more similar to goshawk foraging habitat in the naturally regenerating old growth control sites.

Goshawks also rely on variations in the vertical structure of the canopy for foraging (McClaren et al. 2015). The old growth control plots, taken within existing goshawk foraging territory, had a density of 254 stems per hectare consisting of trees in each diameter class. In contrast, the 2020 treatment areas had over 80% of trees concentrated in the 30-70cm dbh range, and the 2019 polygons had over 90% of the stand in the 15-50cm dbh range. The mix of tree height and age classes in the old growth control sites enables goshawks to utilize perches at different levels of the canopy depending on whether they are hunting for prey on the forest floor (eg. Grouse, red squirrel) or half-way up a tree (e.g., Songbirds, sapsuckers). In an effort to mimic the complex canopy structures of mature forests, the 2020 project prioritized the retention of trees across a range of diameter classes and species to allow for variability in the height and structure of the stand. In certain cases, for example, a western hemlock measuring 25cm dbh would be retained while a 50cm dbh Sitka spruce is girdled, or a Sitka spruce measuring 55 cm dbh may be

selected for a cat-face while an adjacent spruce tree, though much smaller at only 24cm dbh, is retained.

While selectively thinning the forest stand had the objective of improving the accessibility of goshawk prey, the silvicultural methods used on the trees were intended to increase the abundance of prey. Cat-facing was introduced in 2020 as a method to increase cone development, providing more food for red squirrels, the principal prey of goshawks on Haida Gwaii. All of the cone shavings from squirrel feeding detected across the 2020 treatment area quality plots (n=83), old growth control plots (n=15) and 2019 quality plots (n=16) were from Sitka spruce cones. The majority of shavings were detected around larger diameter (>50cm dbh) Sitka spruce trees. Within the 2019 and 2020 quality plots, 56% and 45%, respectively, had evidence of squirrel activity. In contrast, 87% of the old growth plots had evidence of squirrel feeding. Red squirrels favored larger diameter spruce trees for feeding and denning and did not appear to utilize western red cedar or western hemlock as habitat. The 2020 prescription retained all of the largest diameter spruce trees (>70cm) to the benefit of red squirrel populations while simultaneously recruiting additional cone stocks through the selective cat-facing of mature spruce (50-70cm dbh). Red squirrels will continue to provide the majority of goshawk sustenance, as the depletion of the forest understory due to heavy deer browsing has led to the decline of blue grouse, the historically dominant goshawk prey (Doyle, 2003).

Trees were girdled to create high value snag habitat for cavity nesting birds (Quillicum, 2019) such as woodpeckers, passerines and red-breasted sapsuckers, which in turn could provide forage for goshawks. Whereas red-squirrel activity was more prevalent in the old growth sites, the 2019 treatment area quality plots had more evidence of red-breasted sapsucker activity than the old growth plots. For every 2019 plot where evidence of red-breasted sapsucker (88%) was recorded, at least 2 trees within each plot had sapsucker bore holes. Further, I recorded live sightings and audible sapsucker drumming in each of the 2019 work sites. Throughout the control plots and 2019 quality plots, western hemlock was the only species with small vertical boreholes indicative of sapsucker feeding. It is important to acknowledge that I did not take pre-treatment data for sapsucker or squirrel activity within the 2019 treatment area and I do not claim that the treatment created additional sapsucker habitat one year later. However, the consistent presence of sapsuckers in the 2019 work areas indicates that smaller diameter western hemlock trees (<50cm dbh) are providing foraging habitat for red-breasted sapsuckers. Increased sapsucker activity, combined with a more open and complex forest structure, may provide for the recruitment of additional goshawk foraging habitat.

However, as red-breasted sapsuckers are annual migrants to the Islands, they only provide food for goshawks in the summer months, and it is the availability of prey in the winter that remains the main bottleneck for goshawk survival on Haida Gwaii (Doyle, 2003). Red squirrels are the primary prey throughout the year (Doyle, 2003), and their presence in the 2020 and 2019

treatment area is a more important indicator for goshawk forage potential than sapsucker activity, as long as the forest structure allows goshawks to access their prey. The scarcity of prey in the winter and early spring may be leading to an increase in the mortality of adult and recently fledged goshawks due to chicken coop conflicts (Doyle, 2016). In the community of Tlell, on the east side of Graham Island, goshawks often become tangled in wire or fatally injured by chickens, and in some cases have been shot dead by local landowners (pers comm., Wotten, 2020).

For the birds to survive a multitude of threats, forest restoration treatments must be urgently prioritized to recruit new foraging territory for the Haida Gwaii goshawks (Doyle, 2016). Though it will not be immediately evident how effective our project will be in creating new foraging habitat, there is evidence that goshawks will preferentially forage in stands that are more accessible than forests where prey is abundant but less accessible (Beier & Drennan 1997; McClaren et al. 2015). It is clear that prey is present and active in the treatment areas, but the question remains whether or not the forest is accessible to goshawks. The 2020 project, located within a 30-year-old spruce leading floodplain site, has the highest potential to recruit new foraging habitat out of any forest type on Haida Gwaii (Doyle, 2004). The site is located within the foraging range of three goshawk nests, and the treatment prescription is well positioned to successfully improve the accessibility of the stand to goshawk foraging.

7.0 Recommendations and conclusion

The 2020 treatment prescription had the objective of improving the accessibility and abundance of goshawk prey. Given the prevalence of red-breasted sapsucker feeding on western hemlock trees in the 2019 treatment area, I recommend that future treatments retain western hemlock at a greater percentage than that of the 2020 prescription. As I only observed evidence of red squirrel feeding on Sitka spruce cones, I recommend that only spruce trees be cat-faced, and not western hemlock, in order to maximize the potential for additional cone production.

This study did not record data for the presence or absence of red-breasted sapsuckers in the 2020 treatment area, nor was data recorded for the presence or absence of red-squirrels or sapsuckers before the 2019 treatment. In the future, consistent and rigorous scientific monitoring can build on my initial field study to quantify long term changes in ecosystem function for goshawks in thinned second growth stands. I recommend that future restoration prescriptions monitor the relative change in prey abundance before and after thinning treatments. Field work monitoring should include wildlife tree/sign transects (BC, 1999) to determine the relative abundance of sapsuckers and woodpeckers as well as animal sign transect sampling to quantify the relative abundance of red squirrels (BC, 1998). The expectation of recruiting new goshawk foraging habitat within 5-10 years (Taan, 2019) must not be taken on faith alone. The urgency of goshawk

conservation demands increased funding and operational capacity for scientifically informed restoration treatments.

Science-based results will help forest managers improve treatment prescriptions and inform decisions on which sites to select for future projects. Transparent and objective reporting of the project results should be communicated to stakeholders, funders and the general public, which may improve public understanding and long-term support for the project on Haida Gwaii. This project, which will continue in 2021, provides local employment for the Haida, and marks an important step in beginning to recover goshawk foraging habitat in the Yakoun watershed.

8.0 Acknowledgements

I would like to thank Bart Simmons from Quillicum Environmental Services for his flexibility in allowing me to collect data and complete this report while working on Haida Gwaii. I would also like to thank my colleagues from Quillicum and Old Masset village for their sense of humor and work ethic during the 2019 and 2020 field seasons. Thank you to the Council of the Haida Nation for supporting this project and to Jeff Mosher from Taan Forest Products for his perseverance and dedication to making this project happen. Finally, thank you to Nancy Shackelford and Eric Higgs from the University of Victoria's RNS program for their guidance and support in completing this report.

9.0 References

Banner, A., W.H. MacKenzie, J. Pojar, A. MacKinnon, S.C. Saunders, and H. Klassen. 2014. A field guide to ecosystem classification and identification for Haida Gwaii. Prov. B.C., Victoria, B.C. Land Manag. Handb. 68. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh68.htm

Beier, P., & Drennan, J. E. (1997). Forest structure and prey abundance in foraging areas of northern goshawks. *Ecological Applications*, 7(2), 564-571.

B.C. Ministry of Forests, Mines and Lands. (2010). Evaluating the effectiveness of wildlife habitat areas for Northern Goshawks (*Accipiter gentilis laingi*) in coastal British Columbia: selection of indicators. B.C. Min. For. Mines Lands, For. Prac. Invest. Br., Victoria, B.C. FREP. https://www.for.gov.bc.ca/ftp/HFP/external!/publish/FREP/reports/FREP_Report_26.pdf.

B.C. Ministry of Forests and Range, & B.C. Ministry of Environment. (2010). Field manual for describing terrestrial ecosystems. 2nd ed. Forest Science Program, Victoria, B.C. Land Management Handbook No. 25. <http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh25-2.htm>.

British Columbia Resources Inventory Committee. (1998). Inventory methods for pikas and sciurids: pikas, marmots, woodchuck, chipmunks and squirrels. Standards for components of British Columbia's Biodiversity, (29). <https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/piscml20.pdf>.

British Columbia Resources Inventory Committee. (1999). Inventory methods for woodpeckers. Standards for components of British Columbia's Biodiversity, (19). <https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/woodml20.pdf>.

Coast Forest Conservation Initiative. (2012). Maintaining the integrity of Northern Goshawk nesting and post-fledging areas in the ecosystem-based management plan area of coastal British Columbia: guidance for forest professionals. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/bc-timber-sales/ems-sfm-certification/business-area/strait-of-georgia/tsg_goshawk-protocol-loughborough.pdf.

COSEWIC (2013). COSEWIC assessment and status report on the Northern Goshawk *Accipiter gentilis laingi* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. x + 56 pp. https://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_autour_palombes_northern_goshawk_1213_e.pdf

Council of the Haida Nation and the Province of British Columbia. (2014). Haida Gwaii Land Use Objectives Order, HGLUOO. (Consolidated Version). https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/land-use-plans-and-objectives/westcoast-region/haidagwaii-slua/haidagwaii_slua_luor_8may2014 consolidated.pdf.

Davidson, P.J.A and Seneviratne, S. 2015. Red-breasted Sapsucker *in* Davidson, P.J.A., R.J. Cannings, A.R. Couturier, D. Lepage, and C.M. Di Corrado (eds.). *The Atlas of the Breeding Birds of British Columbia, 2008-2012*. Bird Studies Canada. Delta, B.C. <http://www.birdatlas.bc.ca/accounts/speciesaccount.jsp?sp=RBSA&lang=en>.

Doyle, F. I. (2003). Managing for goshawks in TFL39 on Haida Gwaii/Queen Charlotte Islands-Goshawk nest monitoring and diet 2003. [Unpublished Report]. Weyerhaeuser Ltd., Nanaimo B.C. <https://www.for.gov.bc.ca/hfd/library/fia/2003/FIA2003MR044.pdf>.

Doyle, F. I. (2004). Managing for goshawks in TFL39 on Haida Gwaii/Queen Charlotte Islands-Goshawk and marbled murrelet habitat suitability. [Unpublished Report]. Weyerhaeuser Ltd., Nanaimo B.C. <https://www.for.gov.bc.ca/hfd/library/FIA/2004/FIA2004MR027.pdf>.

Doyle, F.I. (2016). Haida Gwaii Goshawks (A.g. laingi). MFLNRO, Haida Gwaii. BCTS. Husby Forest Products Ltd. Parks Canada. Gwaii Haanan National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site. Taan Forest LP.

Esri. "Topographic" [basemap]. Scale Not Given. "Points and Polygons around the Yakoun River, Haida Gwaii". (2019). <https://www.arcgis.com/home/webmap/viewer.html?%20webmap=0b275c8046824382884dd342944dc762>.

Geraldes, A., Askelson, K. K., Nikelski, E., Doyle, F. I., Harrower, W. L., Winker, K., & Irwin, D. E. (2019). Population genomic analyses reveal a highly differentiated and endangered genetic cluster of northern goshawks (*Accipiter gentilis laingi*) in Haida Gwaii. *Evolutionary Applications*, 12(4), 757-772.

Holt, R. (2005). Environmental conditions report for the Haida Gwaii/Queen Charlotte Islands land use plan. British Columbia Ministry of Sustainable Resource Management. https://veridianecological.files.wordpress.com/2010/11/hg_conditions_aug20b_nocedar.pdf.

Mahon, T., & Doyle, F. (2003). Foraging habitat selection, prey abundance, and reproductive success of northern goshawks in northwest British Columbia. [Unpublished Report]. Babine Forest Products Ltd., Burns Lakes, BC and Houston Forest Products Ltd., Houston, BC. <https://www.for.gov.bc.ca/hfd/library/FIA/2003/FIA2003MR253.pdf>.

McClaren, E. L., Mahon, T., Doyle, F. I., & Harrower, W. L. (2015). Science-Based Guidelines for Managing Northern Goshawk Breeding Areas in Coastal British Columbia. *Journal of Ecosystems and Management*, 15(2), 1-91.

Pacific Salmon Commission. (2019). Northern boundary & transboundary rivers restoration and enhancement fund 2019 final report. PSC Northern Funds Committee. <https://www.psc.org/publications/>

Pojar, J. (2008). Changes in vegetation of Haida Gwaii in historical time. In Proceedings from the Research Group on Introduced Species 2002 Symposium. Canadian Wildlife Service, Environment Canada, Ottawa (pp. 32-38). https://www.haidanation.ca/wp-content/uploads/2017/03/CWS_laskeek_lessons_all.pdf.

Quillicum Environmental Services Ltd. (2019). Riparian restoration completion report. Prepared for Old Masset Village Council.

Taan Forest Products. (2019). YAKR01 Stand Management Plan. Prepared by William Crocker, RPF.

The University of British Columbia (2020). Centre for Forest Conservation Genetics, Coastal Western Hemlock Zone. [https://cfcg.forestry.ubc.ca/resources/cataloguing-in-situ-genetic - resources/cwh-zone/](https://cfcg.forestry.ubc.ca/resources/cataloguing-in-situ-genetic-resources/cwh-zone/).

Foraging Ecology of the Northern Goshawk in Coastal British Columbia

by

Gwyn Case

B.Sc., Oregon State University, 2013

Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

in the
Department of Biological Sciences
Faculty of Science

© Gwyn Case 2021
SIMON FRASER UNIVERSITY
Summer 2021

Copyright in this work rests with the author. Please ensure that any reproduction
or re-use is done in accordance with the relevant national copyright legislation.

Declaration of Committee

Name: Gwyn Case

Degree: Master of Science (Biological Sciences)

Title: Foraging Ecology of the Northern Goshawk in Coastal British Columbia

Examining Committee:

Chair: Chris Kennedy
Professor, Biological Sciences

David Green
Supervisor
Professor, Biological Sciences

John Reynolds
Committee Member
Professor, Biological Sciences

Melanie Wilson
Committee Member
Wildlife Biologist
BC Ministry of Forests, Lands, Natural Resource
Operations and Rural Development

Kathy Martin
Examiner
Professor
Forest and Conservation Sciences
University of British Columbia

Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

- a. human research ethics approval from the Simon Fraser University Office of Research Ethics

or

- b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University

or has conducted the research

- c. as a co-investigator, collaborator, or research assistant in a research project approved in advance.

A copy of the approval letter has been filed with the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Simon Fraser University Library
Burnaby, British Columbia, Canada

Update Spring 2016

Abstract

Effective wildlife conservation requires understanding diet composition and its consequences for population demography. I measured the diet of an at-risk population of Northern Goshawks (*Accipiter gentilis*) in southwestern British Columbia during two breeding seasons using pellets, prey remains, and nest cameras. I compared diet composition across two ecological zones and assessed the impact of dietary diversity and specialization on goshawk productivity. Goshawks consumed 33 different species but primarily consumed pine squirrels (*Tamiasciurus* spp.), which composed 14-61% of dietary biomass, depending on source. Diet composition differed slightly between the coastal and transition zones. I also conducted a pilot study of goshawk breeding season movement using GPS-UHF transmitters. Male goshawks used more space and travelled further from the nest than female goshawks. While I found no correlation between dietary diversity or specialization on pine squirrels and goshawk productivity, the abundance of this key prey species may affect goshawk productivity and space use.

Keywords: Northern Goshawk; *Accipiter gentilis*; diet; space use; breeding ecology; British Columbia

Dedication

This thesis is dedicated to itself.

She developed an acute homesickness for Oxford and the *Study of Le Fanu*—a book which would never have any advertising value, but of which some scholar might some day moderately observe, “Miss Vane has handled her subject with insight and accuracy.”

—Dorothy Sayers, *Gaudy Night*

To my thesis. I care.

Acknowledgements

This project would never have happened without help from many wonderful people. I can never give them the full measure of recognition they deserve, but I can use these pages to express a fraction of the gratitude I feel. I am most grateful to my adviser, David Green, for unwavering positivity in the face of relentless pessimism. He believed in this project even when I did not, and his practical guidance led me forward to solutions where I would otherwise have found only dead ends. Without David's support, I would not be writing these words but would instead probably be in hiding somewhere in Mexico, drinking margaritas and feeling sorry for myself. I am equally grateful to my supervisor, Melanie Wilson, for her passion, her vision, and her energy. Mel is a genuinely good person, which is not something I say of many people. Her determination to always go just a little further and just a little longer has been an enormous inspiration to me throughout my work. Finally, I am very grateful to my final committee member, John Reynolds, for his insightful critiques, thoughtful questions, and uplifting comments.

I am indebted to the Habitat Conservation Trust Fund, the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development, and the Simon Fraser University Graduate Fellowships for generous financial and in-kind support. I am likewise indebted to those who worked on this project alongside me: Louise Waterhouse offered many helpful and insightful comments on various drafts; Jeff Kidd and Myles Lamont were crucial in capturing goshawks; John Johnson braved furious goshawk females to install nest cameras; and many field techs bushwhacked up mountains and through devil's club to find the data you see here, including Adam, Shannon, Tomas, William, and Rhianne. I am especially grateful to Gina Sage, for her incredible goshawking skills and her willingness to put up with my whining in the field. I am even more grateful to Chris More O'Ferrall, who put up with my whining not only in the field but also at a desk, as he strained his eyes looking through hundreds of nest camera photos. Without his dedication and hard work this project would never have been completed. I am also thankful to "the amazing" Bruno Grande and the Statz Beerz crew, for their patience with my silly code and statistics questions, respectively.

They say it's hard to make friends as an adult. This is true, unless you go to graduate school with the lovely people with whom I have gone to graduate school. A profound thank-you to everyone in the Centre for Wildlife Ecology and elsewhere in the Biology department for being warm, welcoming, and generally wonderful. An especially heartfelt thanks goes to my science sisters, Tess and Lena, and to the other Super Grads–Sonya, Laura, Rachel, and Jo. Your friendship and support over the past few years has meant everything to me, so here's to the best and most beautiful cohort of grads SFU has ever seen! Of course, I am thankful for my family, who have only the slightest idea what it is I do yet have nonetheless been sympathetic listeners to stories of fieldwork woes, unpublished reports, and bad citations. Finally, but eternally, I am grateful to my partners, Michael and Caroline. They have loved me at my best and at my worst, and if I do nothing else with my life but return that love it will have been enough.

I respectfully acknowledge the nations whose traditional and unceded lands I have worked upon while producing this thesis. These nations include the Shíshálh, Lil'wat, Stó:lö, Nlaka'pamux, Musqueam, Squamish, Tsleil-Waututh, and Kwikwetlem. Working on these lands has been a privilege in every sense of the word.

But in the end I am perhaps most grateful to you, dear reader. This work has taken more than two years of my life to complete, and I am pleased to think it may be of some use or interest to you. Thank you.

Table of Contents

Declaration of Committee	ii
Ethics Statement	iii
Abstract	iv
Dedication	v
Acknowledgements	vi
Table of Contents	viii
List of Tables	ix
List of Figures	x
1 General Introduction	1
2 Northern Goshawk Diet in the South Coast of British Columbia	6
2.1 Introduction	6
2.2 Methods	8
2.3 Results	13
2.4 Discussion	16
2.5 Figures and Tables	19
3 General Conclusion	29
3.1 Overview	29
3.2 Directions for Future Research	32
3.3 Management Implications of Goshawk Diet	35
3.4 Figures and Tables	38
References	42

List of Tables

Table 2.1	Mass of identified prey species and estimated mass of unidentified prey items, categorized by size and class, used to calculate the proportional biomass in the diet of Northern Goshawks in south coast British Columbia. Mass estimates taken from Billerman et al. 2020 and Nagorsen 2002. Mean of both sexes used for sexually dimorphic species.	22
Table 2.2	Summary of prey items recorded at active Northern Goshawk nests in south coast British Columbia in 2019 and 2020 using nest cameras ($n = 13$ sites), pellets ($n = 25$ sites), and prey remains ($n = 30$ sites).	24
Table 2.3	Number of prey items recorded at active Northern Goshawk nests in the coastal ecosystem zone and transitional ecosystem zone in south coast British Columbia during 2019 and 2020 using nest cameras ($n = 13$ sites), pellets ($n = 25$ sites), and prey remains ($n = 30$ sites).	26
Table 2.4	Summary of percent mammalian, avian, and key prey from selected studies of Northern Goshawk diet in North America. Data sources are d (direct observation), r (prey remains), p (pellets), and c (nest cameras). Quantification methods are b (percent of biomass), i (percent of items), m (percent of metabolizable energy), and f (frequency of occurrence).	28
Table 3.1	Summary of data from pilot telemetry study on Northern Goshawk in south coast British Columbia using GPS-UHF tags. Describes location data, maximum distance recorded from nest, percentage of points within 100 m of nest, and breeding season home range size (50% and 95% minimum convex polygons and kernel density estimates.	40
Table 3.2	Summary of Northern Goshawk breeding season home range size (sample size) in ha estimated by 95% minimum convex polygons (MCP) or kernel density methods (KDE) from selected studies in North America. Methods are v (VHF transmitter), g (GPS logger), or s (satellite transmitter), and mcp (minimum convex polygon) or kde (kernel density).	41

List of Figures

Figure 2.1	Map of the south coast of British Columbia showing the coastal (green) and transition (gold) zones as well as sites where nest cameras photos, egested pellets, and prey remains were collected (circles) and sites where only pellets and/or remains were collected (triangles). Sites with one year of data are shown with open symbols and sites with two years of data with closed symbols.	19
Figure 2.2	Diet composition of Northern Goshawks from the coastal (green) and transition (gold) zones of south coast British Columbia estimated using nest cameras, pellets, and pooled pellets-and-remains. Prey categories include three major avian taxa with other birds pooled, two major mammalian taxa with other mammals pooled, and an unknown category containing unidentified items.	20
Figure 2.3	Relationship of diet composition (A) and diet diversity (B) to the productivity of Northern Goshawks at 12 sites in south coast British Columbia in 2019 and 2020.	21
Figure 3.1	Northern Goshawk dietary specialization and pine squirrel (<i>Tamiasciurus</i> spp.) density in the Pacific Northwest. Dietary specialization (percent of prey items) estimated using pooled pellets-and-remains (Watson et al. 1998, Bloxton 2002, this study) or remains only (Thrailkill et al. 2000). Pine squirrel density (individuals per ha) estimated by mark-recapture (Carey et al. 1992, Ransome and Sullivan 2003). Symbol location indicated approximate study location and size represents relative degree of specialization or density.	38

Figure 3.2 Representative examples of breeding season home range and core-use area of one female (A) and one male (B) goshawk tagged at the same site (red diamond) in 2019 and 2020, respectively. Habitat quality from habitat suitability model (Mahon 2008) show in green, with water in white. Breeding season home range and core-use areas estimated using 95% and 50% MCPs, shown with solid lines. Estimated home range (3450 ha) and breeding area (200 ha) buffers used in goshawk management (NGRT 2008, Parks Canada Agency 2018) are shown with dashed lines. Individual location points shown as black circles. 39

Chapter 1

General Introduction

Once valued primarily for high timber yields, temperate rainforests of the Pacific Northwest are now managed with greater emphasis on the conservation of biodiversity (Thomas et al. 2006, Beese et al. 2019). One driver of this shift in management priorities is population declines in several species which rely on mature and old-growth forests. Some of these species have been placed under federal, provincial, or state protection: among others, the Marbled Murrelet (*Brachyramphus marmoratus*) is protected under the Species at Risk Act in Canada (COSEWIC 2014) and the coastal population of the Pacific marten (*Martes caurina*) is protected under the Endangered Species Act in the United States (US Fish and Wildlife Service 2020). Management under these types of legislation is typically reactive and focused on conserving each imperiled species on a case-by-case basis (Simberloff 1998, Waples et al. 2013). The single-species approach has been widely criticized for failing to provide management for wider ecosystems, including the very ecosystems on which the imperiled species depend (Lambeck 1997, Waples et al. 2013). Alternatively, focusing on the broader scale of landscapes or entire ecosystems preserves the ecosystem processes and services on which wild species and humans alike depend (Franklin 1993, Pickett et al. 2004). Yet ecosystem-based management is itself beset by numerous practical and theoretical challenges which have made it difficult to implement (Lambeck 1997, Simberloff 1998).

Managers have often turned to surrogate species as a solution for the dilemma posed by single-species and ecosystem-based management. At the core of the surrogate species concept is the belief that the needs or health of a single species, or a small suite of species, can stand in for the needs and health of numerous co-occurring species or ecosystem function (Caro 2010). Numerous variations and conflicting definitions are present in the literature, but the original concept may be that of the *indicator species*. The presence and population size of an indicator species is believed to reflect ecosystem processes or the

populations of other species (Landres et al. 1988). Perhaps more widespread than indicator species is the *umbrella species* concept. Protections which benefit umbrella species—typically wide-ranging habitat specialists—are assumed to confer protection to co-occurring species with smaller ranges and less restrictive habitat requirements (Roberge and Angelstam 2004, Seddon and Leech 2008). A related concept is the *flagship species*, a species whose protection, like an umbrella species, confers benefit on other species, but which is selected for its charisma and ability to serve as a rallying point for conservation (Andelman and Fagan 2000). These concepts all attempt to extend the relative simplicity of single-species methods to achieve the promise of ecosystem-based management (Lambeck 1997, Wiens et al. 2008).

No species better embodies the challenges of managing forest species and ecosystems in the Pacific Northwest than the Northern Spotted Owl (*Strix occidentalis caurina*, hereafter “spotted owl”). The spotted owl is strongly associated with old-growth temperate rainforests (Forsman et al. 2004) and has at various points been proposed as an indicator (Gutiérrez and Carey 1985), an umbrella (Tracy and Brussard 1994), and a flagship species (Simberloff 1998) for temperate rainforests in the Pacific Northwest. In the late 1980s, public outcry and litigation in the United States led to the development of a spotted owl conservation strategy concurrent with the species’ listing as “threatened” under the Endangered Species Act (Thomas et al. 2006). This single-species plan rapidly expanded to include other species, particularly the Marbled Murrelet and several salmon stocks. The plan ultimately evolved into the Northwest Forest Plan, which currently governs federal lands in Washington, Oregon, and northern California. The Northwest Forest Plan remains rooted in spotted owl management, but also includes protections for watersheds, monitoring of rare species, and a sustainable annual timber harvest (Charnley 2006, DellaSala and Williams 2006). Not all the Northwest Forest Plan’s goals have been achieved—notably, spotted owl and Marbled Murrelet populations have continued to decline, although at a slower rate—and some parts of the plan have been eroded under subsequent presidential administrations (DellaSala et al. 2015). Nonetheless, the Northwest Forest Plan remains a powerful example of an ecosystem-based management plan with a single species at its core.

The story of the Northern Goshawk (*Accipiter gentilis*, hereafter “goshawk”) in North America parallels that of the Northern Spotted Owl. Two goshawk subspecies (*A. g. atricapillus* and *A. g. laingi*) are widely recognized and a third (*A. g. apache*) is acknowledged by some authors (Squires et al. 2020). The widespread *atricapillus* is found in boreal forests across the continent and ranges south into warmer pine-dominated forests in the west and mixed-deciduous forests in the east. The restricted *laingi* subspecies is smaller and sootier than *atricapillus* and found only along the west coast. The precise range of *laingi* is unclear; based on morphometrics, genetics, and ecosystem mapping, it is believed to extend along the west coast and islands of British Columbia, from Southeast Alaska to Washington’s Olympic Peninsula (NGRT 2008, Sonsthagen et al. 2012, cf. Geraldles et al. 2018). The *apache* subspecies, while not widely accepted, is described as larger and darker-backed than *atricapillus*, and found in the high-elevation forests of the American Southwest (Squires et al. 2020). Goshawks are not associated with old-growth forest to the same degree as spotted owls, but do show a clear preference for breeding in extensive tracts of mature forest with large trees and dense canopies (Andersen et al. 2005, Squires and Kennedy 2006). As a wide-ranging predator associated with older forests the goshawk has, like the spotted owl, been proposed as a flagship (Sergio et al. 2006), an indicator (Hanley et al. 2005), and an umbrella species (Ozaki et al. 2006).

At the same time the Northwest Forest Plan was developing in the Pacific Northwest, alarms were sounded in the American Southwest over the impact of timber harvest on goshawks in arid montane forests (Crocker-Bedford 1990). Decades of litigation failed to list the southwestern goshawk population (proposed subspecies *apache*) under the Endangered Species Act, but a new management plan was eventually developed (Peck 2000). The single-species southwestern goshawk management plan disallowed timber harvest near known goshawk nests and required a minimum amount of mature forest be retained within the larger home range surrounding nests (Reynolds et al. 1992). Notably, the plan also specified the inclusion of younger forest, small clearings, snags, and woody debris to provide habitat for eight important goshawk prey species. This recommendation was based on the assumption that goshawks are habitat generalists limited by the abundance, not the availability, of prey—an assumption which has been the subject of heated debate (Greenwald et al. 2005, Reynolds et al. 2008). However, by incorporating

multiple species, dynamic ecosystem processes, and human use, the southwestern goshawk management plan approaches the principles of ecosystem-based management and shows its potential to scale up to a more cohesive plan in the style of the Northwest Forest Plan (Graham et al. 1994, Peck 2000).

In the temperate rainforests of the Pacific Northwest, naturalists described a small, dark subspecies of Northern Goshawk first found on the Haida Gwaii archipelago (Taverner 1940). The small size and sooty plumage of *A. g. laingi* may be an adaptation to the dark, dense forests the subspecies inhabits (Ethier 1999) and the agile avian prey believed to dominate its diet (McClaren et al. 2015, Penteriani et al. 2013). In the portion of its range within the United States the *laingi* subspecies has no additional protections, but in Canada it is designated as Threatened by COSEWIC (Committee on the Status of Endangered Wildlife in Canada; COSEWIC 2013). The *laingi* subspecies is further Red-listed by the British Columbia Conservation Data Centre and is an Identified Wildlife Species under the Forest and Range Practices Act (COSEWIC 2013).

The current management plan for *laingi* in British Columbia—the British Columbia Northern Goshawk Implementation Plan—emphasizes the protection of breeding habitat, particularly at small spatial scales around the nest. The plan focuses on the creation of breeding area reserves consisting of 200 hectares—a small portion of the estimated 3700-8500 hectare breeding season home range (Parks Canada Agency 2018)—of suitable breeding habitat surrounding known goshawk nests and their associated alternate nests (FLNRORD 2018). The identification of suitable breeding habitat is assisted by a habitat suitability index model developed using observed *laingi* nest site characteristics, information available in the literature, and expert knowledge (Mahon et al. 2008, NGRT 2008). A major long-term objective of the implementation plan is to include protection for the entire home range by expanding management to the larger foraging area which surrounds the breeding area (FLNRORD 2018). Some home ranges have already received protection beyond the breeding area through overlap with existing reserves, such as provincial parks or Old Growth Management Areas, or through the creation of Wildlife Habitat Areas. Management of the full home range under the implementation plan is similar to the goshawk management plan from the American Southwest, which also specifies protections for breeding habitat and foraging habitat at small scales and large scales around the nest,

respectively (Reynolds et al. 1992). However, unlike the plan from the American Southwest, the British Columbia Implementation Plan for *laingi* does not include management recommendations to increase the abundance or diversity of goshawk prey at any scale. In part this is due to the single-species nature of the plan, but it is also due to several knowledge gaps. While a habitat suitability index model does exist for goshawk foraging habitat in coastal British Columbia (Mahon et al. 2008), foraging ecology is poorly understood relative to breeding ecology. In particular, goshawk diet and prey communities in coastal British Columbia are not well studied (McClaren et al. 2015).

Ecosystem-based management has been implemented in some parts of coastal British Columbia, most notably in Haida Gwaii and the Great Bear Rainforest (Price et al. 2009, Takeda and Røpke 2010), where the Northern Goshawk has been incorporated as a focal species. Goshawk managers have acknowledged a landscape-scale plan would be an improvement over the practice of managing at the scale of individual nests (NGRT 2008). Together these suggest an ecosystem-based approach incorporating the Northern Goshawk as a focal species may be possible for coastal rainforests throughout in British Columbia. However, the knowledge gaps surrounding goshawk foraging ecology hinder current single-species and potential ecosystem-based management alike.

My thesis sets out to fill one knowledge gap identified by the Northern Goshawk Recovery Team (NGRT) by providing basic ecological information regarding the breeding season diet of goshawks in coastal British Columbia (NGRT 2008). The following chapter describes my research quantifying goshawk diet in coastal British Columbia with a focus on potential dietary variation at the broad ecosystem scale, and investigating potential links between dietary variation and goshawk reproductive success. The final chapter summarizes my results, describes the outcome of a pilot study of goshawk space-use, and discusses the implications of both for management and future research efforts.

Chapter 2

Northern Goshawk Diet in the South Coast of British Columbia

2.1 Introduction

Effective wildlife conservation often requires understanding diet composition and its consequences for population demographics (Ferrer and Negro 2004, Stier et al. 2016). Specialist predators consume a narrow range of prey species, which increases foraging efficiency on preferred prey at the cost of decreased reproductive success for the specialist when that prey is scarce (Newton 1998). Generalist predators consume a greater diversity of prey and readily switch between prey species, so are less sensitive to changes in prey abundance (Steenhof and Kochert 1988, Terraube and Arroyo 2011). However, for a generalist predator a single key prey species may still be a major driver of reproductive success (Elmhagen et al. 2000, Resano-Mayor et al. 2016). For at-risk predators, increasing the abundance of key prey species may consequentially be a useful conservation tool (Ferrer and Negro 2004, Forsman et al. 2004, Resano-Mayor et al. 2016).

The northern goshawk (*Accipiter gentilis*) is a large forest-dwelling raptor with a Holarctic distribution. A generalist predator, the goshawk hunts a variety of small- and medium-sized mammals and birds, including squirrels, rabbits and hares, grouse, jays and crows, and pigeons (Squires et al. 2020). Despite this diverse diet, a single prey species or narrow suite of species has a strong effect on the demographics of many goshawk populations. In the Yukon, goshawks depend on snowshoe hare (*Lepus americanus*) and show strong variation in productivity, mortality, and space use in response to cyclical changes in hare abundance (Doyle and Smith 1994). Goshawks in Scandinavia likewise rely on a single prey taxon and show changes in productivity and occupancy based on the annual abundance of four grouse species (subfamily Tetraoninae; Tornberg et al. 2005). In contrast, goshawks in the American Southwest have a wide prey base and regularly consume some fourteen different

species (Boal and Mannan 1994). Fluctuations in goshawk productivity in this region are small and driven by total prey abundance, though the most influential single prey species is red squirrel (*Tamiasciurus hudsonicus*) (Salafsky et al. 2007). These examples suggest the identity and influence of key prey species in such an adaptable predator may be specific to each population and its respective ecosystem.

In British Columbia, Canada, the coastal population of Northern Goshawks is the subject of federal and provincial management which focuses on the protection of breeding habitat and the increase of nest site availability (COSEWIC 2013, FLNRORD 2018, Parks Canada Agency 2018). Like many raptors, goshawks are generally considered to be limited by both nest site availability and prey abundance (Reynolds et al. 2006, Rutz et al. 2006). However, current management plans contain minimal protections for foraging habitat and do not include actions to increase prey populations, in part due to a lack of knowledge regarding goshawk diet and foraging behavior in coastal British Columbia (FLNRORD 2018, Parks Canada Agency 2018).

Goshawk diet across the wider coastal Pacific Northwest is variable. Goshawks on Vancouver Island, British Columbia, consume primarily red squirrels (Ethier 1999) whereas goshawks in nearby southeast Alaska (Lewis et al. 2006) and western Washington (Bloxtton 2002) consume mostly medium and large birds. Even within coastal British Columbia differences between island and mainland communities, combined with a variation in temperature and precipitation, produce a gradient of forest types which support a range of goshawk prey assemblages. For example, snowshoe hare, a key prey species in many portions of the goshawk's range, is absent from Vancouver Island, scarce on the coastal mainland, and abundant in the British Columbia interior (Nagorsen 2005). Goshawk diet in coastal British Columbia may reflect this variation in available prey between Vancouver Island and the mainland, as well as the variation in prey abundance between the coast and the interior. Where coastal forest types transition to interior forest types, it is unclear how goshawk diet responds to fine variation in prey availability and abundance.

Here we describe the breeding season diet of northern goshawks in the south coast of British Columbia over a two-year period using nest cameras, egested pellets, and prey remains. We assess whether goshawk diet at the nest differs within the south coast region

between the wetter *coastal ecosystem zone* and the drier *transitional ecosystem zone*. We further evaluate whether diet composition and diet diversity influence goshawk reproductive success.

2.2 Methods

2.2.1 Study Area and Species

In North America the northern goshawk ranges from the boreal forests of the Yukon south to the high-elevation forests of Arizona and New Mexico. Two subspecies are recognized: the widespread *atricapillus* and the restricted *laingi* (Squires et al. 2020). The *laingi* subspecies was first described on the Haida Gwaii archipelago in British Columbia and is smaller and darker than the *atricapillus* subspecies found elsewhere on the continent (Taverner 1940). The subspecies' range is limited to the west coast of North America, from southeast Alaska through mainland British Columbia and Vancouver Island, and possibly as far south as Washington's Olympic Peninsula (COSEWIC 2013). Within British Columbia, the Coast Mountains form a major barrier to movement and mark the boundary between the *laingi* subspecies found on the coast and the *atricapillus* subspecies found in the interior. *A. g. laingi* is considered a species at risk in British Columbia by both the federal and provincial governments due to significant habitat loss from industrial timber harvest (NGRT 2008, COSEWIC 2013).

We conducted research in the south coast of British Columbia, where goshawks are considered part of the *laingi* subspecies (NGRT 2008, COSEWIC 2013, but see Gerald et al. 2018). The region is characterized by rugged mountains interspersed with coastal fjords and low-lying valleys. The maritime climate supports temperate rainforest dominated by western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii*; Meidinger and Pojar 1991). Within the south coast of British Columbia, goshawk managers have delineated a *transitional ecosystem zone* (hereafter "transition zone") composed of low-elevation valleys in the Coast Mountain Range which connect the *coastal ecosystem zone* (hereafter "coast zone") and the interior (NGRT 2008). The coast and transition zone are defined using a biogeoclimatic (BEC) zone classification system which incorporates climate, physiography, and climax vegetation characteristics (Meidinger and Pojar 1991). The coast zone follows the boundaries of the Coastal Western

Hemlock (CWH) zone and its variants on the mainland coast of British Columbia, excepting the drier zonal variants (CWH dry submarine, CWH moist submarine, CWH wet submarine) which make up the transition zone (NGRT 2008). The temperate rainforest ecosystems of the narrow transition zone are slightly drier than the forests found further west in the coastal zone and somewhat intermediate with the arid interior forests found further east (Fig. 2.1). The transition zone may represent an area of overlap between the coastal *laingi* population and the interior *atricapillus* population (NGRT 2008).

2.2.2 Data Collection

We assessed goshawk diet during the 2019 and 2020 breeding seasons through a combination of egested pellets, prey remains, and nest camera photos. Active goshawk nests were located as part of long-term population surveys conducted by the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). For detailed survey methodology see McClaren (2005). Some study sites contained active nests in both years of the study.

We collected prey remains and egested pellets from 33 nests at 24 sites (2019 $n = 18$ nests, 2020 $n = 15$ nests, sites with nests in both years $n = 9$). We gathered pellets and remains from beneath active nests, from within nests after juveniles fledged, and from plucking-posts located within the site. Logistic constraints prevented more than one collection of pellets and remains at most sites, but we visited some sites multiple times during the breeding season. All prey remains and all pellets from a collection location (one nest or one plucking post) were combined into a single sample for each visit to that location. The sample size of pellets and remains for each nest varied based on number of surveyor visits, duration of surveyor search, and weather conditions preceding surveyor visit.

We installed nest cameras at a subset of 14 of these nests in 12 sites (2019 $n = 6$ nests, 2020 $n = 8$ nests, sites with nests in both years $n = 2$) to record prey delivered to the nest. Nest cameras are an effective and relatively unbiased method of measuring avian diet (García-Salgado et al. 2015, Harrison et al. 2019). However, cameras may overestimate prey deliveries because goshawks cache prey items for redelivery to the nest at a later time, which creates a risk of double-counting items. Due to the discrete nature of our data

we were unable to differentiate cached, re-delivered items from new items and did not attempt to account for caching in our analysis. Previous nest camera-based studies of goshawk diet have observed low numbers of cached items (Smithers et al. 2005: 8.3%, Lewis et al. 2006: 7.3%). Although we acknowledge caching is a potential source of bias, based on these numbers we do not believe our failure to account for it will substantially alter our results. We also did not attempt to differentiate between prey consumed by the female at the nest and prey consumed by the chicks.

Nest cameras were digital trail cameras (Reconyx brand, UltraFire and HyperFire models) mounted 2-5 meters distant from and slightly above the nest, usually in an adjacent tree. Cameras in 2019 were programmed to take three photos one second apart when triggered by motion and an additional one photo every thirty minutes. Cameras in 2020 were programmed to take five photos one second apart when triggered by motion and an additional one photo every twenty minutes. Installation took place during the early nestling phase (between 4 June and 18 July; mean installation date 7 June) and cameras were left in place until late fall or early winter, after juveniles had dispersed. Camera site selection was not random but constrained by topography, site access, and timing of nest discovery. We observed no nest abandonment following camera installation.

Breeding chronology was not available for most sites. At 12 of the 14 nests with cameras (2019 $n = 6$, 2020 $n = 6$, sites with nests in both years $n = 1$), we aged chicks using a pictorial guide (Boal 1994) from photos taken shortly after camera installation. We defined productivity as the number of chicks to reach 32 days of age (Boal 1994, McClaren et al. 2002).

2.2.3 Diet Quantification

We reconstructed prey from pellets and prey remains following a modification of the protocol used by Lewis et al. (2004). Within each sample, we identified remains to the lowest possible taxonomic category and counted the minimum number of individuals (i.e. 3 hare femurs = 2 *Lepus americanus*). Intact pellets and broken but reassembled pellets were analyzed individually within each sample, while fragmented pellets were combined within each sample. We dissected pellets and identified feathers, fur, and hard parts to the lowest taxonomic level possible. We counted the minimum number of individuals represented

within the pellet or pellet collection. Additionally, we categorized prey items from pellets and remains by size (small = sparrow- or vole-sized, medium = jay- or squirrel-sized, and large = grouse- or hare-sized).

We assigned mass to prey items identified to species using data from the literature. We assigned mass to mammals from Nagorsen (2002) and to birds from Billerman et al. (2020), using the geographically closest estimates available and averaging the mass of males and females. We treated some homogenous genera for which we could not differentiate species (such as *Eutamias* and *Myotis*) as a single taxonomic grouping. For these genera, we assigned mass by averaging the masses of all possible species, based on range maps. Red squirrels (*Tamiasciurus hudsonicus*) were present at a single site within our study area; when unable to distinguish between the two members of the genus *Tamiasciurus* we assigned the item to the more common *T. douglasii*. Unidentified grouse were common among remains; we assigned these the mean mass of the two grouse species present in our study area (*Bonasa umbellus* and *Dendragapus fuliginosus*). We assigned juvenile prey items (primarily grouse) 50% of the adult mass. We assigned prey mass for unidentified items by averaging the masses of the identified species in that size category and taxonomic class (Table 2.1).

Data from prey remains and egested pellets are known to be biased indices of diet (Tornberg and Reif 2007, Simmons et al. 1991). Some authors have found combining data from both sources to produce relatively unbiased results that can serve as a helpful supplement to nest camera data (Lewis et al. 2004, Simmons et al. 1991). A preliminary examination of differences between pooled pellets-and-remains data and camera data indicated large differences between these two sources. We therefore report results from pellets, pooled pellets-and-remains, and cameras separately. We do not report results from prey remains alone.

We reviewed nest camera photos and identified each new prey item delivered to the nest to species when possible. When items could not be identified to species, we identified them to the lowest possible taxonomic level. We assigned prey items identified from photos a size category and biomass by the same method used for remains and pellets. We assigned partial items the average mass for that size category and taxonomic class.

We quantified goshawk diet across the entire study area in several ways using data from pellets, pooled pellets-and-remains, and nest cameras. For ease of comparison, we grouped prey items into eight broad categories based on taxonomy, frequency of occurrence, and predicted importance in the diet based on previous goshawk diet studies: pine squirrels (genus *Tamiasciurus*), hares (genus *Lepus*), all other mammals, grouse (subfamily Tetraoninae), thrushes (family Turdidae), corvids (family Corvidae), all other birds, and unidentified items. We calculated the percent biomass of each group, as well as the percent biomass of all avian and all mammalian items. For nests with cameras, we additionally quantified diet at the level of the individual nest and further calculated diet diversity with Simpson's Diversity Index (Simpson 1949) using counts of items identified to genus or better. We report diet as the percent of biomass or the mean percent biomass $\pm$ the standard deviation, except where counts of items or percent of items are explicitly specified.

2.2.4 Statistical Analysis

We classified sites as either coastal or transition based on whether the site was centered within the transition zone defined by NGRT (2008). We used counts of items assigned to the eight broad prey categories to assess differences in goshawk diet between the coastal and transition zones. We combined all data within each zone and tested each data source separately for disproportionate use of prey in each category between zone and source using a chi-squared test with simulated Monte Carlo *p*-values (2000 permutations) due to small sample sizes (Hope 1968). For nests with cameras, we also calculated the percent *Tamiasciurus* spp. (hereafter "pine squirrel") biomass, which is known to be an important food source for goshawks in British Columbia (Ethier 1999), and diet diversity at the individual nest level and compared these between the zones using a *t*-test. Finally, we tested for differences in goshawk productivity between the two zones using a *t*-test.

To determine the potential reproductive consequences of dietary variation, we examined how two aspects of diet, diet diversity and the percent squirrel biomass in the diet, influenced productivity using simple linear regressions. We pooled data from both years of the study after testing for differences in prey group composition (combining all data within each year and source and applying a chi-square test), diet diversity (using a *t*-test of nest

camera data), proportion squirrel biomass (using a *t*-test of nest camera data), and productivity (using a *t*-test of nest camera data) between years and finding no significant differences. We tested for dietary differences between years using all data sources, but because productivity data were available only from sites with nest cameras and nest-level diet data from pellets and prey remains were sparse, we performed this analysis using only diet data from nest cameras. We included all available nests with productivity data in this analysis, including one site which contained an active nest in both years of the study. Averaging variables for this site across years or including a single randomly selected year does not alter the presented results. All analyses were performed in R version 4.0 (R Core Team 2020). We used a significance level of $P = 0.05$ for all tests.

2.3 Results

2.3.1 Goshawk Diet

We identified a total of 9 unique species from pellets collected at 25 nests. No pellets were collected from 8 sites. Of the 135 prey items obtained from pellets, we identified 58% to genus or better and identified all items at least to class. Of the 121 prey items obtained from remains, we identified 51% to genus or better and identified all items at least to class. We identified 17 species from remains collected at 30 nests, for a total of 20 unique prey species from the pooled pellets-and-remains sample (Table 2.2). No remains were collected from 3 sites.

The majority of prey identified from pellets were mammalian (75% of biomass). Pine squirrels made up 61% of biomass, while other birds (neither grouse, corvids, nor thrushes) made up 21% and other mammals (neither pine squirrels nor hares) made up another 14%. Corvids and thrushes made up the remaining 4% of biomass. No hare or grouse were identified from pellets.

In contrast, the majority of prey identified from the pooled pellets-and-remains sample were avian (64% of biomass). The largest prey group was grouse (36%), followed by other birds (24%) and hare (18%). Pine squirrels made up only 14% of the pooled sample and other mammals made up another 5%. The remaining 3% of biomass was made up of corvids and thrushes.

We identified a total of 25 unique species from 566 prey deliveries recorded on 14 nest cameras (Table 2.2). After excluding 69 deliveries which were completely obscured from the cameras, each nest contributed an average of 36 items (range 1 - 69). We were able to identify 60% to genus or better and 77% at least to class. Small and medium birds were disproportionately represented among items identified only to class, frequently arriving at the nest already plucked and decapitated. Variability in the number of items recorded and the rate of identification was due to differences in camera placement and sensitivity settings.

The majority of prey identified on nest cameras were mammalian (71% of biomass, $\bar{x} = 69 \pm 12$, $n = 14$). Birds accounted for only 18% of biomass ($\bar{x} = 18 \pm 12$), and the remaining 11% could not be identified to class ($\bar{x} = 19 \pm 26$). The high proportion of mammalian biomass was driven by the dominance of pine squirrels (47% of biomass, $\bar{x} = 49 \pm 14$) and other mammals (17%, $\bar{x} = 17 \pm 12$). Unidentified items accounted for 11% of biomass ($\bar{x} = 19 \pm 26$). The remaining biomass was composed of hare (8%, $\bar{x} = 31 \pm 2$), other birds (9%, $\bar{x} = 10 \pm 10$), grouse (5%, $\bar{x} = 9 \pm 5$), thrushes (3%, $\bar{x} = 3 \pm 3$) and corvids (1%, $\bar{x} = 3 \pm 3$). Overall diet diversity for the study area, based on counts of items identified to genus or better, was moderate (0.57). Diet diversity of individual nests was highly variable, ranging from 0 to 0.72 ($\bar{x} = 0.47 \pm 0.21$).

2.3.2 Difference in Northern Goshawk Diet Between Ecological Zones

We observed a difference in the diet of goshawks in the coastal and transition zones (Table 2.3), although these differences were more pronounced in the pooled pellets-and-remains data ($\chi^2 = 19.18$, $P = 0.003$) and camera data ($\chi^2 = 21.52$, $P = 0.005$) than in data from pellets alone ($\chi^2 = 7.53$, $P = 0.11$; Fig. 2.2). A post-hoc test incorporating a Bonferroni correction for multiple comparisons (adjusted $\alpha = 0.007$) revealed the difference between zones observed in the pooled pellet-and-remains data was driven by the number of other birds and hares. Other birds were observed significantly more often in the diet of goshawks in the coastal zone ($\chi^2 = 12.6$, $P = 0.002$), whereas hare were observed significantly more often in the diet of goshawks in the transition zone ($\chi^2 = 7.22$, $P = 0.01$). Similarly, a post-hoc test of the camera data (adjusted $\alpha = 0.006$) found the difference between zones

to be due to the significantly higher frequency of unidentified prey items in the coastal zone relative to the transition zone ($\chi^2 = 15.37$, $P = 0.001$).

We observed no significant difference in diet diversity (study area $\bar{x} = 0.47 \pm 0.21$; coastal zone $\bar{x} = 0.29 \pm 0.24$, $n = 5$, transition zone $\bar{x} = 0.55 \pm 0.14$, $n = 9$; $t = -2$, $df = 3.92$, $P = 0.12$) or the proportion of squirrel biomass (study area $\bar{x} = 49 \pm 14$; coastal zone $\bar{x} = 57 \pm 20$, $n = 5$, transition zone $\bar{x} = 45 \pm 10$, $n = 9$; $t = 1.19$, $df = 3.79$, $P = 0.3$) between the zones when using individual nest-level data from nest cameras.

2.3.3 Productivity

We were able to measure productivity (the number of chicks to reach 32 days of age) for 12 of 14 nests monitored with nest cameras. We were not able to obtain productivity data from two nests because the camera memory cards filled prior to fledging.

Goshawks successfully fledged young from 11 of 12 nests with productivity data available, producing 0-3 chicks per active nest ($\bar{x} = 1.36 \pm 0.81$) and 1-3 chicks per successful nest ($\bar{x} = 1.55 \pm 0.69$). Siblicide was common, accounting for two of the three deaths in the failed nest and one death in each of four other nests. We observed no difference in productivity between years ($\bar{x} = 1.42 \pm 0.79$; 2019 $\bar{x} = 1.67 \pm 1.03$, $n = 6$; 2020 $\bar{x} = 1.17 \pm 0.41$, $n = 6$; $t = 1.1$, $df = 6.53$, $P = 0.31$). Nor did we observe any difference in the prey group composition between years (using counts of items) in either data from nest cameras ($\chi^2 = 5.27$, $P = 0.65$), pooled pellets-and-remains ($\chi^2 = 1.46$, $P = 0.85$), or pellets alone ($\chi^2 = 0.4$, $P = 0.99$). We also observed no difference in diet diversity ($\bar{x} = 0.47 \pm 0.21$; 2019 $\bar{x} = 0.56 \pm 0.16$; 2020 $\bar{x} = 0.4 \pm 0.22$; $t = 1.49$, $df = 10.82$, $P = 0.17$) or proportion of squirrel biomass ($\bar{x} = 49 \pm 14$; 2019 $\bar{x} = 44.57 \pm 9.88$; 2020 $\bar{x} = 45.89 \pm 24.43$; $t = -0.14$, $df = 9.74$, $P = 0.89$) between years.

We found little evidence to suggest goshawk productivity was influenced by either the proportion of diet composed of pine squirrel biomass ($F_1 = 0.72$, $df = 9$, $P = 0.42$) or diet diversity ($F_1 = 1.31$, $df = 9$, $P = 0.28$; Fig. 2.3). There was also no significant difference in goshawk productivity between the coastal and transition zones ($t = 0.93$, $df = 4.71$, $P = 0.4$).

2.4 Discussion

Goshawk survival, migration, reproductive success, and other demographic parameters are often related to the abundance of a key prey species (Doyle and Smith 1994, Tornberg et al. 2005, Rutz and Bijlsma 2006). Although we lacked data on prey abundance within our study area, other authors have found goshawk diet reflects site-level prey abundance (Rogers et al. 2006, Lewis et al. 2006). We observed significant variation in the proportion of pine squirrel biomass delivered to each nest, which may mirror differences in squirrel abundance between sites. However, we did not find evidence to support an effect of this variation on goshawk productivity. When key prey abundance is low, high diet diversity may indicate a reliance on alternate prey, with associated negative reproductive consequences (Resano-Mayor et al. 2016). We found no evidence of an effect of diet diversity on goshawk productivity but, notably, the only nest in our study to experience a complete breeding failure received the smallest percent squirrel biomass we observed. Given the strength of evidence from other studies and the clear importance of pine squirrels in the diet of this population, it seems probable pine squirrel abundance has some effect on goshawk productivity. Tree squirrels experience large fluctuations in abundance following cyclical changes in conifer seed crop size (Smith 1970). Given the potential cascading consequences for goshawks, understanding the relationship between variation in pine squirrel abundance and goshawk demography remains a crucial knowledge gap.

Across much of North America the key goshawk prey species is usually mammalian, often from the family Leporidae or Sciuridae (Table 2.4; Boal and Mannan 1994, Doyle and Smith 1994, DeStefano et al. 2006, Rogers et al. 2006, Miller et al. 2014). However, in the coastal temperate rainforests of the Pacific Northwest, goshawk diet generally contains more birds than mammals and the key prey is usually a species of grouse (subfamily Tetraoninae; Watson et al. 1998, Thraillkill et al. 2000, Bloxton 2002, Lewis et al. 2006). Despite inhabiting coastal rainforests, goshawks on Vancouver Island, British Columbia, consume primarily red squirrels (*T. hudsonicus*; Ethier 1999). Our results from the coastal mainland of British Columbia are consistent with findings from Vancouver Island and more broadly with results from the interior of North America but stand in contrast to findings from elsewhere in the Pacific Northwest. Goshawk diet varies at large scales in response to available prey species and prey abundance (Drennan 2006), suggesting pine squirrel abundance is higher

within Vancouver Island and the south coast than other temperate rainforest ecosystems.

Prey availability and abundance may also vary at fine scales due to differences in habitat type (Kenward 1982, Penteriani et al. 2013). Within our study area, low-elevation mountain valleys bridge the wet forests of the coast and the dry forests of the interior, creating a narrow region of intermediate habitat types (NGRT 2008). Coastal rainforests are believed to contain a lower overall abundance of goshawk prey (McClaren et al. 2015) and a lower abundance of key mammalian prey, such as snowshoe hare (Nagorsen 2005), than interior forests. Available prey species and prey abundance in the transition zone may be intermediate between the coastal zone and the interior, with associated consequences for goshawk diet and demography. We found mixed evidence for a difference in goshawk diet between the two zones. Overall, our analyses show the diet of goshawks in the transition zone is very similar to that of goshawks in the coastal zone. However, data from pooled pellets-and-remains indicate goshawks in the coastal zone consume more small- and medium-sized birds than goshawks in the transition zone, consistent with the hypothesis that the coastal zone is relatively depauperate of mammalian prey. Identifying small and medium birds was more difficult using nest cameras than for other data sources. The high number of unidentified prey items recorded on coastal zone cameras may be further evidence goshawk diet there contains relatively more avian prey than in the transition zone. Given our small sample size and the large variation in diet between nests it is difficult to make any strong conclusions regarding dietary variation between the zones. However, any dietary difference between the coastal and transition zone appears to be minor and the importance of pine squirrels appears to be universal.

Raptor diet is studied through a variety of indirect methods, such as the collection of pellets and prey remains, and direct methods, such as nest cameras and observation from blinds. Nest cameras are considered one of the least biased methods for measuring diet at the nest in raptors (Tornberg and Reif 2007, García-Salgado et al. 2015, Harrison et al. 2019). Cameras in this study provided significantly more data at a finer resolution than either pellets or prey remains, which could only be collected during the infrequent surveys each site received. However, the cost, effort, and logistical challenges of camera installation restricted the number of sites from which camera data could be collected. Additionally,

technical issues relating to camera settings and placement resulted in a loss of data at some sites. Despite these limitations, we believe nest cameras provided the most accurate and complete picture of goshawk diet. Compared to cameras, pellets were relatively unbiased in measuring coarse diet composition, but severely underestimated prey species richness. The pooled pellets-and-remains sample captured a much greater prey richness, including several species not detected on nest cameras, but greatly overestimated the proportion of avian biomass relative to camera data. Measuring diet composition by counts or biomass adds further uncertainty, with measurements of counts overestimating avian prey relative to measurements of biomass. These complex results highlight the importance of clearly reporting the source and measurement of raptor diet data. Because these methods have all been used in past studies we believe there is value in reporting the results of each for ease of comparison. However, we advocate for future diet studies to prioritize collecting data via cameras, either video or still images, rather than physical specimens.

Our study addresses a fundamental question regarding the basic ecology of an at-risk population of the northern goshawk. This population is currently considered part of *A. g. laingi*, a subspecies restricted to the coastal Pacific Northwest. In portions of *laingi*'s range the diet is dominated by mammalian prey, specifically pine squirrels (this study, Ethier 1999), and in others by avian prey (Bloxtton 2002, Lewis et al. 2006). Pine squirrels clearly play a key role in the diet of some *laingi* populations, including the population of Haida Gwaii (Roberts 1997, cited in COSEWIC 2013), where red squirrel is an introduced species. Genetic evidence indicates goshawks on this isolated archipelago may be distinct from goshawks on the mainland coast and Vancouver Island (Sonsthagen et al. 2012, cf. Geraldtes et al. 2018). Regardless of their taxonomic relationship, dietary evidence suggests the goshawk populations of Haida Gwaii, Vancouver Island, and the mainland coast are more similar to each other in foraging habits and habitats than to other putative *laingi* populations. Ecological similarity, such as diet and habitat characteristics, may therefore prove a better guide than genetic similarity when incorporating foraging habitat protection or prey population management into conservation plans.

2.5 Figures and Tables

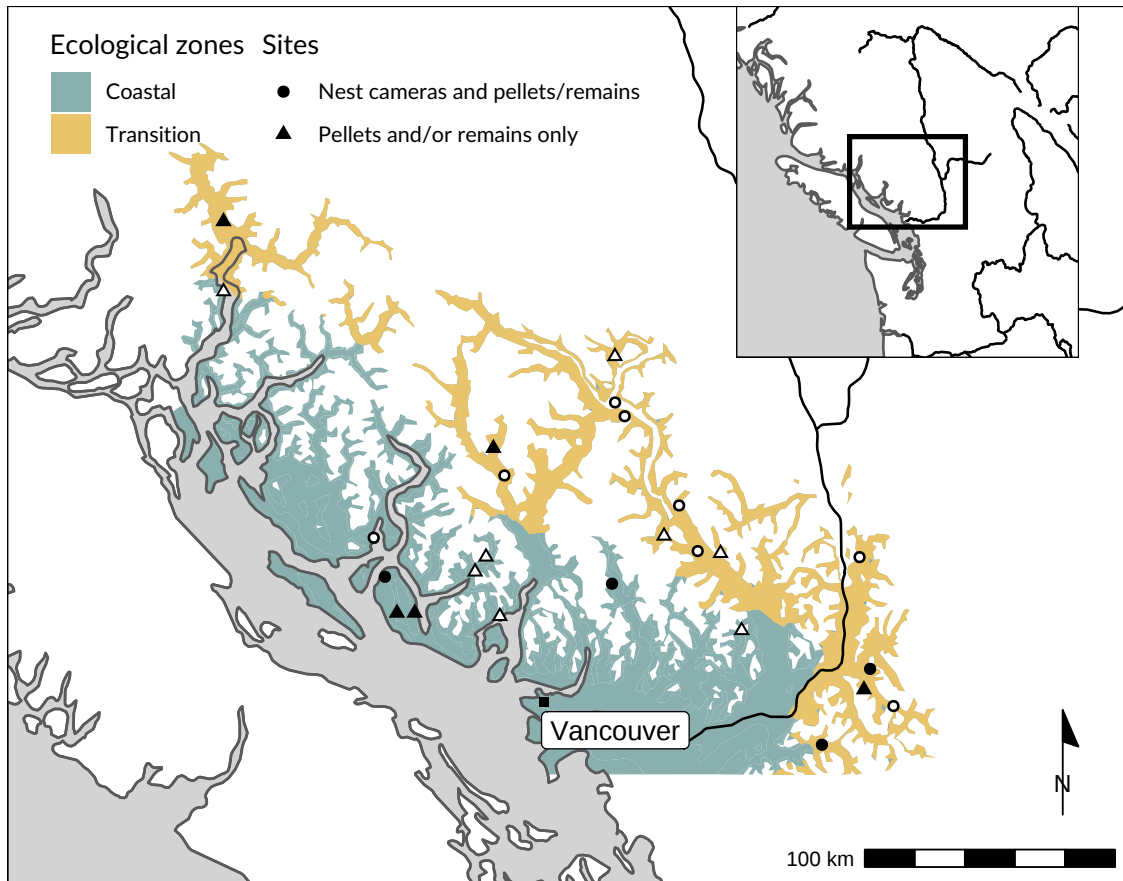


Figure 2.1: Map of the south coast of British Columbia showing the coastal (green) and transition (gold) zones as well as sites where nest cameras photos, egested pellets, and prey remains were collected (circles) and sites where only pellets and/or remains were collected (triangles). Sites with one year of data are shown with open symbols and sites with two years of data with closed symbols.

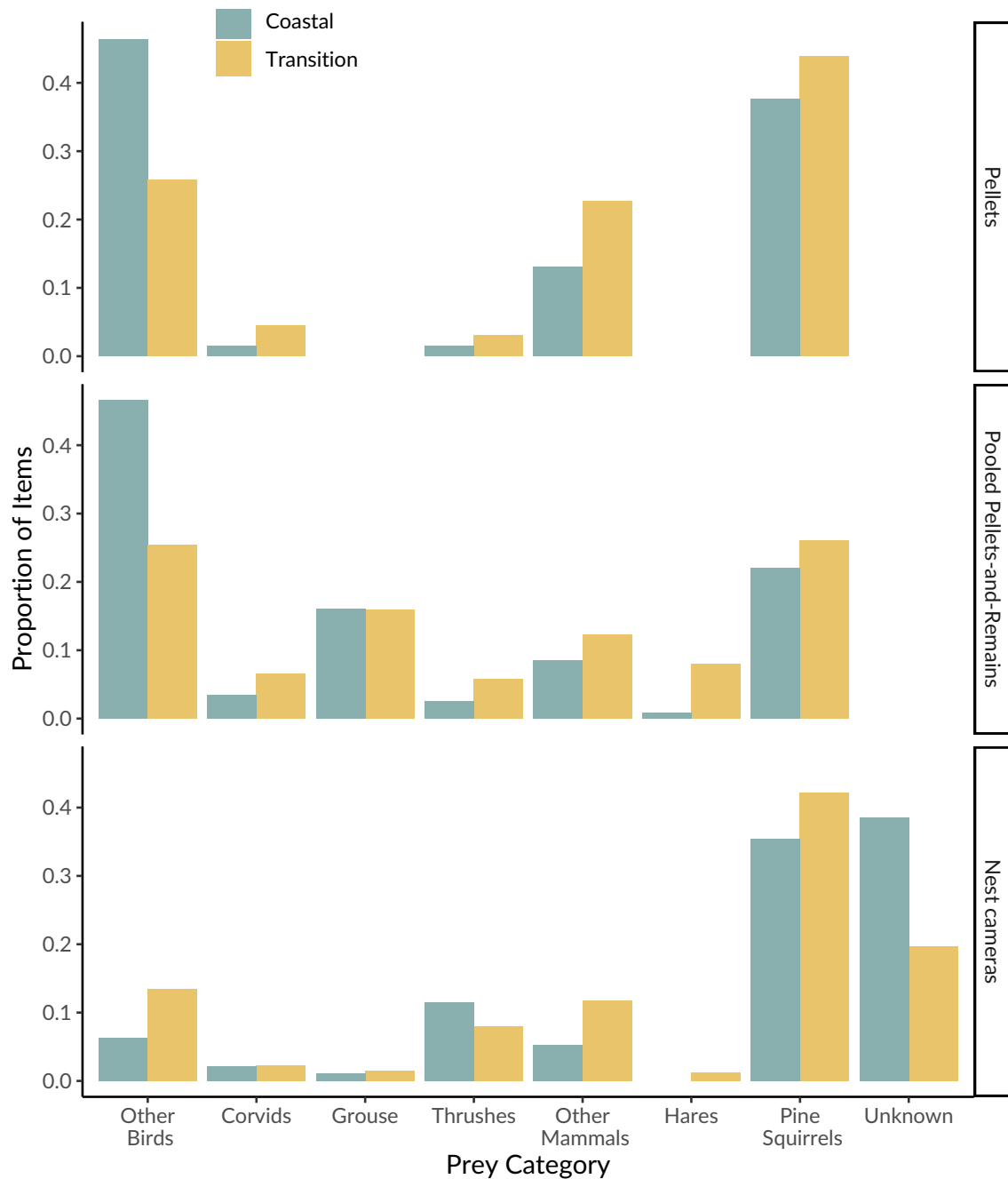


Figure 2.2: Diet composition of Northern Goshawks from the coastal (green) and transition (gold) zones of south coast British Columbia estimated using nest cameras, pellets, and pooled pellets-and-remains. Prey categories include three major avian taxa with other birds pooled, two major mammalian taxa with other mammals pooled, and an unknown category containing unidentified items.

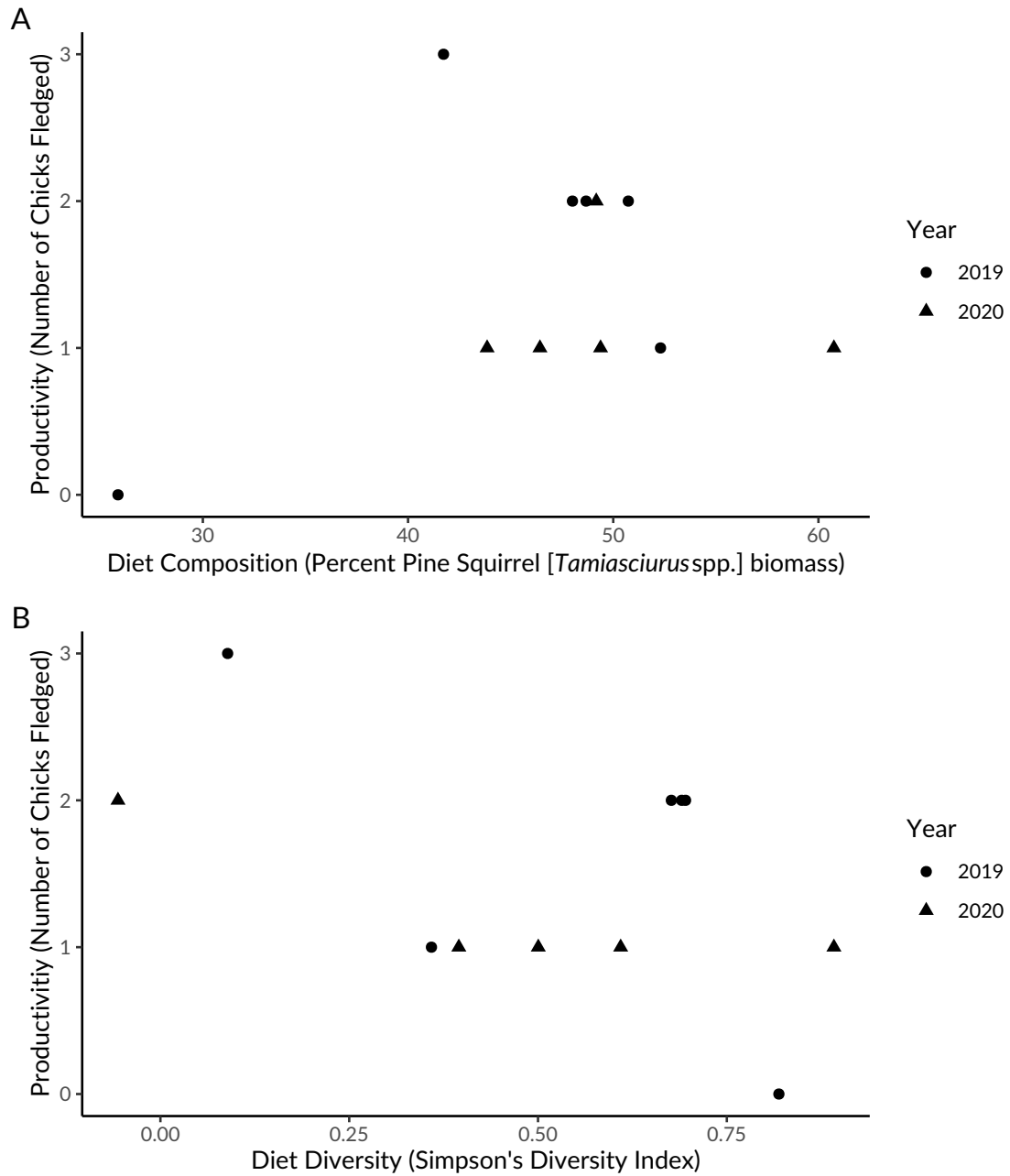


Figure 2.3: Relationship of diet composition (A) and diet diversity (B) to the productivity of Northern Goshawks at 12 sites in south coast British Columbia in 2019 and 2020.

Table 2.1: Mass of identified prey species and estimated mass of unidentified prey items, categorized by size and class, used to calculate the proportional biomass in the diet of Northern Goshawks in south coast British Columbia. Mass estimates taken from Billerman et al. 2020 and Nagorsen 2002. Mean of both sexes used for sexually dimorphic species.

Prey type		Mass (g)
Large Bird		
Northern Goshawk	<i>Accipiter gentilis</i>	857.2
Mallard	<i>Anas platyrhynchos</i>	1138.5
Duck	<i>Anas</i> sp.	867.3
Ruffed Grouse	<i>Bonasa umbellus</i>	523.4
Great Horned Owl	<i>Bubo virginianus</i>	1505.0
Red-Tailed Hawk	<i>Buteo jamaicensis</i>	563.0
Northwestern Crow	<i>Corvus caurinus</i>	802.9
Sooty Grouse	<i>Dendragapus fuliginosus</i>	1055.5
Pileated Woodpecker	<i>Dryocopus pileatus</i>	287.5
Mew Gull	<i>Larus canus</i>	388.5
Band-Tailed Pigeon	<i>Patagioenas fasciata</i>	379.4
Barred Owl	<i>Strix varia</i>	716.5
Unidentified Grouse	Subfamily: Tentaoninae	789.5
Average Large Bird	-	802.9
Medium Bird		
Northern Flicker	<i>Colaptes auratus</i>	157.4
Steller's Jay	<i>Cyanocitta stelleri</i>	128.0
Hairy Woodpecker	<i>Dryobates villosus</i>	80.3
Varied Thrush	<i>Ixoreus naevius</i>	79.4
Canada Jay	<i>Perisoreus canadensis</i>	70.2
Red-Breasted Sapsucker	<i>Sphyrapicus ruber</i>	58.2
American Robin	<i>Turdus migratorius</i>	79.9
Average Medium Bird	-	93.4
Small Bird		
Swainson's Thrush	<i>Catharus ustulatus</i>	29.8

Downy Woodpecker	<i>Dryobates pubescens</i>	27.9
Spotted Towhee	<i>Pipilo maculatus</i>	41.8
Average Small Bird	-	33.2
Large Mammal		
Mountain Beaver	<i>Aplodontia rufa</i>	1005.0
Snowshoe Hare	<i>Lepus americanus</i>	1340.0
Average Large Mammal	-	1172.5
Medium Mammal		
Short-Tailed Weasel	<i>Mustela erminea</i>	219.0
Bushy-Tailed Woodrat	<i>Neotoma cinerea</i>	374.7
Rat	<i>Rattus</i> sp.	269.8
Douglas Squirrel	<i>Tamiasciurus douglasii</i>	203.5
Red Squirrel	<i>Tamiasciurus hudsonicus</i>	224.5
Small Mammal		
Average Medium Mammal	-	258.3
Flying Squirrel	<i>Glaucomys sabrinus</i>	155.5
Bat	<i>Myotis</i> sp.	5.8
Chipmunk	<i>Neotamias</i> sp.	66.4
Shrew	<i>Sorex</i> sp.	7.1
Vole	Subfamily: Avicolinae	34.4
Unidentified Items		
Average Small Mammal	-	53.8
Average Large Item	-	987.7
Average Medium Item	-	175.8
Average Small Item	-	43.5

Table 2.2: Summary of prey items recorded at active Northern Goshawk nests in south coast British Columbia in 2019 and 2020 using nest cameras ($n = 13$ sites), pellets ($n = 25$ sites), and prey remains ($n = 30$ sites).

Common name	Scientific name	Total count	Camera		Pellets		Remains	
			% items	% biomass	% items	% biomass	% items	% biomass
Aves								
Northern goshawk	<i>Accipiter gentilis</i>	2	-	-	-	-	1.65	1.76
Mallard	<i>Anas platyrhynchos</i>	1	-	-	-	-	0.83	1.56
Ruffed grouse	<i>Bonasa umbellus</i>	5	0.80	2.06	-	-	0.83	0.72
Great horned owl	<i>Bubo virginianus</i>	2	0.40	2.54	-	-	-	-
Red-tailed hawk	<i>Buteo jamaicensis</i>	1	0.20	0.63	-	-	-	-
Swainson's thrush	<i>Catharus ustulatus</i>	7	1.21	0.20	0.74	0.16	-	-
Northern flicker	<i>Colaptes auratus</i>	14	-	-	6.67	7.78	4.13	1.08
Steller's jay	<i>Cyanocitta stelleri</i>	18	1.21	0.72	2.96	2.81	6.61	1.31
Sooty grouse	<i>Dendragapus fuliginosus</i>	8	0.60	2.97	-	-	4.13	6.50
Downy woodpecker	<i>Dryobates pubescens</i>	3	0.60	0.09	-	-	-	-
Hairy woodpecker	<i>Dryobates villosus</i>	4	0.40	0.18	1.48	0.88	-	-
Pileated woodpecker	<i>Dryocopus pileatus</i>	3	0.20	0.32	-	-	1.65	0.79
Varied thrush	<i>Ixoreus naevius</i>	22	2.41	1.03	1.48	0.87	6.61	0.81
Mew gull	<i>Larus canus</i>	1	-	-	-	-	0.83	0.53
Band-tailed pigeon	<i>Patagioenas fasciata</i>	4	0.60	1.28	-	-	0.83	0.52
Canada jay	<i>Perisoreus canadensis</i>	5	1.01	0.39	-	-	-	-
Spotted towhee	<i>Pipilo maculatus</i>	3	-	-	1.48	0.46	0.83	0.06
Red-breasted sapsucker	<i>Sphyrapicus ruber</i>	5	-	-	1.48	0.64	2.48	0.24

Table 2.3: Number of prey items recorded at active Northern Goshawk nests in the coastal ecosystem zone and transitional ecosystem zone in south coast British Columbia during 2019 and 2020 using nest cameras (n = 13 sites), pellets (n = 25 sites), and prey remains (n = 30 sites).

Common name	Scientific name	Total count	Camera		Pellets		Remains	
			Coastal	Transition	Coastal	Transition	Coastal	Transition
Aves								
Northern goshawk	<i>Accipiter gentilis</i>	2	-	-	-	-	-	2
Mallard	<i>Anas platyrhynchos</i>	1	-	-	-	-	1	-
Ruffed grouse	<i>Bonasa umbellus</i>	5	-	4	-	-	-	1
Great horned owl	<i>Bubo virginianus</i>	2	-	2	-	-	-	-
Red-tailed hawk	<i>Buteo jamaicensis</i>	1	-	1	-	-	-	-
Swainson's thrush	<i>Catharus ustulatus</i>	7	3	3	-	1	-	-
Northern flicker	<i>Colaptes auratus</i>	14	-	-	6	3	4	1
Steller's jay	<i>Cyanocitta stelleri</i>	18	2	4	1	3	3	5
Sooty grouse	<i>Dendragapus fuliginosus</i>	8	1	2	-	-	2	3
Downy woodpecker	<i>Dryobates pubescens</i>	3	-	3	-	-	-	-
Hairy woodpecker	<i>Dryobates villosus</i>	4	-	2	1	1	-	-
Pileated woodpecker	<i>Dryocopus pileatus</i>	3	-	1	-	-	1	1
Varied thrush	<i>Ixoreus naevius</i>	22	1	11	1	1	2	6
Mew gull	<i>Larus canus</i>	1	-	-	-	-	1	-
Band-tailed pigeon	<i>Patagioenas fasciata</i>	4	-	3	-	-	1	-
Canada jay	<i>Perisoreus canadensis</i>	5	-	5	-	-	-	-
Spotted towhee	<i>Pipilo maculatus</i>	3	-	-	1	1	-	1
Red-breasted sapsucker	<i>Sphyrapicus ruber</i>	5	-	-	2	-	1	2

Barred owl	<i>Strix varia</i>	2	-	1	-	-	1	-
American robin	<i>Turdus migratorius</i>	4	2	2	-	-	-	-
Unknown	-	162	11	57	22	12	30	30
TOTAL BIRDS		276	20	101	34	22	47	52
Mammalia								
Mountain beaver	<i>Aplodontia rufa</i>	1	-	1	-	-	-	-
Flying squirrel	<i>Glaucomys sabrinus</i>	3	1	2	-	-	-	-
Snowshoe hare	<i>Lepus americanus</i>	17	-	5	-	-	1	11
Short-tailed weasel	<i>Mustela erminea</i>	1	-	1	-	-	-	-
Bat	<i>Myotis</i> sp.	1	-	1	-	-	-	-
Chipmunk	<i>Neotamias</i> sp.	8	-	7	-	1	-	-
Bushy-tailed woodrat	<i>Neotoma cinerea</i>	2	1	-	-	-	-	1
Rat	<i>Rattus</i> sp.	22	1	21	-	-	-	-
Shrew	<i>Sorex</i> sp.	1	-	1	-	-	-	-
Douglas squirrel	<i>Tamiasciurus douglasii</i>	255	34	160	26	29	-	6
Red squirrel	<i>Tamiasciurus hudsonicus</i>	10	-	9	-	-	-	1
Unknown	-	40	2	13	9	14	1	1
TOTAL MAMMALS		361	39	221	35	44	2	20
Unknown								
Unknown	-	116	37	79	-	-	-	-
GRAND TOTAL		753	96	401	69	66	49	72

Table 2.4: Summary of percent mammalian, avian, and key prey from selected studies of Northern Goshawk diet in North America. Data sources are d (direct observation), r (prey remains), p (pellets), and c (nest cameras). Quantification methods are b (percent of biomass), i (percent of items), m (percent of metabolizable energy), and f (frequency of occurrence).

Study	Location	Ecosystem type	Source	Method	% mammal	% bird	Key prey sp.	% key prey
Schaffer (1998)	central Alberta	aspen forest	d	b	88.60	11.40	<i>Lepus americanus</i>	63.97
Younk and Bechard (1994)	northern Nevada	aspen shrubsteppe	d	i	65.00	32.00	<i>Urocitellus beldingi</i>	47.00
Doyle and Smith (1994)	Yukon	boreal forest	d, r	b	85.00	-	<i>Lepus americanus</i>	56.00
Grzybowski and Eaton (1976)	New York	eastern deciduous forest	p, r	i	39.00	61.00	<i>Bonasa umbellus</i>	18.20
Bosakowski and Smith (2006)	New York, New Jersey	eastern deciduous forest	p, r	i	34.00	66.00	<i>Bonasa umbellus</i>	25.20
Miller et al. (2014)	south-central Idaho	pine forest, sagebrush	c	b	78.70	18.50	<i>Urocitellus beldingi</i>	74.80
Schnell (1958)	eastern California	pine, mixed-conifer forest	d	b	46.00	54.00	<i>Cyanocitta stelleri</i>	23.10
Reynolds and Meslow (1984)	eastern Oregon	pine, mixed-conifer forest	p, r	i	45.00	55.00	-	-
Kennedy (1991)	New Mexico	pine, mixed-conifer forest	d	i	67.00	33.00	<i>Sciurus aberti</i>	30.60
	New Mexico	pine, mixed-conifer forest	p	i	49.00	51.00	<i>Sciurus aberti</i>	41.30
	New Mexico	pine, mixed-conifer forest	r	i	48.00	52.00	<i>Sylvilagus</i> spp.	20.00
Boal and Mannan (1994)	Arizona	pine, mixed-conifer forest	d	b	94.00	6.00	<i>Sylvilagus</i> spp.	26.10
Reynolds et al. (1994)	Arizona	pine, mixed-conifer forest	p, r	i	62.00	38.00	<i>Sylvilagus</i> spp.	18.00
Watson et al. (1998)	eastern Washington	pine, mixed-conifer forest	p, r	b	53.80	46.20	<i>Lepus americanus</i>	40.60
McCoy (1999)	northern California	pine, mixed-conifer forest	d	m	76.00	24.00	<i>Spermophilus lateralis</i>	30.00
Rogers et al. (2006)	Arizona	pine, mixed-conifer forest	c	b	88.69	6.92	<i>Sylvilagus floridanus</i>	42.31
Smithers et al. (2005)	Minnesota	pine, mixed-hardwood forest	c	i	62.00	38.00	<i>Tamiasciurus hudsonicus</i>	31.00
Watson et al. (1998)	western Washington	temperate rainforest	p, r	b	47.10	52.60	Grouse (subfamily Tetraoninae)	43.20
Ethier (1999)	Vancouver Island	temperate rainforest	p	f	-	-	<i>Tamiasciurus hudsonicus</i>	69.00
Thrallkill et al. (2000)	western Oregon	temperate rainforest	r	i	16.00	84.00	<i>Bonasa umbellus</i>	45.00
Lewis et al. (2006)	southeast Alaska	temperate rainforest	c	i	-	72.80	<i>Dendragapus obscurus</i>	21.00
	southeast Alaska	temperate rainforest	c	i	-	90.60	<i>Falcapennis canadensis</i>	18.00
Case (2021)	south coast BC	temperate rainforest	c	b	71.00	18.00	<i>Tamiasciurus</i> spp.	47.00
	south coast BC	temperate rainforest	p	b	75.00	25.00	<i>Tamiasciurus</i> spp.	61.00
	south coast BC	temperate rainforest	p, r	b	36.00	64.00	Grouse (subfamily Tetraoninae)	36.00

Chapter 3

General Conclusion

3.1 Overview

Specialist and generalist predators differ in their degree of dependence on prey species, with cascading consequences for many aspects of their life history (Korpimäki and Norrdahl 1991, Resano-Mayor et al. 2016). Specialist predators are efficient hunters of their main prey at the cost of poor success when hunting other species, whereas generalist predators hunt many species with equal skill (Terraube et al. 2011) and readily switch between alternate prey (Steenhof and Kochert 1988, Terraube and Arroyo 2011). As a result, specialist predators depend on a single species and their demographic parameters—such as migration, reproductive success, and survival—and population density vary in synchrony with its abundance (Korpimäki and Norrdahl 1991, Terraube et al. 2011). In contrast, generalist predators make use of many prey species and their populations are relatively stable (Andersson and Erlinge 1977, Hanski et al. 1991).

The familiar dichotomy between specialist and generalist predators is, of course, an oversimplification. The abundance of a single prey species can be a major driver of demographic parameters for generalist and specialist predators alike (Elmhagen et al. 2000, Resano-Mayor et al. 2016). Furthermore, within a single species some populations (Salamolard et al. 2000, Roth et al. 2007), or some individuals within a population (Woo et al. 2008), may be more or less specialized. A single individual may also become a more specialized hunter over its lifetime as a result of age and experience (Rutz 2006). Correctly identifying the degree of specialization and understanding its effect on demographic parameters is more than a matter of theory or curiosity: the consequences of specialization can scale up from individuals through populations to entire species, with profound implications for conservation (Ferrer and Negro 2004, Terraube et al. 2011, Resano-Mayor et al. 2016).

The complex relationship between dietary specialization and conservation is exemplified by the northern spotted owl (*Strix occidentalis caurina*). Spotted owls depend on old-growth forests, but the cause of this association has been a source of speculation since the early years of spotted owl research (Gutiérrez and Carey 1985). The spotted owl's reliance on old-growth forest appears to be driven, in part, by its relatively specialized diet (Carey et al. 1992, Ward et al. 1998). More than half the biomass spotted owls consume comes from just two taxa, flying squirrels (*Glaucomys sabrinus*) and woodrats (bushy-tailed woodrat *Neotoma cinerea* and dusky-footed woodrat *N. fuscipes*; Smith 1963, Ward et al. 1998, Forsman et al. 2001, 2004). The dominance of flying squirrels and woodrats in the diet holds true across the subspecies' range, although the relative contribution of each taxa varies with geographic region and forest type in response to local abundance. In Washington's Olympic Peninsula, where woodrats are absent, spotted owls consume primarily flying squirrels (Carey et al. 1992), whereas in northern California flying squirrels make up a smaller portion of the diet and woodrats, which are more abundant, dominate (Ward et al. 1998). Even within a single spotted owl population some individuals specialize on one taxa or the other (Zabel et al. 1995). Home range sizes in the flying squirrel-dependent Olympic Peninsula are among the largest ever recorded (Carey et al. 1992), and where both taxa are present owls which consume primarily flying squirrels have larger home ranges than those which consume mostly woodrats (Zabel et al. 1995). Evidently diet and prey abundance affect some demographic parameters, such as breeding density, which has led some authors to recommend increasing prey abundance as a route to increase owl abundance (Forsman et al. 2004). Yet prey abundance alone does not appear to affect spotted owl productivity (Rosenberg et al. 2003). Instead, productivity appears to result from complex interactions between climate and prey abundance (Glenn et al. 2011).

In contrast to the spotted owl's dependence on a few prey species, the northern goshawk is considered a generalist predator and consumes an enormous diversity of prey across its wide geographic range (reviewed in Drennan 2006, Rutz et al. 2006). I identified 29 different prey species in the diet of goshawks in coastal British Columbia, which is consistent with a generalist foraging strategy. However, nearly half of goshawk diet in my study area was composed of *Tamiasciurus* spp. (hereafter "pine squirrels"), which indicates a

level of specialization similar to that of the spotted owl. Some goshawk populations appear to be strongly generalist (e.g. Arizona: Salafsky et al. 2007), whereas in others a key prey species is a major driver of productivity, survival, and other demographic parameters (e.g. Yukon: Doyle and Smith 1994, and Finland: Tornberg et al. 2005). I did not find an effect of the degree of dietary specialization on goshawk productivity. There are several explanations for this unexpected finding. First, specialists may not be more productive than generalists (Woo et al. 2008). Specialist individuals may selectively consume pine squirrels but have similar levels of fitness as generalist individuals in this population. Alternately, specialization may not be the result of selection. Individuals may lack strong prey preferences and take pine squirrels in proportion to their abundance. Total prey abundance, rather than pine squirrel abundance, may then drive productivity (Penteriani et al. 2002). Finally, as in the spotted owl, prey abundance and diet during the breeding season may be a lesser driver of productivity than other factors, such as weather or winter prey abundance.

Goshawk diet varies across its range in response to the regional presence and abundance of specific prey species (Drennan 2006). I found the key prey of goshawks in the south coast region to be pine squirrels. This contrasts with studies of goshawk diet elsewhere in the Pacific Northwest, where the key prey is generally grouse (Watson et al. 1998, Thrailkill et al. 2000, Bloxton 2002, Lewis et al. 2006), but is similar to work on Vancouver Island, where the key prey is also pine squirrels (Ethier 1999). My results also contrast with studies from other regions of western North America, where the key prey may occasionally be a species of squirrel but is most often a species of hare or rabbit. The unexpected difference between diet in my study area and the larger Pacific Northwest may be due in part to differences in methodology. When the results from studies across temperate rainforest ecosystems are standardized (data from pooled pellets-and-remains or remains only, measured by counts), the contrast between regions within the Pacific Northwest is much less pronounced. However, the proportion of mammalian prey in the diet, particularly pine squirrels, remains markedly higher within coastal British Columbia than outside it even after accounting for methodological differences. The relatively high specialization on pine squirrels may be a result of higher pine squirrel abundance compared to other temperate rainforest ecosystems (Carey 1995, Ransome and Sullivan 2003). No Pacific Northwest

study has assessed goshawk diet and absolute prey abundance simultaneously (though see Ethier 1999). Nonetheless, regional data hint at a pattern of higher dietary specialization in areas or forest types with higher pine squirrel abundance (see Fig. 3.1). Across the two ecological zones present in my study area I observed only minor variation in goshawk diet and no variation in the dominance of pine squirrels in the diet. If goshawks are more specialized on pine squirrels in areas where pine squirrels are more abundant, this indicates a slight difference in the prey community of these two zones but a similar abundance of pine squirrels. The wide variety of prey species consumed, combined with the consistent specialization on pine squirrels despite variation in prey community, suggests goshawks in my study are generalist predators opportunistically exploiting a locally abundance prey species.

3.2 Directions for Future Research

Comparing the foraging ecology of the northern spotted owl and the northern goshawk highlights significant knowledge gaps regarding goshawk biology. The controversy surrounding spotted owl conservation, combined with its position at the heart of a major management plan, has made it one of the most-studied birds in the world (Gutiérrez et al. 2020). The northern goshawk, although likewise shrouded in controversy, has not received the same level of study. Where data are available, it is more difficult to generalize research on the widespread, generalist northern goshawk than for the more restricted, relatively specialized spotted owl. As a result, there is a pressing need for detailed, local information on goshawks in the Pacific Northwest, particularly in coastal British Columbia.

One knowledge gap related to the work I present here is how variation in prey abundance affects the degree of dietary specialization, productivity, and survival of individual goshawks. Dietary specialization such as goshawks in my study area exhibit may be the result of a preference for the main prey or simply an absence of other options. Data on prey abundance is necessary to understand the mechanism of goshawk specialization and whether it is the result of high selectivity for pine squirrels, high abundance of pine squirrels, or some combination of both. This information can in turn be used to evaluate how changes in key prey abundance and total prey abundance influence goshawk demographic parameters, particularly productivity. Without this knowledge it is impossible

to fully understand the factors limiting goshawk populations in coastal British Columbia.

A second knowledge gap is how the amount and type of habitat goshawks use for foraging varies with diet and prey abundance. Goshawk home range size varies across their geographic range and goshawks have been observed foraging in diverse habitat types, leading to ongoing debate over how and why goshawks select habitat (Greenwald et al. 2005, Reynolds et al. 2008). Research on spotted owls indicates that home range size is inversely related to prey abundance and foraging habitat selection varies with the identity of the main prey (Zabel et al. 1995). Variation in goshawk home range size and habitat selection may likewise be explained by diet and prey abundance (Kenward 1982, Penteriani et al. 2013). If so, foraging habitat management could only be conducted with knowledge of goshawk diet, and recommendations made for one population could be applied to others only with great caution. Filling this knowledge gap with information specific to coastal British Columbia is vital and has been identified as a priority by goshawk managers (NGRT 2008, Parks Canada Agency 2018).

To address the crucial foraging habitat knowledge gap, the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and I conducted a pilot study of foraging habitat use in coastal British Columbia. Between 2018-2020 we tagged and tracked 4 male and 9 female goshawks. Captures were conducted during the early breeding season using a dho-gaza trap with a live great-horned owl (*Bubo virginianus*) as a lure (Bloom et al. 2007). Goshawks were fitted with 14-gram solar-powered GPS-UHF tags (Ecotone Telmetry brand, Harrier model) with an additional VHF tag, attached via backpack-style harness. Tags were programmed to take a location point every 15 minutes and to download data to a base station when within range (approximately 100 m from the station). Base stations were placed beneath or above nests and tags were program to check for proximity to the station every 15 minutes.

We were able to retrieve data from 10 out of 13 birds, collecting location data from 3 - 73 (mean = 37.9 ± 26.7 standard deviation) days of the breeding season (20 April - 15 September; Table 3.1). Tracked birds provided 45 - 2964 location points ($\bar{x} = 837.78 \pm 923$) with an average of $31.03 (\pm 62.28)$ locations per bird per day. Over the study period we

observed only one probable mortality. I estimated breeding season home ranges and core-use areas using 95% minimum convex polygons (MCPs) and 50% MCPs, respectively. The mean breeding season home range was 2008.9 ha, but male home ranges were far larger than female home ranges (male $\bar{x} = 4409.2 \pm 1408.4$, $n = 4$; female $\bar{x} = 88.7 \pm 115.8$, $n = 5$; $t = -6.12$, $df = 3.03$, $P = 0.01$). Male core-use areas were also larger than female core-use areas, but not significantly so (male $\bar{x} = 851.5 \pm 508.3$; female $\bar{x} = 1.3 \pm 2.3$; $t = -3.35$, $df = 3$, $P = 0.04$). Female home ranges and core-use areas were smaller due to the significantly higher amount of time females spent within approximately 100 meters of the nest ($t = -3.32$, $df = 6.9$, $P = 0.01$). Males also traveled further from the nest than females. The average furthest distance from the nest a male traveled was 7.05 (± 1.76) km, while on average females only ventured 2.86 (± 2.02) km from the nest ($t = -3.32$, $df = 6.9$, $P = 0.01$). Home ranges were rarely circular, but rather shaped by geographic constraints such as coastlines or mountains peaks (see Fig. 3.2). Within home ranges, kernel density estimates show habitat use is not even across a male's territory. Instead, there are clusters of activity around areas which are likely high-quality foraging habitat.

We encountered several challenges over the course of the three-year pilot. First, the location data we obtained were biased toward females. Females are more aggressive near the nest than males and so are more likely to be captured when using the dho-gaza trapping method. Data from female tags downloaded more frequently onto the base stations than data from male tags because of the large amount of time females spent near the nest, where the base stations were located. Consequently, we collected far more location data on females than males, which offered relatively little insight into foraging habitat use since males provide most of the food during the breeding season. Second, we were unable to retrieve data from some tagged birds. Several birds were detected via the VHF transmitter but could not be relocated with sufficient precision to download data from the UHF tag. As a result, we could not retrieve data from the winter or subsequent breeding season. Our inability to relocate birds is likely due to a combination of the limited range of the VHF tags and the difficult topography of our study area, compounded by the birds' failure to return to known breeding areas. Finally, technical malfunctions resulted in no data downloads for two birds, too many location points for one birds, and too few location points for several others. Future work should consider more powerful VHF tags

for easier relocation and an alternate-days duty cycle to increase battery life and reduce the number of missed locations.

Despite these setbacks, the pilot study provided insight into goshawk movement and habitat use, with relevance to goshawk management. The GPS data we were able to retrieve, although less than anticipated, was of higher resolution than VHF data and higher accuracy than satellite data. It may therefore be uniquely well-suited to studies of foraging habitat selection. Our average breeding season home-range for males are slightly larger than most reported elsewhere in North America, but our average female home range is much smaller (Table 3.2). The high fidelity of females to the nest area confirms the importance of protected buffers around nests to prevent the disturbance of habitat critical for breeding females and fledglings. However, the large distances traveled by males and the irregular shape of their home ranges shows that circular buffers based on estimates of mean home range size are not good approximations of true space use. Areas used extensively by males usually fall outside the nest area and are not captured by current nesting habitat protections. Preliminary inspection of movement data indicates goshawks readily crossed narrow barriers such as roads, rivers, and powerline cuts, and sometimes appeared to use these features for travel or foraging. On the other hand, goshawks seemed to generally route around larger barriers such as lakes or clearcuts. This suggests managed areas around nests should be tailored to the amount and configuration of suitable foraging habitat present in the surrounding landscape, and that any timber harvest within the foraging area should prioritize the preservation of connectivity between patches of high-quality foraging habitat. However, a great deal of additional research is needed to confirm and refine these suggestions, particularly regarding the characteristics of suitable and high-quality foraging habitat.

3.3 Management Implications of Goshawk Diet

Climate change is one of the largest and most difficult to anticipate threats facing biodiversity (Bellard et al. 2012). The current understanding of how climate change will impact goshawks in coastal British Columbia is largely speculative (Parks Canada Agency 2018). Although I found no evidence of a link between the degree of dietary specialization and goshawk productivity, the level of specialization I observed and findings from other

studies suggest goshawks in my study area are highly dependent on pine squirrels for successful reproduction. Notably, Ethier (1999) found goshawk productivity on Vancouver Island to be significantly correlated with red squirrel abundance. Pine squirrels are themselves highly dependent on conifer seeds and their abundance varies with the size of the annual cone crop (Smith 1970). Seed production is cyclical but may be promoted by higher temperatures and inhibited by drought (Boucher et al. 2020). As the climate warms and drought risk rises, climate-driven changes in seed production may cascade through prey abundance to impact goshawk populations in coastal British Columbia. Significantly more work is needed to understand the relationship between prey abundance, the buffering ability of alternate prey, and goshawk productivity, but my results provide an important starting point for incorporating climate change into goshawk management.

Wildlife management, whether founded on a single-species or ecosystem-based approach, generally centers around species, subspecies, or unique populations at risk of extinction. My thesis examines a single population of goshawks on the south coast of British Columbia which is currently classified as part of the subspecies *laingi*. The precise range of *laingi* has never been entirely clear, but recent genetic evidence indicates the Haida Gwaii population is highly unique and distinct from other putative *laingi* populations (Geraldes et al. 2018). My results suggest a strong ecological similarity between goshawks within my study area, Vancouver Island, and Haida Gwaii, where goshawks are also highly dependent on pine squirrels (COSEWIC 2013). The diet of these populations stands in contrast to others in temperate rainforest ecosystems which are currently considered *laingi*, such as the Olympic Peninsula or Southeast Alaska, where goshawks consume mainly birds. Goshawks in coastal British Columbia may therefore be ecologically similar to each other, and ecologically distinct from other populations, regardless of their genetic relationship. The ecological similarity of these populations supports the strategy used by the Northern Goshawk Recovery Team to delineate the boundaries of the *laingi* range, which emphasizes ecosystem mapping over genetics (NGRT 2008).

Rooting management in ecosystems, rather than individual species, has been a success—albeit a conditional one—for forest conservation in the United States. Ecosystem-based management has also been applied in the temperate rainforests of

British Columbia. In the early 2000s an ecosystem-based management plan, which includes the northern goshawk as a focal species, was developed for the Great Bear Rainforest on the northern coast of British Columbia (Price et al. 2009). My work provides some of the habitat-specific ecological information needed to broaden existing single-species goshawk management, or even to incorporate goshawks as a focal species in future ecosystem-based management. While it will be years before the success of Great Bear Rainforest agreement can be assessed, the groundbreaking plan offers a glimpse of the future of forest management in British Columbia—and the role northern goshawks may play in it.

3.4 Figures and Tables

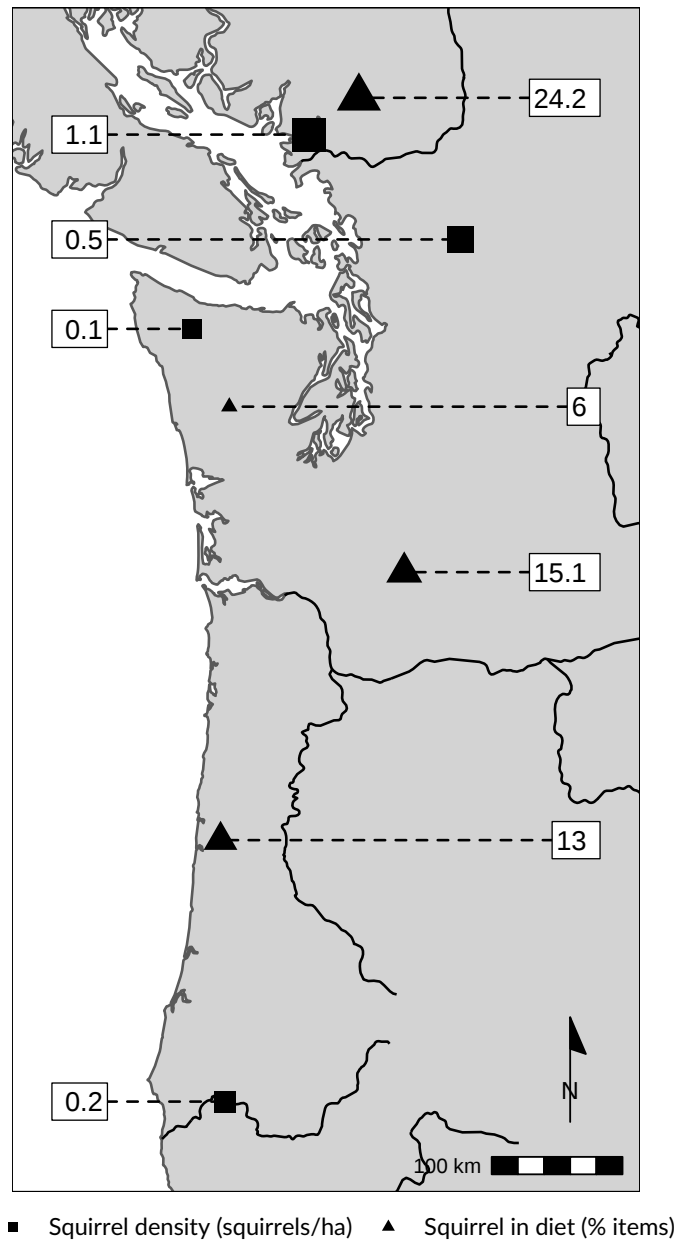


Figure 3.1: Northern Goshawk dietary specialization and pine squirrel (*Tamiasciurus* spp.) density in the Pacific Northwest. Dietary specialization (percent of prey items) estimated using pooled pellets-and-remains (Watson et al. 1998, Bloxton 2002, this study) or remains only (Thrallikill et al. 2000). Pine squirrel density (individuals per ha) estimated by mark-recapture (Carey et al. 1992, Ransome and Sullivan 2003). Symbol location indicated approximate study location and size represents relative degree of specialization or density.

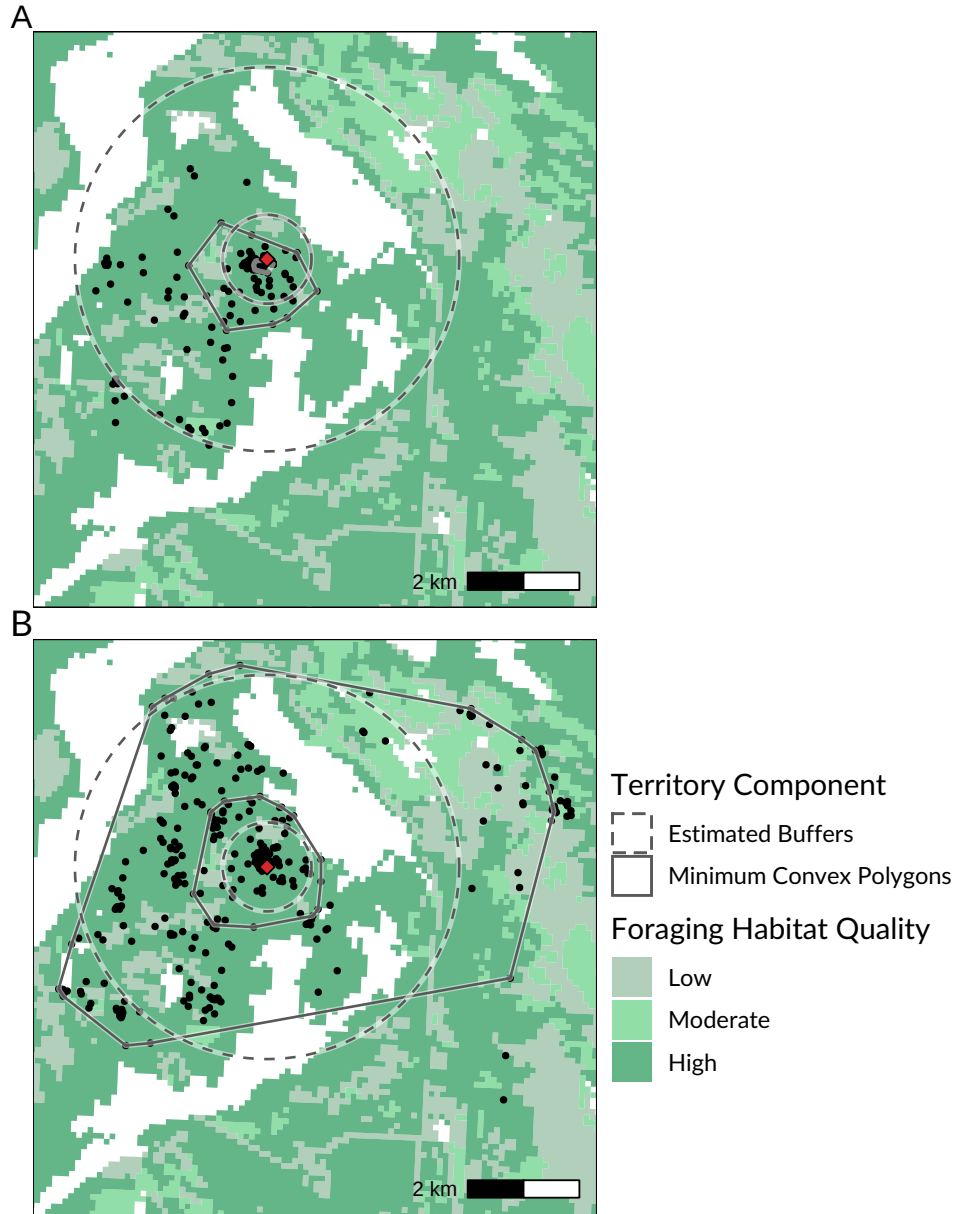


Figure 3.2: Representative examples of breeding season home range and core-use area of one female (A) and one male (B) goshawk tagged at the same site (red diamond) in 2019 and 2020, respectively. Habitat quality from habitat suitability model (Mahon 2008) show in green, with water in white. Breeding season home range and core-use areas estimated using 95% and 50% MCPs, shown with solid lines. Estimated home range (3450 ha) and breeding area (200 ha) buffers used in goshawk management (NGRT 2008, Parks Canada Agency 2018) are shown with dashed lines. Individual location points shown as black circles.

Table 3.1: Summary of data from pilot telemetry study on Northern Goshawk in south coast British Columbia using GPS-UHF tags. Describes location data, maximum distance recorded from nest, percentage of points within 100 m of nest, and breeding season home range size (50% and 95% minimum convex polygons and kernel density estimates).

ID	Site	Location data				Relation to nest		Home range (ha)			
		First point	Last point	N. days	N. points	Max. distance	% at nest	50% MCP	95% MCP	50% KDE	95% KDE
Female											
HAR10	MTC	2019-05-02	2019-06-29	58	315	5457	78.4	0.3	58.9	8.7	113.4
HAR08	TCR	2019-06-10	2019-06-27	17	45	76	82.2	0.0	0.2	0.0	0.4
HAR03	GRV	2020-06-08	2020-06-28	20	2964	2441	95.9	0.0	0.0	0.0	0.0
HAR02	RLK	2020-06-13	2020-07-08	25	977	4013	72.1	5.4	280.6	12.7	267.4
HAR12	FMT	2020-06-25	2020-06-28	3	104	2302	3.9	0.7	103.7	13.0	152.1
AVERAGE				25	881	2858	66.5	1.3	88.7	6.9	106.7
Male											
HAR07	TCR	2018-07-08	2018-09-14	68	637	7977	0.0	904.8	4531.4	850.6	5263.1
HAR09	MTC	2019-05-02	2019-07-02	61	409	4413	2.4	530.1	2611.2	636.3	3032.8
HAR04	RLK	2019-06-22	2019-07-08	16	532	7773	9.0	423.0	4441.1	662.3	4407.6
HAR05	SKA	2019-06-23	2019-09-04	73	1557	8026	0.0	1548.2	6052.9	1642.2	6674.7
AVERAGE				54	784	7047	2.9	851.5	4409.2	947.9	4844.5

Table 3.2: Summary of Northern Goshawk breeding season home range size (sample size) in ha estimated by 95% minimum convex polygons (MCP) or kernel density methods (KDE) from selected studies in North America. Methods are v (VHF transmitter), g (GPS logger), or s (satellite transmitter), and mcp (minimum convex polygon) or kde (kernel density).

Study	Location	Ecosystem Type	Method	Home range (ha)		
				Comb.	Female	Male
Doyle and Smith (1994)	Yukon	boreal forest	v, mcp		2880 (1)	4000 (1)
Moser and Garton (2019)	northern Idaho	mixed conifer forest	s, kde		3859 (12)	5146 (7)
Hasselbad and Bechard (2007)	south-central Idaho	pine and aspen forest, sage shrubsteppe	v, mcp			790 (6)
Hargis et al. (1994)	eastern California	pine forest	v, kde		1340 (7)	2400 (2)
Austin (1993)	southern Oregon	pine, mixed-conifer forest	v, mcp		3774 ^a (5)	2425 ^a (5)
Blakey et al. (2020)	northern California	pine, mixed-conifer forest	g, kde		1619 (12)	3926 (8)
Bright-Smith and Mannan (1994)	northern Arizona	pine, mixed-conifer forest	v, mcp			1758 (11)
Sonsthagen et al. (2006)	Utah	pine, mixed-conifer forest	s, kde		10140 ^b -17650 ^c (16)	
Boal et al. (2003)	northern Minnesota	pine, mixed-deciduous forest	v, mcp		2495 (11)	2593 (17)
Bloxton (2002)	Western Washington	temperate rainforest	v, kde	3516 (12)		
Case (2021)	south coast British Columbia	temperate rainforest	g, mcp		88.7 (5)	4409.2 (4)
Titus et al. (1996)	southeast Alaska	temperate rainforest	v, mcp		19215 ^d (8)	5847 (8)

^a 100% MCP

^b Residents

^c Migrants

^d Several females tagged late in season or abandoned nest

References

- Andelman, S. J., and W. F. Fagan (2000). Umbrellas and flagships: Efficient conservation surrogates or expensive mistakes? *Proceedings of the National Academy of Sciences of the United States of America* 97:5954–5959.
- Andersen, D. E., S. DeStefano, M. I. Goldstein, K. Titus, C. Crocker-Bedford, J. J. Keane, R. G. Anthony, and R. N. Rosenfield (2005). Technical review of the status of Northern Goshawks in the western United States. *Journal of Raptor Research* 39:18.
- Andersson, M., and S. Erlinge (1977). Influence of Predation on Rodent Populations. *Oikos* 29:591–597.
- Austin, K. K. (1993). Habitat use and home range size of breeding Northern Goshawks in the southern Cascades. Master's thesis, Oregon State University, Corvallis, OR, USA.
- Beese, W. J., J. Deal, B. G. Dunsworth, S. J. Mitchell, and T. J. Philpott (2019). Two decades of variable retention in British Columbia: A review of its implementation and effectiveness for biodiversity conservation. *Ecological Processes* 8:1–22.
- Billerman, S. M., B. K. Keeney, P. G. Rodewald, and T. S. Schulenberg, editors (2020). *Birds of the World*. Cornell Lab of Ornithology, Ithaca, NY, USA.
- Blakey, R. V., R. B. Siegel, E. B. Webb, C. P. Dillingham, M. Johnson, and D. C. Kesler (2020). Northern Goshawk (*Accipiter gentilis*) home ranges, movements, and forays revealed by GPS-tracking. *Journal of Raptor Research* 54:388–401.
- Bloom, P. H., W. S. Clark, and J. W. Kidd (2007). Capture Techniques. Pages 193–219 in D. M. Bird and K. L. Bildstein, editors. *Raptor Research and Management Techniques*. Second edition. Hancock House Publishers, Blaine, WA, USA.
- Bloxton, T. D., Jr. (2002). Prey Abundance, Space Use, Demography, and Foraging Habitat of Northern Goshawks in Western Washington. Master's thesis, University of Washington, Seattle, WA, USA.
- Boal, C. W. (1994). A photographic and behavioral guide to aging nestling Northern Goshawks. *Studies in Avian Biology* 16:32–40.
- Boal, C. W., D. E. Andersen, and P. L. Kennedy (2003). Home Range and Residency Status of Northern Goshawks Breeding in Minnesota. *The Condor* 105:811–816.
- Boal, C. W., and R. W. Mannan (1994). Northern Goshawk diets in ponderosa pine forests on the Kaibab Plateau. *Studies in Avian Biology* 16:97–102.
- Bosakowski, T., and D. G. Smith (2006). Ecology of the Northern Goshawk in the New York-New Jersey highlands. *Studies in Avian Biology* 31:109–118.

- Boucher, D., S. Gauthier, N. Thiffault, W. Marchand, M. Girardin, and M. Urli (2020). How climate change might affect tree regeneration following fire at northern latitudes: A review. *New Forests* 51:543–571.
- Bright-Smith, D. J., and R. W. Mannan (1994). Habitat use by breeding male Northern Goshawks in northern Arizona. *Studies in Avian Biology* 16:58–65.
- Carey, A. B. (1995). Sciurids in Pacific Northwest managed and old-growth forests. *Ecological Applications* 5:648–661.
- Carey, A. B., S. P. Horton, and B. L. Biswell (1992). Northern Spotted Owls: Influence of prey base and landscape character. *Ecological Monographs* 62:223–250.
- Caro, T. (2010). *Conservation by Proxy: Indicator, Umbrella, Keystone, Flagship, and Other Surrogate Species*. Island Press, Washington, DC, USA.
- Charnley, S. (2006). The Northwest Forest Plan as a model for broad-scale ecosystem management: A social perspective. *Conservation Biology* 20:330–340.
- COSEWIC (2013). COSEWIC assessment and status report on the Northern Goshawk *Accipiter gentilis laingi* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON, Canada.
- COSEWIC (2014). COSEWIC Assessment and Status Report on the Marbled Murrelet *Brachyramphus marmoratus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa.
- Crocker-Bedford, D. C. (1990). Goshawk reproduction and forest management. *Wildlife Society Bulletin (1973-2006)* 18:262–269.
- DellaSala, D. A., R. Baker, D. Heiken, C. A. Frissell, J. R. Karr, S. K. Nelson, B. R. Noon, D. Olson, and J. Strittholt (2015). Building on two decades of ecosystem management and biodiversity conservation under the Northwest Forest Plan, USA. *Forests* 6:3326–3352.
- DellaSala, D. A., and J. E. Williams (2006). Special section: The Northwest Forest Plan: A global model of forest management in contentious times. *Conservation Biology* 20:274–276.
- DeStefano, S., M. T. McGrath, S. K. Daw, and S. M. Desimone (2006). Ecology and habitat of breeding Northern Goshawks in the inland Pacific Northwest: A summary of research in the 1990s. *Studies in Avian Biology* 31:75–84.
- Doyle, F. I., and J. M. N. Smith (1994). Population responses of Northern Goshawks to the 10-year cycle in numbers of snowshoe hares. *Studies in Avian Biology* 16:122–129.
- Drennan, J. E. (2006). Northern Goshawk food habits and goshawk prey species habitats. *Studies in Avian Biology* 31:198–218.
- Elmhagen, B., M. Tannerfeldt, P. Verucci, and A. Angerbjörn (2000). The arctic fox (*Alopex lagopus*): An opportunistic specialist. *Journal of Zoology* 251:139–149.

- Ethier, T. J. (1999). Breeding Ecology and Habitat of Northern Goshawks (*Accipiter gentilis laingi*) on Vancouver Island: A Hierarchical Approach. PhD, University of Victoria, Victoria, BC.
- Ferrer, M., and J. J. Negro (2004). The near extinction of two large European predators: Super specialists pay a price. *Conservation Biology* 18:344–349.
- FLNRORD (2018). Implementation plan for Northern Goshawk *laingi* subspecies in British Columbia. British Columbia Ministry of Forests, Lands, Natural Resource Operations; Rural Development, Victoria, BC.
- Forsman, E. D., R. G. Anthony, E. C. Meslow, and C. J. Zabel (2004). Diets and foraging behavior of Northern Spotted Owls in Oregon. *Journal of Raptor Research* 38:214–230.
- Forsman, E. D., I. A. Otto, S. G. Sovern, M. Taylor, D. W. Hays, H. Allen, S. L. Roberts, and D. E. Seaman (2001). Spatial and temporal variation in diets of Spotted Owls in Washington. *Journal of Raptor Research* 35:141–150.
- Franklin, J. F. (1993). Preserving biodiversity: Species, ecosystems, or landscapes? *Ecological Applications* 3:202–205.
- García-Salgado, G., S. Rebollo, L. Pérez-Camacho, S. Martínez-Hestekamp, A. Navarro, and J.-M. Fernández-Pereira (2015). Evaluation of trail-cameras for analyzing the diet of nesting raptors using the Northern Goshawk as a model. *PLoS ONE* 10.
- Geraldes, A., K. K. Askelson, E. Nikelski, F. I. Doyle, W. L. Harrower, K. Winker, and D. E. Irwin (2018). Population genomic analyses reveal a highly differentiated and endangered genetic cluster of Northern Goshawks (*Accipiter gentilis laingi*) in Haida Gwaii. *Evolutionary Applications*:1–16.
- Glenn, E. M., R. G. Anthony, E. D. Forsman, and G. S. Olson (2011). Reproduction of Northern Spotted Owls: The role of local weather and regional climate. *The Journal of Wildlife Management* 75:1279–1294.
- Graham, R. T., R. T. Reynolds, M. H. Reiser, R. L. Bassett, and D. A. Boyce (1994). Sustaining forest habitat for the Northern Goshawk: A question of scale. *Studies in Avian Biology* 16:12–17.
- Greenwald, N. D., D. C. Crocker-Bedford, L. Broberg, K. F. Suckling, and T. Tibbitts (2005). A review of Northern Goshawk habitat selection in the home range and implications for forest management in the western United States. *Wildlife Society Bulletin* 33:120–129.
- Grzybowski, J. A., and S. W. Eaton (1976). Prey items of goshawks in southwestern New York. *Wilson Bulletin* 88:669–670.
- Gutiérrez, R. J., and A. B. Carey, editors (1985). Ecology and Management of the Spotted Owl in the Pacific Northwest. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest; Range Experiment Station, Portland, OR, USA.

- Gutiérrez, R. J., A. B. Franklin, and W. S. LaHaye (2020). Spotted owl (*Strix occidentalis*), version 1.0. in A. F. Poole and F. B. Gill, editors. Birds of the World. Cornell Lab of Ornithology, Ithaca, NY, USA.
- Hanley, T. A., W. P. Smith, and S. M. Gende (2005). Maintaining wildlife habitat in southeastern Alaska: Implications of new knowledge for forest management and research. *Landscape and Urban Planning* 72:113–133.
- Hanski, I., L. Hansson, and H. Henttonen (1991). Specialist predators, generalist predators, and the microtine rodent cycle. *Journal of Animal Ecology* 60:353–367.
- Hargis, C. D., C. McCarthy, and R. D. Perloff (1994). Home ranges and habitats of northern goshawks in eastern California. *Studies in Avian Biology* 16:66–74.
- Harrison, J. T., M. N. Kochert, B. P. Pauli, and J. A. Heath (2019). Using motion-activated trail cameras to study diet and productivity of cliff-nesting Golden Eagles. *Journal of Raptor Research* 53:26–37.
- Hasselblad, K., and M. Bechard (2007). Male Northern Goshawk home ranges in the Great Basin of south-central Idaho. *Journal of Raptor Research* 41:150–155.
- Hope, A. C. A. (1968). A simplified Monte Carlo significance test procedure. *Journal of the Royal Statistical Society. Series B (Methodological)* 30:582–598.
- Kennedy, P. (1991). Reproductive strategies of Northern Goshawks and Cooper's Hawks in north-central New Mexico. Ph.D. dissertation, Utah State University, Logan, UT, USA.
- Kenward, R. (1982). Goshawk hunting behaviour and range size as a function of food and habitat availability. *The Journal of Animal Ecology* 51:69.
- Korpimäki, E., and K. Norrdahl (1991). Numerical and functional responses of Kestrels, Short-Eared Owls, and Long-Eared Owls to vole densities. *Ecology* 72:814–826.
- Lambeck, R. J. (1997). Focal Species: A Multi-Species Umbrella for Nature Conservation. *Conservation Biology* 11:849–856.
- Landres, P. B., J. Verner, and J. W. Thomas (1988). Ecological uses of vertebrate indicator species: A critique. *Conservation Biology* 2:316–328.
- Lewis, S. B., M. R. Fuller, and K. Titus (2004). A comparison of 3 methods for assessing raptor diet during the breeding season. *Wildlife Society Bulletin* 32:373–385.
- Lewis, S. B., K. Titus, and M. R. Fuller (2006). Northern Goshawk diet during the nesting season in southeast Alaska. *The Journal of Wildlife Management* 70:1151–1160.
- Mahon, T., E. L. McClaren, and F. I. Doyle (2008). Northern Goshawk (*Accipiter gentilis laingi*) habitat models for coastal British Columbia. Nesting and foraging habitat suitability models and territory analysis model. Unpublished report, Northern Goshawk *Accipiter gentilis laingi* Recovery Team, Habitat Recovery Implementation Group, Nanaimo, BC, Canada.

- McClaren, E. L. (2005). Northern Goshawk (*Accipiter gentilis laingi*) population inventory summary for Vancouver Island, British Columbia 1994-2002. Ministry of Environment, Victoria, BC.
- McClaren, E. L., P. L. Kennedy, and S. R. Dewey (2002). Do some Northern Goshawk nest areas consistently fledge more young than others? *The Condor* 104:343–352.
- McClaren, E., T. Mahon, F. I. Doyle, and W. Harrower (2015). Science-based guidelines for managing Northern Goshawk breeding areas in coastal British Columbia. *Journal of Ecosystems and Management* 15:1–91.
- McCoy, R. H. (1999). Effects of prey delivery on the fledging success of the northern goshawk. Master's thesis, Humbolt State University, Arcata, CA, USA.
- Meidinger, D., and J. Pojar (1991). *Ecosystems of British Columbia*. Ministry of Forests, Victoria, BC.
- Miller, R. A., J. D. Carlisle, and M. J. Bechard (2014). Effects of prey abundance on breeding season diet of Northern Goshawks (*Accipiter gentilis*) within an unusual prey landscape. *Journal of Raptor Research* 48:1–12.
- Moser, B. W., and E. O. Garton (2019). Northern goshawk space use and resource selection. *The Journal of Wildlife Management* 83:705–713.
- Nagorsen, D., W. (2002). *An Identification Manual to the Small Mammals of British Columbia*. British Columbia Ministry of Water, Land; Air Protection, Biodiversity Branch, Victoria, BC, Canada.
- Nagorsen, D., W. (2005). *Rodents and Lagomorphs of British Columbia*. Royal BC Museum, Victoria, BC, Canada.
- Newton, I. (1998). *Population Limitation in Birds*. Academic Press, San Diego, CA, USA.
- NGRT (2008). *Recovery Strategy for the Northern Goshawk, laingi Subspecies (Accipiter gentilis laingi) in British Columbia*. Northern Goshawk Recovery Team; BC Ministry of Environment, Victoria, BC.
- Ozaki, K., M. Isono, T. Kawahara, S. Iida, T. Kudo, and K. Fukuyama (2006). A mechanistic approach to evaluation of umbrella species as conservation surrogates. *Conservation Biology* 20:1507–1515.
- Parks Canada Agency (2018). *Recovery Strategy for the Northern Goshawk laingi subspecies (Accipiter gentilis laingi) in Canada*. Parks Canada Agency, Ottawa, ON, Canada.
- Peck, J. (2000). Seeing the forest through the eyes of a hawk: An evaluation of recent efforts to protect Northern Goshawk populations in southwestern forests. *Natural Resources Journal* 40:125–156.
- Penteriani, V., M. Gallardo, and P. Roche (2002). Landscape structure and food supply affect eagle owl (*Bubo bubo*) density and breeding performance: A case of intra-population heterogeneity. *Journal of Zoology* 257:365–372.

- Penteriani, V., C. Rutz, and R. Kenward (2013). Hunting behaviour and breeding performance of Northern Goshawks *Accipiter gentilis*, in relation to resource availability, sex, age and morphology. *Naturwissenschaften* 100:935–942.
- Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope, and K. J. Sainsbury (2004). Ecosystem-based fishery management. *Science* 305:346–347.
- Price, K., A. Roburn, and A. MacKinnon (2009). Ecosystem-based management in the Great Bear Rainforest. *Forest Ecology and Management* 258:495–503.
- Ransome, D. B., and T. P. Sullivan (2003). Population dynamics of *Glaucomys sabrinus* and *Tamiasciurus douglasii* in old-growth and second-growth stands of coastal coniferous forest. *Canadian Journal of Forest Research* 33:587–596.
- R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Austria.
- Resano-Mayor, J., J. Real, M. Moleón, J. A. Sánchez-Zapata, L. Palma, and A. Hernández-Matías (2016). Diet–demography relationships in a long-lived predator: From territories to populations. *Oikos* 125:262–270.
- Reynolds, R. T., R. T. Graham, and D. A. Boyce (2008). Northern Goshawk habitat: An intersection of science, management, and conservation. *The Journal of Wildlife Management* 72:1047–1055.
- Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, G. Goodwin, R. Smith, and E. L. Fisher (1992). Management Recommendations for the Northern Goshawk in the Southwestern United States. General Technical Report, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest; Range Experiment Station, Ft. Collins, CO.
- Reynolds, R. T., S. M. Joy, and D. G. Leslie (1994). Nest productivity, fidelity, and spacing of Northern Goshawks in Arizona. *Studies in Avian Biology* 16:106–113.
- Reynolds, R. T., and E. C. Meslow (1984). Partitioning of food and niche characteristics of coexisting *accipiter* during breeding. *The Auk* 101:761–779.
- Reynolds, R. T., J. D. Wiens, and S. R. Salafsky (2006). A Review and evaluation of factors limiting Northern Goshawk populations. *Studies in Avian Biology* 31:260–273.
- Roberge, J.-M., and P. Angelstam (2004). Usefulness of the umbrella species concept as a conservation tool. *Conservation Biology* 18:76–85.
- Rogers, A. S., S. DeStefano, and M. F. Ingraldi (2006). Diet, prey delivery rates, and prey biomass of northern goshawks in east-central Arizona. *Studies in Avian Biology* 31:221–229.
- Rosenberg, D. K., K. A. Swindle, and R. G. Anthony (2003). Influence of prey abundance on Northern Spotted Owl reproductive success in western Oregon. *Canadian Journal of Zoology* 81:1715–1725.

- Roth, J. D., J. D. Marshall, D. L. Murray, D. M. Nickerson, and T. D. Steury (2007). Geographic gradients in diet affect population dynamics of Canada lynx. *Ecology* 88:2736–2743.
- Rutz, C. (2006). Home range size, habitat use, activity patterns and hunting behaviour of urban-breeding Northern Goshawks *Accipiter gentilis*. *ARDEA* 94:185–202.
- Rutz, C., and R. G. Bijlsma (2006). Food-limitation in a generalist predator. *Proceedings: Biological Sciences* 273:2069–2076.
- Rutz, C., R. G. Bijlsma, M. Marquiss, and R. E. Kenward (2006). Population limitation in the Northern Goshawk in Europe: A review with case studies. *Studies in Avian Biology* 31:158–197.
- Salafsky, S. R., R. T. Reynolds, B. R. Noon, and J. A. Wiens (2007). Reproductive responses of Northern Goshawks to variable prey populations. *The Journal of Wildlife Management* 71:2274–2283.
- Salamolard, M., A. Butet, A. Leroux, and V. Bretagnolle (2000). Responses of an avian predator to variations in prey density at a temperate latitude. *Ecology* 81:2428–2441.
- Schaffer, W. W. (1998). Northern goshawk (*Accipiter gentilis*) habitat characterization in central Alberta. Master's thesis, University of Alberta, Edmonton, AB, Canada.
- Schnell, J. H. (1958). Nesting behavior and food habits of goshawks in the Sierra Nevada of California. *The Condor* 60:377–403.
- Seddon, P. J., and T. Leech (2008). Conservation short cut, or long and winding road? A critique of umbrella species criteria. *Oryx* 42:240–245.
- Sergio, F., I. Newton, L. Marchesi, and P. Pedrini (2006). Ecologically justified charisma: Preservation of top predators delivers biodiversity conservation. *Journal of Applied Ecology* 43:1049–1055.
- Simberloff, D. (1998). Flagships, umbrellas, and keystones: Is single-species management passé in the landscape era? *Biological Conservation* 83:247–257.
- Simmons, R., D. M. Avery, and G. Avery (1991). Biases in diets determined from pellets and remains: Correction factors for a mammal and bird-eating raptor. *Journal of Raptor Research* 25:63–67.
- Simpson, E. H. (1949). Measurement of diversity. *Nature* 163:688–688.
- Smith, C. C. (1963). First breeding record of the Spotted Owl in British Columbia. *Condor* 65:440.
- Smith, C. C. (1970). The coevolution of pine squirrels (*tamiasciurus*) and conifers. *Ecological Monographs* 40:349–371.
- Smithers, B. L., C. W. Boal, and D. E. Andersen (2005). Northern Goshawk diet in Minnesota: An analysis using video recording systems. *Journal of Raptor Research* 39:264–273.

- Sonsthagen, S. A., E. L. McClaren, F. I. Doyle, K. Titus, G. K. Sage, R. E. Wilson, J. R. Gust, and S. L. Talbot (2012). Identification of metapopulation dynamics among Northern Goshawks of the Alexander Archipelago, Alaska, and Coastal British Columbia. *Conservation Genetics* 13:1045–1057.
- Sonsthagen, S. A., R. Rodriguez, and C. M. White (2006). Satellite Telemetry of Northern Goshawks Breeding in Utah - I. Annual Movements. *Studies in Avian Biology* 31:239–251.
- Squires, J. R., and P. L. Kennedy (2006). Northern goshawk ecology: An assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology* 31:8–62.
- Squires, J. R., R. T. Reynolds, J. Orta, and J. S. Marks (2020). Northern Goshawk (*Accipiter gentilis*). in S. M. Billerman, editor. *Birds of the World*. version 1.0. Cornell Lab of Ornithology, Ithaca, NY, USA.
- Steenhof, K., and M. N. Kochert (1988). Dietary responses of three raptor species to changing prey densities in a natural environment. *Journal of Animal Ecology* 57:37–48.
- Stier, A. C., J. F. Samhouri, M. Novak, K. N. Marshall, E. J. Ward, R. D. Holt, and P. S. Levin (2016). Ecosystem context and historical contingency in apex predator recoveries. *Science Advances* 2:e1501769.
- Takeda, L., and I. Røpke (2010). Power and contestation in collaborative ecosystem-based management: The case of Haida Gwaii. *Ecological Economics* 70:178–188.
- Taverner, P. A. (1940). Variation in the American Goshawk. *The Condor* 42:157–160.
- Terraube, J., and B. Arroyo (2011). Factors influencing diet variation in a generalist predator across its range distribution. *Biodiversity and Conservation* 20:2111–2131.
- Terraube, J., B. Arroyo, M. Madders, and F. Mougéot (2011). Diet specialisation and foraging efficiency under fluctuating vole abundance: A comparison between generalist and specialist avian predators. *Oikos* 120:234–244.
- Thomas, J. W., J. F. Franklin, J. Gordon, and K. N. Johnson (2006). The Northwest Forest Plan: Origins, components, implementation experience, and suggestions for change. *Conservation Biology* 20:277–287.
- Thraillkill, J. A., L. S. Andrews, and R. M. Claremont (2000). Diet of Breeding Northern Goshawks in the Coast Range of Oregon. *Journal of Raptor Research* 34:339–340.
- Titus, K., C. Flatten, and R. Lowell (1996). Goshawk ecology and habitat relationships on the Tongass National Forest. Alaska Department of Fish; Game, Division of Wildlife Conservation, Douglas; Ketchikan, AK, USA.
- Tornberg, R., E. Korpimäki, S. Jungell, and V. Reif (2005). Delayed numerical response of goshawks to population fluctuations of forest grouse. *Oikos* 111:408–415.
- Tornberg, R., and V. Reif (2007). Assessing the diet of birds of prey: A comparison of prey items found in nests and images. *Ornis Fennica* 84:21–31.

- Tracy, C. R., and P. F. Brussard (1994). Preserving biodiversity: Species in landscapes. *Ecological Applications* 4:206–207.
- US Fish and Wildlife Service (2020). Endangered and Threatened Wildlife and Plants; Threatened Species Status for Coastal Distinct Population Segment of the Pacific Marten With a Section 4(d) Rule. *Federal Register* 85:63806–63831.
- Waples, R. S., M. Nammack, J. F. Cochrane, and J. A. Hutchings (2013). A tale of two acts: Endangered species listing practices in Canada and the United States. *BioScience* 63:723–734.
- Ward, J. P., R. J. Gutiérrez, and B. R. Noon (1998). Habitat selection by Northern Spotted Owls: The consequences of prey selection and distribution. *The Condor* 100:79–92.
- Watson, J. W., D. W. Hays, S. P. Finn, and P. Meehan (1998). Prey of breeding Northern Goshawks in Washington. *Journal of Raptor Research* 32:397–305.
- Wiens, J. A., G. D. Hayward, R. S. Holthausen, and M. J. Wisdom (2008). Using surrogate species and groups for conservation planning and management. *BioScience* 58:241–252.
- Woo, K. J., K. H. Elliott, M. Davidson, A. J. Gaston, and G. K. Davoren (2008). Individual specialization in diet by a generalist marine predator reflects specialization in foraging behaviour. *Journal of Animal Ecology* 77:1082–1091.
- Younk, J. V., and M. J. Bechard (1994). Breeding ecology of the Northern Goshawk in high-elevation aspen forests of Northern Nevada. *Studies in Avian Biology* 16:119–121.
- Zabel, C. J., K. McKelvey, and J. P. Ward Jr. (1995). Influence of primary prey on home-range size and habitat-use patterns of northern spotted owls (*Strix occidentalis caurina*). *Canadian Journal of Zoology* 73:433–439.



Report to Ecosystem Planning and Natural Resources USDA Forest Service, Alaska Region

TONGASS NATIONAL FOREST: 2023 SAWMILL CAPACITY AND PRODUCTION REPORT

INTRODUCTION

Since 2000, the United States Forest Service (USFS), Alaska Region Office has conducted an annual key-informant survey of sawmills across the Tongass National Forest. The purpose of the annual survey is to gather information regarding sawmill operations including total estimated production capacity, actual production, wood supply source, forest products produced, market destinations, and business challenges. The *Tongass National Forest: 2023 Sawmill Capacity and Production Report* summarizes key survey findings, provides a brief supplemental discussion, and presents a longitudinal perspective of sawmill performance over the past twenty-three years. Results are organized into ten sections:

- Longitudinal survey results
- Sawmill overview
- Capacity and production volume
- Wood supply source
- Primary product by species
- Production volume by product
- Young growth timber utilization
- Markets
- Preferred timber sale size and volume under contract
- Log exports

Sawmill key-informant survey results provide a framework for assessing sawmill performance and trends over time, business conditions and challenges, manufactured products and markets, timber harvest from public and private lands, and regional trends in timber utilization.

The survey instrument and population frame remained unchanged from 2000 to 2019 to allow comparative longitudinal analysis over time. The survey was not conducted for 2020 because of challenges during the COVID-19 pandemic. In 2021, the sawmill survey underwent several changes. The survey pool was expanded with the addition of seven sawmills to improve representation of the region's small mills and gain a better understanding of their operations, wood demand, and markets. In addition, two questions were added to the survey instrument to gather key data to support planning efforts on the Tongass National Forest. Last, two sections focusing on Tongass National Forest timber volume under contract and log exports were added to expand the discussion around timber markets, supply, and demand.



METHODS

The 2023 sawmill survey, covering January to December 2023 production, was conducted from April to May 2024 via onsite and telephone interviews. Rather than utilize a random sampling method, the Alaska Region conducts a key-informant survey with a subset of Southeast sawmills operating on a regular basis. Participation is voluntary. The survey instrument includes questions about capacity, equipment, jobs, sawmill activity, products, markets, young growth timber utilization, and timber sale size preference (Table 1). Information about Tongass National Forest harvest and log exports and timber volume under contract are not included in the survey instrument but instead gathered from the [Forest Management Reports and Accomplishments website](#) hosted by the Alaska Region.

Table 1. Survey instrument summary

Business Profile	Sawmill Activity	Primary Products	Other
Business Name, Owner's Name, Location, Sawmill equipment description	Estimated processing capacity, Actual production, Log source, Employment	Primary products, Destination markets	Tongass log exports, Young growth utilization, Preferred timber sale size

POPULATION FRAME

The survey population frame listed in Table 2 represents a subset of the total number of mills in Southeast Alaska. The original population frame was established in 2000 using criteria that required: 1) regular, consistent operation and 2) medium to large size classification. When the survey was initiated in 2000, 20 medium (1.0-5.0 MMBF annually)- to large-scale sawmills (> 5.0 MMBF annually) operated across the Tongass National Forest. Between 2000 and 2019, more than half (59 percent) of these sawmills were closed and uninstalled or had contracted to fraction of their 2000 output. No sawmills were ever added to the survey pool. The mill survey conducted for 2019¹ found four of the original pool of sawmills were operating and five were idle; thus, the entire Southeast Alaska wood products industry was being represented by four active mills.

During same period, small sawmills (0.1-1.0 MMBF annually) were also a component of the greater Southeast Alaska forest products industry but were not included. In 2021, seven small sawmills were added to better reflect recent trends in forest industry and raise awareness of their business requirements and contributions. These mills were not new; they were selected from a larger population of all known mills using a combination of three criteria: a history of purchasing timber from the Tongass National Forest, a valid Alaska business license to manufacture wood products, and a recommendation from

¹ Survey not conducted for 2020 owing to staffing issues and challenges associated with the COVID-19 pandemic.



Tongass timber management staff. To preserve longitudinal time series constancy, results for the seven small mills are separated from the original set of mills in the tables below.

Table 2 shows during the 2023 cycle, D&L Woodworks and The Mill were idle. The Good Faith Lumber Company, which reverted to Thorne Bay Wood Products in 2017, was purchased in late 2022 by JK Forest Products and was doing business as JK Forest Products in 2023. Accordingly, equipment and capacity information for Thorne Bay Wood Products was combined with JK Forest Products, and Thorne Bay Wood Products (formerly Good Faith Lumber Company) has been removed from the mill survey pool. For the second consecutive year, the Viking Lumber Company declined to provide information on the previous year's operations. In response, we continue to assume operations are unchanged from 2021. We recognize that this approach introduces error in the regional estimates. Several mills were in the process of installing new equipment in 2022, but the equipment was not operating yet in 2023.

Table 2. Sawmill population frame, calendar years 2000 – 2023. Small mills added to survey pool in 2021 in bold

Active (12)	Idle (2)	Uninstalled since 2000 (14)
Alaska Specialty Woods Alaska Timber and Truss (name changed from Peak Engineering 2022) Fair and Square Lumber Icy Straits Lumber and Milling Company JK Forest Products K&D Lumber Company Luther Coby Mike Allen Enterprises St. Nick Forest Products Tenakee Logging Company Viking Lumber Company Western Gold Cedar Products	D & L Woodworks The Mill	Alaska Fibre Annette Island Sawmill Chilkoot Lumber Company Gateway Forest Products Ketchikan Renaissance Group Herring Bay Lumber Pacific Log and Lumber Metlakatla Forest Products Silver Bay Incorporated Kasaan Mountain Lumber and Log Thorne Bay Enterprises Porter Lumber Company Northern Star Cedar Thuja Plicata Lumber

LONGITUDINAL SURVEY RESULTS

To avoid disrupting the continuous time series of sawmill data collected since 2000, results are separated with subtotals for the original survey pool and small mills added in 2021. Total installed capacity includes the wood processing capacity of twelve active and two idle sawmills (N = 14). Capacity is estimated according to manufacturer specifications for the equipment installed in the mill observed during annual visits. For this report, capacity has been defined as the net sawlog volume that could be utilized by the sawmill, as currently configured, during a standard 250-day per year, two shifts per day annual operating schedule – and not limited by the availability of workforce, raw materials, or market conditions. Table 3 shows that total installed capacity in surveyed mills in 2023 was 135,556 MBF, a modest increase from 2022 because of firewood processing equipment added to Mike Allen Enterprises in 2023. Actual sawmill production during 2023 was approximately 16,465 MBF, a decrease of 545 MBF compared to 2022.

PREPARED BY: JEAN DANIELS PHD, REGIONAL ECONOMIST, PRISCILLA MORRIS PHD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



Sawmill capacity remained significantly underutilized in 2023; regional capacity utilization rate, based on an installed capacity of 135,556 MBF, is 13 percent. Sawmill employment fell from 77 full time equivalents (FTEs) in 2022 to 76 FTEs in 2023, including owners, operators, and other employees.

Table 3. Annual active sawmill survey results, calendar years 2000 – 2023 (Volume in MBF, Scribner Log Scale)

Year	Total Active Sawmills (#)	Installed Sawmill Capacity (MBF) ^a	Estimated Sawmill Production (MBF) ^b	Manufactured Product Volume not Included in Sawmill Production (MBF) ^{b,c}	Sawmill Capacity Utilization (%) ^d	Sawmill Employment (FTEs) ^b
2023	12	135,556	16,465	745	13	76
2022	12	135,500	17,010	691	13	77
2021	14	137,000	16,741	1,003	12	80
2019	4	125,400	15,210	500	12	50
2018	7	107,900	15,250	750	14	52
2017	8	113,650	15,544	550	14	51
2016	9	113,650	17,912	1,300	16	58
2015	9	113,650	18,540	145	16	51
2014	10	119,400	18,830	570	16	54
2013	10	120,400	17,593	920	15	60
2012	10	120,400	13,842	899	12	58
2011	10	160,000	11,546	1,295	7	56
2010	10	155,850	15,807	385	10	64
2009	11	249,350	13,422	1,250	5	58
2008	11	282,350	23,666	3,513	8	94
2007	14	292,350	31,717	4,015	11	158 ^e
2006	11	354,350	32,141	7,620	9	123
2005	12	359,850	34,695	0	10	136
2004	13	370,350	31,027	509	8	148
2003	13	369,850	32,005	763	9	155
2002	11	453,850	39,702	9,164	9	160
2000	19	501,850	87,117	46,079	17	321

^a Estimated from inspection of equipment on site; includes idle mills

^b Estimated from mill operator response to survey question

^c Primarily includes firewood and woodchips

^d Calculated value

^e Included 35 positions reported at the reopened Ketchikan Renaissance Group veneer mill, which only operated for a few months.

Note: The annual sawmill capacity and production survey was not conducted during 2001 and 2020.

SAWMILL OVERVIEW

Table 4 shows location and installed equipment, operation status, and employment for each mill. Past reports included a list of equipment in uninstalled mills, but we discontinued the practice in 2021. See the 2019 report for that information. Total employment in the original survey pool was 58 FTEs in 2023, a gain of 2 FTEs since 2022. Small sawmill employment declined by three for a total of 18 FTEs in 2023. Note that equipment in the Thorne Bay Wood Products (formerly Good Faith) was removed from the mill

PREPARED BY: JEAN DANIELS PhD, REGIONAL ECONOMIST, PRISCILLA MORRIS PhD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



list after adding its equipment to the JK Forest Products mill in 2023. In addition, the Mike Allen Enterprises added a firewood processor that was operating in 2023.

Table 4. Equipment, location, and employment in active and idle sawmills, CY2023 (Includes 12 active and 2 idle sawmills, N = 14)

Sawmill	Community	Description	Current Status	Sawmill FTEs
Original survey pool				
Icy Straits Lumber and Milling Company	Hoonah	Mighty Mite sawmill, horizontal band resaw, log debarker and merchandiser (not installed), dry kiln, planer, moulder	Active	2.5
Alaska Timber and Truss (formerly Peak Engineering)	Petersburg	Portable circle sawmill, trim saw, log deck	Active	6
St. Nick Forest Products	Craig	Portable circle sawmill	Active	1
Viking Lumber Company	Klawock	Conventional carriage, band saw headrig, linebar and gang resaws, edgers, trim saw, log debarker and merchandiser, end-dogging circle saw scragg. Added chipping head slabber to large mill in 2018.	Active	45
Western Gold Cedar Products	Thorne Bay	Shake and shingle mill, Meadows carriage mill, chain-fed scragg added in 2018	Active	3
D & L Woodworks	Hoonah	Portable circle sawmill	Idle	0
The Mill	Petersburg	Two portable circle sawmills	Idle	0
Subtotal				58
Small mills added in CY 2021				
Alaska Specialty Woods	Craig	3 Mighty Mite bandsaws, 2 head horizontal resaw, 2 planers	Active	3
Fair and Square Lumber	Coffman Cove	Portable circle sawmill	Active	2
JK Forest Products ^a	Thorne Bay	Bandsaw, resaw, portable circle sawmill, trim saw, log and lumber decks, dry kiln, planer, moulder	Active	3.5
K&D Lumber Company	Thorne Bay	Sawmill: auto log deck/turner, resaw; shake and shingle mill	Active	4
Luther Coby	Kake	Mighty Mite circle sawmill	Active	1
Mike Allen Enterprises	Wrangell	Mighty Mite circle sawmill; Cord King model 48 firewood processor	Active	2.5
Tenakee Logging Company	Tenakee Springs	Woodmizer portable band saw, Mobile dimension circle saw, Woodmaster planer shaper (electric)	Active	1.5
Subtotal				18

^a Includes equipment from the former idled Thorne Bay Wood Products (formerly Good Faith Lumber Company), which JK Forest Products purchased in 2022. Thorne Bay Wood Products (formerly Good Faith Lumber Company) has been removed from the mill survey pool.

CAPACITY AND PRODUCTION VOLUME

Table 5 shows that the largest sawmill, in terms of capacity, production, and employment, is the Viking Lumber Company. Viking again opted to not participate in this year's survey; we again moved forward with this report by assuming their operations were unchanged from 2021. Capacity in the 13 other active and idled mills combined (43,056 MBF) equals about half of the Viking mill (92,500), which contains 68 percent of total production capacity in the region. Capacity and production in the small mills added in 2021 were 15 and 6 percent of the regional total, respectively. Common challenges operators reported for 2023 included difficulty finding reliable workers, timber supply, and fuel costs, with several still reliant



on diesel powered generators to run milling equipment. Several mills were installing new and updating existing equipment in late 2022 and throughout 2023. The new equipment and updated equipment were not included in this year's report because they were not fully operating in 2023. These upgrades will be captured in next year's survey if they are reported as running during calendar year 2024.

Table 5. Estimated sawmill capacity, production, and utilization rate, CY2023 (Includes 12 active and 2 idle sawmills, N = 14)

Sawmill Name	Estimated Sawmill Capacity (Scribner Log Scale, MBF) ^a	Actual Sawmill Production (Scribner Log Scale, MBF) ^b	Sawmill Capacity Utilization (%)
Original survey pool			
Icy Straits Lumber and Milling Company	3,000	256	8.5
Alaska Timber and Truss (formerly Peak Engineering)	3,000	200	6.7
St. Nick Forest Products	1,000	120	12
Viking Lumber Company	92,500	14,400	15.6
Western Gold Cedar Products	11,500	500	4.35
D & L Woodworks	1,000	Idle	--
The Mill	2,500	Idle	--
Subtotal	114,500	15,476	13.5
Small mills added in CY 2021			
Alaska Specialty Woods	2,500	24	1.0
Fair and Square Lumber	1,000	115	11.5
JK Forest Products	7,250	300	4.1
K & D Lumber Company	3,000	150	5.0
Luther Coby	2,500	20	0.8
Mike Allen Enterprises	3,056	325	10.6
Tenakee Logging Company	1,750	55	3.1
Subtotal	21,056	989	4.7
Total	135,556	16,465	12.1%

^a Estimated Sawmill Capacity: An estimate of sawmill processing from installed equipment based on the amount of net sawlog volume (Scribner log scale) that could be utilized by the sawmill, as currently configured, during an industry standard 250-day per year, two shifts per day, annual operating schedule, and not limited by availability of workforce, raw materials, or market. Estimated from equipment installed in the mills.

^b Actual Sawmill Production: Net sawlog volume (Scribner log scale) used to manufacture sawn products. Estimated from survey responses.

WOOD SUPPLY SOURCE

Table 6a and 6b show the source of wood received by Southeast Alaska sawmills in 2023. Like last year, the majority wood originated from lands managed by the State of Alaska (70 percent), followed by the Tongass National Forest (23 percent). A modest amount of material originated from Native lands (assuming the Viking Lumber Company obtained similar volume from Native lands in 2023 as in 2021)

PREPARED BY: JEAN DANIELS PhD, REGIONAL ECONOMIST, PRISCILLA MORRIS PhD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



and private timber sources, mostly from right-of-way and private lot clearing for development. Volume reported in Table 6b was about one quarter wood chips for biomass heat and three quarters firewood.

Table 6a. Actual sawmill production by log source, CY2023 (Scribner Log Scale, MBF, N = 12 active sawmills)

Sawmill	National Forest	Other Federal	State of Alaska	Private Native	Private Other	Import	Total
Original survey pool							
Icy Straits Lumber and Milling Company	256	0	0	0	0	0	256
Alaska Timber and Truss (formerly Peak Engineering)	132	0	0	0	68	0	200
St. Nick Forest Products	0	0	0	0	120	0	120
Viking Lumber Company	2,160	0	11,520	720	0	0	14,400
Western Gold Cedar Products	475	0	25	0	0	0	500
Subtotal	3,023	0	11,545	720	188	0	15,476
Small mills added in CY 2021							
Alaska Specialty Woods	12	0	12	0	0	0	24
Fair and Square Lumber	104	0	0	0	12	0	115
JK Forest Products	300	0	0	0	0	0	300
K & D Lumber Company	0	0	0	0	150	0	150
Luther Coby	20	0	0	0	0	0	20
Mike Allen Enterprises	325	0	0	0	0	0	320
Tenakee Logging Company	55	0	0	0	0	0	55
Subtotal	816	0	12	0	162	0	990
Total	3,839	0	11,557	720	350	0	16,465
Percent	23.3	0	70.2	4.4	2.1	0	100

Table 6b. Processed log sources, volume not included^a in actual sawmill production (Scribner Log Scale, MBF)

Sawmill	National Forest	Other Federal	State of Alaska	Private Native	Private Other	Import	Total
Total	395	0	350	0	0	0	745
Percent	53.0	0	47.0	0	0	0	100

^a Primary manufactured products NOT included in actual sawmill production consists of all non-sawn products (e.g., chips, firewood, poles, house logs) that are manufactured independently of normal sawmill operations – products from logs that do not go through the sawmill. Non-sawn products that result from processing sawmill residues and byproducts are not included in this category.

PRODUCTION VOLUME BY SPECIES

Table 7a and 7b show the species of wood processed in Southeast Alaska sawmills in 2023. Western hemlock led with 48 percent of total production. Western redcedar products represent 35 percent of the total followed by Sitka spruce at 16 percent and Alaska yellow cedar at 0.7 percent. Most of the volume not included in actual sawmill production (Table 7b) consisted of western hemlock used for firewood.

PREPARED BY: JEAN DANIELS PHD, REGIONAL ECONOMIST, PRISCILLA MORRIS PHD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



Table 7a. Actual sawmill production by species, CY2023 (Scribner Log Scale, MBF, active mills N = 12)

Sawmill	Sitka Spruce	Western Hemlock	Western Redcedar	Alaska Yellow Cedar	Other	Total
Original survey pool						
Icy Straits Lumber and Milling Company	115	115	0	26	0	256
Alaska Timber and Truss (formerly Peak Engineering)	120	60	0	20	0	200
St. Nick Forest Products	6	24	78	12	0	120
Viking Lumber Company	2,160	7,200	5,040	0	0	14,400
Western Gold Cedar Products	25	25	450	0	0	500
Subtotal	2,426	7,424	5,568	58	0	15,476
Small mills added in CY 2021						
Alaska Specialty Woods	23	0	1	0	0	24
Fair and Square Lumber	92	23	0	0	0	115
JK Forest Products	60	135	105	0	0	300
K & D Lumber Company	0	120	30	0	0	150
Luther Coby	19	1	0	0	0	20
Mike Allen Enterprises	50	150	100	25	0	325
Tenakee Logging Company	28	0	0	27	0	55
Subtotal	271	429	236	53	0	989
Total	2,697	7,853	5,804	111	0	16,465
Percent	16.4	47.7	35.3	0.7	0	100.0

Table 7b. Primary product by species, volume not included^a in actual sawmill production (Scribner Log Scale, MBF)

Sawmill	Sitka Spruce	Western Hemlock	Western Redcedar	Alaska Yellow Cedar	Other	Total
Total	89	618	15	19	5	745
Percent	11.9	82.9	2.0	2.6	1	100

^a Primary manufactured products NOT included in actual sawmill production consists of all non-sawn products (e.g., chips, firewood, poles, house logs) that are manufactured independently of normal sawmill operations – products from logs that do not go through the sawmill. Non-sawn products that result from processing sawmill residues and byproducts are not included in this category.

PRODUCTION VOLUME BY PRODUCT

Table 8 shows the majority of wood received by Southeast Alaska sawmills in 2023 was processed into dimension lumber, shop lumber, and cants and timbers. Higher grade products like shop lumber, cants and timbers, and niche products generally command a price premium. Dimension lumber is a commodity product for structural use that is highly price competitive. Southeast Alaska sawmills compete with both domestic and international suppliers to make inroads in these markets. The “Other” category contains information about niche production, primarily shingles, shakes, and music wood. Western Gold Cedar Products and K & D Lumber, which both produce lumber and shingles, reported 450 and 54 MBF of shingle production, respectively. All of Alaska Specialty Woods production (24 MBF) was music wood.

PREPARED BY: JEAN DANIELS PhD, REGIONAL ECONOMIST, PRISCILLA MORRIS PhD, NATURAL RESOURCES SPECIALIST, DAN O’LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



Table 8. Actual sawmill production volume by product, CY2023 (Scribner Log Scale, MBF, active mills N = 12)

Sawmill	Dimension Lumber	Shop Lumber	Cants Timbers	Other	Total
Original survey pool					
Icy Straits Lumber and Milling Company	113	66	78	0	256
Alaska Timber and Truss (formerly Peak Engineering)	90	42	68	0	200
St. Nick Forest Products	18	90	12	0	120
Viking Lumber Company	3,276	6,300	4,824	0	14,400
Western Gold Cedar Products	50	0	0	450	500
Subtotal	3,547	6,498	4,982	450	15,476
Small mills added in CY 2021					
Alaska Specialty Woods	0	0	0	24	24
Fair and Square Lumber	115	0	0	0	115
JK Forest Products	84	216	0	0	300
K & D Lumber Company	96	0	0	54	150
Luther Coby	19	1	0	0	20
Mike Allen Enterprises	280	0	45	0	325
Tenakee Logging Company	45	3	6	0	55
Subtotal	639	220	51	78	989
Total	4,186	6,718	5,033	528	16,465
Percent	25.4	40.8	30.6	3.2	100

YOUNG GROWTH TIMBER UTILIZATION

Mill operators were asked to estimate how much young growth timber they milled as a percent of total production. Because there is considerable interest in quantifying the extent that young growth timber is being milled by regional sawmills, this question was added to the survey instrument in 2021. Table 9 shows that overall young growth utilization increased to three percent in 2023, up one percent from the previous year. Small mill young growth utilization averaged 18 percent, down from 22 percent in 2022 while the original mills' average rose modestly from 1.8 to 2 percent. Discussions with operators revealed that several had no desire to purchase young growth, but several others would purchase more if it was offered because logs were more uniform in size, had less defect than old growth, and met customer needs for rough cut dimension lumber. Several mills surveyed continue to incrementally retool for a young growth industry and invest in firewood processing capacity for community wood heating. Three grants awarded by the Forest Service in 2023 brought almost \$775,000 into Southeast Alaska to fund a one-pass log sawmill in Petersburg, a community firewood distribution program in Klawock, and a wood fired boiler to heat kilns at a sawmill in Thorne Bay.



Table 9. Sawmill young growth timber utilization, CY2023 (Scribner Log Scale, MBF, active mills N = 12)

Sawmill [1]	Actual Sawmill Production (Scribner Log Scale, MBF) ^b	Young growth volume (MBF)	Young growth percent of total sawmill production (%)	Young growth percent of total sawmill production (%) previous year
Original survey pool				
Icy Straits Lumber and Milling Company	256	0	0	0
Alaska Timber and Truss (formerly Peak Engineering)	200	150	75	95
St. Nick Forest Products	120	12	10	10
Viking Lumber Company	14,400	144	1	1
Western Gold Cedar Products	500	0	0	0
Subtotal	15,476	306	2.0	1.8
Small mills added in CY 2021				
Alaska Specialty Woods	24	0	0	0
Fair and Square Lumber	115	115	100	100
JK Forest Products	300	38	13	15
K & D Lumber Company	150	0	0	0
Luther Coby	20	0	0	0
Mike Allen Enterprises	325	0	0	0
Tenakee Logging Company	55	28	50	80
Subtotal	989	180	18.2	22.0
Total	16,465	486		
Average	1,372	41	3	3.7
Minimum	20	0	0	0
Maximum	14,400	150	100	100

MARKETS

Tables 10a and 10b contain information about markets served by Southeast Alaska sawmills. In 2021, market categories were revised in two ways: 1) the Continental U.S. destination category was divided into U.S. Pacific Northwest and U.S. Other and 2) the Other category was changed to International Other. The majority (79 percent) of processed material was sent to destinations in the Lower 48 states, primarily the Pacific Northwest. Markets in Pacific Rim nations and within Alaska both received about 8 percent of total sawmill production. Production from the original survey pool went primarily to Lower 48 destinations. Small mill production mostly stayed within Alaska except for music wood from Alaska Specialty Woods, which had the most diverse set of markets of all surveyed mills. Most volume (93 percent) not included in actual production was utilized within Alaska.



Table 10a. Actual sawmill production by product destination (market), CY2023 (Scribner Log Scale, MBF, active mills N = 12)

Sawmill	Alaska	U.S. Pacific Northwest ^a	U.S. Other	Canada	International Pacific Rim ^b	International Other	Total
Original survey pool							
Icy Straits Lumber and Milling Company	256	0	0	0	0	0	256
Alaska Timber and Truss (formerly Peak Engineering)	200	0	0	0	0	0	200
St. Nick Forest Products	120	0	0	0	0	0	120
Viking Lumber Company	144	7,200	5,040	0	1,440	576	14,400
Western Gold Cedar Products	50	450	0	0	0	0	500
Subtotal	770	7,680	5,040	0	1,440	576	15,476
Small mills added in CY 2021							
Alaska Specialty Woods	0.2	5.6	11.2	1.2	2.9	2.9	24
Fair and Square Lumber	115	0	0	0	0	0	115
JK Forest Products	300	0	0	0	0	0	300
K & D Lumber Company	135	0	0	0	0	15	150
Luther Coby	20	0	0	0	0	0	20
Mike Allen Enterprises	32.5	292.5	0	0	0	0	325
Tenakee Logging Company	55	0	0	0	0	0	55
Subtotal	658	298	11	1	3	18	989
Total	1,428	7,948	5,051	1	1,443	594	16,465
Percent	8.7	48.3	30.7	0.01	8.8	3.6	100

^a Pacific Northwest is defined as the states of Oregon and Washington.

^b Pacific Rim is the combined nations of China, Japan, and South Korea.

Table 10b. Product destination, volume not included ^a in actual sawmill production, CY2022 (Scribner Log Scale, MBF)

Sawmill	Alaska	U.S. Pacific Northwest	U.S. Other	Canada	International Pacific Rim	International Other	Total
Total	695	50	0	0	0	0	745
Percent	93	7	0	0	0	0	100

^a Primary manufactured products NOT included in actual sawmill production consists of all non-sawn products (e.g., chips, firewood, poles, house logs) that are manufactured independently of normal sawmill operations – products from logs that do not go through the sawmill. Non-sawn products, including chips and firewood, that result from processing sawmill residues and byproducts are not included in this category.

TIMBER SALE SIZE AND FOREST SERVICE VOLUME UNDER CONTRACT

Survey respondents were asked what size of timber sale, in terms of volume, would be ideal to meet the raw material needs of their mill. This information is compared against end of year reported Tongass timber volume under contract for each sawmill. Table 12 shows the preferred timber sale size, number of existing sales, and volume under contract in 2023. Preferred timber sale size for mills participating in the survey varied from 50 MBF to 10 MMBF and averaged 1,915 MBF. Survey respondents purchased 38 of the 56 total sales under contract, averaging three sales per sawmill. Volume remaining under contract for surveyed mills at the end of 2023 was 15.6 MMBF, down 0.26 MMBF from 2022. Although survey

PREPARED BY: JEAN DANIELS PhD, REGIONAL ECONOMIST, PRISCILLA MORRIS PhD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



respondent's proportion of volume under contract rose from 48.2 percent in 2022 to 65.9 percent in 2023, the total remaining volume under contract fell from 32.8 to 23.7 MMBF (-9 MMBF).

Table 12. 2023 Preferred timber sale size and Tongass timber volume under contract at the end of calendar year 2023
(Scribner log scale, MBF, includes two idle mills with volume under contract and all active mills N = 14)

Sawmill	Preferred timber sale size (MBF) ^a	Number of USFS sales under contract	Total sale volume awarded (MBF) ^b	Total remaining volume under contract (MBF)
Original survey pool				
Icy Straits Lumber and Milling Company	200	3	502.5	502.5
Alaska Timber and Truss (formerly Peak Engineering)	4,000	7	375.3	340.0
St. Nick Forest Products	n/a	0	0	0
Viking Lumber Company ^c	10,000	4	128,973.3	3,333.2
Western Gold Cedar Products	2,000	5	5,203.5	3,883.2
D & L Woodworks	idle	1	161.2	161.2
The Mill	idle	1	599.2	599.2
Subtotal	16,200	21	135,815.1	8,819.3
Small mills added in CY 2021				
Alaska Specialty Woods	50	0	0	0
Fair and Square Lumber	120	0	0	0
JK Forest Products	200	5	1,031.3	750.9
K & D Lumber Company	300	1	158.00	36.0
Luther Coby	100	3	85.4	51.6
Mike Allen Enterprises	4,000	4	12,516.8	5,846.4
Tenakee Logging Company	100	4	171.8	88.4
Subtotal	4,870	17	13,963.3	6,773.2
Respondents Total	21,070	38	149,778.4	15,592.5
All sale average	1,915	3	10,698.5	1,113.7
All other Tongass sale purchasers ^d	n/a	18	70,126.0	8,075.7
Grand Total	n/a	56	219,904.4	23,668.2

^a Respondents answers to survey question: "what is your preferred timber sale size in terms of volume in MBF?". When respondents provided a range, we used the average.

^b Total sale volume awarded is the full contracted volume initially awarded after the sale bidding process.

^c In 2014 Viking Lumber Company was awarded 97,717 MBF under the Big Thorne Stewardship Contract. Three MBF remains under contract as of December 2023.

^d Predominantly Good Neighbor Authority sales administered by the State of Alaska and a Stewardship sale purchased by Alcan Forest Products, a log exporter.

LOG EXPORTS

Information about log exports from the Tongass National Forest was added to this report in 2021. The Tongass National Forest is unique because its Limited Export Policy makes it the only national forest west

PREPARED BY: JEAN DANIELS PHD, REGIONAL ECONOMIST, PRISCILLA MORRIS PHD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025



of the 100th meridian of the United States authorized to export unprocessed logs to international destinations. Shipments of unprocessed timber from Alaska to destinations in the Lower 48 is also considered export. Although log exports are not a sawn product and thus are not part of mill operations per se, log exports represent another market available to purchasers of timber throughout the region. Tongass timber purchasers can process timber into forest products, buy and sell logs among each other, or divert wood into log export markets to respond to economic conditions and fluctuating product prices. One could infer that because exported logs are not available to local sawmills, they do not support forest industry jobs in the region. However, logging, trucking, and forestry support industries are still supported, and industries associated with water transportation typically see more activity. Exports of logs originating from the Tongass National Forest represent a subset of total log exports in the region; timber harvested from state, Native, and other private lands are also exported as logs. Discussion here is limited to log export and timber harvest from federal lands managed by the Tongass National Forest.

Figure 1 shows the proportion of Tongass harvest volume exported as logs to international and Lower 48 destinations by **calendar year**. Cut timber volume (sawtimber only) data were downloaded from the Timber Information Manager database and organized into calendar years. Tongass log exports and interstate shipments reports are posted annually on the [Alaska Region Forest Management Reports and Accomplishments website](#). Figure 1 shows between 2013-2023, harvested volume peaked in 2016 then fell almost 60 percent in 2017 to average near 15 MMBF per year until 2022, when it hit a 10-year low of 3.3 MMBF and the volume of logs exported from the Tongass (4.1 MMBF) exceeded harvest for the first time since the survey's inception in 2000. In 2023, log exports again exceeded harvest, but by a more modest amount (354 MBF vs. 841 MBF in 2022). This result is explained by the sizeable volume of young growth timber exported as logs from Good Neighbor Authority sales administered by the State of Alaska, which outpaced Tongass volume available for domestic processing. In addition, sale volume harvested in 2022 could have been exported in 2023. The Tongass is not the only source of timber supply; the majority of wood sawn by survey respondents has originated from State of Alaska managed lands since CY2021.

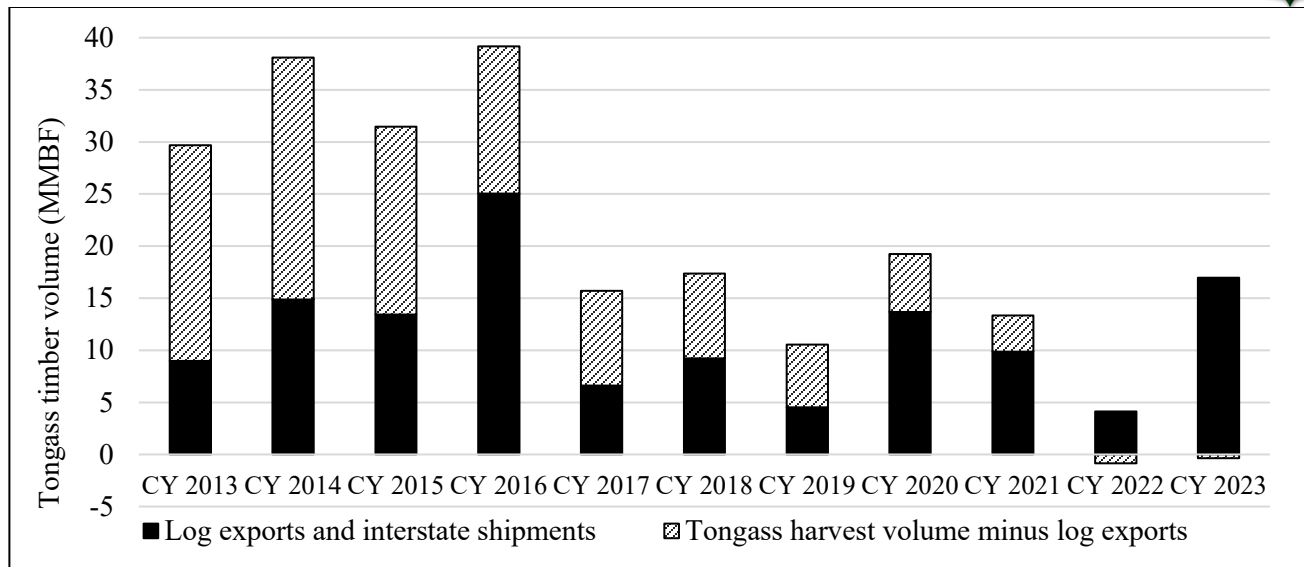


Figure 1. Tongass log exports and timber harvest volume by calendar year

CONCLUSION

Typical of every year, Tongass sawmills remain significantly underutilized. Although the Viking Lumber Company declined to provide information about their 2023 operations and we selected to use their information from 2021, results are predictably skewed by the Viking Lumber Company as the largest operator in the region. Surveyed sawmill employment declined from 77 full time equivalents (FTEs) in 2022 to 75 FTEs in 2023. Of the log volume received by surveyed mills in 2023, 70 percent originated from lands managed by the State of Alaska, followed by the Tongass (23 percent). Utilization of young growth logs varied widely among surveyed mills, ranging from 0 to 100 percent but overall comprising 3.0 percent of total production, down from 3.7 percent in 2022. Preferred timber sale size ranged from 50 MBF to 10,000 MBF with an average of 1.9 MMBF. However, the average total volume remaining under Forest Service contract per surveyed mill was 1.1 MMBF, or 58 percent of the average preferred timber sale size. Because a sawmill typically needs two or more open timber sale contracts to sustain operations, this suggests a considerable gap in Forest Service volume under contract for the region's operating sawmills. For the second year in a row, the volume of logs exported exceeded volume of timber harvested on the Tongass, even though harvest was up by 13.3 MMBF from the historic low in CY 2022. This trend is largely due to increased harvest of young growth from the Tongass National Forest, which comprised only 3 percent of total volume milled by survey respondents. The majority of young growth was exported in 2023, suggesting few accessible markets for young growth timber processed in Alaska. We observed mills continuing to be awarded grants to invest in young growth milling equipment and upgrades and wood energy infrastructure and look forward to evaluating impacts on regional production and employment next year.

For more information, contact Jean M. Daniels, Ph.D, Alaska Region Economist at jean.daniels@usda.gov

PREPARED BY: JEAN DANIELS PHD, REGIONAL ECONOMIST, PRISCILLA MORRIS PHD, NATURAL RESOURCES SPECIALIST, DAN O'LEARY, FOREST PRODUCTS PROGRAM LEAD.

USDA FOREST SERVICE, ALASKA REGION (REGION 10)

JANUARY 2025

Habitat Relations

Longevity and Reuse of Black Bear Dens in Managed Forests of Coastal British Columbia

HELEN DAVIS,¹ *Artemis Wildlife Consultants, 4515 Hullcar Road, Armstrong, BC, Canada V0E 1B4*

ANTHONY N. HAMILTON, *Ministry of Environment, P.O. Box 9338, STN PROV GOVT, Victoria, BC, Canada V8W 9M1*

ALTON S. HARESTAD, *Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada V5A 1S6*

RICHARD D. WEIR, *Artemis Wildlife Consultants, 4515 Hullcar Road, Armstrong, BC, Canada V0E 1B4*

ABSTRACT We evaluated longevity and reuse of denning structures by American black bears (*Ursus americanus*) in coastal temperate rainforests of British Columbia from 1992 to 2010 to assess potential impacts of forest management on these critical habitat features over time. We identified 67 dens during a 4-yr intensive radio-telemetry study (1992–1995): 40 dens of 21 radio-collared black bears and 27 dens found incidentally. Dens occurred in or beneath large diameter trees or wooden structures derived from trees (i.e., logs, root boles, and stumps; $\bar{x}$ = 143 cm diameter, SD = 49 cm). Longevity of dens varied by type, tree species that formed the den, and forest management that occurred at or near the den. Twenty-four of 28 dens of radio-collared bears that were monitored were still usable in 2010, whereas only 5 of 14 dens found incidentally were still usable in 2010. We assessed reuse of bear dens 3 times following initial identification: during the radio-telemetry study, again in 2000, and finally in 2010. Radio-collared bears reused dens from previous years on 7 of 25 potential occasions during the course of the radio-telemetry study. Upon assessment in 2000 and 2010, 17 of 24 (71%) available dens first used by radio-collared bears were reused at least once between 1993 and 2010. The high rate of reuse may indicate low availability of den structures in our study area. Because black bears in coastal British Columbia only used trees or structures derived from trees for winter dens and forest harvesting reduces the supply of these necessary structures, conservation and recruitment of suitable den trees is necessary if maintaining black bear populations is a management goal in these areas. © 2011 The Wildlife Society.

KEY WORDS American black bear, British Columbia, dens, forest management, reuse, *Ursus americanus*.

American black bears (*Ursus americanus*) hibernate to survive periods of low food availability and low temperatures by accumulating body fat, entering a period of dormancy in which metabolic expenditures are lowered, and drawing on these stored energy reserves. Consequently, winter hibernation is a vital aspect of the life history of bears and selection of winter den sites is important because dens meet several life requisites during the over-wintering period. Specifically, dens must confer thermal benefits, protect bears from inclement weather, and provide security from disturbance and predation (Johnson and Pelton 1981).

A wide range in frequency of reuse of winter dens by black bears has been reported. In various studies, reuse has ranged from nonexistent (Tietje and Ruff 1980, Kolenosky and Strathearn 1987), to low (15%; Crook and Chamberlain 2010) to high (47–71%; Schwartz et al. 1987). Lindzey and Meslow (1976) found that at least 6 of 12 dens of black bears were reused in an area of Washington with extensive forest harvesting.

Bears may occasionally use previously occupied dens for a variety of reasons. In areas with few denning opportunities, bears have few sites from which to select and therefore may reuse dens frequently. Many researchers have concluded that the rate of reuse may be linked to the supply of potential den sites. Several researchers have suggested that high rates of reuse may indicate low availability of suitable den sites (Johnson 1978, Beecham et al. 1983, LeCount 1983, Alt and Gruttadauria 1984). Alternatively, bears may reuse dens from year-to-year because a site was successfully used during 1 over-wintering period, so use continues in subsequent periods.

In coastal temperate rainforests of western North America, black bears hibernate through cool, wet winters that present denning animals with considerable environmental challenges that limit the range of structures suitable for denning. The combination of persistent rainfall, lack of permanent snow cover, and cool temperatures affects the types of structures that provide shelter from these abiotic factors. Because black bears in coastal British Columbia rely heavily upon large diameter trees or wooden structures derived from trees (i.e., logs, root boles, and stumps; Noble et al. 1990, Davis 1996), the broad-scale harvest of late-successional forests may diminish the supply of dens for black bears. Our objectives were

Received: 29 March 2011; Accepted: 22 July 2011;
Published: 18 October 2011

¹E-mail: hdavis@artemiswildlife.com

to 1) report reuse of black bear dens to determine whether special management actions were necessary to preserve an adequate supply of dens for coastal black bear populations, and 2) investigate the efficacy of past management actions at retaining existing dens.

STUDY AREA

Our 20,000-ha study area was located in the Nimpkish Valley (50° 14', 126° 52'), 40 km south of Port McNeill on northern Vancouver Island, British Columbia, Canada. The study area was comprised of the Coastal Western Hemlock and Mountain Hemlock biogeoclimatic zones (Nuszdorfer 1991), with elevations ranging from 20 m to >1,500 m. Average annual precipitation was 1,780 mm, with 4–5% of that falling as snow. Dominant species of coniferous trees included Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), mountain hemlock (*T. mertensiana*), western redcedar (*Thuja plicata*), yellow-cedar (*Chamaecyparis nootkatensis*), Pacific silver fir (*Abies amabilis*), and Sitka spruce (*Picea sitchensis*). Deciduous tree species were rare except in riparian zones.

Our study area had a long history of commercial forest harvesting typical of coastal temperate rainforests in British Columbia. Forests in the area had been harvested by clear-cutting since the 1920s and most clearcuts regenerated to conifer-dominated, structurally and floristically depauperate, second-growth stands with closed canopies. Approximately 45% of the forests in the study area were exposed to disturbance (primarily forest harvesting) between 1923 and 1995 (Green 2000). Most harvesting occurred in old-growth forests but harvesting of second-growth forests began in the 2000s. When forest harvesting began in the valley, tall stumps and large pieces of coarse woody debris were left in clearcuts because of lower utilization standards than present day.

METHODS

We identified winter dens of black bears using 2 methods. Between 1992 and 1995, we followed radio-collared black bears to their dens (Davis 1996). We also found other dens incidentally while collecting field data and forestry crews found dens while surveying proposed cutblocks during both denning and non-denning seasons. We initially radio-collared bears in 1992, so dens for each individual were first identified during the winter of 1992–1993. Thus, the first opportunity to observe reuse occurred during the winter of 1993–1994. For each den, we recorded den type, species and diameter of tree used, the amount and species of vegetation used as bedding material inside the den, and searched the immediate area for fecal plugs (Hamilton and Marchinton 1980). We photographed dens and den bedding to allow for comparisons among years.

We used several methods to assess reuse of known dens by black bears. During visits to dens of radio-collared bears in the spring, we noted that recently used dens contained green vegetation that the bears carried into the den for bedding. We used this obvious sign as the primary criteria to evaluate recent reuse in subsequent visits. We also considered reuse to

have occurred if additional bedding had been added or modifications were made since we last visited the den. Furthermore, we looked for recent fecal plugs near the den and the presence of spider-webs and fungus growing within cavities to determine whether use was recent or not. Our estimates of reuse may be conservative because we were probably only able to conclusively detect reuse during the previous 2–3 yr.

We monitored each den structure for reuse by black bears during 3 periods. During 1993–1995, we tracked radio-collared bears to dens. Radio-collared bears were monitored for up to 3 consecutive winters, which allowed us to estimate an intensive, annual rate of reuse of dens by these bears. We then assessed a sample of known dens again in 2000 and in 2010. The same observer visited the dens during each assessment period to reduce observer bias. These subsequent visits allowed us to assess whether dens were reused at least once during the intervening period. We were unable to revisit all dens because of closed roads and funding constraints; we did not continue to assess dens that were decayed or destroyed.

We also examined the efficacy of several forest management prescriptions for conserving den structures. With the cooperation of forest managers, several dens identified during our radiotelemetry study were retained in or around proposed forest harvest units. Dens in hollow trees were retained as single trees within clearcuts, within retention patches in clearcuts, or on edges of clearcuts through boundary modifications. Some dens in logs were also retained in clearcuts. Prescriptions were typically applied in old-growth and second-growth stands that were scheduled for clearcut harvesting. We visited these dens to determine if they were still usable (i.e., structurally intact) in 2000 and 2010.

RESULTS

We identified 40 unique dens of 21 radio-collared black bears and incidentally located 27 dens of unmarked black bears during the 3 winters of 1992–1993, 1993–1994, and 1994–1995. Black bears used dens in or beneath large diameter trees or wooden structures derived from trees (i.e., logs, root boles, and stumps; $\bar{x}$ = 143 cm diameter, SD = 49 cm). We categorized dens found between 1992 and 1995 into 5 types (Davis 1996): in live or dead hollow trees (n = 37, 55%), under the root masses of overturned trees (root bole, n = 15, 22%), in the base of high-cut tree stumps (n = 8, 12%), inside or under large logs (n = 4, 6%) or amongst the roots of standing live trees (n = 3, 4%).

During the radio-telemetry monitoring period, we had the potential to observe 25 incidents of reuse (i.e., the bear was monitored during a denning period subsequent to its first-detected den period). Radio-collared black bears reused dens on 7 occasions (28%). The proportions of reuse during the radio-telemetry study were not noticeably different between male and female bears (4 cases of reuse by 3 males, 3 cases of reuse by 3 females). Five bears used the same den twice (2 males, 3 females) and 1 adult male used the same den for 3 consecutive winters. We did not observe any radio-collared

bears reusing dens of other radio-collared bears during our radio-telemetry monitoring period.

We revisited known dens during 2000 and 2010 to verify whether they were still intact and useable and to evaluate reuse by black bears since initial den identification in the 1990s (Table 1). We assessed 28 dens of radio-collared bears during the 2 visits, 22 of which we visited in both 2000 and 2010. Additionally, we assessed 14 incidentally found dens in 2000 and 2010; we visited 8 in both years, whereas 6 were only visited once. Many dens showed conspicuous signs of reuse, with obvious recent, green bedding and several had clearly been reused the previous winter. In other cases, although reuse had occurred since the previous assessment, it was not possible to determine the year in which the den had been reused. Use of den sites among years was not limited to a single bear; we documented dens being used after the known occupant had perished.

Most dens of radio-collared bears and incidentally located dens were reused at some time between 1993 and 2010, with 17 of 24 (71%) dens of radio-collared bears reused during this period (Table 1). Similarly, 3 of 5 incidentally located dens were reused between 1993 and 2010; only 5 of 14 incidentally located dens were available for reuse by 2010 because 9 dens had either decayed, been cut down during forest harvesting, or had blown down after being retained during forest harvesting.

Longevity of den structures used by radio-collared bears varied by den type and tree species (Table 1). Of the 9 root bole structures that were used as dens between 1992 and 1995, 6 remained after 18 yr. Three were decayed or destroyed in second-growth harvesting, and thus no longer available for bears. However, only 3 of the 9 root bole dens were still well-suited for bear dens as of 2010; 3 were judged to be of low quality due to decay since use was first documented. In contrast, all 12 dens in hollow western redcedar and yellow-cedar trees, and 3 dens in stumps (2 Sitka spruce and 1 western hemlock) showed no significant signs of decay that made them unusable. Dens in standing trees remained usable through the entire assessment period, unless they were

cut down during forest harvesting operations or blew down after retention as single trees. Of the 19 dens in or under standing trees, 5 were still usable as dens in old-growth forests as of 2010, 7 were retained by modifying forest harvest plans, 1 was felled and 6 could not be visited because of remoteness but were not known to be within harvested areas.

Dens that occurred in second-growth forests showed considerable decline in suitability over the assessment period (Table 1). Only 7 of 14 dens (50%) of radio-collared bears that occurred in second-growth forests in 1995 were fully intact and useable in 2010. Of the other 7, 4 were of much decreased quality (i.e., decay had increased the entrance size) but could possibly still be suitable, 2 were too decayed for use, and 1 was destroyed during second-growth harvesting.

The frequency of reuse varied considerably among different types of den structures used by radio-collared bears (Table 1). All 3 dens in large high-cut stumps showed evidence of recent reuse in 2000 and 2010. We assessed 3 log dens in 2000, all of which had recently been reused; however, by 2010, 1 den under a Douglas-fir log had decayed considerably and was marginally useable. Eight of 12 hollow tree dens were reused at some time between 1993 and 2010. However, we observed considerably less reuse of root bole dens: 3 of 9 root bole dens had been reused (3 were too decayed for use). We were unable to assess reuse of any dens located under trees because of their remote locations.

Reuse of dens by radio-collared bears also varied by disturbance history of the stand in which they occurred. Although reuse was high across the landscape, reuse was greater in second-growth stands (9 of 11 dens reused, 82%) than in old growth stands (8 of 13 dens reused, 62%). Four of the 8 reused dens that were within old growth forests when first used continued to be used after they were retained within clearcuts.

We investigated the efficacy of forest management prescriptions to conserve 15 dens between 1993 and 2010. One den that was found incidentally was not suitable for retention as a standing tree because of safety concerns, it was cut so that a stump approximately 2 m in height remained. This den had

Table 1. Number of dens suitable for reuse and frequency of den reuse by American black bears in the Nimpkish Valley, British Columbia, Canada between 1993 and 2010. Not all dens that were identified could be assessed for reuse during each assessment period.

Den type	No. revisited	Old-growth dens			Second-growth dens				Total available for reuse	Reused ≥ 1 time
		Intact in old-growth	Retained in harvested areas ^a	Cut down in old-growth harvesting	Intact in second-growth	Of decreased quality	Decayed, not reuseable	Destroyed during second-growth harvesting		
Dens of radio-collared bears										
Hollow tree	13	6	6	1					12	8
Log	3				2	1			3	3
Root bole	9	1			2	3	2	1	6	3
Stump	3				3				3	3
Total	28	7	6	1	7	4	2	1	24	17
Incidentally located dens										
Hollow tree	12	2	6 ^b	4					5	3
Log	1		1							
Root bole	1						1			
Total	14	2	7	4			1		5	3

^a Retained as a single tree, retention patch, or on edge of clearcut.

^b Three trees blew down of the 6 retained.

not been reused when checked in 2000 and 2010. One den in a Douglas-fir log was retained in a clearcut but it was subsequently destroyed by a bear foraging for insects. A den in a hollow tree used by a male radio-collared bear was preserved through boundary modifications so that the den remained 30 m inside contiguous old-growth forest. A road was constructed approximately 50 m below the den the summer after we first documented use of the den; despite this, the bear reused the den for a second winter. Prior to the third winter of consecutive use, a clearcut was harvested 30 m away. The den was reused again between 1995 and 2000. Six dens in hollow trees were left as single trees within clearcuts; 2 of these had blown down by 2010. Five dens in hollow trees were retained as wildlife tree patches; none of these dens had blown down by 2010, although 1 was only checked in 2000 and could not be surveyed in 2010. One hollow tree den left on the boundary of a cutblock had also blown down by 2000. This den, and 1 other den in a hollow tree within the cutblock that also blew down, may be suitable for use by bears in the future as log dens.

DISCUSSION

Black bears in coastal environments prefer hollow trees for denning, likely for the thermal and security benefits that these structures confer relative to other structures (Johnson et al. 1978, Noble et al. 1990, Davis 1996), but large hollow trees are generally removed during forest harvesting operations. Hence, denning opportunities are likely substantially lesser in areas with extensive forest harvesting compared to less disturbed landscapes (Johnson and Pelton 1981). Depending on the forest utilization standards, few suitable structures (e.g., logs and high stumps) remain after forest harvesting, and these are likely much rarer in managed forests than hollow trees in old-growth forests. Thus, in second-growth forests, bears likely have a narrower range of structures in which to den and this may be reflected in a high rate of reuse of the few remaining structures.

The different types of structures used by bears for denning appeared to have different longevity rates, which likely further affected the rate of den reuse that we observed. Den structures can only be reused if they remain structurally sound. For example, dens excavated into the ground and brush piles may only last 1 or 2 yr before collapsing, whereas rock cavities may persist for many years (Alt and Gruttaduria 1984, Beck 1991). Longevity of tree dens in our study depended upon tree species and the type of den structure. Dens comprised of western redcedar may persist for hundreds of years because of this species' relatively high resistance to decay (Minore 1983). Living hollow trees appeared to have the highest longevity rate of den structures that we observed, and thus are the most likely to be available for longer durations than other structures. However, large old trees are also those most likely to be removed during forest harvesting. Because of their growth and decay characteristics, dens in hollow cedar trees may be very important structural legacies that should be protected during harvesting of future forest rotations.

In the temperate rainforests of coastal British Columbia, we found considerable reuse of den structures by black bears among years by the same bear and even among bears. The frequency of repeated use of dens during the telemetry study (28%; Davis 1996) was relatively high compared to that reported in several studies (e.g., 4.8%, Pennsylvania, Alt and Gruttaduria 1984; 15%, Louisiana, Crook and Chamberlain 2010) but not others. Over our longer period of monitoring, the high rate of 71% reuse of dens over the >15 yr was greater than that found in other studies in coastal temperate forests with extensive forest harvesting (e.g., ≥50%, coastal Washington, Lindzey and Meslow 1976), although their monitoring period was shorter.

Black bears may not reuse dens every year for a number of reasons. First, dens may not be reused because predators, such as other bears (Alt and Gruttaduria 1984, Davis and Harestad 1996) or wolves (*Canis lupus*; Horejsi et al. 1984), may repeatedly check low-security dens for occupants. In fact, 1 of only 2 dens not reused in second-growth forests was a root bole den at which a female and cubs were killed by another bear (Davis and Harestad 1996). Second, repeated use may increase the load of ectoparasites in the den structure, as suspected by Beck (1991). We encountered fleas (Siphonaptera: Vermipsyllidae *Chaetopsylla* spp.) in numerous black bear dens in the study area, although the presence and longevity of fleas was not assessed directly. Fleas that we collected were alive several months after bears had left their dens and may be able to remain dormant in dens for long periods, supporting the hypothesis that ectoparasite load may affect reuse. Other species of fleas have been found to rest for long periods as larva (up to 600 days; Bacot 1914). For this reason, it may be important to quantify reuse over longer periods of times; den structures may need to be vacant for several years for the ectoparasite load to diminish.

The high rate of den reuse that we observed may be linked to either the low supply of these structures, the benefits that known dens confer upon the individual, or both. Bears may reuse a specific den in consecutive years because the benefits of the den are known to the bear and the individual does not risk using an unknown den site. However, the most likely explanation is that the availability of den sites is constrained in the Nimpkish Valley. In portions of the study area with extensive second-growth forests, 9 of 11 (82%) dens were reused at least once, with several being used at least 4 times. This suggests that den structures are limited in these structural stages; high reuse may indicate low availability of suitable alternatives (Beecham et al. 1983, LeCount 1983, Alt and Gruttaduria 1984). However, although reuse rates in old growth were somewhat lesser than that in second-growth forests, the rate was still high (62%) which suggests that the overall landscape supply of dens may be diminished.

MANAGEMENT IMPLICATIONS

Conversion of late-successional forests to younger even-aged stands is detrimental to the supply of dens for black bears in coastal British Columbia. Conservation of adequate dens and denning habitat in forest management plans is appropriate because individual den sites are important structural legacies

to black bear populations and a lack of suitable den sites may lead to decreased black bear populations because of increased cannibalism (Alt and Gruttdauria 1984, Davis and Harestad 1996), predation by wolves (Horejsi et al. 1984), or deaths due to increased energetic costs from using less thermally advantageous dens (e.g., dens prone to inundation; Alt 1984). If maintaining current population levels is a management goal, then conservation and recruitment of adequate numbers of safe winter den sites across the landscape needs to be included in forest management plans. Our findings suggest that the most effective method for retaining highly persistent, hollow tree dens is to retain these important structures within contiguous forests or patches of trees rather than as single trees. In other forest types, researchers have found that retention patches >1 ha in size, placed in topographically sheltered locations, with minimized edge exposure to prevailing winds, are more windfirm (Steventon 2011). Further research on the longevity of wildlife tree patches is required in coastal forests to determine the most effective management prescriptions for long-term retention of individual den trees. However, managing habitat for black bears must include not only retention of current den structures but also recruitment of new den structures and the ecological processes that create those structures.

ACKNOWLEDGMENTS

Funding for our research was provided by the Habitat Silviculture Protection Account, Habitat Conservation Trust Fund, and Habitat Conservation Trust Foundation, Canadian Forest Products Ltd. and Western Forest Products, Inc., Wildlife Habitat Canada, and Global Forest (GF-18-1999-23). We thank J. Deal and Canadian Forest Products Ltd. for initiating the project and voluntarily implementing management prescriptions to retain den structures. We are indebted to A. Hahn, A. Friedman, P. Kaczensky, M. Kellner, C. Mueller, R. Ramcharita, and D. Wellwood for their assistance in the field and T. Poland for insect identification.

LITERATURE CITED

Alt, G. L. 1984. Black bear cub mortality due to flooding of natal dens. *Journal of Wildlife Management* 48:1432–1434.

Alt, G. L., and J. M. Gruttdauria. 1984. Reuse of black bear dens in northeastern Pennsylvania. *Journal of Wildlife Management* 48:236–239.

Bacot, A. 1914. A study of the bionomics of the common rat fleas and other species associated with human habitations, with special reference to the influence of temperature and humidity at various periods of the life history of the insect. *Journal of Hygiene* 13:447–654.

Beck, T. D. I. 1991. Black bears of west-central Colorado. Colorado Division of Wildlife Technical Publication Number 39, Denver, USA.

Beecham, J. J., D. G. Reynolds, and M. G. Hornocker. 1983. Black bear denning activities and den characteristics in west-central Idaho. *International Conference on Bear Research and Management* 5:79–86.

Crook, A. C., and M. J. Chamberlain. 2010. A multiscale assessment of den selection by black bears in Louisiana. *Journal of Wildlife Management* 74:1639–1647.

Davis, H. 1996. Characteristics and selection of winter dens by black bears in coastal British Columbia. Thesis, Simon Fraser University, Burnaby, British Columbia, Canada.

Davis, H., and A. S. Harestad. 1996. Cannibalism by black bears in the Nimpkish Valley, British Columbia. *Northwest Science* 70:88–92.

Green, R. N. 2000. Terrestrial ecosystem mapping of Canadian Forest Products' Tree Farm License 37. Canadian Forest Products Limited, Woss, British Columbia, Canada.

Hamilton, R. J., and R. L. Marchinton. 1980. Denning and related activities of black bears in the coastal plain of North Carolina. *International Conference on Bear Research and Management* 4:121–126.

Horejsi, B. L., G. E. Hornbeck, and R. M. Raine. 1984. Wolves, *Canis lupus*, kill female black bear, *Ursus americanus*, in Alberta. *Canadian Field-Naturalist* 98:368–369.

Johnson, K. G. 1978. Den ecology of black bears (*Ursus americanus*) in the Great Smoky Mountains National Park. Thesis, University of Tennessee, Knoxville, USA.

Johnson, K. G., D. O. Johnson, and M. R. Pelton. 1978. Simulation of winter heat loss for a black bear in a closed tree den. *Proceedings of the Eastern Workshop on Black Bear Research and Management* 4:155–166.

Johnson, K. G., and M. R. Pelton. 1981. Selection and availability of dens for black bears in Tennessee. *Journal of Wildlife Management* 45:111–119.

Kolenosky, G. B., and S. M. Strathearn. 1987. Winter denning of black bears in east-central Ontario. *International Conference on Bear Research and Management* 7:305–316.

LeCount, A. L. 1983. Denning ecology of black bears in central Arizona. *International Conference on Bear Research and Management* 5:71–78.

Lindzey, F. G., and E. C. Meslow. 1976. Characteristics of black bear dens on Long Island, Washington. *Northwest Science* 50:236–242.

Minore, D. 1983. Western redcedar: a literature review. Pacific Northwest Forest and Range Experiment Station. U.S. Department of Agriculture, Forest Service general technical report PNW-150, Portland, Oregon, USA.

Noble, W. O., E. C. Meslow, and M. D. Pope. 1990. Denning habits of black bears in the central coast range of Oregon. Oregon State University, Corvallis, USA.

Nuszdorfer, F. C., compiler. 1991. Biogeoclimatic units of the Vancouver Forest Region. 1:250 000 scale. B.C. Ministry of Forests, Research Branch, Victoria, British Columbia, Canada.

Schwartz, C. C., S. D. Miller, and A. W. Franzmann. 1987. Denning ecology of three black bear populations in Alaska. *International Conference on Bear Research and Management* 7:281–291.

Steventon, J. D. 2011. Retention patches: windthrow and recruitment of habitat structure 12–16 years after harvest. *BC Journal of Ecosystems and Management* 11:18–28.

Tietje, W. D., and R. L. Ruff. 1980. Denning behavior of black bears in boreal forest of Alberta. *Journal of Wildlife Management* 44:858–870.

Associate Editor: Michael Chamberlain.

Analysis of Carbon Storage in Roadless Areas of the Tongass National Forest

Prepared by Dominick A. DellaSala, Ph.D, in consultation with Brian Buma, Ph.D

We have reviewed the Draft Environmental Impact Statement (DEIS) for the proposed Alaska Roadless Rulemaking and, in particular, its analysis of carbon storage in the inventoried roadless areas of the Tongass National Forest. The DEIS substantially undervalues the global and national importance of old-growth trees on the Tongass for carbon storage. Research shows, for example, that primary (unlogged) forests on the Tongass store much more carbon than logged forests because of the relatively high percentage of old growth and long stable residence times of carbon stored in these forests. The DEIS incorrectly assumes the carbon emitted from logging represents a zero-sum game with carbon recapture in wood product pools and reforestation – this argument is completely false (see below).

- The Tongass is part of a global network of temperate rainforests that make up ~2.5% of the world's total forest coverage but these rainforests have exceptional carbon stores for their relatively small spatial extent and are critically important in climate regulation collectively and individually.¹
- The Tongass is one of only 4 other temperate rainforests world-wide that is still largely intact, which is a value of global importance grossly undervalued in the DEIS.²
- The Tongass occurs within the Pacific Coastal Temperate Rainforest bioregion (extends from Coast Redwoods to Alaska) that includes temperate rainforest ecoregions and climatically distinguishable subregions (subpolar, perhumid, seasonal, warm temperate) considered globally outstanding for their biodiversity and that collectively comprise over one-third of the world's entire temperate rainforest biome based on latest rainforest mapping that should be cited and elevated in importance in the DEIS.³
- Tongass carbon stores are substantially greater than any other national forest in the US and are irreplaceable as carbon sinks.⁴
- Primary (unlogged) forests on the Tongass store much more carbon than logged forests because of the relatively high percentage of old growth and long stable residence times of carbon stored in these forests, and in fact old growth forests are accruing biomass at a rate of approximately a Teragram a year.⁵ The DEIS incorrectly assumes the carbon

¹ DellaSala et al. 2011.

² DellaSala et al. 2011.

³ DellaSala et al. 2011.

⁴ Leighty et al. 2006; Keith et al. 2009; Buma and Thompson 2019. Also, using the dataset in Krankina et al. 2014, the Tongass is a national carbon champion.

⁵ See Leighty et al. 2006; Keith et al. 2009; Buma and Barrett 2015

emitted from logging represents a zero sum game with carbon recapture in wood product pools and reforestation – this is completely false (see below).

- The Tongass may function as a climate refuge for species facing more extreme climatic conditions in the interior of Alaska and coastal rainforests further south if managed to protect old-growth forests and roadless areas, based on climate envelope modeling and downscaled climate projections for the region.⁶
- Globally, wilderness and intact areas have been declining at an accelerated rate, contain irreplaceable biodiversity and carbon stores, and these losses can be attributed to the “degazetting” (removal of protection status) globally – while roadless areas are not designated wilderness per se – the DEIS continues the alarming global trend of degazetting wild, irreplaceable places.⁷ Instead, maintaining and restoring the integrity of intact forests and wild places is an urgent global priority for conservation and sustainability efforts designed to halt the biodiversity and climate crises.⁸ Intact areas are also much more likely to retain their native biodiversity than fragmented areas in a rapidly changing climate.⁹
- Large, old growth trees are critically important globally and scientists are calling for protecting places like the Tongass where large trees are especially concentrated to help avoid a biodiversity crisis.¹⁰
- Because of the global importance of primary (unlogged) forests and high concentration of old-growth forests on the Tongass, scientists are calling on governments to manage these forests to reach their maximum carbon potential via “proforestation” (nature-based climate solutions that allow forests to mature) in order to mitigate climate change.¹¹
- The best option for storing carbon long term on public lands is the “no harvest option” for the Tongass and all US public timberlands.¹² Forgoing timber harvest in these areas is projected to result in a net increase of 43% in carbon stores nation-wide, for instance, and an increase in sequestration potential on the national forests such as the Tongass¹². The DEIS needs to reflect these published estimates and provide a science-based assessment of carbon stored by old forests and estimated emissions from proposed logging given the national and global significance of the Tongass.

⁶ DellaSala et al. 2015.

⁷ Watson et al. 2016a.

⁸ Watson et al. 2017; Ripple et al. 2019.

⁹ Watson et al. 2016b.

¹⁰ Keith et al. 2009; Lindenmayer et al. 2012, 2013; Krankina et al. 2014.

¹¹ Mackey et al. 2014; Moomaw 2019.

¹² Leighty et al. 2006; Depro et al. 2008

In sum, the Forest Service is responsible for stewarding arguably the most important national forest in the nation and has an ethical-moral and legal obligation to maintain remaining untrammelled areas on the Tongass as irreplaceable assets within the national forest system (as noted by 234 scientists in an October 2019 letter calling on land managers to leave the Roadless Rule in place in Alaska). These irreplaceable values need to be fully acknowledged and protected for their national and global significance.

Additionally, the Forest Service is taking unacceptable climate and biodiversity risks at a time when thousands of scientists have been calling for stricter protections as climate mitigation/adaptation strategies due to the global biodiversity and climate crises we now face.¹³ The best alternative for storing carbon long term on public lands is a “no harvest option” for the Tongass and all US public timberlands.¹⁴ Forgoing timber harvest in these areas is projected to result in a net increase of 43% in carbon stores nation-wide, for instance, and an increase in sequestration potential on national forests such as the Tongass. The DEIS needs to reflect these published estimates and provide a science-based assessment of carbon stored by old forests and emitted from proposed logging given the national and global significance of the Tongass and in relation to these cited studies.

A. THE DEIS UNDERVALUES FOREST CARBON AND GROSSLY UNDERESTIMATES EMISSIONS ATTRIBUTABLE TO LOGGING.

NEPA regulations state that:

NEPA procedures must insure that environmental information is available to public officials and citizens before decisions are made and before actions are taken. The information must be of high quality. Accurate scientific analysis, expert agency comments, and public scrutiny are essential to implementing NEPA.¹⁵

To ensure that the agency has taken the required “hard look,” courts hold that the agency must utilize “public comment and the best available scientific information.”¹⁶

¹³ Watson et al. 2016a,b; Ripple et al. 2017; Ripple et al. 2019.

¹⁴ Leighty et al. 2006; Depro et al. 2008.

¹⁵ 40 C.F.R. § 1500.1(b).

¹⁶ *Biodiversity Cons. Alliance v. Jiron*, 762 F.3d 1036, 1086 (10th Cir. 2014) (internal citation omitted). Regulations implementing the planning provisions of National Forest Management Act (NFMA) also require the use of the best available scientific information (BASI). 36 C.F.R. § 219.3. As noted above, the proposed action includes adding 185,000 acres to the suitable timber base, which requires that the Forest Service amend the Tongass Forest Plan. The Forest Service’s planning regulations apply to Forest Plan amendments. 36 C.F.R. § 219.1. Even if they do not apply, they establish sound agency practice and comport with NEPA’s mandates regarding best available scientific information and high quality data.

Further, NEPA requires agencies to explain opposing viewpoints and their rationale for choosing one viewpoint over the other.¹⁷ Federal courts have set aside NEPA analysis where the agency failed to respond to scientific analysis that calls into question the agency's assumptions or conclusions.¹⁸

The DEIS does not present or consider the best available scientific information about the impact of the proposed action on forest carbon. The DEIS presents a contradictory, scientifically flawed, inappropriately scaled and biased accounting of forest carbon losses associated with suspending the national roadless conservation rule on the Tongass. Not a single forest carbon life cycle analysis is presented, yet, the Forest Service draws sweeping conclusions that undervalue the global importance of carbon stored in old growth and roadless areas (IRAs) on the Tongass, while inappropriately minimizing the emissions footprint from roadless entry at a time when overwhelming scientific consensus urges governments to avoid additional emissions from forest degradation and to store more carbon in forest ecosystems.¹⁹ Because agencies and academics have quantified and compared the carbon emissions of alternative logging proposals, the Forest Service cannot fail to undertake a similar analysis on the basis that it is too complex or complicated. Dr. DellaSala's 2016 report addressed carbon stores from wood products and concluded that logging Tongass old-growth forest under the 2016 Forest Plan would result in net annual CO₂ emissions totaling between 4.2 million tons and 4.4 million tons, depending on the time horizon chosen.²⁰ The Bureau of Land Management a decade ago completed an EIS for its Western Oregon Resource Management Plan in which that agency also predicted and quantified the net carbon emissions from its forest and other resource management programs.²¹

Opening up roadless areas and logging in old-growth forests, as the proposed rule would do, conflicts with published research showing the most effective/efficient means to maintain the

¹⁷ 40 C.F.R. § 1502.9(b) (requiring agencies to disclose, discuss, and respond to "any responsible opposing view").

¹⁸ See *Ctr. for Biological Diversity v. U.S. Forest Serv.*, 349 F.3d 1157, 1168 (9th Cir. 2003) (finding Forest Service's failure to disclose and respond to evidence and opinions challenging EIS's scientific assumptions violated NEPA); *Seattle Audubon Soc'y v. Moseley*, 798 F. Supp. 1473, 1482 (W.D. Wash. 1992) ("The agency's explanation is insufficient under NEPA – not because experts disagree, but because the FEIS lacks reasoned discussion of major scientific objections."), *aff'd sub nom. Seattle Audubon Soc'y v. Espy*, 998 F.2d 699, 704 (9th Cir. 1993) ("[i]t would not further NEPA's aims for environmental protection to allow the Forest Service to ignore reputable scientific criticisms that have surfaced"); *High Country Conservation Advocates v. Forest Service*, 52 F. Supp. 3d 1174, 1198 (D. Colo. 2014) (finding Forest Service violated NEPA by failing to mention or respond to expert report on climate impacts).

¹⁹ Mackey et al. 2013, Mackey 2014, Mackey et al. 2016a,b, Griscom et al. 2017, Law et al. 2018, Ripple et al. 2019, Moomaw 2019.

²⁰ D. DellaSala, *The Tongass Rainforest as Alaska's First Line of Climate Change Defense and Importance to the Paris Climate Change Agreements* (2016) at 14, and available at <https://forestlegacies.org/wp-content/uploads/2016/01/tongass-report-emissions-2016-01.pdf> (last viewed Dec. 13, 2019).

²¹ See Bureau of Land Management, Western Oregon Proposed RMP Final EIS (2009) at 165-181, excerpts attached.

enormous Tongass carbon sink is to protect all remaining old-growth forests from logging.²² The DEIS carbon assessment does not present the best scientific information, particularly in reference to the global climate emergency²³ or the importance of keeping carbon tied up in Tongass forests as recommended by scientists.²⁴ In fact, the DEIS goes as far as to boldly proclaim, without a single published scientific reference, that “the management mechanisms applied in all alternatives are consistent with internationally recognized climate change adaptation and mitigation practices identified by the IPCC (IPCC 2000, 2007).”²⁵ To the contrary, the IPCC (2018)²⁶ does not endorse roadless development as an appropriate climate mitigation/adaptation strategy. Rather, the IPCC has repeatedly recommended storing more carbon in ecosystems by avoiding additional emissions in the land sector.²⁷ The same is true for the published sources cited in these comments. We are unaware of any other research that supports the DEIS assertion that clearcutting old-growth rainforests and building roads into intact watersheds is consistent with adaptation and mitigation strategies.

Based on the recent IPCC assessment (2019), an estimated 23% of total anthropogenic greenhouse gas emissions (2007-2016) derive from agriculture, forestry, and other land use. Thus, IPCC recommends avoiding additional emissions from these sectors.

Notably from the IPCC (2019)

“Achieving land degradation neutrality will involve a balance of measures that avoid and reduce land degradation, through adoption of sustainable land management, and measures to reverse degradation through rehabilitation and restoration of degraded land. Many interventions to achieve land degradation neutrality commonly also deliver climate change adaptation and mitigation benefits. The pursuit of land degradation neutrality provides impetus to address land degradation and climate change simultaneously (high confidence).”

There are at least two fundamental flaws (inherent *biases*) in the DEIS carbon assessment: (1) undervaluing long-term carbon stored in intact watersheds and old-growth forests compared to logged areas; and (2) understating cumulative emissions from logging and road building by using an inappropriate analysis scale and by overstating wood product stores that do not comport with recent published estimates (discussed below).

²² Leighty et al. 2006.

²³ Ripple et al. 2019.

²⁴ Leighty et al. 2006, DellaSala et al. 2011, Moomaw 2019.

²⁵ DEIS at 3-128.

²⁶ Given the large size of this report and the fact that the IPCC report is readily available online, we have provided only the only link and not the full pdf - https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf.

²⁷ See also Griscom et al. 2017, Moomaw 2019.

The DEIS also does not sufficiently meet the Forest Service’s substantive obligation to protect Tongass resources because it: (1) proposes to enter intact watersheds that are acting as irreplaceable strongholds for fish and wildlife populations in a changing climate;²⁸ and (2) degrades intact areas containing nationally recognized carbon sinks at a time when scientists recommend avoiding entry into intact areas as critical to preventing the escalating climate and biodiversity crises underway globally.²⁹ Specifically, the DEIS should continue *to protect, preserve, manage, and restore* natural systems (roadless, old growth) on the Tongass, rather than degrade them by development, and then expecting them to somehow be miraculously restored and recovered with all emissions offset by regrowth and wood product stores – an assumption directly contradicted by the best available science (see below).

To assess properly the impacts of the proposed exemption on carbon emissions and sequestration, the agency must address the following key elements and information not now considered in the DEIS.

Trees accumulate carbon over their entire lifespan. While growth efficiency declines as the tree matures, corresponding increases in a tree’s total leaf area overcome this slow down as the **whole-tree carbon accumulation rate increases with age and tree size** (Figure 1 – the figure below and some of the text in this section was modified from materials sent to DellaSala by M.G. Anderson, pers. comm). A study of 673,046 trees across six countries and 403 species found that at the extreme, a large old tree may sequester as much carbon in one year as growing an entire medium size tree.³⁰ At one site, large trees comprised 6 percent of the trees but 33 percent of the annual forest growth. More recent studies show the largest 1% of trees in old-growth forests worldwide store ~50% of the total stand level carbon.³¹ In the Tongass, old growth forests continue to accrue biomass and carbon at an amazing rate³². In sum, young trees grow fast, but old trees store a disproportionate amount of carbon over time given the larger leaf surface area for absorption and massive tree trunks and root wads that represent centuries of accumulated carbon.

Quoting directly from the abstract in Lutz et al. (2018):

Main conclusions: Because large-diameter trees constitute roughly half of the mature forest biomass worldwide, their dynamics and sensitivities to environmental change represent potentially large controls on global forest carbon cycling. We recommend managing forests for conservation of existing large-diameter trees or those that can soon

²⁸ See DellaSala et al. 2011, DellaSala et al. 2015, Watson et al. 2016a,b; 2017.

²⁹ Watson et al. 2016a,b; 2017; Ripple et al. 2019.

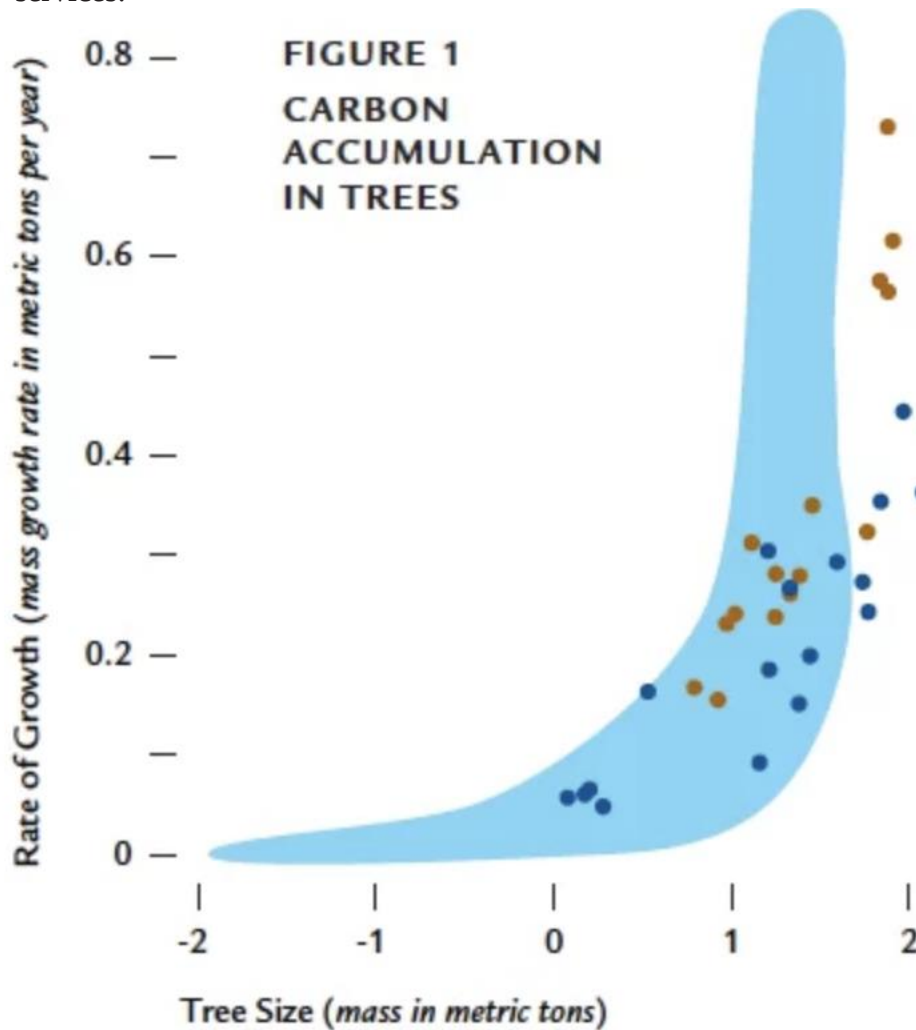
³⁰ Stephenson et al. 2014.

³¹ Lutz et al. 2018.

³² Buma and Barrett 2015

³³ Lutz et al. 2018

reach large diameters as a simple way to conserve and potentially enhance ecosystem services.³³



Aboveground mass growth rates for 58 species (shaded area) juxtaposed with two of the most massive tree species on earth: Swamp Gum (*Eucalyptus regnans*—brown dots) and Coast Redwood (*Sequoia sempervirens*—blue dots). Mass growth rate equals the total mass accumulated each year after accounting for respiration. The mass of a tree is primarily carbon, so the figure shows that annual carbon accumulation increases with the size of the tree. (Adapted from Stephenson et al. 2014.)

Old forests accumulate carbon and contain vast quantities of it. Although individual trees experience an increasing rate of carbon sequestration, forest stands experience an “S-curve” of

net sequestration rates (e.g. slow, rapid, slow).³² The expected decline in older stands is due to tree growth balanced by mortality and decomposition. For instance, an international team of scientists reviewed 519 published forest carbon-flux estimates from stands 15 to 800 years old and found that, in fact, net carbon storage was positive for 75 percent of the stands over 180 years old and the chance of finding an old-growth forest that was carbon neutral was less than 1 in 10.³³ They concluded that old-growth forests are substantial carbon sinks, steadily accumulating carbon over centuries and containing vast quantities of it in relatively stable form.

Old forests accumulate carbon in soils. Soil organic carbon levels in old forests are generally thought to be in a steady state. However, as Alaska's climate increasingly overheats (twice the rate of the rest of the US), soils will be exposed to increased drying and reduced snowpack, and this will lead to methane release. Notably, Tongass soils store >50% of the carbon in the already incredibly dense ecosystem³³. Moreover, protecting remaining unlogged forests provides for more stable microclimates (with less desiccation and lower temperatures). In fact, recent research shows that old-growth forests may act as a climate buffer as studies comparing logged vs. old growth in the Oregon Cascades found that old growth reduced maximum spring and summer air temperatures as much as 2.5 degrees C.³⁴ Thus, scientists have repeatedly acknowledged the superior climate benefits inherent to old-growth forests that are irreplaceable in human lifetimes.

Forests share carbon among tree species. Trees compete for sunlight and soil resources, and competition for resources is commonly considered the predominant tree species interactions in forests. However, recent research on carbon isotope labeling has shown that trees interact in more complex ways, including substantial exchange and sharing of carbon below ground. Aided by mycorrhiza networks, interspecific transfer among trees accounts for 40% of the fine root carbon: totally ~280 kg ha⁻¹ per year tree-to-tree transfer.³⁵ Morrien et al. (2017), found that mycorrhiza soil networks become more connected and take up more carbon as forest succession progresses even without major changes in dominant species composition. Notably, old-growth forests compared to young growth contain more complex below-ground processes that connect trees at the subsurface level.³⁶ Thus, the Forest Service needs to provide information on the impacts of logging on soil microbial and mycorrhizae carbon exchange before concluding it is insignificant. Failure to include such information would violate NEPA's hard look and BASI mandates.

Primary forest carbon can help slow climate change. Griscom et al. (2017) systematically evaluated 20 conservation, restoration, and improved land management actions that increase carbon storage and avoid greenhouse gas emissions. They found that the maximum potential of

³³ McNicol et al. 2019

³³ Luyssaert et al. 2014.

³⁴ Frey et al. 2016.

³⁵ Klein et al. 2016.

³⁶ Morrien et al. 2017.

natural climate solutions was ~2.4 Pg of carbon per-year while safeguarding food security and biodiversity.³⁷ To put the Tongass in this perspective – total Tongass stores = 2.8 Pg carbon with 16%-23% of that in IRAs – additionally, by maximizing carbon in IRAs and old growth (the scientifically recommended climate strategy) – the entire national forest benefits through the maintenance of linked ecosystem services and biodiversity (i.e., multifunctionality of forests maintained via carbon management).³⁸ New research (see below) suggests this strategy is the most cost-feasible option by a large margin³⁹ (also see below) and it should receive highest priority as a policy consideration⁴⁰ especially on the Tongass.⁴¹ In addition to carbon, old forests also build soil, cycle nutrients, mitigate pollution, purify water, release oxygen, and provide habitat for wildlife at levels far superior than logged forests.⁴²

Primary (unlogged) forests are far superior to logged forests in climate mitigation and biodiversity benefits. Globally, primary forests store 30-50% more carbon than logged forests (which is similar to the estimates provided in the DEIS on mature vs. logged Tongass forest stores⁴³) and up to half of the carbon stored in a forest is represented by the largest/oldest 1% of trees at the stand level as noted.⁴⁴ As stated, logging primary forests results in a net carbon debt and other irreplaceable losses that are not made up for via reforestation or wood product stores as the carbon present in primary forests and soils takes centuries to accumulate compared to much shorter-lived wood products that represent only a fraction of the original forest store.

In part because the DEIS analysis fails adequately to account for this basic scientific information relevant to an assessment of the impact of the proposed exemption on carbon and climate impacts, the DEIS is flawed in at least the specific ways described herein.

Tongass carbon stores need to be prioritized as globally and nationally significant climate mitigation/adaptation strategies to be protected, preserved, and managed as unique ecological communities. Old-growth forests, in general, store massive amounts of carbon in trees, foliage, and soils. Pacific coastal rainforests, in particular, are global champions in this regard.⁴⁵ Of relevance, temperate rainforests in Alaska store >2.8 Petagrams (Pg) C (1 Pg = 1 billion tonnes) in biomass and soils, the equivalent of >8% of the carbon in all contiguous US forests, most of which is on the Tongass.⁴⁶ Based on FIA datasets, Tongass roadless areas

³⁷ Griscom et al. 2017.

³⁸ See Brandt et al. 2014.

³⁹ Moomaw et al. 2019.

⁴⁰ McKinley et al. 2011.

⁴¹ Leighty et al. 2006; Buma and Thompson 2019

⁴² Mackey et al. 2014, Brandt et al. 2014.

⁴³ DEIS at 3-124.

⁴⁴ Lutz et al. 2018.

⁴⁵ Leighty et al. 2006, Keith et al. 2009, Krankina et al. 2014.

⁴⁶ Leighty et al. 2006; Buma and Thompson 2019; McNicol et al. 2019

represent ~16% to 23% of total carbon on the Tongass forest depending on categories used (Table 1, 2). Thus, roadless areas – especially those with old-growth forests – are uniquely valuable as a long-term stable carbon sink compared to logged areas that emit most of their carbon (see below).

The Tongass stores a massive amount of carbon--the total carbon stored in Tongass roadless areas are equivalent to annual emissions of ~128, 550-watt coal-fired power plants.⁴⁷ Keeping carbon in forests is a fundamental climate mitigation strategy directly responsive to the climate emergency⁴⁸ and essential to offsetting some of the emissions from the energy sector. The Tongass stores a massive amount of carbon in its old growth forests, at levels that if emitted into the atmosphere would approach the emission equivalents of coal-fired power plants. At a time when the world is looking for leadership on cutting emissions at all scales, removing protection for this carbon storage is unsupportable. Table 1 provides a breakdown of Tongass old-growth roadless carbon values (including congressionally withdrawn areas), Table 2 just the IRA carbon values, and Figure 1 shows the spatial distribution of carbon stores on Tongass IRAs. Table 3 shows that Alternative 6 will place at risk 71.5% of the carbon stored in old-growth forests and soils, with most of that carbon emitted to the atmosphere (see Leighty et al. 2006). Table 4 provides an economic estimate of the carbon value at risk to logging on the Tongass under Alternative 6 (>\$234 million), which may far exceed timber values. Additionally, if the Forest Service enters all roadless areas in this century >\$2.2 billion in carbon assets will be squandered away, should an offset market develop. All these data were available to the Forest Service (Forest Inventory Assessment - FIA) and they need to be fully analyzed in the DEIS to provide reliable estimates of carbon assets and their relative (to timber), tradeoffs involved, and the economic importance on the Tongass of carbon, along with reliable estimates of emissions from logging. Disclosing these tradeoffs is especially relevant at a time when the IPCC (2018, 2019) and other reports (Ripple et al. 2017, 2019) have warned that we have about 10 years before severe climate impacts are locked in with irreversible consequences to biodiversity and the planet's life-giving systems.

⁴⁷ https://www.oregonlive.com/business/2010/12/pges_coal-fired_boardman_plant.html.

⁴⁸ See Moomaw 2019, Ripple et al. 2019.

Table 1. Estimated carbon biomass in old-growth forest among categories of roadless areas on the Tongass NF						
OwnerType_2019	USDA FOREST SERVICE					
POG	OG Only					
	low estimate	high estimate	Total area		Estimate C in OG forest biomass	
Row Labels	Average of Carbon_ratio 58	Average of Carbon_ratio 46	Sum of GIS_Hectares		(low estimage in Mg)	(high est. in Mg)
Roadless in 2001 Rule	264.7	333.7	999,179		264,443,913	333,444,106
Lg. Roadless Areas not in	257.1	324.1	76,166		19,580,156	24,689,023
Small Rdls Areas	242.4	305.6	58,329		14,139,031	17,828,070
Roaded-Roadless	249.3	314.4	14,357		3,579,634	4,513,860
Roaded Areas	263.3	332	156,023		41,076,507	51,794,893
Wilderness or NM	247.7	312.3	662,496		164,101,837	206,915,638
Non-USFS Lands	261.5	329.8	4,171		1,090,861	1,375,453
Unknown	187.5	236.5	982		184,209	232,273
Grand Total	255.6	322.3	1,971,704		503,969,209	635,467,036

Table 2. Carbon stored in roadless area categories on the Tongass.

Large Roadless Areas		"Roaded Roadless"		Small Rdls Areas		Roaded Areas		Protected by Congress		Non-USFS Lands		Total Average Mg per ha	Total Total Mg Carbon
Average Mg per ha	Total Mg Carbon	Average Mg per ha	Total Mg Carbon	Average Mg per ha	Total Mg Carbon	Average Mg per ha	Total Mg Carbon	Average Mg per ha	Total Mg Carbon	Average Mg per ha	Total Mg Carbon		
242.58	47,208,021	274.78	98,058	313.89	1,867,886	361.48	10,026,227	207.71	66,457,805	263.80	5,436,143	260.64	131,094,140
245.92	2,081,610					317.13	83,671	224.49	36,976,406	205.86	248,378	224.82	39,390,064
224.39	7,939,491	248.04	7,679	361.21	317,926	374.39	1,469,914	179.03	2,579,177	277.13	198,836	277.09	12,513,023
255.70	18,610,022	295.11	85,792	305.53	1,322,520	356.44	6,423,528	210.15	11,972,020	286.92	3,550,567	278.05	41,964,449
231.40	17,172,289	226.63	4,587	304.03	227,439	371.92	2,025,237	144.80	7,123,632	252.95	1,407,175	261.84	27,960,360
190.38	1,404,610					234.51	23,876	185.47	7,806,570	228.97	31,187	192.89	9,266,244
232.20	58,182,471	262.79	1,429,232	261.26	4,248,583	303.66	15,895,643	196.32	22,381,595	253.61	11,984,173	249.11	114,121,697
236.71	9,363,695	232.25	279,800	213.54	756,243	291.33	3,979,300	167.72	2,705,67	252.31	1,048,227	244.24	18,133,031
248.42	4,621,788			282.27	61,790	345.31	264,235	231.39	6,290,381	200.47	149,533	246.54	11,387,728

201.6 3	14,044, 010	240.7 8	675,8 71	236. 58	1,737, 670	276. 70	4,000, 336	199.1 6	2,694,6 88	216. 69	3,418, 960	225. 90	26,571,535
289.3 9	4,013,7 21	317.0 4	8,473	337. 44	1,008, 771	340. 32	3,176, 035	284.3 1	1,032,3 43	291. 65	521,09 0	311. 71	9,760,434
237.9 6	26,139, 257	301.0 6	465,0 88	286. 21	684,1 09	320. 59	4,475, 736	177.9 3	9,658,4 16	268. 36	6,846, 362	254. 25	48,268,969
229.9 6	31,318, 111	247.6 6	892,2 78	238. 48	2,941, 262	290. 26	16,874 ,911	239.8 6	16,293, 468	268. 92	21,060 ,394	255. 37	89,380,425
264.7 3	5,634,5 63			226. 80		356. 33				265. 96	3,679, 426	266. 56	9,317,233
219.8 8	15,720, 049	244.8 1	775,4 92	234. 97	2,586, 253	287. 67	15,078 ,975	258.0 7	7,425,9 74	261. 59	14,491 ,136	252. 13	56,077,879
281.1 0	2,088,0 47	230.6 7	21,44 3	251. 59	236,8 29	294. 96	1,465, 398	196.9 9	4,999,4 43	315. 98	468,65 2	278. 44	9,279,811
231.4 9	7,875,4 51	293.1 4	95,34 3	284. 60	117,7 83	322. 67	327,69 2	192.5 6	3,868,0 51	296. 39	2,421, 180	256. 94	14,705,501
186.1 3	53,884, 796	336.7 8	287,4 12	333. 72	595,5 65	312. 46	2,942, 711	149.4 4	66,534, 550	259. 89	5,757, 139	213. 28	130,002,173
192.5 6	11,619, 409	369.3 4	120,6 27	327. 18	275,9 72	313. 76	861,29 5	118.5 7	3,208,9 27	268. 13	1,822, 554	235. 07	17,908,784
62.94	1,228,3 45			368. 10	96,49 0	136. 68		159.8 4	18,154, 192	284. 05	46,875 06	168. 06	19,604,876
						123. 88	78,974 45	181.0 2	31,003, 210	148. 94	46,875 170	179. 52	31,003,425
187.6 2	21,671, 798	288.4 9	136,4 81	309. 91	31,94 3	325. 86	1,478, 419	118.4 1	7,974,9 12	260. 51	721,35 8	212. 07	32,014,912
192.0 2	19,365, 243	314.3 3	30,30 4	440. 91	191,1 61	322. 72	523,97 8	118.6 7	6,193,3 09	251. 30	3,166, 182	215. 24	29,470,176
225.3 2	190,59 3,399	264.3 8	2,706, 980	265. 82	9,653, 295	312. 40	45,739 ,492	196.0 9	171,66 7,419	263. 11	44,237 ,849	247. 37	464,598,434

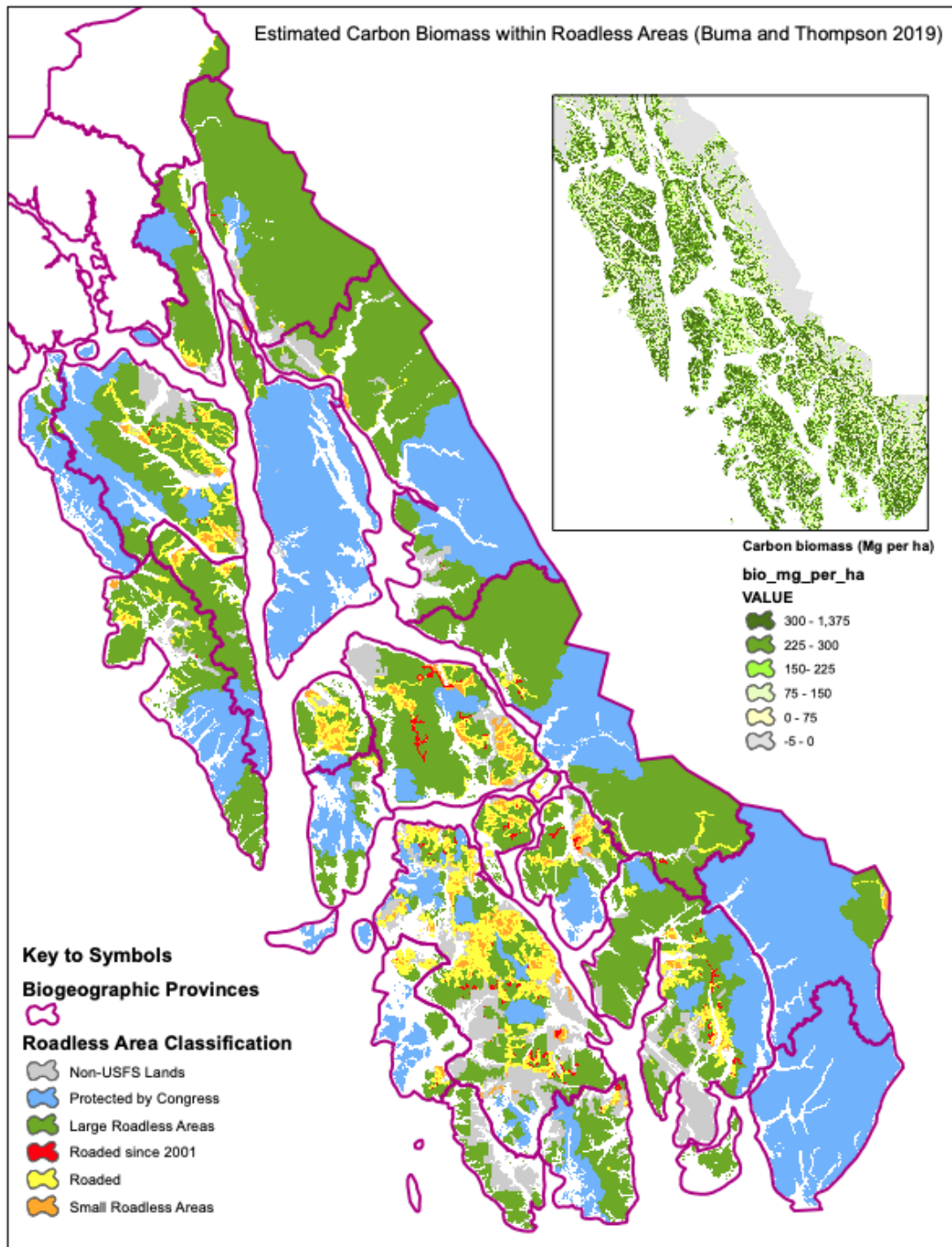


Table 3. Estimated Mg of forest and soil carbon on lands suitable for old-growth logging under DEIS Alternatives

	Alternatives					
Forest & Soil Carbon Estimates	1	2	3	4	5	6
Suitable Acres (with Data)	229,564	249,888	307,778	387,941	394,997	394,997
Net Change from Alt 1 (acres)	0	20,325	78,214	158,377	165,433	165,433
Suitable Hectares (w/data)	92,901	101,126	124,554	156,994	159,850	159,850
Net Change from Alt 1 (hectares)	0	8,225	31,652	64,093	66,948	66,948
Total Forest C (low est)	23,625,799	25,643,535	31,591,558	39,655,731	40,508,557	40,508,557
% Increase from Alt 1 (low est)	0.0%	8.5%	33.7%	67.8%	71.5%	71.5%
Total Forest C (high est)	29,790,661	32,334,884	39,834,901	50,003,261	51,078,589	51,078,589
% Increase from Alt 1 (high est)	0.0%	8.5%	33.7%	67.8%	71.5%	71.5%
Total Soil C	34,284,875	37,153,086	45,699,226	56,497,163	57,468,262	57,468,262
% increase from Alt 1 (soil)	0.0%	8.4%	33.3%	64.8%	67.6%	67.6%
Forest + Soil C (low)	57,910,675	62,796,621	77,290,783	96,152,894	97,976,819	97,976,819
Forest + Soil C (high)	64,075,536	69,487,970	85,534,126	106,500,424	108,546,851	108,546,851
% Increase from Alt 1 (high)	0.0%	8.4%	33.5%	66.2%	69.4%	69.4%

Table 4. Economic value of at-risk carbon (Alternative 6 plus all suitable)

	Alt 6 suitable timber at-risk	All suitable timber at-risk
Acres	42,500	394,997
Low est total carbon	40,508,577	40,508,577
CO2 (carbon x 3.67)	148,666,478	148,666,478
Value of CO2 at-risk in suitable timber base* at \$15/ton CO2	\$240,839,694 40% logged in first decade = \$96.3 million	\$2.2 billion

*Suitable timber base = 10.8% of at-risk carbon under Alt 6, 100% at risk under all suitable acres

Carbon emissions assessment by the Forest Service provides a misleading comparison to other emissions and fails to include a social cost analysis. The DEIS is woefully inadequate as it compares emissions (prior and current logging) on the Tongass to gross emissions from the **entire US electric power sector in 2012 and all US emissions in 2017.**⁴⁹ Federal courts have rejected this kind of skewed comparisons.⁵⁰ This arbitrary baseline ignores the incremental nature of carbon emissions and impacts and is inconsistent with recommendations of the IPCC (2018) to avoid additional emissions, and with the broader scientific consensus of fully protecting carbon sinks like the Tongass.⁵¹ To comply with NEPA, the Forest Service must, at a minimum, explain why it is choosing to ignore these expert conclusions. The global community also has signaled its intent to protect carbon sinks under Article 5 of the Paris Climate Agreement. While the US is irresponsibly withdrawing from the agreement, it is also irresponsible for the Forest Service to downplay the substantial regional emissions from Tongass roadless and old growth logging when the rest of the world is looking for ways to reduce and avoid emissions **at all scales**. Instead, the agency should choose the alternative with the least

⁴⁹ DEIS at 3-124.

⁵⁰ See *High Country*, 52 F. Supp. 3d at 1190 (“Beyond quantifying the amount of emissions relative to state and national emissions and giving general discussion to the impacts of global climate change, [the agencies] did not discuss the impacts caused by these emissions.”); *Mont. Env’tl. Info. Ctr. v. U.S. Office of Surface Mining*, 274 F. Supp. 3d 1074, 1096–99 (D. Mont. 2017) (rejecting the argument that the agency “reasonably considered the impact of greenhouse gas emissions by quantifying the emissions which would be released if the [coal] mine expansion is approved, and comparing that amount to the net emissions of the United States”); *WildEarth Guardians v. Zinke*, 368 F. Supp. 3d 41, 76-78 (D.D.C. 2019) (holding BLM’s conclusion that the emissions from oil and gas leases “represent an incremental contribution to the total regional and global GHG emissions level” was arbitrary and capricious because it was not supported by any data).

⁵¹ Keith et al. 2009, DellaSala et al. 2011, Stephenson et al. 2014, Mackey et al. 2014, Law et al. 2018, Moomaw et al. 2019.

emissions – no action – and compare alternatives against no action with respect to reliable and accurate direct, indirect, and cumulative emissions. This also needs to be expressed in carbon dioxide equivalents to estimate the socio-economic cost of carbon. Additionally, the emissions need to be expressed at an appropriate **regionally specific scale**, as for instance, coal-fired power plant equivalents as mentioned above so that the public understands the true regional climate consequences of opening roadless areas to logging and development.

Further, the DEIS falsely asserts that “it is difficult and highly uncertain to ascertain the indirect effects of emissions resulting from these alternatives on global climate.”⁵² The Forest Service could easily express the indirect impacts of climate emissions by quantifying or estimating climate pollution volumes by alternative (as noted above in our analysis) and then using the social cost of carbon (SCC) to assess and compare the significance of the effects on global climate. The very purpose of the SCC is to assist decisionmakers in (conservatively) estimating the marginal damages from each additional ton of greenhouse gas emissions. To avoid this analysis irresponsibly kicks the emissions can down the road.

The DEIS incorrectly states that most of the carbon in trees after logging will be recovered via reforestation and stored in wood products for buildings instead of stored in forest ecosystems and this is completely false. As noted, a substantial portion of the total forest carbon is contained in foliage, branches and bark, root wads and soils.⁵³ Because much of the carbon in logs hauled to mills becomes waste, only a relatively minor portion of the total tree carbon ultimately ends up in wood products.⁵⁴ Up to 40% of the harvested material does not become forest products and is burned or decomposes quickly on site, and a majority of manufacturing waste is burned for heat. One study found that 65% of the carbon from West Coast forests logged over the past 100 years is still in the atmosphere with just 19% stored in long-lived products; the remainder is in landfills.⁵⁵ Additionally, Leighty et al. (2006) reported that a century of Tongass logging has emitted 6.4-17.2 Tg C that is still in the atmosphere (again – it matters most what the atmosphere “sees” more than what is stored in wood products). Further, Hudiburg et al. (2019) note that state and federal reporting of emissions has erroneously excluded some product-related emissions, resulting in 25-55% underestimation of total CO₂ emissions from logging. Thus, the Forest Service needs to fully disclose and provide reliable estimates on how much carbon is emitted by clearcutting given the substantial fall down and problems with underestimating emissions as noted. Large amounts of logs, stumps, root wads and slash are left on the ground after clearcutting and soils are noticeably disturbed by heavy equipment. This cannot be simply dismissed as an insignificant impact in the DEIS.

It is also wrong for the Forest Service to assert that carbon stored in Tongass saw logs (wood product pools) compensates for carbon emitted by logging long-lived (hundreds of years) trees in

⁵² DEIS at 3-127

⁵³ Campbell et al. 2007.

⁵⁴ See, e.g., Harmon et al. 1990, Harmon et al. 1996, Ingerson 2008, Law et al. 2018, Harmon 2019.

⁵⁵ Hudiburg et al. 2019.

the Tongass old-growth carbon sink.⁵⁶ The carbon debt created by expansive clearcut logging (past, present, future) must be calculated using reliable and accurate estimates via a carbon life cycle analysis that accounts for how long carbon remains in the atmosphere (after all, it's what the atmosphere "sees" that matters most in the long run). Thus, at a minimum, NEPA requires that the Forest Service conduct a carbon life cycle analysis using published sources and the Forest Service should use FIA/timber stand data on estimated carbon uptake and stores in old growth vs. young growth to calculate age-related differences in carbon stores and associated emissions from logging (e.g., using the carbon values for Tongass old growth and IRAs in our comments) at the regional scale. The following analysis components should be included in the DEIS:

- In-boundary emissions – at the stand and landscape level, this includes carbon entering the atmosphere from the substantial “fall down” and defect of uneconomical logs, slash, and stumps – based on Tongass timber stand inventory data (2016-18) fall down alone (uneconomical material) may be as high as 70% of felled trees (carbon emitted directly to the atmosphere) with old-growth defect at least 30%.
- Out-of-boundary emissions – this includes: (1) carbon emitted via wood processing waste at the mill (see Law et al. 2018 for example); (2) fossil fuels used in transport and manufacture of wood products, including emissions from log exports sent to China and then exported for distribution as products, the lower 48 states and elsewhere (note - transport emissions are easily obtained from the Alaska Department of Environmental Conservation Division of Air Quality (greenhouse gas emission inventory⁵⁷); and (3) estimated emissions from road building.⁵⁸
- Use more recent studies on wood product substitution estimates – Harmon (2019), for instance, re-examined substitution assumptions questioning their *reliability* in life cycle analysis and concluding that any benefits depend on duration of fossil carbon displacement, longevity of buildings being assumed, and nature of the forest supplying building materials (also see below):

“Substitution of wood for more fossil carbon intensive building materials has been projected to result in major climate mitigation benefits often exceeding those of the forests themselves. A reexamination of the fundamental assumptions underlying these projections indicates long-term mitigation benefits related to product substitution may have been overestimated 2- to 100-fold (*emphasis added*). This suggests that while product substitution has limited climate mitigation benefits, to be effective the value and duration of the fossil carbon displacement, the longevity of buildings, and the

⁵⁶ See, e.g., DEIS at 3-127.

⁵⁷ See <https://dec.alaska.gov/air/anpms/projects-reports/greenhouse-gas-inventory>

⁵⁸ See Loeffler et al. 2008 for how to estimate this -note – this is a Forest Service publication easily accessible to the agency.

nature of the forest supplying building materials must be considered.”⁵⁹ Failure to address this scientific study would violate NEPA’s and NFMA’s mandate that the Forest Service use the best available science and that the agency explain why its approach differs from that of experts.

- The need for reliable published references to estimate wood product stores— Researchers report most carbon is emitted to the atmosphere when old trees are logged, accounting for wood product stores is only a fraction of the carbon pool (e.g., ~35% of the live carbon is rapidly emitted when an old-growth forest is logged with another 30% emitted at the mill and even more in transportation).⁶⁰
- The reference to an albedo effect in the DEIS (at 3-123) is unreliable, cannot be verified, is inconsistent with the BASI requirement, and should be dropped. The DEIS provides no citation or support for its unsubstantiated albedo assumption, which likely was extrapolated from the boreal regions where albedo has been reported as having a potential cooling affect because of the reflectance properties of snow. The Forest Service cannot make this same claim for the Tongass given that low-elevation temperate rainforests experience relatively little snow (and therefore have low albedo/reflectance properties), especially in a changing climate (as noted in the DEIS). Without a life cycle analysis that first estimates logging emissions and then compares emissions to whatever insignificant albedo effect is anticipated in temperate regions with little snow, the albedo cooling assumption is falsified and cannot be used for disclosing climate impacts of Tongass logging. In sum, large regional and ecosystem type variations have been observed in albedo and one cannot compare albedo from one region to another or one forest type to another.

In this regard, the DEIS echoes unsupportable claims and assumptions by the wood products industry that substituting wood for concrete and steel reduces the overall carbon footprint of buildings and thus is unreliable and inaccurate. The agencies’ wood production substitution claim has been refuted by recent analyses that reveal forest industries have been using unrealistic and erroneous assumptions in their models, overestimating the long-term mitigation benefits of substitution by 2- to 100-fold.⁶¹ An additional recent analysis concluded that the carbon footprint of wood is 6% higher than concrete (Stiebert et al. 2019), and that assessment did not include the reduced forest carbon sequestration and storage caused by forest losses as discussed. Importantly, a very recent breakthrough in solar energy production will soon make it possible to dramatically reduce the carbon footprint of concrete and steel even further.⁶² Additionally, regarding the noted problems with exaggerated wood substitution benefits,⁶³ there is no

⁵⁹ Harmon 2019. –

⁶⁰ See Harmon et al. 1990, Harmon et al. 1996, Law et al. 2018, Harmon 2019.

⁶¹ As discussed, Law et al. 2018, Harmon 2019.

⁶² <https://www.cnn.com/2019/11/19/business/heliogen-solar-energy-bill-gates/index.html>.

⁶³ See DEIS at 3-123.

assurance that concrete and steel replaced by wood will not be used in application somewhere else (i.e., leakage from using steel/concrete used elsewhere). For the substitution benefit to accrue, an equivalent amount of concrete or steel would need to not be produced and used in construction; otherwise, substitution is purely speculative (not best science) and unreliable. Further, the DEIS did not account for the high recycled content in most steel or recent/future anticipated advances in reducing the carbon footprint of concrete. For instance, changing manufacturing methods impact embodied energy, as for example, if fly ash is added to concrete it could yield 22-38% reductions in embodied energy required in manufacturing processes, thereby reducing the displacement value of wood.⁶⁴ Using clean, renewable energy instead of coal in concrete and steel manufacturing also can lower the substitution value and is part of the mix of energy sources being expanded upon by the global community (i.e., over the next few decades new energy sources and processing efficiencies will emerge to reduce concrete/steel emissions and this needs to be factored into a “best case scenario” for energy efficiency upgrades in the DEIS). This change is already underway.⁶⁵

To construct a proper life cycle analysis that provides a science-based assessment of carbon stocks and flows on the Tongass, the DEIS should adopt a method similar to the approach used by Hudiburg et al. in their 2019 life cycle analysis of emissions from logging. The following abstract summarizes their methodologies:

Abstract

Atmospheric greenhouse gases (GHGs) must be reduced to avoid an unsustainable climate. Because carbon dioxide is removed from the atmosphere and sequestered in forests and wood products, mitigation strategies to sustain and increase forest carbon sequestration are being developed. These strategies require full accounting of forest sector GHG budgets. Here, we describe a rigorous approach using over one million observations from forest inventory data and a regionally calibrated life-cycle assessment for calculating cradle-to-grave forest sector emissions and sequestration. We find that Western US forests are net sinks because there is a positive net balance of forest carbon uptake exceeding losses due to harvesting, wood product use, and combustion by wildfire. However, over 100 years of wood product usage is reducing the potential annual sink by an average of 21%, suggesting forest carbon storage can become more effective in climate mitigation through reduction in harvest, longer rotations, or more efficient wood product usage (emphasis added). Of the ~10,700 million metric tonnes of carbon dioxide equivalents removed from west coast forests since 1900, 81% of it has been returned to the atmosphere or deposited in landfills (emphasis added). Moreover, state and federal reporting have erroneously excluded some product-related emissions, resulting in 25%–55% underestimation of state total CO₂ emissions. For states seeking to reach GHG reduction mandates by 2030, it is important that state CO₂ budgets are

⁶⁴ Harmon 2019.

⁶⁵ See J. Gillis, *The Steel Mill That Helped Build the American West Goes Green*, *The New York Times* (Oct. 16, 2019) (describing Colorado steel mill’s decision to manufacture steel using only renewable energy), available at <https://www.nytimes.com/2019/10/16/opinion/solar-colorado-steel-mill.html> (last viewed Dec. 13, 2019).

effectively determined or claimed reductions will be insufficient to mitigate climate change.⁶⁶

Logging involves transportation of trucks and machinery across long distances between the forest, the mill, and point of distribution and the DEIS needs to properly disclose these emission sources. For every ton of carbon emitted from logging, an additional ~17% is estimated from fossil fuel consumption to support transportation, extraction, and processing of wood⁶⁷, not including the significant emissions from building roads.⁶⁸ There is no indication that this was even accounted for in the DEIS.⁶⁹ As noted, the Forest Service should consult with state emissions data to obtain reliable estimates of emissions from transport and manufacturing of wood products, particularly the incredibly long hauling distances involved with exporting logs to China and the burning of fossil fuels to get them there (plus when manufactured products are shipped again to retail and distribution areas). In the Tongass this is an especially valid concern given the remote location, no road access (necessitating saltwater barges), and weather which requires extensive and long transportation chains.

The DEIS does not account for the reduction in carbon sequestration and storage potential in forests due to logging-caused soil compaction and nutrient loss. This is despite the fact that these combined impacts can reduce forest carbon storage potential contributing to an overall carbon debt not explained or assessed in the DEIS. We note that this debt is not trivial because ~60% of the carbon lost through logging since 1700s has not yet been recovered by the land sector⁷⁰ and 81% of carbon previously stored in West Coast forests has been returned to the atmosphere via logging since 1900.⁷¹ These are centuries-long atmospheric carbon emissions coming at a time when we are in a climate emergency.⁷² This is why scientists are calling for policies that avoid emissions and store more carbon in forests compared to wood product pools.⁷³ Additionally, there are other greenhouse gas effects such as methane and nitrous oxide emissions from soil impacts that will impact the climate from logging.⁷⁴

⁶⁶ Hudiburg et al. 2019.

⁶⁷ Ingerson 2008.

⁶⁸ See Loeffler et al. 2008.

⁶⁹ The DEIS at 3-127 includes “transporting wood products” in a laundry list of potential cumulative impacts to consider in its climate analysis, but provides no analysis at all of the scale or nature of that impact, violating NEPA’s hard look mandate.

⁷⁰ McKinley et al. 2011.

⁷¹ Hudiburg et al. 2019.

⁷² Ripple et al. 2019.

⁷³ Hamon et al. 1990, 1996, Leighty et al. 2006, McKinley et al. 2011, Mackey et al. 2016a,b, Law et al. 2018, Moomaw 2019.

⁷⁴ McKinley et al. 2011.

In sum, the DEIS fails to include peer-reviewed science on forest carbon and emissions that shows: (1) primary (unlogged) forests are far superior to logged forests at carbon uptake and storage long term; (2) trees accumulate carbon over their entire lifespan; older trees capture and store far more carbon than young trees; (3) old, primary forests accumulate far more carbon than they lose through decomposition and respiration, thus acting as net carbon sinks; (4) logged forests are an emission source for at least the first decade and never fully recapture the emitted carbon stored in the pre-logged old-growth forest due to short rotation harvests and carbon losses throughout the wood product distribution chain; and (5) the superior carbon benefits of old forests are especially evident when taking into account the role of undisturbed soils (which may contain ~50% of carbon stores⁷⁵,) and below ground carbon exchange losses from logging and climate change impacts.

B. DEIS CLAIMS ABOUT TEMPERATE RAINFORESTS AND FOREST MANAGEMENT ARE NOT BASED ON BEST AVAILABLE SCIENCE

In addition to failing to analyze important information about the Tongass and its value for climate and carbon storage, the DEIS fails to analyze important information about the value of temperate rainforests.

- **Temperate rainforest amount reported in the DEIS is incorrect** – The DEIS grossly underestimates the global importance of coastal temperate rainforests, including the Tongass, for carbon regulation (0.5% global cover; no citation given).⁷⁶ DellaSala et al. (2011) provided the first computer generated map of all the world's temperate rainforests reporting that the total area for this rainforest biome is actually 2.5% of all forests globally (5 times that reported in the DEIS). The Pacific Coastal rainforests (California Coast Redwoods to Alaska) are globally significant as they represent over one-third of all temperate rainforests world-wide and because the Tongass is one of only 4 other relatively intact temperate rainforests (Great Bear – BC; Valdivia – Chile; Russian Far East; Southern Siberia). Thus, even though the overall global footprint of this rainforest biome is relatively small, the climate regulation properties of these forests – because of their enormous carbon stores – along with their myriad biodiversity and ecosystem benefits⁷⁷ – are globally significant and irreplaceable.⁷⁸ The Forest Service therefore has a national and global responsibility to maintain the intactness of this region and opening up roadless areas will have global ramifications contributing to the pace and scale of forest degradation globally. This is why 234 scientists signed a letter urging the Forest Service to protect the region's roadless areas (attached). The decision to open up roadless areas therefore is not based on best available science. At an absolute minimum, the Forest Service must correct its evaluation of the global importance of the Tongass's temperate rain forests and respond to these expert reports.

⁷⁵ Campbell et al. 2007; McNicol et al. 2019

⁷⁶ DEIS at 3-122.

⁷⁷ Brandt et al. 2014.

⁷⁸ DellaSala et al. 2011.

- **Unsubstantiated claims are made about management activities approximating and promoting natural processes** – The Forest Service states, without a single citation, that logging and prescribed fire tend to approximate and promote natural processes and that such actions can result in long-term carbon uptake and storage that somehow increases resilience.⁷⁹ We note that prescribed fire is not even relevant on the Tongass rainforest and has no purpose in this DEIS. The statement overall also has no basis in the ecological literature, and certainly none for the Tongass’s temperate rainforest, and seems to imply that forest degradation is a net gain in carbon and ecosystem processes even though the IPCC (2018, 2019) and numerous scientific studies indicate otherwise.⁸⁰ As discussed, the Forest Service needs to provide a reliable life cycle analysis and evidence-based review of the literature to back assertions that clearcut logging and road building somehow resemble natural disturbance processes – including effects on biodiversity (e.g., deer, wolves, murrelets and other old growth species). The statement, in fact, is reflective of old-school forestry ideologies long dismissed in the ecological literature and even by many foresters. Notably, given the lack of fire on the Tongass, primary disturbance agents are blow down from wind storms (canopy gap, stand, landscape level), landslides (watershed-landscape level), and tree mortality (stand level – canopy gaps – and watershed-landscape yellow cedar death from climate impacts). In no way do clearcuts, roads, mines, dams, etc. resemble any of these natural disturbances as natural disturbances leave prodigious amounts of biological legacies⁸¹ that “life-boat” a forest through successional stages while these developments in old growth and IRAs will remove nearly all biological legacies. The long return interval of natural disturbances allows for old growth to develop over centuries, whereas, logged areas can be logged again in <100 years; this is insufficient time for forests to recoup carbon emitted from logging and to reach their maximum carbon potential.⁸² We note that Public Law 113-291 (2014) allows up to 15,000 acres of young growth to be logged from 2016-2025 in stands < 95% CMAI and there is flexibility in NFMA to allow a continuation of harvesting at young ages beyond 2025 – thus, the carbon debt from re-logging these forests on a sustained yield basis is never recaptured and remains in the atmosphere for over a century at a time when we are in a climate emergency. The Forest Service needs to properly account for this carbon debt in the DEIS.

⁷⁹ DEIS at 3-123.

⁸⁰ See e.g., Harmon et al. 1990, Harmon et al. 1996, Mackey et al. 2014, Law et al. 2018, Moomaw 2019.

⁸¹ DellaSala 2019; Buma et al. 2019.

⁸² Moomaw 2019.

THE TONGASS RAINFOREST AS ALASKA'S FIRST LINE OF CLIMATE CHANGE DEFENSE AND IMPORTANCE TO THE PARIS CLIMATE CHANGE AGREEMENTS

Dominick A. DellaSala, Ph.D.
Chief Scientist, Geos Institute (Dominick@geosinstitute.org)



photo: J. Schoen

Executive Summary: the Tongass is a global champion in sequestering (absorbing) atmospheric carbon and storing it long-term in its ancient trees, productive soils, and dense rainforest foliage. Because it is one of the world's last relatively intact temperate rainforests, and it has a maritime climate, the Tongass is Alaska's first line of climate change defense and a climate refuge for its world-class salmon and wildlife populations. Logging of the Tongass rainforest produces greenhouse gas emissions that damages the region's contribution to a safe climate. Recognizing the critical need to reduce greenhouse gas emissions to keep global warming temperatures below a dangerous 2° C (~4° F) anticipated increase, a climate change agreement was reached in Paris by 195 members of the Conference of Parties (COP 21 also known as the 2015 Paris Climate Conference), including the USA. Articles of the agreement called for forests to be managed as a global "sink" for carbon. Therefore, protecting carbon sinks and reducing forestry emissions are pivotal steps to ensure a safe climate for Alaskans and for future generations.

Given the global importance of the Tongass as a carbon sink, we wanted to: (1) determine if the Tongass Draft Forest Plan Amendment (preferred alternative) was generally consistent with the Paris articles regarding managing forests as a carbon sink; (2) consistent with the Obama Administration's policies on climate change; and (3) whether the timeline for the proposed transition out of old-growth logging was consistent with efforts to end global deforestation under global forest and climate change agreements (e.g., COP 2, [NY Forest Declaration](#)). Thus, we estimated CO₂ emissions anticipated from logging old growth and young-growth forests as proposed by the Forest Service on the Tongass over the next 25 and 100 years and compared them to emissions under a conservation alternative designed to speed up the transition by relying mostly on soon-to-be-ready-for logging young growth as a replacement for old-growth logging.

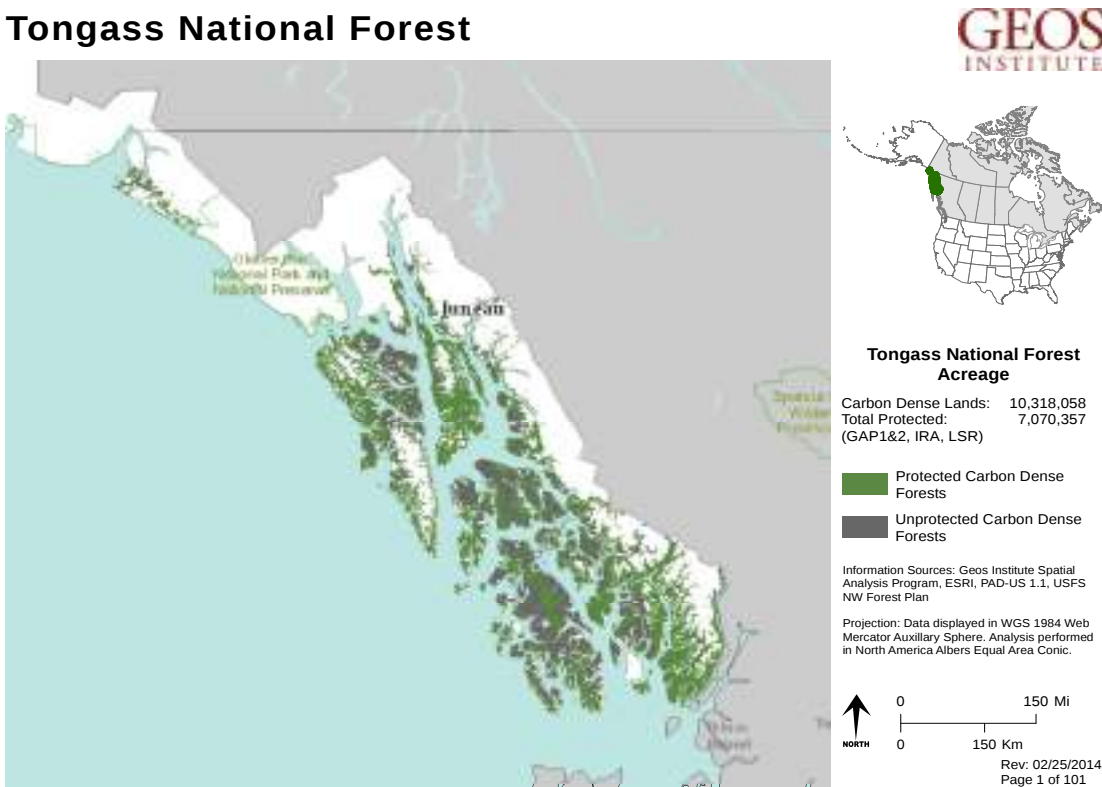
Key Findings (for 100 years):

- The agencies' preferred alternative would log 43,167 acres of old growth (OG) and 261,850 acres of young growth (YG) resulting in the equivalent emissions of ~4 million vehicles annually on Alaska roads for the next 100 years. These

estimates account for carbon stored in wood products and capture of carbon by forest regrowth.

- Logging emissions are ~175 times greater than the “reference point” for project emissions recommended by the White House’s Council of Environmental Quality (CEQ). Emissions would result in a “social cost of carbon” conservatively estimated at >\$100 million annually in global warming damages by the end of the century. Losses are ~10 times the projected timber revenues on the Tongass.
- A conservation alternative proposed by conservation groups (but dismissed by the Forest Service) would rely predominately on 76,000 acres of low controversy YG to support the transition with much less OG (9,125 acres over 100 years) to support specialty products. This alternative yields the equivalent emissions of over ~400,000 vehicles annually for 100 years, 16 times above CEQ emissions reference, but a tenth of the emissions from Forest Service proposed logging.
- The Tongass preferred alternative is out-of-step with efforts by the global community to reduce emissions. The conservation alternative better complies with CEQ guidelines, the Paris climate agreement, and efforts to reduce climate damages from CO₂ pollution.
- President Obama showed great interest in Alaska’s already extensive climate impacts during his September 2015 Alaska visit to showcase his climate change initiatives prior to the Paris conference. Continued OG logging on the Tongass would further jeopardize Alaska’s climate and is out of step with the President’s climate change agenda.

NO OTHER NATIONAL FOREST STORES MORE CARBON THAN THE TONGASS (map shows concentration of Tongass forest-carbon stores)



THE TONGASS IS A NATIONAL CARBON SINK

Photo: D. DellaSala



*“This is as good of a signpost as any when it comes to the impacts of climate change.”
President Obama during his September 2015 tour to Alaska glaciers.*

Alaska’s First Line of Climate Defense—Alaska is at the front lines of climate change, experiencing higher temperature increases than any other region in the nation along with increasing floods, coastal erosion and displacement of native villages, interior wildfires, die off of certain conifers, thawing of permafrost, and glacial melting (among other changes anticipated over the coming century)¹. If Alaska is on the front lines, then the Tongass is Alaska’s first line of climate defense.

At 16.8 million acres, the Tongass National Forest in southeast Alaska is the crown jewel of the national forest system. It is the nation’s largest national forest and one of the world’s last relatively intact temperate rainforests and thus it has global significance². Its world-class salmon runs are the backbone of a thriving subsistence, commercial fishery, and recreation-based economy³. The Tongass is by far the nation’s champion in storing carbon long-term⁴ and, in doing so, represents a unique opportunity for the Obama Administration to lead by example regarding its global commitments to the Paris climate change agreements designed to keep global warming below the dangerous 2° C (~4° F) presumed tipping point. During COP 21, the parties recognized the importance of forests as global “sinks” for storing greenhouse gases and called for steps by the global

¹Alaska Department of Environmental Conservation. 2010. Alaska’s climate change strategy: addressing impacts in Alaska. <http://www.climatechange.alaska.gov>

²DellaSala, D.A. 2011. Temperate and boreal rainforests of the world: ecology and conservation. Island Press: Washington, D.C.

³Crane, L.K., and J.R. Mehrkens. 2013. Indigenous and commercial uses of the natural resources of the North Pacific Rainforest with a focus on Southeast Alaska and Haida Gwaii. Pp. 89-126. In G.H. Orians & J.W. Schoen (eds.). North Pacific Temperate Rainforests. University of Washington Press, Seattle.

⁴Leighty, W.W. et al. 2006. Effects of management on carbon sequestration in forest biomass in southeast Alaska. *Ecosystems* 9:1051-1065

community to *conserve and enhance* forest sinks to help stabilize what may soon become run-away climate chaos.



[Conference of the Parties \(COP 21\)](#) Twenty-First session, Paris, December 12, 2015

“Recognizes the importance of adequate and predictable financial resources, including for results-based payments, as appropriate, for the implementation of policy approaches and positive incentives for reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks; as well as alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests.....

Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d), of the Convention, including forests.”

Photo: D. DellaSala



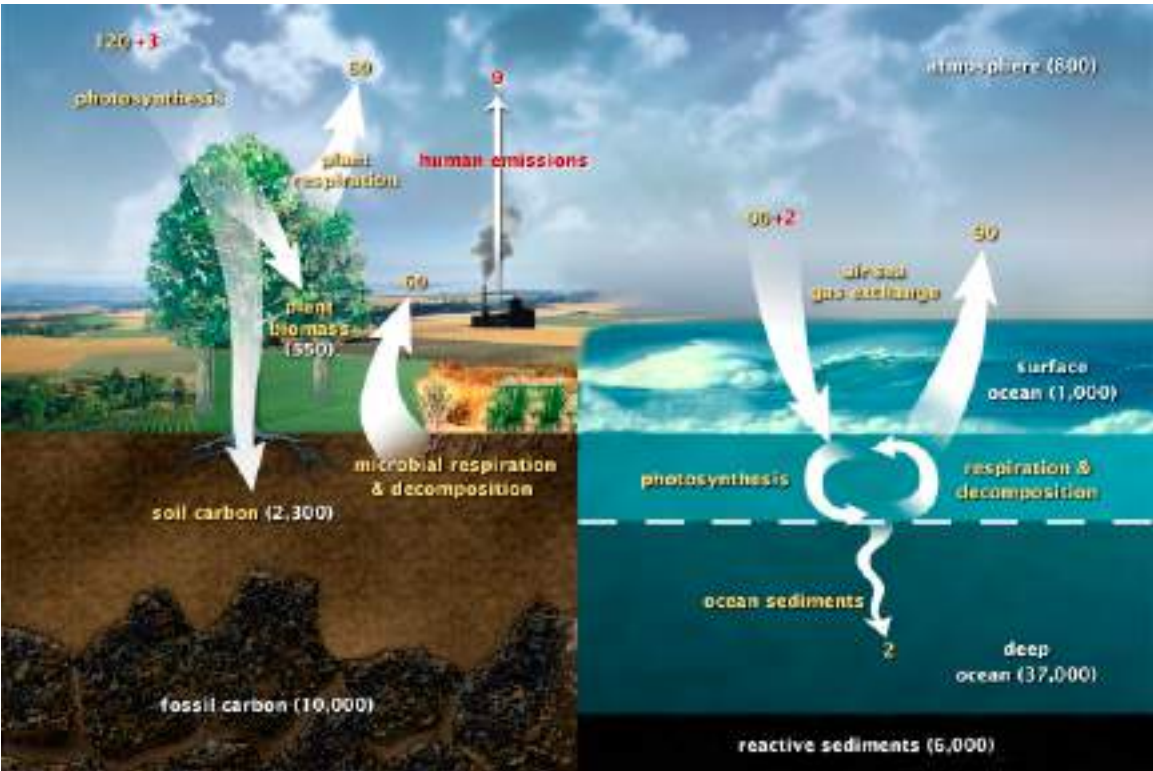
The Tongass is pivotal to the Obama Administration’s climate change commitments. The region’s forests not only store more carbon than any national forest, but also may function as a climate refuge (i.e., first line of defense) given maritime influences may moderate more extreme climate events anticipated for interior Alaska and temperate rainforests further south⁵. Relatively intact watersheds provide a refuge for old-growth dependent species (including many that are important to subsistence needs), and buffer salmon populations from cumulative effects of climate change and more extensive logging in the surroundings (non-federal lands)⁶.

Notably, prior estimates of net carbon flux from logging scenarios on the Tongass indicate that *only a no-logging scenario* maintains carbon stores through time⁴. Carbon

⁵DellaSala, D.A. et al. 2015. Climate change may trigger broad shifts in North America’s Pacific coastal rainforests. Online module – Earth Systems and Environmental Sciences – published by Science Direct

⁶For examples, see Watson, et al. 2013. Mapping vulnerability and conservation adaptation strategies under climate change. Nature Climate Change 3:989-994.

also has future economic value in terms of avoided costs from global warming pollution and development of carbon-offset markets. For instance, if carbon were stored long-term in old-growth forests instead of being released to the atmosphere by logging, the estimated annual economic value of carbon would be comparable to revenue generated from Tongass timber sales should carbon markets mature⁴. Moreover, the Interagency Working Group on Social Cost of Carbon estimated the cost of carbon in economic impacts from global warming would be \$27-221 per ton by 2050⁷. Recent evidence suggests the anticipated costs maybe much higher, including large demographic displacements of human populations along coastlines⁸.



Planetary carbon cycle with exchange of carbon among land, atmosphere, and oceans (billions of tons of carbon per year)⁹. Yellow numbers represent natural carbon fluxes, red are carbon dioxide emissions in billions of tons of carbon per year. White numbers show stored carbon. Note the fossil fuel related carbon stores in the diagram. Forests are integral to the earth’s carbon filtration system. http://en.wikipedia.org/wiki/Carbon_cycle

Photo: D. DellaSala



Forests as a Carbon Sink – forests are a vital part of the global atmospheric carbon cycle that contribute to climate stabilization by absorbing (sequestering) and storing vast amounts of carbon dioxide (CO₂) in trees (live and dead), soils, and understory foliage. As a forest ages, it continues to sequester and store carbon, functioning as a net “sink” for centuries if undisturbed. Ongoing carbon sequestration and storage has been measured in forests >800 years old¹⁰.

When a forest is cut down, roughly 66% to 80% of the stored carbon in the forest¹¹ is released overtime as CO₂ (some carbon is stored in wood products) thereby converting forests from a sink to a “source” or “emitter.” The minimal storage in wood products is an accounting misstep typical of federal agency carbon

⁷ Interagency Working Group on Social Cost of Carbon, United States Government. 2013. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866*. May.
⁸ Pizer et al. 2014. Using and improving the social cost of carbon. *Science* 346:1189-1190. DOI:10.1126/science.125974
⁹ Reprinted from DellaSala, D.A. In 2013. The carbon cycle and global change: too much of a good thing. Reference Module in Earth Systems and Environmental Sciences, Elsevier. 3 pp. <http://dx.doi.org/10.1016/B978-0-12-409548-9.05874-7>
¹⁰ Luyssaert, S. et al. 2008. Old-growth forests as global carbon sinks. *Nature* 455:213-215
¹¹ Wayburn, L.A. 2000 (several citations included). *Forest carbon in the United States: opportunities and options for private lands*. Pacific Forest Trust, San Francisco.

pronouncements that over value carbon in wood products¹².

Soon after logging, carbon is emitted to the atmosphere via rapid decomposition of logging slash, fossil-fuel emissions from transport and wood processing, and decay or combustion (within 40-50 years) of forest products in landfills¹³. Planting or growing young trees or storing carbon in wood products does not make up for emissions released from a logged forest. Indeed, after an old forest is clearcut, the young forest remains a net CO₂ emitter for 5 to 50 years, depending on site productivity¹⁴.

Logging on the Tongass is global warming pollution(photo: D. DellaSala)



Globally, deforestation (8-15%) and forest degradation (6-13%) **contribute more greenhouse gas pollution than the world’s entire transportation network¹⁵**, which is why countries, including the U.S., have committed to reducing emissions and protecting forest sinks (COP 21 climate agreements). Recognizing the importance of unlogged forests as carbon sinks, scientists also have repeatedly called on countries to protect their vast forest carbon stores as integral to stabilizing global climate change¹⁶.

¹²The White House. 2015. Climate change and the land sector: improving measurement, mitigation and resilience of our natural resources.

¹³Harmon, M.E. W.K Ferrel, J. F. Franklin. 1990. Effects on carbon storage of conversion of old –growth forests to young forests. Science 247:699-702.

¹⁴Law, B. E., and M.E. Harmon. 2011. Forest sector carbon management, measurement and verification, and discussion of policy related to climate change. Carbon Management 2:73-84.

¹⁵Estimates are conservative as they were mainly derived from the tropics where the majority of forest losses occur – boreal and temperate losses are not available at this time. Intergovernmental Panel on Climate Change. 2007. Synthesis report. An assessment of the IPCC on climate change. Houghton, R.A., B.Byers, and A.A. Nassikas. 2012. A role for tropical forests in stabilizing atmospheric CO₂. Nature Climate Change 5:1022-1023.

¹⁶MackeyB., et al. 2014. Policy options for the world’s primary forests in multilateral environmental agreements. Conservation Letters 8:139-147 DOI: 10.1111/conl.12120. Also letters sent to the Forest Service and USDA in 2015 signed by 7 scientific societies and hundreds of the nation’s leading natural resource scientists calling on the Administration to protect the Tongass old-growth rainforest sink.

Photo: The Big Thorne logging operation on Prince of Wales Island converted Tongass old-growth rainforest from a carbon sink to a source of emissions (S. Ballhorn)



"The Tongass National Forest is a national treasure. Today, I am outlining a series of actions by USDA and the Forest Service that will protect the old-growth forests of the Tongass while preserving forest jobs in southeast Alaska. I am asking the Forest Service to immediately begin planning for the transition to harvesting second growth timber while reducing old-growth harvesting over time." July 3, 2013 Press Release, USDA Secretary Tom Vilsack.

Tongass Is Transitioning But Not Soon Enough – Agriculture Secretary Tom Vilsack announced in July 2013 that a transition away from old-growth logging would need to occur rapidly on the [Tongass National Forest](#) while maintaining a viable timber industry. In November 2015, the Forest Service released a [Draft Environmental Impact Statement \(DEIS\) Plan Amendment](#) to transition the Tongass from predominately old growth to predominately young-growth logging with the preferred alternative adopting recommendations of a multi-stakeholder Tongass Advisory Committee that incorporated years of additional old growth volume as “bridge timber” to accommodate the transition. Here, we compare the Forest Service preferred alternative to a conservation alternative prematurely dismissed by the Forest Service as not producing enough volume. The agencies’ decision to dismiss this alternative occurred before completion of independent field inventories that now show sufficient volume from young growth can accommodate a more rapid transition with minimal old growth (Appendix I, report in preparation).

In conducting the Tongass logging emissions analysis, we compared the following:

- *Forest Service Preferred Alternative* – proposes logging 43,167 acres of old growth and 261,850 acres of young growth over 100 years with extensive road building (road building was not calculated in emissions scenarios although it certainly contributes to emissions).
- *Conservation Alternative* – proposed by conservation groups to accelerate the transition while meeting timber demand targets of the Forest Service using much less old growth (OG) to transition. Young growth (YG) estimates were provided by Mater Engineering (Appendix I) from field-verified 55-year old pre-commercially thinned (PCT) YG sampled from a land base of 76,000 acres of relatively low controversy areas (i.e., areas not considered environmentally sensitive based on a suite of attributes, manuscript in preparation). An additional 9,125 acres of old growth was estimated for specialty wood products over 100 years (Appendix I).

We estimated carbon stored in young and old forests by interpolating data from prior estimates on the Tongass⁴ for above ground biomass, which was higher than estimates used by the Forest Service for live tree carbon only. We projected logging emissions of the two alternatives over 25- and 100-year increments. We then converted logging emissions to equivalent emissions from vehicles using [EPAs equivalencies calculator](#) and compared these projected emissions to CEQ’s draft “reference point” for minimizing emissions of federal actions. CEQ directs agencies to adopt projects with low emission using a reference of 25,000 metric tons of CO₂(e)¹⁷ on an annual basis¹⁸. We used the CEQ reference for two reasons: (1) to determine if the preferred alternative is generally consistent with the Obama Administration’s global warming commitments (COP 21, Paris agreements); and (2) to provide an appropriate regional comparison of logging emissions that is based on easy to understand emissions comparable. Notably, the Forest Service based logging emissions projections on comparisons to the entire U.S. annual greenhouse gas emissions (the wrong scale of comparison), masking the severity of regionally specific climate impacts.

ESTIMATING LOGGING EMISSIONS USING VEHICLE EQUIVALENTS

Photo: Juneauempire.com



Forest Service Preferred Alternative – In general, the agencies’ preferred alternative to log substantially more OG and YG than proposed by the conservation alternative is estimated to generate **annual** emissions that are:

- equivalent to 4 million vehicles annually for 100-years (Appendix II); and
- 175 times > the CEQ emissions reference.

Conservation Alternative – the transition proposed by the conservation alternative uses much less OG and is estimated to generate **annual** emissions that are:

- equivalent to 419,535 vehicles annually (Appendix II); and
- 16 times > the CEQ emissions reference.

The conservation alternative, while also exceeding CEQ’s reference, yields 10 times less emissions in the long-term compared to the agencies’ preferred alternative and therefore should have been kept in the DEIS as a reasonable alternative under NEPA. The agencies’ preferred alternative is generally inconsistent with the COP 21 climate agreements

¹⁷Carbon dioxide equivalents (CO₂e) are an internationally accepted term for comparing different greenhouse gas emissions using a common (standardized) unit of analysis.
¹⁸CEQ 2014. Draft published for public review and comment Dec. 2014. White House.https://www.whitehouse.gov/sites/default/files/docs/nepa_revised_draft_ghg_guidance_searchable.pdf

(Article 4 on greenhouse sinks) to conserve forests as a sink for atmospheric carbon and is well above the CEQ emissions reference.

SOCIAL COSTS OF CARBON

Photo: S. Ballhorn



[Executive Order 12866](#) requires federal agencies to “*assess both the costs and benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that benefits of the intended regulation justify its costs.*”

We provide an estimate of the social cost of carbon (SCC) derived from relevant published sources as a means for costing emissions in a regional context and to illustrate how the Forest Service could achieve compliance with the Executive Order by documenting climate costs of logging and the benefits of maintaining the Tongass carbon sink.

In any cost-benefit analysis, it is imperative to incorporate the *benefits* (or cost savings) of avoiding damages to the environment, or, in this case, the climate, so as to level the economic playing field (although many ecosystem services critical to properly functioning forests are difficult to quantify). In this case, SCC is expressed as monetized damages associated with incremental increases in emissions, including, but not limited to changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. An Interagency Working Group on SCC estimated the **annual** cost of releasing emissions to be \$27-221 per ton of carbon using 2050 projections. For this analysis, we used the lower bound of \$27 per metric ton of CO₂(e) to estimate potential costs of logging emissions recognizing costs will escalate overtime as a result of the accumulation of regional and global emissions under status quo emissions scenarios.

Forest Service Preferred Alternative - CO₂ (e) released from logging would contribute to:

- ~\$108 million annually in global warming costs over 100 years. Estimated costs are 10 times greater than the \$8-10 million in annual wood products value anticipated by the Forest Service (DEIS Table 3.22-16).

Conservation Alternative - CO₂(e) released from logging would contribute to:

- ~\$11 million annually in global warming costs, a tenth as costly as the Forest Service alternative.

Thus, the conservation alternative represents a cost savings to the foreseeable future climate compared to the Forest Service's preferred alternative that would result in much higher costs due to greater logging emissions and this should have been included in the agencies' NEPA analysis. It should be noted that *only a no-logging alternative* results in maximizing carbon sinks and generating a positive SCC. This is because removing carbon from a forest always results in some costs to the climate (costs are based on the combination of regional logging intensity and global emissions contributions).

LIMITATIONS, UNCERTAINTIES, AND THE FUTURE CLIMATE

Photo: A. DellaSala



Follow Up Research and Monitoring – accurately estimating carbon in regional forest assessments requires the use of new carbon assessment tools and improved inventories (including soils) along with inclusion of sequestration rates (e.g., Net Ecosystem Productivity). Carbon assessments are costly but necessary to develop proper carbon flux estimates from logging and to evaluate SCC as a multiple-use objective. In this case, we approximated emissions from published sources, published estimates of carbon stored in wood products (using conversion factors), and published estimates of carbon capture via forest regrowth (using nationally recognized [online carbon tools](#)).

Without the benefit of a comparable analysis, however, the Forest Service claims that logging old-growth forests could result in *either a net loss or gain* of carbon depending on logging practices even though clearcut logging (a substantial emissions source) is the method of choice on the Tongass (some young tree retentions and small (<10 ac) clearcuts are proposed in young forests within Old Growth Reserves and Beach buffers by the agency). Our findings are meant to provide a better estimate of emissions than the DEIS. Moreover, we used an appropriate scale of analysis that tiers to CEQ emissions guidelines and used comparable emission sources (e.g., vehicle equivalents that are locally applicable) to evaluate the magnitude of regional impacts. Follow up work, ideally conducted by the Forest Service in collaboration with scientists, is needed to improve upon these estimates and address uncertainties.

Climate Shift Happens – Notably, the effects of climate change on forest productivity represents additional uncertainties. As the climate warms in Alaska, other vegetation types may replace conifer forests that evolved under a cooler climate³. For instance, during the Miocene millions of years ago Alaska was a much warmer place dominated by hardwood forests. As climate change now accelerates, it could lower carbon storage in conifer forests as the climate conducive to hardwoods gradually replaces conifers and some conifers die off from climate change effects (thereby releasing CO₂ as is currently

happening with an extensive die-off of Alaska yellow cedar¹⁹). However, the maritime climate of the Tongass might ameliorate some of these shifts compared to more extreme changes anticipated for interior Alaska and temperate rainforests to the south³.

Photo: A. DellaSala



**ALASKA’S FIRST LINE OF CLIMATE CHANGE DEFENSE AT RISK:
CONCLUSIONS**

Although the Obama Administration took a leadership position during the climate negotiations in Paris, its global commitments to lower emissions and end deforestation ostensibly do not extend to Alaska’s globally significant Tongass rainforest carbon sink.

The Administration has a unique opportunity to demonstrate to the world that it takes its climate change commitments seriously by quickening the pace of transition without relying on controversial timber sales that will cost more in future economic losses from climate change than the revenues generated by logging. The Forest Service has not conducted a logging emissions analysis as directed by CEQ. It has not conducted a cost-benefit analysis of the SCC implications of more OG logging and is out of compliance with Executive Order 12866. The feasibility of an accelerated transition was demonstrated in the conservation alternative summarily dismissed by the agency but which uses much less OG and generates far less emissions over time.

A robust analysis using carbon life cycle accounting is needed to more fully assess the social cost of carbon using advancements in forest carbon accounting as declared in recent climate change policies of the White House¹¹. The Tongass is a known carbon sink, yet land-use emissions¹¹ references the importance of climate resilience best achieved through ecosystem and landscape conservation. Ecosystem resilience, and therefore the Tongass carbon sink, will decline on the Tongass with another 100 years of OG logging and road building. Proposed logging will be occurring at a time when the climate is changing the likelihood that the Tongass can function as a climate refuge³.

“I loved Alaska and met so many inspiring people. Have to keep up the fight on climate change for their sake—and ours.” President Obama on his September visit

The international community clearly spoke up in Paris about the strategic value of forest sinks in keeping global warming below the dangerous 2° C threshold. Choosing a climate responsible alternative for the Tongass would allow the Obama Administration to live up to its commitments to safeguard Alaska’s climate, comply with the COP 21 climate agreements and its pledge to end global deforestation.

¹⁹Hennon P.E.et al. 2012. Shifting climate, altered niche, and a dynamic conservation strategy for yellow-cedar in the North PacificCoastal Rainforest. Bioscience 62: 147–158.

“We share the vision of slowing, halting, and reversing global forest loss while simultaneously enhancing food security for all. Reducing emissions from deforestation and increasing forest restoration will be extremely important in limiting global warming to 2°C.” United Nations Climate Summit New York Declaration on Forests (agreed to by 157 governments, including the U.S, indigenous groups, corporations, NGOs, and others)

APPENDIX I. YOUNG GROWTH LOGGING LEVELS NEEDED TO HIT TIMBER DEMAND THRESHOLDS OF THE FOREST SERVICE CALCULATED FROM MATER 2015 PHASE II CRUISE RESULTS (IN PUBLICATION PREPARATION).

Estimated Avg Length of Tree Residual for PCT Stands When Harvest at 55 yrs Based on 2015 Cruise Results <i>(lineal ft from top of merchantable log to tree top)</i>			
	Trees producing <i>two</i> 34' logs (ft)	Trees producing <i>one and a half</i> 34' logs (ft)	Trees producing <i>only one</i> 34' log (ft)
2020	36	27.4	40.86
2025	38.7	41.1	45.23
2030	33.4	31.9	39.39

Conservation Alternative

- With 80% merchantable volume growth every 5 yrs per 2015 cruise results
- Focus on *one and a half* log-producing trees

Annual mbf harvested 2020-2024
33,074
Annual mbf harvested starting 2025
46,000

Industry Demand (DEIS)	46,000
Public Law 113-291	
Total acres harvested; first 10 years	15,000 ac max
Annual acres harvested; first 5 years	3,000 ac max
Annual acres harvested; next 5 years	3,000 ac max
Total acres harvested overall	50,000 ac max
Acres harvested per year after 10 years	5,000 ac max
Total acres harvested: 25 years	23,727
Total acres harvested: 100 years	76,002 (44,636 before re-harvest)

APPENDIX II: ESTIMATED LOGGING EMISSIONS UNDER THE FOREST SERVICE PREFERRED ALTERNATIVE (DEIS) VS. A CONSERVATION ALTERNATIVE IN 25- AND 100-YEAR INCREMENTS AND IN RELATION TO CEQ'S EMISSIONS GUIDELINES (25,000 METRIC TONS CO₂ (E) ANNUALLY)

	DEIS	Conservation Alternative
	- Comply with PL 113-291 (harvest <u>below</u> CMAI) on 14% of acres - Harvest <u>above</u> CMAI on 86% of acres - Harvest <u>above</u> stated FS demand volume (46 mmbf/yr)	- Comply with PL 113-291 (harvest <u>below</u> CMAI) on 100% of acres - Harvest <u>capped</u> at FS demand volume (46 mmbf/yr)
Acres to be harvested first 25 years	37,390 ac SG below CMAI (@65 yrs) 23,223 ac OG (@ 120 yrs)	23,727 ac SG below CMAI (@55 yrs) 3,500 ac OG (@ 120 yrs)
Acres to be harvested next 75 years	224,460 ac SG above CMAI (@120 yrs) 19,944 ac OG (@ 120 yrs)	52,273 ac SG below CMAI (@55 yrs) 5,625 ac OG (@ 120 yrs)
	After initial harvest, re-growth, and (where applicable) re-harvest:	
Total CO ₂ (e) emissions	In 25 years	In 25 years
	105,347,668 tons (4,213,907 tons/yr)	36,576,407 tons (1,463,056 tons/yr)
	In 100 years	In 100 years
	441,068,733 tons (4,410,733 tons/yr)	41,953,532 tons (419,535 tons/yr)
Multiplier above CEQ annual CO ₂ (e) emissions limit of 25,000/yr	In 25 years	In 25 years
	x 168	x 58
	In 100 years	In 100 years
	x 175	x 16

Calculation Notes (all other calculations will be posted online):

- Carbon values interpolated from Leighty et al. 2006 Fig. 2 for age classes as follows: 55 years (494 tons per ac), 65 years (585 tons per acre), 120 years (776 tons per acre).
- Emissions adjusted to account for wood products stores using published estimates in footnote 10 and then multiplied by 3.67 to convert to metric tons CO₂ (e).
- Logging emissions are equivalent to passenger vehicle emissions <http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>.
- CEQ reference = 25,000 metric tons CO₂ (e): <https://www.federalregister.gov/articles/2014/12/24/2014-30035/revised-draft-guidance-for-federal-departments-and-agencies-on-consideration-of-greenhouse-gas>
- PL 113-291 requires: no more than 50,000 acres of initial YG (not including re-harvest acres) logging; total YG logging in first ten years cannot exceed 15,000 ac; 3,000 ac annual acres in first five years; 3,000 acres annual in 6-10 yrs; and 5,000 YG acres annual after 10 years. If the timber volume goal is 46 mmbf/yr and compliance with PL113-291, the conservation alternative would log: 8,480 acres YG in 2020-2024 (1,696 ac/yr @ 13mbf/ac with a 1.5 multiplier for long log to short log recovery factor) producing 33 mmbf/yr.; not enough pre-commercially thinned 55-yr old stands are available at this time to meet the timber target exclusively from YG); 4,790 acres in 2025-2029(958 ac/yr @ 32mbf/ac with a 1.5 multiplier for long log to short log recovery factor meets that target); 697 acres YG annual logging beginning in 2030 (1.5 multiplier for long log to short log recovery factor producing 46 mmbf/yr @ 44 mbf/ac). See Appendix I for Mater 2015 YG numbers plus specialty OG products (e.g., 3 mmbf/yr = 75 ac OG logged per year using a mid point of 40,000 board feet per acre Class 6 old growth (Tongass DEIS: 3-295) to back calculate to acres logged).

Article

The Tongass National Forest, Southeast Alaska, USA: A Natural Climate Solution of Global Significance

Dominick A. DellaSala ^{1,*}, Seth R. Gorelik ²  and Wayne S. Walker ²

¹ Wild Heritage, a Project of Earth Island Institute, 222 Joseph Drive, Talent, OR 97540, USA

² Woodwell Climate Research Center, 149 Woods Hole Road, Falmouth, MA 02540, USA; sgorelik@woodwellclimate.org (S.R.G.); wwalker@woodwellclimate.org (W.S.W.)

* Correspondence: dominick@wild-heritage.org

Abstract: The 6.7 M ha Tongass National Forest in southeast Alaska, USA, supports a world-class salmon fishery, is one of the world's most intact temperate rainforests, and is recognized for exceptional levels of carbon stored in woody biomass. We quantified biomass and soil organic carbon (C) by land use designation, Inventoried Roadless Areas (IRAs), young and productive old-growth forests (POGs), and 77 priority watersheds. We used published timber harvest volumes (roundwood) to estimate C stock change across five time periods from early historical (1909–1951) through future (2022–2100). Total soil organic and woody biomass C in the Tongass was 2.7 Pg, representing ~20% of the total forest C stock in the entire national forest system, the equivalent of 1.5 times the 2019 US greenhouse gas emissions. IRAs account for just over half the C, with 48% stored in POGs. Nearly 15% of all C is within T77 watersheds, >80% of which overlaps with IRAs, with half of that overlapping with POGs. Young growth accounted for only ~5% of the total C stock. Nearly two centuries of historical and projected logging would release an estimated 69.5 Mt CO₂e, equivalent to the cumulative emissions of ~15 million vehicles. Previously logged forests within IRAs should be allowed to recover carbon stock via proforestation. Tongass old growth, IRAs, and priority watersheds deserve stepped-up protection as natural climate solutions.

Keywords: carbon emissions; carbon stores; inventoried roadless areas; old-growth forest; southeast Alaska; temperate rainforest; Tongass National Forest; natural climate solutions



Citation: DellaSala, D.A.; Gorelik, S.R.; Walker, W.S. The Tongass National Forest, Southeast Alaska, USA: A Natural Climate Solution of Global Significance. *Land* **2022**, *11*, 717. <https://doi.org/10.3390/land11050717>

Academic Editor: Svetlana Turubanova

Received: 13 April 2022

Accepted: 4 May 2022

Published: 10 May 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The 6.7 M ha Tongass National Forest (TNF) in southeast Alaska, USA, is the largest national forest managed by the USDA Forest Service in the 77.2 M ha national forest system. The region's productive old-growth forests (POGs; wood standing volume >46.6 m³/ha; forests ≥150 years old) [1,2] contain far more old growth than any other national forest, providing opportune settings for large-landscape conservation in one of the world's most relatively intact temperate rainforests [2,3]. The TNF also has been the focus of logging debates for decades with pro-conservation presidential administrations enacting forest protections and pro-development ones allowing increased timber removals. Under President Bill Clinton, the National Roadless Conservation Rule of 2001 [4] protected from development 23.4 M ha of federally Inventoried Roadless Areas (IRAs ≥ 2000 ha) across the entire national forest system, 3.7 M ha of which was in the TNF, the largest such expanse. Roadless areas tend to have higher levels of biodiversity and intact ecosystem services than logged and roaded areas [5–7].

To date, there have been 14 legal attempts to overturn roadless protections as they apply to the Tongass; none have invalidated the conservation rule in appellate courts (e.g., <https://earthjustice.org/features/timeline-of-the-roadless-rule>; accessed on 15 April 2022). However, both the George W. Bush and Donald Trump administrations used executive powers to roll back roadless protections on the Tongass in favor of old growth logging

and development. The Joe Biden administration is set to “repeal or replace” the Trump reversal [8], and thus it is imperative that roadless values are well documented, particularly as conservation outcomes are ostensibly tied to political parties changing hands.

Industrial-scale POG logging began ramping up on the Tongass with passage of the Tongass Timber Act of 1947 that authorized two federally subsidized fifty-year pulp contracts [9]. The contracts expired in 2000 and, in 2016, the Barack Obama administration amended the Tongass Land Management Plan (TLMP) of 2008 with the intent to transition logging out of POGs and into suitable young-growth forests (previously logged, naturally reforested, and now commercially viable) [10]. Professional fish and wildlife societies and many scientists have repeatedly called for stepped-up protections for all POGs and IRAs on the TNF (e.g., <https://conbio.org/policy/scb-and-other-science-societies-call-on-president-obama-to-save-tongass-rai>; accessed on 12 February 2022). Conservation groups also have proposed 77 priority watersheds for salmon and wildlife known as the “Salmon Forest Proposal” or the “Tongass 77” (herein T77) [11]. Notably, POG logging was prohibited within the T77 under the 2016 TLMP transition amendment; however, that too was reversed by the Trump administration shortly thereafter. On 15 July 2021, the Biden administration announced plans to end all “large-scale old-growth logging” on the TNF, thereby providing de facto protections once again for most POGs, IRAs, and T77 priority areas while restarting the transition to timber harvests focused on young growth (<https://www.whitehouse.gov/briefing-room/presidential-actions/2021/07/15/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/>; accessed on 12 April 2022). Some small-scale POG logging would be permitted in transition.

Carbon (C) stocks have been quantified previously on the TNF [12] and recognized as nationally significant by USDA Forest Service researchers [13–15] and in congressional policy reviews [16]. However, the USDA Forest Service has undervalued the C stock importance of the TNF by routinely dismissing stock change from logging as inconsequential to total US greenhouse gases (GHGs) [10,17]. Further, the agency believes that logging emissions are simply offset by the storage of C in harvested wood product (HWP) pools and natural reforestation [10,17,18]. The significance of the region to the development of US forest policy around natural climate solutions demands that spatially explicit data on Tongass carbon stocks be updated and an assessment of stock change be attributable to historical, contemporary, and anticipated logging levels.

It follows that our objectives are to: (1) quantify current biomass and soil carbon stocks within land cover (POG, young growth) and land use categories (IRAs, T77 watersheds); and (2) estimate C emissions spanning ~2 centuries of logging on the TNF. Our analysis is key to shedding light on the importance of IRA protections and policy options for both old growth and young-growth forests. Given the national significance of C stocks on the TNF [12], managing forests to maximize C stock potential would demonstrate the US has made a forest-based nationally determined contribution (NDC) to the Paris Climate Agreement. Article 5.1 of the agreement recognizes the need for countries to take specific actions that conserve and enhance nature-based solutions as C sinks and reservoirs [19].

2. Methods

2.1. Study Area

The TNF in southeast Alaska is within the North Pacific Coastal Forest bioregion, which includes several WWF Global 200 ecoregions. At a finer scale, the Tongass also spans the perhumid temperate rainforest climate subzone [20], recognized as globally unique [2,3] (Figure 1). Temperate rainforests are distributed on the Alaskan mainland juxtaposed against the windward edge of the Coast Mountains, separating Alaska from British Columbia. Rainforests are scattered across an archipelago of thousands of islands from the Dixon Entrance (54° N) northward to Yakutat Bay (just north of Glacier Bay, 59° N), a distance of 835 km that includes 30,000 km of shoreline [3]. Interspersed are tree-stunted muskegs, tidewater glaciers, and deeply dissected fjords. Approximately 20% of the TNF is non-forested [10]. Importantly, about 90% of temperate rainforest on the TNF was

considered POG in the early 1990s [21], among the largest such concentrations of temperate rainforests [3]. However, only 3% of forested areas include the largest old-growth trees (highest timber volumes) due to high-grade logging prior to the 1990s [1]. “Unproductive” old growth also occurs mostly in muskegs having no commercial timber value [10].



Figure 1. Study area (dark gray), defined as land managed by the United States Department of Agriculture Forest Service within the administrative boundary of the Tongass National Forest, southeast Alaska, and the spatial distribution of young-growth forest (light green) and productive old-growth forest (dark green).

The Koppen Climate Classification subtype for the southeast Alaska region of our study area is “Dfc” (Continental Subarctic Climate). Mean precipitation during the winter is 642 mm (125 mm to 1473 mm range) and mean temperature in the summer is 12.5 °C (9.9° to 17.9 °C range), which is on the wetter, cooler side of temperate rainforests globally [3].

Due to the northern latitude and short growing seasons, treeline on the TNF is generally 300 m, declining northward. Old-growth forests are characterized by multi-layered forest canopies mainly of western hemlock (*Tsuga heterophylla*), yellow-cedar (*Callitropsis nootkatensis*), mountain hemlock (*T. mertensiana*), Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), and low growing shore pine (*Pinus contorta*) on wetter sites such as muskegs. Rainforest understories are rich in forbs and shrubs [20,21] with dense mats of oceanic lichens and bryophytes that carpet the ground and extend into the overstory canopy.

Prolific salmonid runs include chum (*O. keta*), coho (*O. kisutch*), king (*O. tshawytscha*), pink (*O. gorbuscha*), sockeye (*O. nerka*), and steelhead trout (*O. mykiss*) that support some of the largest concentrations of brown bears (*Ursus arctos*) and bald eagles (*Haliaeetus*

leucocephalus) in the world [2,3]. Notably, old-growth forests and IRAs provide important refugia for salmonids and Sitka-black tailed deer (*Odocoileus hemionus sitkensis*), considered staple food sources for Alaskan tribes [2,3].

The T77 portion of the study area was based on a spatially explicit ranked-analysis performed by Trout Unlimited, the Nature Conservancy, and Audubon Alaska [11] (<https://databasin.org/datasets/72977f90d25a4fc9f455b9017f2a5e2/>; accessed on 5 May 2022).

This dataset includes the highest ranked watersheds in 14 biogeographical provinces on the TNF based on a suite of attributes, including: top-ranked habitat for the six salmonid species; habitat of the marbled murrelet (*Brachyramphus marmoratus*), a federally threatened seabird species that nests in old-growth forests from California to Washington; black bear (*Ursus americanus*) and brown bear summer habitat; Sitka black-tailed deer wintering habitat; and estuaries and riparian areas that have large-tree, old-growth forests [11]. Excluded were watersheds already protected, in non-federal ownership, managed for other values (such as urban recreation, experimental forest, or timber), and lacking public support [11]. T77 watersheds total 764,855 ha (~11% of the TNF land base); however, they have never been analyzed for C stocks.

2.2. Timber Sale Datasets

We accessed USDA Forest Service datasets on timber volume sold on the TNF and allocated them into five time periods (bins): (1) early historical (ca 1909–1951) [9]; (2) pulp (1952–2000) [22,23]; (3) post pulp (2001–2015) [9]; (4) transition (2016–2021) [10,24]; and (5) future (2022 projected to the end of century) [10].

Tongass management priorities are based on a zoning process known as Land Use Designations (LUDs). In general, there are 18 LUDs nested within three major groupings (summarized herein). LUD 1 includes strictly protected Wilderness and National Monuments; LUD 2 includes Natural Settings managed for non-motorized recreation, old-growth and watershed protections, and Research Natural Areas; and LUD 3 (Development) is managed mainly for timber and mineral extraction. This is in addition to IRAs that are a separate administrative category that precludes most development.

2.3. Carbon Datasets

Our spatially explicit gridded estimates of C density (ca. 2019) in woody plant biomass are derived from a combination of published datasets spanning the study area (Table S1). Researchers [25] combined FIA ground measurements ($n > 1000$ plots) with environmental covariates (e.g., topography, climate, and disturbance) to calibrate a machine learning algorithm producing lower and upper bound 30 m gridded estimates of C density (metric tons of carbon per hectare, $t\ C\ ha^{-1}$). These were grouped by woody biomass pools including live trees, roots, woody debris, seedlings/saplings, snags, and understory vegetation. C density estimates represent potential C storage, which should closely approximate current storage in old-growth ecosystems, but do not account for active or historical removals of C from logging. Thus, we applied pixel-level adjustments to estimate current (ca. 2019) C density in woody plant biomass. This was accomplished using tree cover data [26] to establish a baseline of ca. 2000 forest cover (>25% tree canopy within a 30 m grid cell), which we then used to remove (i.e., set to zero) all non-forested pixels from the ca. 2000 C density layers. Grid cells were also set to zero if they were identified in the tree cover data [26] as having lost forest cover during the 2001–2019 period. The remaining grid cells reflect the lower and upper bound estimates of current C density in all woody biomass pools. As a result of logging activities prior to 2000, these data are expected to overestimate C stock in young-growth forest.

For a small portion of the study region not included in prior work [25], we estimated C density using a multi-step approach. First, we combined the forest cover loss information for the 2001–2019 period [26] with the 30 m map of aboveground live dry woody biomass (AGB) density (ca. 2000) [27] to estimate current (ca. 2019) AGB density. Next, for grid cells in which we had estimates (ca. 2019) of both AGB ([27], modified data) and all woody

biomass pools combined [25] (modified data), we computed the ratio of C in AGB to all biomass pools by forest group (using USFS data). Finally, we applied these ratios as a scaling factor—again by forest group—to the grid cells in which we had only estimates of AGB density, thus producing lower and upper bound estimates, as well as pixel-level mean estimates, of C density in all woody biomass pools Tongass-wide.

Soil C stocks were included using recently published data for the region. We used a 90 m gridded estimate of soil organic C for the top 1 m of mineral soil, including surface organic horizons [28]. We extracted the study region, resampled the grid cells to 30 m using a nearest neighbor approach and re-projected the data to the same coordinate reference system as the biomass density layers.

C stock herein refers to the total amount of C within a defined area and is generally displayed in units of millions (M) of metric tons (t) or petagrams (1 Pg = 1 billion t). Additional information on the errors and uncertainties associated with the biomass and soil C data sets incorporated here can be found in [25,26,28].

2.4. GIS Overlays

Several geospatial datasets were used to further characterize C stocks within the study area. First, the administrative boundary of the study area, land ownership information, and IRAs designated by the 2001 Roadless Area Conservation Rule were retrieved from the USFS Geodata Clearinghouse (<https://data.fs.usda.gov/geodata/>; accessed on 12 April 2022). Forest growth information, including spatially explicit delineations of young growth and POG—also produced by the USFS—were obtained via [databasin.org](https://data.basin.org). All GIS layers were acquired as Esri (polygon) shapefiles. Additional geospatial data used to identify scenarios of IRAs at risk from potential forest management plan changes were acquired from The Nature Conservancy and Audubon Alaska (18 September 2019, personal communication, D. Albert). We rasterized, re-projected, and resampled all layers to match the spatial resolution (30 m) and coordinate reference system of the C density estimates. Next, across all layers, areas outside of the study region were masked as No-Data grid cells. Areas of overlap between the young growth and POG layers were allocated to the young growth category. We then used raster-based zonal statistics to quantify the magnitude of C stored in woody biomass and soil organic matter (to a depth of 1 m) inside and outside of the areas defined by the various GIS overlays described above. All geoprocessing, analysis, and visualization were performed using R statistical software (version 3.4, <https://www.r-project.org>; accessed on 5 May 2020), Python (version 3.6, <https://www.python.org>; accessed on 5 May 2020), GDAL (version 3.2, <https://gdal.org>; accessed on 5 May 2020), and Esri ArcGIS Pro (version 2.9, <https://www.esri.com>; accessed on 5 May 2020).

2.5. Evaluating At-Risk IRA and POG Scenarios

Administrative policy changes on the TNF have mainly centered on IRAs. Therefore, using the GIS methods and spatial data sets described above, we analyzed existing C stocks and thus, the potential loss of these C stocks, as part of three policy scenarios: (1) all IRAs within the 2016 TLMP Development LUDs are vulnerable; (2) only IRAs with POGs within 2016 TLMP Development LUDs are vulnerable; and (3) all IRA POGs within the 2016 TLMP Development LUDs considered suitable for logging are vulnerable based on reversion to the 2008 TLMP plan (which could happen under a pro-development future administration).

2.6. Estimating Emissions from Harvested Wood Products

We estimated CO₂ emissions associated with past (1909–2021) and projected (2022–2100) logging for wood product pools (HWP) on the TNF following published methods [29]. Logging for wood products removes C from the forest, transferring it to a series of production phases and end uses. Some fraction of the extracted C (i.e., roundwood) is temporarily stored in wood products (e.g., lumber, plywood, paper, etc.) while they remain in use, followed by eventual disposal and emission to the atmosphere [30]. Determining the

climate impacts of HWP typically involves estimating C that is temporarily stored in wood products and in solid waste disposal (SWD) sites. The difference between the amount of C in roundwood removed from the forest and that stored in products and SWD sites at any given time constitutes realized emissions [29,30].

The most common method used to estimate CO₂ emissions from HWP is the Production Approach, which tracks C in wood that was harvested in a specified area regardless of where the wood is ultimately consumed. There are several accounting options that guide this calculation [29]. Here, we estimated the amount of C from a given year's logging (annually 1909–2100) that remains stored in end uses and landfills over a subsequent 100-year period [30]. This approach approximates the annual climate impact of withholding C from the atmosphere (i.e., C temporarily stored in HWPs) by a certain amount each year for 100 years as described by a series of decay curves [29]. The 100-year disposition approach facilitates tracking the full temporal impact of harvesting and attribution from the year in which the logging occurs to the year when emissions are ultimately realized (i.e., “seen” by the atmosphere).

Figure S1 illustrates the basic set of calculations used to track C in HWP from forest removal to timber products to primary wood products to end uses and finally to disposal, applying regional estimates for product ratios and half-lives at each stage. Harvest records are used to distribute annual cut volumes among specific timber product classes (e.g., softwood, sawtimber). Timber products are further distributed to specific primary wood products (e.g., softwood lumber, softwood plywood, softwood mill residue used for non-structural panels, etc.) using default average primary product ratios from national level accounting that describe primary products output according to regional forest industry structure [31,32].

We implemented the following multi-step procedure [29] in the R software package: (1) enter roundwood harvest data for the reporting period; (2) allocate harvest to product classes (e.g., sawtimber softwood, pulpwood softwood); (3) estimate the weight of harvested wood using average specific gravities by species group; (4) calculate the weight of harvested C for each harvest year; (5) estimate the 100-year annual disposition of C as fractions of roundwood by product class; (6) calculate C stock changes in the HWP pool and emissions for the inventory period; and (7) calculate annual additions to the HWP pool and associated emissions for the inventory period.

As inputs to this procedure, we used TNF timber harvest records for the period 1909–2021 obtained from USDA Forest Service cut history reports [9]. Harvest projections (2022–2100) were based on the Tongass Forest Plan [10]. We applied the average annual proportions of Alaska region harvests distributed to timber product classes ([33]: Table 3). We established decay rates following disposition patterns contained in the literature ([29]: Table 6-A-5) for the Pacific Northwest-West (PNW-W) region. Other researchers [29] did not include comprehensive (i.e., 100-year) decay functions, but rather included disposition patterns based on a subset of points along the trajectory of each function (i.e., years 1–10 and five-year intervals thereafter beginning in year 15). We estimated decay functions for PNW-W softwood sawlog and pulpwood emissions by fitting asymptotic regression functions to these data (SSasymp) in R.

We note that our results do not reflect total gross emissions from logging; rather, they are limited to the fate of harvested roundwood removed from the forest. Other logging-related emissions, including decay of logging residue, decomposition of litter, and loss of soil organic C were not included. Similarly, the results do not reflect net emissions as they do not consider, for example, C sequestration associated with forest regrowth nor do they account for emissions reductions that might be realized through material substitution, i.e., when wood is substituted for other building materials such as concrete or steel, although wood substitution benefits have been grossly overstated [34].

3. Results

3.1. Young vs. Productive Old Growth Forests

POGs represent about 30% of the Tongass land base and 92% of the productive forests overall. The balance includes unproductive old growth mainly on muskegs as well as non-forest types (see Figure 1). About 8% of the productive forest on the TNF or 3% of the total land base is in young growth condition, almost exclusively the result of old-growth clearcut logging. POG logging and associated road building has resulted in high levels of localized fragmentation, particularly on Prince of Wales Island (*Taan* in Tlingit), the largest and most productive island in terms of POG in the archipelago (Figure 1).

3.2. Timber Volume Sold by Time Period

Annual logging levels throughout the first half of the 20th century (i.e., early historical era) were 243,000 m³ yr^{−1}, with the lowest levels recorded in 1909 at 37,000 m³ (Table 1, Table S2). Logging ramped up substantially in the second half of the 20th century (pulp era), averaging ~2 million m³ yr^{−1} and peaking in 1973 at nearly 3.6 million m³, followed by a sharp decline in the late 1990s to <900,000 m³ yr^{−1} (Table 1, Table S2). Between 2001 and 2015 (post pulp era), average logging volume was 230,000 m³ yr^{−1}. From 2016 to 2021 (transition), average logging fell to 132,000 m³ yr^{−1}, with the lowest level recorded at 71,000 m³ in 2019 (Table 1, Table S2). Projecting forward, annual logging levels are expected to rise to 279,000 m³ yr^{−1} from 2022 to 2031, and then to 595,000 m³ yr^{−1} from 2032 to the end of the century (Table 1, Table S2). Nearly all of the projected harvest volume would come from young-growth forests should the transition to young-growth logging hold.

Table 1. Past (1909–2021) and projected (2022–2100) timber harvest levels on the Tongass National Forest by era, including average (thousand cubic meters per year) and total (thousand cubic meters) harvest levels. Projections are based on [10]. See Table S2 for annual harvest data.

Years	Era	Average Harvest (1 × 10 ³ m ³ yr ^{−1})	Total Harvest (1 × 10 ³ m ³)
1909–1951	Early Historical	243	10,450
1952–2000	Pulp	2041	100,018
2001–2015	Post Pulp	230	3452
2016–2021	Transition	132	789
2022–2031	Projections	279	2793
2032–2100	Projections	595	41,059

3.3. Carbon Stocks

Total C stocks on the TNF are approximately 2679 Mt C (or ~2.7 Pg C, Table 2) with C density varying spatially across the region (Figure 2). Nearly half (48%; 1283.3 Mt) of the C is stored in POGs, split nearly evenly between soil (52.7%; 676.5 Mt C) and woody biomass (47.3%; 607.3 Mt C) (Table 2, Figures 3 and S2). Young growth accounts for just 4.8% (128.8 Mt C) of the total C, with nearly all of it (96%; 124.0 Mt C) outside IRAs (Table 2, Figure 3). IRAs account for just over half (51.3%; 1373.7 Mt) of the C, with soil and woody biomass accounting for 61.5% (845.4 Mt C) and 38.5% (528.3 Mt C) of that C, respectively (Table 2, Figures 3 and S3). Nearly 15% (392.9 Mt C) of all C in the study area is within T77 watersheds, with >80% (328.1 Mt C) of that C overlapping with IRAs and half of that (163.7 Mt C) overlapping with POG (Table 2, Figure 3). As anticipated, the C density of woody biomass in POG (293.5 (259–327) t C ha^{−1}) is greater than the C density of woody biomass in young-growth forest (281.6 (249–314) t C ha^{−1}) (Table 2); however, given the source data used in our analysis [25], C density in young-growth forest is likely overestimated.

Table 2. Carbon stocks (million metric tons) in woody plant biomass and soil organic matter by forest age class (productive old growth vs. young growth) inside and outside of Inventoried Roadless Areas (IRAs) and within the T77 watersheds in the Tongass National Forest, southeast Alaska. POG = Productive Old Growth; YG = Young Growth. Values in parentheses indicate ranges (lower and upper bounds). Biomass was scaled [25] to determine lower and upper bounds using the range of ratios between the live trees measured by Forest Inventory Analysis (FIA) plot data and the other C pools (excluding soils) [12]. Soil was not scaled (see [28]), hence the lack of ranges.

		Area	Soil	Woody Biomass	Total
		(ha)	(Mt C)	(Mt C)	(Mt C)
<i>Inside T77 Watersheds</i>					
Inside IRAs					
		256,897	92.2	71.6 (63.2–79.8)	163.7 (155.4–171.9)
POG		1112	0.4	0.2 (0.2–0.3)	0.6 (0.6–0.7)
YG		429,312	117.6	46.1 (40.7–51.3)	163.7 (158.3–168.9)
Other					
	Subtotal	687,321	210.2	117.9 (104.1–131.3)	328.1 (314.4–341.5)
Outside IRAs					
		52,143	18.8	16.1 (14.3–18.0)	35.0 (33.1–36.8)
POG		20,904	8.4	6.1 (5.4–6.8)	14.5 (13.8–15.2)
YG		35,251	10.6	4.7 (4.2–5.3)	15.4 (14.8–15.9)
Other					
	Subtotal	108,298	37.8	27.0 (23.8–30.1)	64.8 (61.7–67.9)
Total					
		309,040	111.0	87.7 (77.5–97.8)	198.7 (188.5–208.8)
POG		22,015	8.8	6.3 (5.6–7.0)	15.1 (14.4–15.9)
YG		464,563	128.2	50.8 (44.9–56.6)	179.0 (173.1–184.8)
Other					
	Total	795,619	248.1	144.8 (128.0–161.4)	392.9 (376.0–409.4)
<i>All Tongass</i>					
Inside IRAs					
		1,060,035	349.5	311.7 (275.5–347.4)	661.2 (625.0–696.9)
POG		7978	2.9	1.8 (1.6–2.0)	4.7 (4.5–5.0)
YG		2,657,417	493.0	214.8 (189.8–239.3)	707.8 (682.7–732.3)
Other					
	Subtotal	3,725,431	845.4	528.3 (466.9–588.7)	1373.7 (1312.3–1434.1)
Outside IRAs					
		1,009,308	327.0	295.6 (261.3–329.5)	622.6 (588.3–656.5)
POG		178,473	73.3	50.7 (44.8–56.5)	124.0 (118.1–129.8)
YG		1,860,951	376.8	181.6 (160.5–202.3)	558.4 (537.3–579.2)
Other					
	Subtotal	3,048,732	777.1	527.9 (466.6–588.3)	1305.1 (1243.7–1365.4)
Total					
		2,069,344	676.5	607.3 (536.8–676.9)	1283.8 (1213.3–1353.3)
POG		186,451	76.3	52.5 (46.4–58.5)	128.8 (122.7–134.8)
YG		4,518,369	869.8	396.5 (350.2–441.6)	1266.3 (1220.0–1311.4)
Other					
	Total	6774,163	1622.6	1056.3 (933.4–1177.0)	2678.8 (2556.0–2799.5)

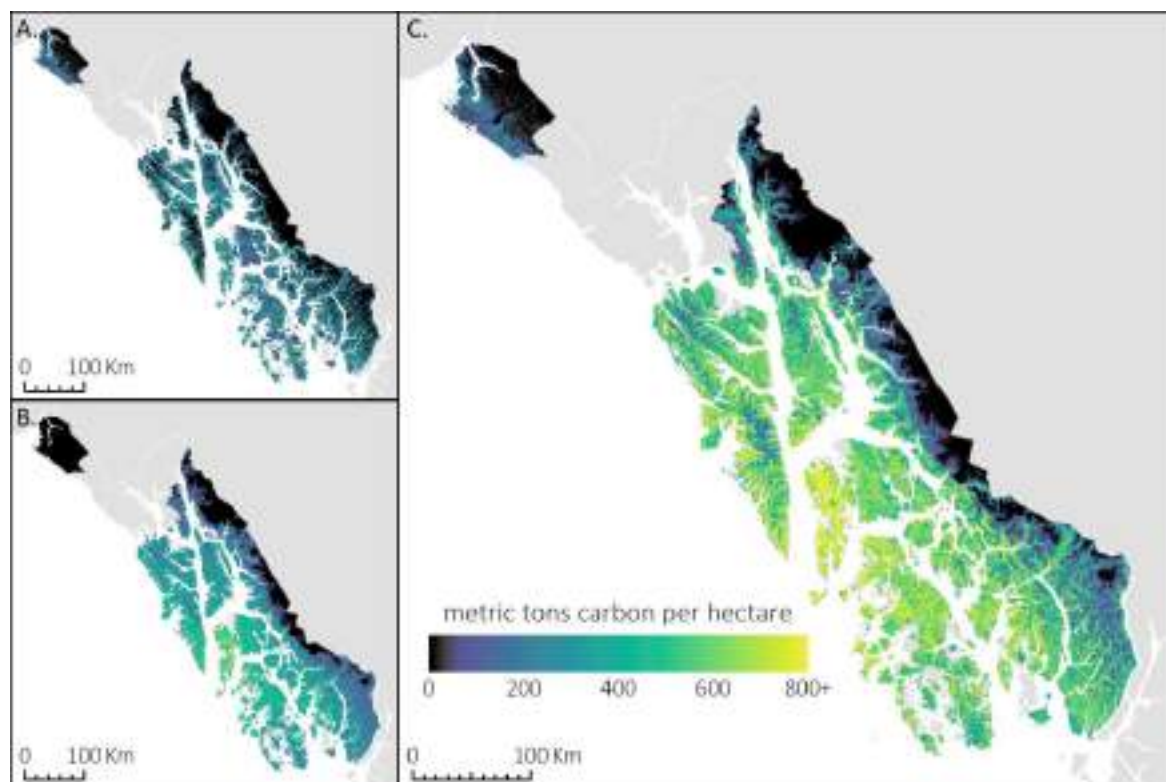


Figure 2. Spatial distribution of carbon (metric tons ha^{-1}) stored in (A) woody plant biomass (carbon pools include trees, roots, woody debris, seedlings/saplings, snags, and understory vegetation), (B) soil organic matter (top 1 m of mineral soil plus surface organic horizons), and (C) the sum of biomass and soil in the Tongass National Forest.

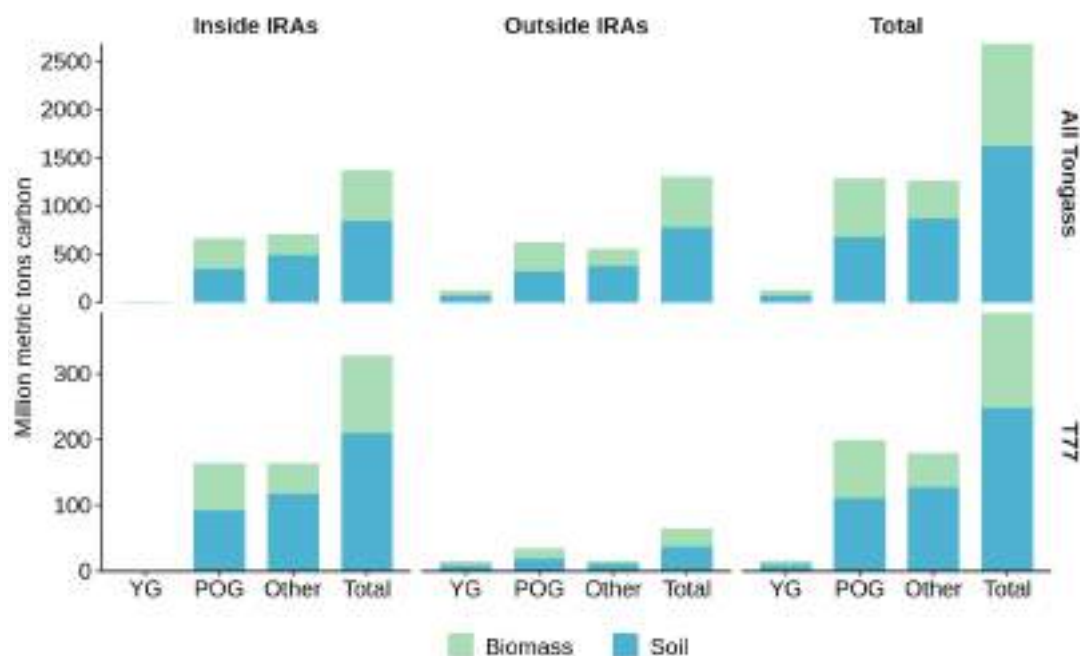


Figure 3. Carbon (million metric tons) stored in woody plant biomass and soil by forest age class (YG = young growth; POG = productive old growth) both inside and outside of Inventoried Roadless Areas (IRAs) and inside Tongass 77 watersheds (T77; bottom row) on the Tongass National Forest (top).

3.4. At-Risk Scenarios

About 11% of the total IRAs on the TNF are within LUDs that could be developed (Scenario 1, Table 3). Some 40% of the vulnerable IRAs and their C stock contain POG (Scenario 2, Table 3). About half those in at-risk IRAs would be exposed to development under the Trump administration's rollback of roadless protections (Scenario 3, Table 3). Notably, West Chichagof-Yakobi and Prince of Wales Island, along with several smaller islands close to the mainland, show the highest concentration of IRA vulnerabilities to development (Figure 4). Overall, our analysis illustrates the importance of retaining the protective measures of IRAs on the TNF.

Table 3. Area (hectares, ha) and carbon stocks (million metric tons) affected by three policy scenarios centered on at-risk inventoried roadless areas. See Section 2.5. for description of scenarios. Note, the areas of these regions are not mutually exclusive and are depicted visually in Figure 4. Values within parentheses are ranges (lower and upper bound). Biomass was scaled [25] to determine lower and upper bounds using the range of ratios between the live trees measured by Forest Inventory Analysis (FIA) plot data and the other C pools (excluding soils) [12]. Soil was not scaled (see [28]), hence the lack of ranges.

	Area	Soil	Woody Biomass	Total
Scenario	(ha)	(Mt C)	(Mt C)	(Mt C)
1.	1,015,701	342.6	196.8 (173.9–219.3)	539.4 (516.5–561.9)
2.	408,808	148.1	117.5 (103.9–131.0)	265.6 (252.0–279.1)
3.	201,483	75.3	60.6 (53.6–67.6)	135.9 (128.8–142.8)

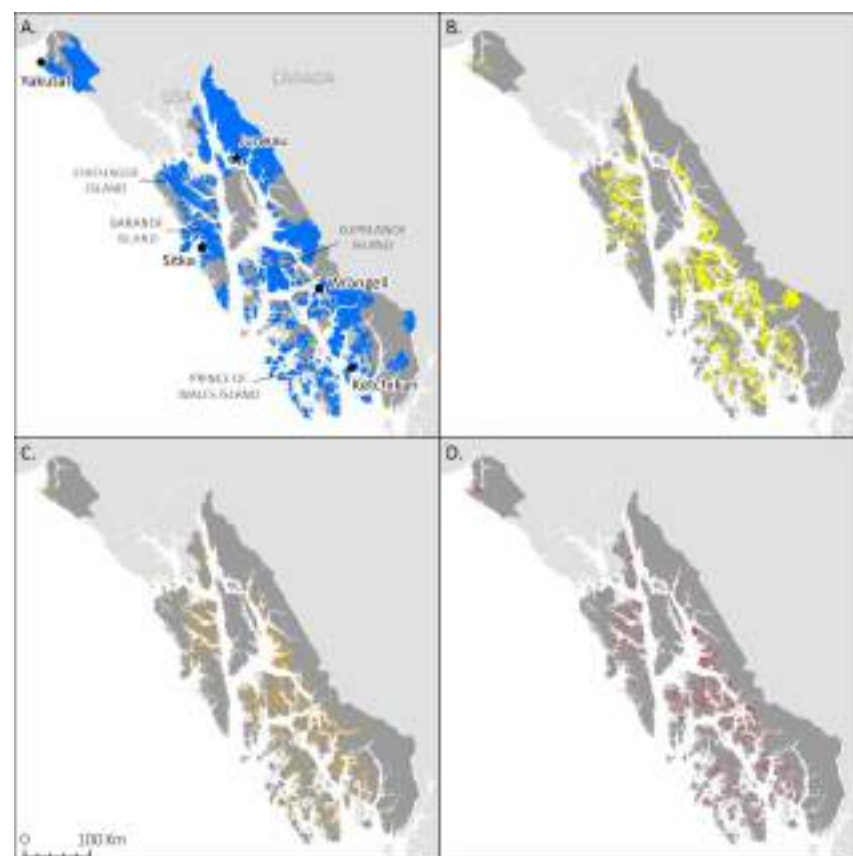


Figure 4. Spatial distribution of inventoried roadless areas based on: (A) all roadless areas (blue), (B) scenario 1 (yellow), (C) scenario 2 (orange), and (D) scenario 3 (red). Study area shown in gray. See Section 2.5. for description of scenarios.

3.5. Estimated Carbon Emissions

Our estimates of committed 100-year carbon dioxide emissions attributable to HWP (1910–2013) exhibit strong agreement with previous estimates [33] for the USFS Alaska Region (Tongass and Chugach National Forests combined; Figure S4). On the TNF, over the period 1909–2100, committed 100-year emissions track annual logging levels, rising sharply from the 1950s and peaking in the 1970s, followed by a decreasing trend into the 21st century (Figure 5). During this period (pulp era, 1952–2000), committed 100-year emissions average $>900,000 \text{ t CO}_2 \text{ yr}^{-1}$, the most of any period (Table 4). By the transition era (2016–2021), average committed emissions dropped more than 90% to $60,449 \text{ t CO}_2 \text{ yr}^{-1}$ (Table 4). With logging levels projected to rise into the future, committed emissions are anticipated to more than double to approximately $128,374 \text{ t CO}_2 \text{ yr}^{-1}$ between 2022 and 2031 and then more than double again to $273,492 \text{ t CO}_2 \text{ yr}^{-1}$ from 2032 onward (Table 4). Despite the expected increases, projected emissions should remain far below the peak emissions of the 1970s (Figure 5B, Table 4). Following a similar trend, annual realized emissions peaked during the pulp era (1952–2000), averaging $>750,000 \text{ t CO}_2 \text{ yr}^{-1}$ followed by a drop to $<250,000 \text{ t CO}_2 \text{ yr}^{-1}$ by the present day (Figure 5B, Table 4). Cumulative realized emissions show the fastest increase during the second half of the 20th century (Figure 5B), and over the full period of the analysis (1909–2100), we estimated 69.5 Mt CO_2 of cumulative emissions from HWP (Table S2).

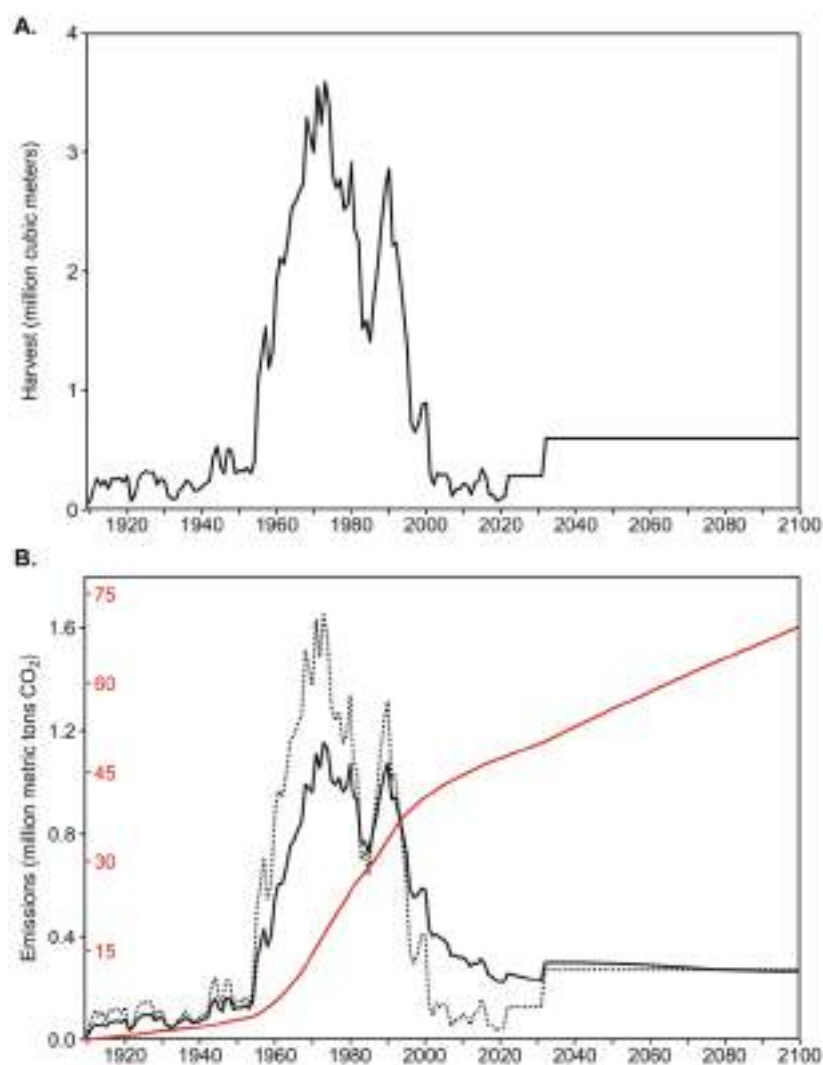


Figure 5. (A) Historic (1909–2021) and projected (2022–2100) annual harvest volumes (million cubic meters) for the Tongass National Forest. (B) Estimated 100-yr emissions from harvested wood products

(i.e., based on (A)), including annual committed (black dotted line), annual realized (black solid line), and cumulative realized (red line) emissions (million metric tons CO₂). Committed emissions reflect the CO₂ emissions that are annually committed to reach the atmosphere given the total harvested volume in a given year. Realized emissions model a more temporally realistic disposition of CO₂ emissions to the atmosphere following published wood product decay curves (see methods). Cumulative realized emissions track the cumulative sum of annual realized emissions through time.

Table 4. Historic (1909–2021) and projected (2022–2100) carbon dioxide emissions from harvested wood products (HWP) on the Tongass National Forest by era. Average (metric tons CO₂ per year) and total (million metric tons CO₂) annual committed and realized emissions are based on a 100-year HWP disposition period. See Table S2 for all annual-level estimates as well as cumulative realized emissions for the 1909–2100 timeframe.

Years	Era	Committed 100-Year Emissions		Realized 100-Year Emissions	
		Average (t CO ₂ yr ^{−1})	Total (Mt CO ₂)	Average (t CO ₂ yr ^{−1})	Total (Mt CO ₂)
1909–1951	Early Historical	111,692	4.8	81,673	3.5
1952–2000	Pulp	938,147	46.0	761,687	37.3
2001–2015	Post Pulp	105,763	1.6	346,387	5.2
2016–2021	Transition	60,449	0.4	244,912	1.5
2022–2031	Projections	128,374	1.3	242,374	2.4
2032–2100	Projections	273,492	18.9	284,168	19.6

4. Discussion

4.1. Timber Volume and Associated Impacts

Logging on the TNF can be traced back to at least 1909 with timber volume at 37,000 m³; logging remained at relatively low levels of $\leq 243,000$ m³ yr^{−1} for decades prior to World War II. The relatively low early historical levels were mainly because Alaska was the last old growth timber frontier in the USA and the high cost of access (roads) and shipping logs overseas. However, the onset of the pulp era, and signing of two 50-year contracts in the 1950s, ushered in nearly a 15-fold increase over the early historical period, with a peak in logging volume in 1973 followed by a precipitous decline when the pulp contracts expired in 2000. During peak years, the largest tree POG forests were disproportionately targeted due to high levels of timber volume at the stand level [1]. Timber volumes hit their lowest contemporary levels in 2019, a 50-fold decrease from the 1973 peak. Logging levels are projected to increase ~8-fold from the 2019 low through the end of the century, with most of the volume anticipated from young forests (if the transition to young-growth logging holds). In general, future fluctuations in timber volumes are anticipated under the TLMP transition plan due to a range of factors, including timber demand (e.g., exports vs. domestic), political pressure (presidential administrations), forest plan amendments, and institutional factors related to the time required by the agency to fully transition.

Historical logging on the TNF has come at the expense of primary, old-growth rainforest and intact forest landscapes (roadless areas), which have been replaced by >186,451 ha of production, high road density (>2.6 km/km²), and naturally regenerated monocultures lacking the structural complexity, C storage capacity, and biodiversity of old growth [2,3]. Much of the logging has been concentrated on Prince of Wales Island, the largest island with the most POG in the Alexander Archipelago [35]. Notably, over 8000 km of roads crisscross the TNF, 2400 km (30%) of which are on Prince of Wales Island alone (<https://dot.alaska.gov/stwdplng/scenic/byways-pow.shtml>, accessed on 11 February 2022). The impacts of road building can extend 1 km on either side of the road, potentially affecting sensitive taxa, water quality, C storage and sequestration among other impacts [6]. Additionally, since 1980, the timber volume sold from the TNF has generated a deficit, with administrative expenses exceeding revenues and sales proceeding regardless due to congressionally subsidized below-cost timber sales at a cost of approximately \$1.7 billion (<https://dot.alaska.gov/stwdplng/scenic/byways-pow.shtml>, accessed on 11 February 2022).

[//www.taxpayer.net/energy-natural-resources/cutting-our-losses-tongass-timber-2/](https://www.taxpayer.net/energy-natural-resources/cutting-our-losses-tongass-timber-2/), accessed on 11 February 2022). The TNF represents the most expensive timber program in the national forest system mainly because of road construction and maintenance costs in a remote, island-dominated region.

Despite peak logging periods and high-grade logging practices [1], 92% of productive forests on the TNF remain in old growth condition, compared to 8% in young growth (following previous clearcut logging). Earlier studies reported 90% of productive forests were POG based on USDA reports in 1991 [21]. Others [1,35] reported 88% of the entire region of southeast Alaska (state and native Alaskan corporation lands included) was POG at the time. Slight differences in POG estimates are likely due to differences in spatial extent and methods among studies. Nevertheless, the TNF is unique in that most of its forests remain POG, unlike those in the conterminous USA where nearly all old growth was logged long ago and replaced by intensively managed timber lands.

4.2. Carbon Stock (Carbon Reservoir)

Our findings underscore the significance of the C stock on the TNF. Using FIA plot data, researchers [12] reported the total Tongass C stock of 2.8 ± 0.5 Pg as compared to 2.7 Pg (upper bound 2.8) in our study. The earlier study [12] also noted that the TNF represented 8% of the total C stock in all forests in the conterminous USA. Our figure of 20% compares the Tongass C stock to that of the national forest system [36] rather than all conterminous USA forests [12], showcasing the significance of the TNF among federally managed national forests. The high C stock value of the TNF is particularly noteworthy given that the TNF represents just under 9% of the total area of the national forest system but has a relatively large share (20%) of the national forest C stock. This relative comparison speaks not only to the significance of the TNF as a C reservoir, but also as a region of conservation focus, allowing decision makers to prioritize strategically important natural climate solutions [37,38]. Notably, the 2.7 Pg C stock estimate for the TNF represents a CO₂e of 1.5 times US aggregate GHG emissions in 2019 (<https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf?VersionId=uua7i8WoMDBOc0M4ln8WVXMgn1GkujvD>; accessed on 15 April 2022).

In this study and a prior one [12], a substantial amount of the stored C was in the soils. We reported ~53% and 47% of C in soils and woody biomass, respectively, compared to the earlier [12] estimate of 66% and 36% of C in the soil and woody biomass pools. Our findings for IRAs are closer to earlier figures [12], with 62% and 39% of C in soils and biomass, respectively. Differences in C stock estimates likely reflect the datasets used (FIA plots vs. pooled datasets in our study) and perhaps differences in site productivity among sampled areas. Importantly, our study provides a spatially explicit and updated dataset that can be publicly accessed (databasin.org).

It should be noted that we assessed only the C stock value of the TNF. Prior researchers [12] provided an estimate of the annual C sequestration rate of unlogged forests at 0.04–0.33 Tg C yr^{−1}, which would build on the C sink potential of the TNF as logging transitions out of the most C rich and biodiverse areas.

4.3. Importance of IRAs and Tongass 77 Watersheds

Inventoried roadless areas have a long history of conservation in the USA, beginning in the 1970s with the RARE I and RARE II (Roadless Area Review and Evaluation) mapping processes used for making wilderness nominations to Congress [39]. Subsequently, a lot of attention has focused on IRAs, with some areas being designated wilderness, and most others protected administratively (National Roadless Conservation Rule) because of their superior biodiversity values compared to logged areas [5–7].

The TNF is a “hot spot” of IRA values and challenges, representing 16% of the nation’s total IRAs and the subject of numerous court cases. While IRA fish and wildlife habitat values have been documented on the TNF [40], our study is the first to quantify the C

stock value of IRAs, which contain over half the entire C stock on the TNF. Importantly, the C stock within IRA POGs (and POGs generally) are likely to remain relatively stable compared to the interior of Alaska and the southern extent of the North Pacific coastal temperate rainforest biome subject to more extreme climate change [41–43].

The protection of IRAs also has enjoyed broad public support (>95% of thousands of comments received by the USDA Forest Service have been supportive; <https://www.usda.gov/media/press-releases/2021/11/19/usda-announces-steps-restore-roadless-protections-tongass-national>; accessed on 14 February 2022) from Alaskan tribes, scientists, conservation groups, and fishing and recreational interests that may benefit economically and culturally (traditional tribal values) from these intact ecosystems if they are fully protected.

The T77 watersheds also contain important POG habitat, but the T77 conservation strategy alone represents far less C savings than IRAs, with only about 15% of the total C stock in T77s, mostly within the T77 POGs. The lower C stock value is likely an artifact of the selection process for the T77, which was weighted toward salmon conservation regardless of the presence of POGs, so long as watersheds were intact (no roads) and productive in terms of salmon. Nevertheless, the T77 watersheds have biodiversity and other values that extend well beyond the C-centric focus of our study [11].

4.4. Stock Change Due to Logging

The USDA Forest Service has repeatedly stated that emissions from logging on the TNF are insignificant compared to total US GHGs and thus logging emissions can be summarily dismissed since they are offset by both natural forest regeneration and storage in HWP pools [10,24]. However, offsetting emissions by forest regrowth involves a time lag of at least a century for an equivalent stock of C to be re-sequestered [30]. While forest regeneration on productive Tongass sites proceeds quickly (within a decade), and is from natural seed sources (nearby standing trees), young forests are expected to remain on short logging rotations with harvests planned every 55–70 years on productive sites under the TLMP transition plan. On average, after 100 years, storage in wood products from the PNW, for example, accounts for ~13% of the original C stock with an additional ~29% in landfills [29]. Thus, wood products represent little more than delayed emissions [30]. Additionally, the extensive road network, including log-landings and haul-out sites, means an unknown amount of the C stock may never be replaced so long as those areas remain treeless.

Our estimates of logging emissions from the TNF are conservative given that they involve the conversion of roundwood in cubic meters to CO₂ emissions. Accounting for out-of-boundary emissions in wood processing and log transport is beyond the scope of our study; however, these additional emissions can be substantial given that up to 50% of roundwood logs can be exported over large distances (e.g., to China and Japan) [10].

5. Conclusions

As one of the world's last relatively intact temperate rainforests, the TNF provides ecosystem services that are of global significance and warrant expanded conservation. The TNF represents ~12% of the entire Pacific Northwest Coastal Forest bioregion, an expansive rainforest region spanning several globally distinctive ecoregions and climatic subzones from the Coast Redwoods to the northern Kodiak archipelago in Alaska, which collectively make up 34% of all the world's temperate rainforests, the largest such concentration [3]. Some 2.1 M ha of the TNF remains as POG, also among the largest such amounts for temperate rainforests [2,3]. The TNF, contains 16% of the nation's IRAs, which, along with the Chugach National Forest to the north, represent the most relatively intact national forest in the national forest system. Its abundant salmon runs (all six *Oncorhynchus* species) and wildlife populations, some of which are imperiled in the lower 48 states, achieve their highest densities in intact watersheds such as the Tongass 77 [11].

Our study builds on the knowledge base of the Tongass' disproportionate values by documenting that some 20% of the entire national forest C stock is remarkably held by this single national forest alone, providing if nothing else a C reservoir of national significance.

Most of the C stock is in POGs, roughly distributed between roaded areas and IRAs. By contrast, only ~5% of the C stock is within young growth and mostly roaded areas.

The maritime climate and intact forests of the TNF have climate refugia properties compared to more extreme climatic zones in the interior of Alaska and temperate rainforests further south [41–43], thereby offering a relatively stable C reservoir. However, due to declining late-season snow cover that prevents late-winter root freezing, yellow-cedar is experiencing a range contraction, and is a climate-sensitive focal species [44]. Importantly, many fish and wildlife species that benefit from IRAs and POGs are the staple foods of Native Alaskans, representing an important bio-cultural connection made possible by the relative intactness of the Tongass rainforest system.

Despite its global recognition, including its near incomparable position among old-growth temperate rainforests, the TNF is a dynamic system where island biogeographic effects have contributed to isolation factors with potentially high species turnover rates [45]. Notably, the cumulative addition of novel anthropogenic fragmentation from expansive roads and clearcuts may result in more consequential isolation of vulnerable species over time, especially on Prince of Wales Island where logging and roads are greatest. For instance, the Alexander Archipelago wolf (*Canis lupus ligoni*) has been repeatedly proposed for listing under the USA Endangered Species Act with the US Fish and Wildlife Service recently determining that listing may be warranted (<https://www.fws.gov/alaska/stories/service-completes-initial-review-petition-list-alexander-archipelago-wolf-species-status#:~:text=The%20U.S.%20Fish%20and%20Wildlife,you%20can%20access%20the%20document;accessed%20on%2014%20February%202022>). Concerns over the status of wolf populations on Prince of Wales Island are mainly due to declining deer populations and hunting pressures [46]. However, the relative intactness of IRAs, POGs, and the T77 offer the best prospects for maintaining viable wildlife populations that are otherwise under combined pressures of climate change and anthropogenic habitat fragmentation.

Our results, coupled with broad scientific and public interest in the TNF as “America’s rainforest,” provide a foundation for a multi-pronged conservation strategy that includes: (1) protecting all remaining old growth, IRAs, and T77 priority areas from logging as strategic carbon reserves [38]; (2) supporting the transition to logging young-growth forests that by some accounts can already accommodate a full transition without further POG logging [47]; and (3) increasing ecological-based restoration of high road density areas (e.g., road decommissioning). A small portion (7978 ha) of young-growth forest is within IRAs where logging was likely conducted by helicopter. Those areas should be candidates for proforestation [37] to restore carbon stocks over time. Thus, a climate-smart strategy centered on sequestration and accumulation of C is generally essential to addressing the climate crisis [37] and would offer co-benefits, including a host of ecosystem services derived from C dense forests [48] as well as potential climate refugia [41–43].

The TNF is uniquely positioned for large-landscape conservation that protects remaining primary rainforest given that the transition out of old growth logging is taking place before most, if not all, of the primary forests are gone, unlike most nations that only transition when primary forests are liquidated and replaced by industrial forest lands [49]. As the national champion of forest C stocks, federally mandated protection of TNF POGs, IRAs, and T77 areas would offer global leadership on the establishment of land-based targets under the Paris Climate Agreement, while following through on the Glasgow leaders’ declaration to end global forest losses by 2030 (which included President Biden) [50].

Notably, Article 5.1 of the Paris Agreement states [19], “Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases.” Additionally, the Summary for Policy Makers (SPM) of the Working Group II contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report [51] noted that “safeguarding biodiversity and ecosystems is fundamental to climate resilient development, in light of the threats climate change poses to them and their roles in adaptation and mitigation (very high confidence).” Our results support the inclusion of the Tongass National Forest in a forest carbon reserve system centered on IRAs, POGs, the T77, and

a portion of young growth to conserve and enhance the substantial carbon values and resilience potential of this forest.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/land11050717/s1>, <http://www.databasin.org>, Figure S1: Approach to quantifying harvested wood product pools (HWP) storage and emissions; Figure S2: Spatial distribution of total carbon (metric tons ha^{−1}) in woody plant biomass and soil in at-risk scenarios for IRAs (inventoried roadless areas): (A) all IRAs, (B) Scenario 1, (C) Scenario 2, and (D) Scenario 3. Figure S3: Spatial distribution of T77 watersheds and total carbon (metric tons ha^{−1}) in woody plant biomass and soil pools combined. Figure S4: Committed 100-year emissions from both Tongass and Chugach National Forest timber harvests (1910–2013). Comparison of our study with prior research. Table S1: Carbon datasets used in this study. Table S2: Historic (1909–2021) and projected (2022–2100) harvest levels (thousand cubic meters per year, $1 \times 10^3 \text{ m}^3 \text{ yr}^{-1}$), committed 100-year emissions (thousand metric tons carbon dioxide equivalents per year, $1 \times 10^3 \text{ tCO}_2 \text{ yr}^{-1}$), annual realized emissions ($1 \times 10^3 \text{ tCO}_2 \text{ yr}^{-1}$), and cumulative realized emissions ($1 \times 10^3 \text{ tCO}_2 \text{ yr}^{-1}$) on the Tongass National Forest. All emissions estimates are based on a 100-year HWP disposition period. Supplemental references provided [52].

Author Contributions: All authors were involved in writing and approval of this manuscript. D.A.D. was involved in all aspects of the research including conceptualization, methods, formal analysis, investigation, data curation, and writing; W.S.W. was involved in concept development, methods, and writing; S.R.G. was involved in writing, data analysis and visualization, and methods. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Woodwell Climate Research Center Fund for Climate Solutions as well as grants to Wild Heritage from the Weeden and Sweetgrass foundations, two anonymous donors, and One Earth.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data in this study were posted for public access at databasin.org.

Acknowledgments: We thank Dave Albert for providing data to identify at-risk IRA scenarios, Brian Buma for assistance in interpretation of the [25] carbon data set, Catherine Mater for assistance identifying young-growth forest extent, and Richard Birdsey for consultation on emissions modeling.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Albert, D.M.; Schoen, J.W. Use of Historical Logging Patterns to Identify Disproportionately Logged Ecosystems within Temperate Rainforests of Southeastern Alaska. *Conserv. Biol.* **2013**, *27*, 774–784. [[CrossRef](#)] [[PubMed](#)]
2. Orians, G.; Schoen, J.W. *North Pacific Temperate Rainforests: Ecology and Conservation*; University of Washington Press: Seattle, WA, USA, 2013.
3. DellaSala, D.A.; Moola, F.; Alaback, P.; Paquet, P.C.; Schoen, J.W.; Noss, R.F. Temperate and boreal rainforests of the Pacific Coast of North America. In *Temperate and Boreal Rainforests of the World: Ecology and Conservation*; DellaSala, D.A., Ed.; Island Press: Washington, DC, USA, 2011; pp. 42–81.
4. USDA Forest Service. National Roadless Conservation Rule. *66 Fed. Reg.* **2001**, *3*, 244–248.
5. Strittholt, J.R.; DellaSala, D.A. Importance of roadless areas in biodiversity conservation in forested ecosystems: A case study—Klamath-Siskiyou ecoregion, U.S.A. *Conserv. Biol.* **2001**, *15*, 1742–1754. [[CrossRef](#)]
6. Ibisch, P.L.; Hoffmann, M.T.; Kreft, S.; Pe'er, G.; Kati, V.; Biber-Freudenberger, L.; DellaSala, D.A.; Vale, M.M.; Hobson, P.R.; Selva, N. A global map of roadless areas and their conservation status. *Science* **2017**, *354*, 1423–1427. [[CrossRef](#)]
7. Dietz, M.S.; Barnett, K.; Belote, R.T.; Aplet, G.H. The importance of U.S. national forest roadless areas for vulnerable wildlife species. *Glob. Ecol. Conserv.* **2021**, *32*, e01943. [[CrossRef](#)]
8. Executive Office of the President. Roadless Rule Revision. 2021. Available online: <https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202104&RIN=0596-AD51> (accessed on 5 April 2022).

9. USDA Forest Service. Forest Management Reports and Accomplishments. Cut History 1908 to Present. 2021. Available online: https://www.fs.usda.gov/wps/portal/fsinternet/cs/detail/!ut/p/z1/04_Sj9CPykssy0xPLMnMz0vMAfljo8zjjQwgwNHCwN_DI8zPyBcqYKAfjIVBmA9cQRQx-g1wAEci9eNREIXfHD9KH0CHtDHb4KfR35uqn5BbmhohEGWCQCHVD_f/dz/d5/L2dBISEvZ0FBIS9nQSEh/?position=Not&ss=1110&navtype=&pnavid=1600000000000000&navid=1601200000000000&cid=fsbdev2_038785 (accessed on 12 April 2022).
10. USDA Forest Service. Tongass National Forest—Land and Resource Management Plan Amendment. 2016. Available online: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd527907.pdf (accessed on 12 April 2022).
11. Smith, M.A. (Ed.) Ecological Atlas of Southeast Alaska. Audubon Alaska. 2016. Available online: <https://indd.adobe.com/view/bb243dff-5852-44c5-bdf5-4b1be96bdc53> (accessed on 12 April 2022).
12. Leighty, W.W.; Hamburg, S.P.; Caouette, J. Effects of Management on Carbon Sequestration in Forest Biomass in Southeast Alaska. *Ecosystems* **2006**, *9*, 1051–1065. [CrossRef]
13. Barrett, T.M. *Storage and Flux of Carbon in Live Trees, Snags, and Logs in the Chugach and Tongass National Forests*; Gen. Tech. Rep. PNW-GTR-889; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: Portland, OR, USA, 2014; 44p.
14. Birdsey, R.A.; Dugan, A.J.; Healey, S.P.; Dante-Wood, K.; Zhang, F.; Mo, G.; Chen, J.M.; Hernandez, A.J.; Raymond, C.L.; McCarter, J. *Assessment of the Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks of U.S. National Forests*; Gen. Tech. Rep. RMRS-GTR-402; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO, USA, 2019.
15. D’Amore, D.; McGuire, A.D. Forestry as a Natural Climate Solution: The Positive Outcomes of Negative Carbon Emissions. USDA Forest Service PNW Research Station. 2020. Available online: <https://www.fs.fed.us/pnw/science/scifi225.pdf> (accessed on 12 April 2022).
16. Congressional Research Center (CRS). U.S. Forest Carbon Data: In Brief. Updated 5 May 2020. Prepared for Members and Committees of Congress. 2020. Available online: <https://crsreports.congress.gov> (accessed on 12 April 2022).
17. USDA Forest Service. Draft Environmental Impact Statement Rulemaking for Alaska Roadless Areas. 2019. Available online: https://www.fs.usda.gov/nfs/11558/www/nepa/109834_FSPLT3_4876629.pdf (accessed on 12 April 2022).
18. USDA Forest Service. Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System Units. Alaska Region. Climate Change Advisors Office of the Chief. Alaska Region, 34p. 6 March 2015. Available online: <https://www.fs.fed.us/climatechange/documents/AlaskaRegionCarbonAssessment.pdf> (accessed on 5 April 2022).
19. United Nations. Paris Agreement. 2015. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 5 April 2022).
20. Alaback, P. Biodiversity patterns in relation to climate: The coastal temperate rainforests of North America. In *High-Latitude Rain Forests and Associated Ecosystems of the West Coast of the Americas: Climate, Hydrology, Ecology and Conservation*; Lawford, R., Alaback, P., Fuentes, E.R., Eds.; Ecological Studies 116; Springer: Berlin/Heidelberg, Germany, 1995; pp. 105–133.
21. DellaSala, D.A.; Hagar, J.C.; Engel, K.A.; McComb, W.C.; Fairbanks, R.L.; Campbell, E.G. Effects of silvicultural modifications of temperate rainforest on breeding and wintering bird communities, Prince of Wales Island, Southeast Alaska. *Condor* **1996**, *98*, 706–721. [CrossRef]
22. USDA Forest Service. Tongass National Forest Land Management Plan Revision. 1997. Available online: <https://www.fs.usda.gov/detail/tongass/landmanagement/planning/?cid=stelprdb5445359> (accessed on 5 April 2022).
23. Brackley, A.M.; Rojas, T.D.; Haynes, R.W. Timber Products Output and Timber Harvests in Alaska: Projections for 2005–25. Gen. Tech. Rep. PNW-GTR-677. 2006. Available online: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev2_038293.pdf (accessed on 5 April 2022).
24. USDA Forest Service. Cut and Sold (New)—CUTS203F. 2020. Available online: https://www.fs.fed.us/forestmanagement/documents/sold-harvest/reports/2020/2020_Q1-Q4_CandS_R10.pdf (accessed on 12 April 2022).
25. Buma, B.; Thompson, T. Long-term exposure to more frequent disturbances increases baseline carbon in some ecosystems: Mapping and quantifying the disturbance frequency-ecosystem C relationship. *PLoS ONE* **2019**, *14*, e0212526. [CrossRef]
26. Hansen, M.C.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **2013**, *342*, 850–853. [CrossRef]
27. Harris, N.L.; Gibbs, D.A.; Baccini, A.; Birdsey, R.A.; De Bruin, S.; Farina, M.; Fatoyinbo, L.; Hansen, M.C.; Herold, M.; Houghton, R.A.; et al. Global maps of twenty-first century forest carbon fluxes. *Nat. Clim. Chang.* **2021**, *11*, 234–240. [CrossRef]
28. McNicol, G.; Bulmer, C.; D’Amore, D.; Sanborn, P.; Saunders, S.; Giesbrecht, I.; Arriola, S.G.; Bidlack, A.; Butman, D.; Buma, B. Large, climate-sensitive soil carbon stocks mapped with pedology-informed machine learning in the North Pacific coastal temperate rainforest. *Environ. Res. Lett.* **2019**, *14*, 014004. [CrossRef]
29. Hoover, C.M.; Birdsey, R.; Goines, B.; Lahm, P.; Marland, G.; Nowak, D.; Prisley, S.; Reinhardt, E.; Skog, K.; Skole, D.; et al. Chapter 6: Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems. In *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*; Eve, M., Pape, D., Flugge, M., Steele, R., Man, D., Riley-Gilbert, M., Biggar, S., Eds.; Technical Bulletin Number 1939; Office of the Chief Economist, US Department of Agriculture: Washington, DC, USA, 2014; 606p.
30. Hudiburg, T.W.; Law, B.E.; Moomaw, W.R.; Harmon, M.E.; Stenzel, J.E. Meeting GHG reduction targets requires accounting for all forest sector emissions. *Environ. Res. Lett.* **2019**, *14*, 095005. [CrossRef]
31. Skog, K.E. Sequestration of carbon in harvested wood products for the United States. *For. Prod. J.* **2008**, *58*, 56–72.

32. Smith, J.E.; Heath, L.S.; Skog, K.E.; Birdsey, R.A. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*; US Department of Agriculture, Forest Service, Northern Research Station: Newtown Square, PA, USA, 2006.
33. Loeffler, D.; Anderson, N.; Stockman, K.; Skog, K.; Healey, S.; Jones, J.G.; Morrison, J.; Young, J. *Estimates of Carbon Stored in Harvested Wood Products from United States Forest Service Alaska Region, 1910–2012*; Unpublished Report; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory: Missoula, MT, USA, 2014; 27p.
34. Harmon, M.E. Have product substitution carbon benefits been overestimated? A sensitivity analysis of key assumptions. *Environ. Res. Lett.* **2019**, *14*, 065008. [\[CrossRef\]](#)
35. Albert, D.; Schoen, J.W. A conservation assessment for the Coastal Forests and Mountains Ecoregion of Southeastern Alaska and the Tongass National Forest. In *Chapter 2, The Coastal Forests and Mountains Ecoregion of Southeastern Alaska and the Tongass National Forest: A Conservation Assessment and Resource Synthesis*; Schoen, J., Dovichin, E., Eds.; The Nature Conservancy: Anchorage, AK, USA, 2007.
36. Smith, J.E.; Domke, G.M.; Nichols, M.C.; Walters, B.F. Carbon stocks and stock change on federal forest lands of the United States. *Ecosphere* **2019**, *10*, e02637. [\[CrossRef\]](#)
37. Moomaw, W.R.; Masino, S.A.; Faison, E.K. Intact forests in the United States: Proforestation mitigates climate change and serves the greatest good. *Front. For. Glob. Chang.* **2019**, *2*, 27. [\[CrossRef\]](#)
38. Law, B.E.; Berner, L.T.; Buotte, P.C.; Mildrexler, D.J.; Ripple, W.J. Strategic forest reserves can protect biodiversity in the western United States and mitigate climate change. *Commun. Earth Environ.* **2021**, *2*, 254. [\[CrossRef\]](#)
39. Turner, T. *Roadless Rules: The Struggle for the Last Wild Forests*; Island Press: Washington, DC, USA, 2009.
40. Albert, D.M. Conservation Significance of Large Inventoried Roadless Areas on the Tongass National Forest. Audubon Alaska. 2019. Available online: https://ak.audubon.org/sites/default/files/2019_conservation_significance_of_roadless_12-14-19.pdf (accessed on 12 April 2022).
41. DellaSala, D.A.; Brandt, P.; Koopman, M.; Leonard, J.; Meisch, C.; Herzog, P.; Alaback, P.; Goldstein, M.I.; Jovan, J.; MacKinnon, A.; et al. Climate Change May Trigger Broad Shifts in North America's Pacific Coastal Rainforests. In *Reference Module in Earth Systems and Environmental Sciences*; DellaSala, D.A., Goldstein, M.I., Eds.; Elsevier: Oxford, UK, 2015. [\[CrossRef\]](#)
42. Vynne, C.; Dovichin, E.; Fresco, N.; Dawson, N.; Joshi, A.; Law, B.E.; Lertzman, K.; Rupp, S.; Schmiegelow, F.; Trammell, E.J. The importance of Alaska for climate stabilization, resilience, and biodiversity conservation. *Front. For. Glob. Chang.* **2021**, *4*, 1–17. [\[CrossRef\]](#)
43. Buma, B.; Batllori, E.; Bisbing, S.; Holz, A.; Saunders, S.C.; Bidlack, A.L.; Creutzburg, M.K.; DellaSala, D.A.; Gregovich, D.; Hennon, P.; et al. Emergent freeze and fire disturbance dynamics in temperate rainforests. *Austral Ecol.* **2019**, *44*, 812–826. [\[CrossRef\]](#)
44. Hennon, P.E.; A'more, D.V.; Schaberg, P.G.; Wittwer, D.T.; Shanley, C.S. Shifting climate, altered niche, and a dynamic conservation strategy for yellow-cedar in the North Pacific coastal rainforest. *BioScience* **2012**, *62*, 147–158. [\[CrossRef\]](#)
45. Dawson, N.; MacDonald, S.O.; Cook, J.A. Endemic Mammals of the Alexander Archipelago. Southeast Alaska Conservation Assessment, Chapter 6.7. 2007. Available online: http://www.unm.edu/~jmsbweb/isles/Dawson_et_al%202007%20endemics%20AA.pdf (accessed on 5 April 2022).
46. Schoen, J.; Person, D. Alexander Archipelago Wolf (*Canis lupus ligoni*). Chapter 6.4. Southeast Alaska Conservation Assessment. 2016. Available online: https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/alaska/seak/era/cfm/Documents/6.4_Wolf.pdf (accessed on 5 April 2022).
47. DellaSala, D.A.; Furnish, J. Can young-growth forests save the Tongass Rainforest in Southwest Alaska? In *Encyclopedia of the World's Biomes*; Goldstein, M.I., DellaSala, D.A., Eds.; Elsevier: Oxford, UK, 2019. [\[CrossRef\]](#)
48. Brandt, P.; Abson, S.O.; DellaSala, D.A.; Feller, R.; von Wehrden, H. Multifunctionality and biodiversity: Ecosystem services in temperate rainforests of the Pacific Northwest, USA. *Biol. Conserv.* **2014**, *169*, 362–371. [\[CrossRef\]](#)
49. Keenan, R.J.; Reams, G.A.; Achard, F.; de Freitas, J.V.; Grainger, A.; Lindquist, E. Dynamics of global forest area: Results from the Global Forest Resource Assessment 2015. *For. Ecol. Manag.* **2015**, *352*, 9–20. [\[CrossRef\]](#)
50. United Nations Climate Change. Glasgow Leaders' Declaration on Forests and Land Use. UN 2104 Clim. Change Conf. COP26 SEC—Glasg. 2021. Available online: <https://ukcop26.org/glasgow2105leaders-declaration-on-forests-and-land-use/> (accessed on 19 April 2022).
51. Intergovernmental Panel on Climate Change (IPCC). Climate Change Impacts, Adaptation, and Vulnerability. 2022. Available online: <https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/> (accessed on 15 April 2022).
52. Stockmann, K.; Anderson, N.; Stockman, K.; Young, J.; Skog, K.; Healey, S.; Morrison, J.; Young, J. Loeffler. *Estimates of Carbon Stored in Harvested Wood Products from United States Forest Service Intermountain Region, 1911–2012*; Unpublished Report; USDA, Forest Service, Rocky Mountain Research Station: Missoula, MT, USA, 2014.

Best Management Practices for Northern Goshawk Foraging Habitat

Retaining Old Growth Structural Attributes



(goshawk juvenile and nest. F. Doyle)

Patrick Ferguson, RPF
Frank I. Doyle, RPBio
Mike Buirs, RPF (retired)

Managing for Goshawk Foraging Habitat

Goshawk foraging habitat is a critical component of a functioning goshawk territory (McClaren et al, 2015, Stuart-Smith et al. 2013). Unfortunately, clear-cut harvest and the subsequent even-aged conifer plantations do not support the forest structure on which the goshawks, and many of their prey depend. In addition, restoration of these clearcut areas will take 100's of years and at least a generation of trees, to restore back to its original forest structure. This BMP provides guidance as to the stewardship objectives and approaches required to maintain a functioning territory, through the retention of critical old forest structural attributes, within the foraging area of the remaining known and suitable goshawk territory areas.

This BMP is intended as a companion document to existing BMP and Science Based Guidance documents (Manning C. 2012, McClaren et al. 2015, and Stuart-Smith et al. 2012) that are focused on the Goshawk Breeding Area Management.

NOTE: This BMP should only be applied within the framework of a coordinated regional population goshawk plan, as any harvest within an active or suitable goshawk territory area incrementally increases the risk of abandonment of that territory. In the absence of a coordinated plan, we do not recommend any harvest within the remaining suitable or known occupied goshawk foraging (or breeding) territory areas.

Given the rapidly declining numbers of suitable and occupied goshawk territories (and thus goshawks themselves), we recommend a strong adaptive management monitoring component, both pre- and post-harvest. Further, this should be coordinated within an agreed-upon regional Adaptive Management Framework (as per the Skeena Region Planning App, below). In the context of harvest activities, there is still much to learn about what – and how much – is required to sustain a goshawk territory. This monitoring will help managers and biologists to determine whether the harvest/stewardship plan was successful in maintaining old-growth forest structural attributes - the associated biodiversity, and the long-term occupancy and breeding success of the goshawk territory. Through this feedback and lessons learned, we can ensure the development and implementation of an effective BMP.

Specific to understanding the challenges here, the foraging home range habitat threshold of each territory predictably changes both with habitat, and with fluctuations in prey, such that on an individual territory basis we do not know that threshold until it has been past, and that territory is abandoned. With this knowledge, this management approach looks to maintain the forest structure, and associated abundance and availability of prey across the breadth of a goshawk territory area, at a scale that is comparable with the observed largest home ranges of birds in BC.

Suggested citation:

Ferguson, P., F. I. Doyle and M. Buirs. 2023. Best Management Practices for Northern Goshawk Foraging Habitat: Retaining Old Growth Structural Attributes; V. 1.0 May 2023. Wildlife Dynamics Consulting and Molly Creek Forestry. Published by <https://skeenawild.org>

Territory Harvest Management

As a management approach, this strategy has used the large territory requirements (~6,000ha) (Mahon 2008, Chase 2021), and habitat needs of the goshawk as an umbrella species for the forest habitat needs of many other focal species including fisher, moose, marten, and old-growth dependent birds and small mammals.

Table 1. Management zones in the Skeena Region with recommended percent retention for partial cutting treatments.

Goshawk Territory Management Zones						
Zone	Radius from center point [m]	Area (ha)	Description*	Treatment Type: Timber Removal	Maximum % of Zone Area Disturbed	% Retention of Gross Block Area
A - Coastal (i.e., CWH BEC zone) [Kalum]	800	200	Core	No Harvest - Complete Retention	0	100
A - Interior (all other BEC zones and "transition" portion of CWH) [Kalum transition, Kispiox, Bulkley, Morice, Lakes TSAs]	560	100	Core	No Harvest - Complete Retention	0	100
B	1000	350	Breeding Area Buffer	Partial Cutting	20	80
C	2787	2400	Summer Foraging Zone	Partial Cutting	50	70
D - Manage for in Bulkley, Morice, Lakes TSAs	4371	3600	Winter Foraging Zone	Partial Cutting	70	50

*Total home range = zone C + D with areas A and B internal to that total area. The harvest target is 100% partial cutting.

Core: Encompasses the nest site(s) and is critical to preserve intact.

Breeding Area Buffer: Partial cutting harvest systems can occur in this zone to a maximum of 20% of the area. Focus disturbance further from the Core where possible. Harvest entry once every 30 years.

Summer Foraging Zone: Only partial cutting recommended in this zone. Total disturbance of the zone is 50% of the area using a silviculture system with an average of 70% retention (partial cut) of gross block area. Disturbed areas become active again once they reach "mature" seral stage as defined by the Biodiversity Guidebook (BC, 1995).

Winter Foraging Zone: Additional forage area to manage for in the Bulkley, Morice and Lakes TSAs due to less intact old and mature forest. Only partial cutting is recommended in this zone. Total disturbance of the zone is 70% using a silviculture system with an average of 50% retention (partial cut) of gross block area. Disturbed areas become active again once they reach "mature" seral stage as defined by the Biodiversity Guidebook (BC, 1995). Annual home range area can overlap between adjacent territories.

Partial Cutting Defined for this Guidance: Partial cutting refers to any silviculture system that does not include a clearcut system and that does include rotational reserves. Examples of partial cutting silviculture systems include patch cut, seed tree, shelterwood, coppice, retention systems and selection systems. No matter what partial cut silviculture system is used, the retention requirements identified in Table 1 are necessary for suitable habitat structure.



Figure 1. 4 zone territory management for the Bulkley, Morice, and Lakes TSAs. Winter foraging (blue) area can overlap between territories. Specific to areas with low % of constrained timber.

A short biology lesson: The male goshawk is smaller than the female. During the nesting and rearing phase from February to August the male feeds the female and chicks. His ability to carry food back to the nest is limited by prey weight and the distance he must fly to find food. Preferentially he forages in larger areas of suitable habitat closer to the nest. If there is abundant food in winter, the female will have enough to prepare herself for breeding the following spring.

Goshawk Territory Design: The assumption is that you are working with a goshawk territory that has already been designed (Figures 1 and 2). Designing or re-designing territory instructions can be found here:

<https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=feb9d7e2add94cbba54313db59c112a4> UserID – PX.Skeena
Password – Skeena1234



Figure 2. 3 zone territory management for the Kispiox and Kalum TSA's. Specific to areas with a high % of forest retention.

Harvest Implementation Strategies

Focus on promoting forage for Goshawk by promoting habitat for forage species and features for hunting. These features come from:

- *Coarse woody debris (CWD)*
- *Snags and live retention (mature perch trees for hunting)*
- *Habitat and food sources for forage species*

CWD: Make maintaining large CWD a priority.

- Collect pre-harvest data to understand what is present to start with.
- Larger is better: >30cm diameter and >7m length.
- Maintain what you have: protect good CWD patches through Machine Free Zones; avoid crushing it; maintain root wads; winter harvest when possible.
- Vertical and Horizontal structure: Place logs in jackstraw fashion so they are elevated above ground (25-50cm). Create connectivity by using windrows of CWD.
- Create CWD piles larger than 3m x 5m (x 2m high). At least one pile every 4ha located adjacent to standing retention on sunny aspect is recommended for marten habitat.
- Recruit future CWD through standing retention.



Snags and Live retention: Dispersed and clumped.

- Larger is better: snags >30cm DBH.
- Target 40% retention of existing snags and a minimum of 12-15/ha.
- Recruit new snags through girdling if necessary: Aim for the stand to have a continuum of decay classes as per Figure 3.
- Aim for 50% of the standing retention as clumped and 50% as dispersed.
- Maintain live retention in the form of deciduous, clumps of non-merch, and a mix of merchantable sizes present within the stand.
- Retain tree species that are uncommon in the stand.
- Maximum distance between standing timber (i.e., edge trees and/or internal retention) in the range 50-70m.

Wildlife Tree Class								
Live		Dead						Dead Fallen
		Hard →			Spongy	→ Soft		Not Sampled
1	2	3	4	5	6 = 2/3 original height	7 = 1/2 original height	8 = 1/3 original height	9
								
Live		Dead					Dead Fallen	
		Hard →		Spongy	→ Soft	Not Sampled		
1	2	3	4	5	6			
								
CWD Decay Class								
								
Log class 1	Log class 2	Log class 3	Log class 4	Log class 5				
Hard	Sap rot (but still hard)	Advanced decay (spongy)	Extensive decay (crumbles/mushy)	Many small pieces, soft				
Bark firm	Loose bark	Bark trace/absent	Bark absent	Bark absent				
Elevated	Sagging	Sagging to settled on ground	Fully settled on ground	Partly sunken in ground				
Hard branches with twigs	Soft branches	Branches stubs/absent	No branches	No branches				
Supports person	May not support person	Breaks easy	Shape collapses when stepped on	Collapsed oval				
No invading roots	No invading roots	Roots in sapwood	Roots in heartwood	Roots in heartwood				

Figure 3. Wildlife tree and coarse woody debris decay classes used for stand-level biodiversity resource stewardship monitoring in British Columbia (Province of BC, 2009).

Habitat and food sources for forage species: Who are you catering to?

Retaining snags and CWD are important for typical summer prey such as squirrels, woodpeckers, jays and thrushes. Retention and recruitment of high-quality snags is a critical structure for over 67 primary and secondary nesting and denning birds and mammal species in BC (Bunnell, 2012). Additionally, grouse and hares are critical winter food sources for the northern goshawk and have specific habitat needs.



Figure 4. Ruffed grouse in winter.

- Spruce and Blue grouse eat conifer needles (typically spruce of any age) in the winter. Identify feed trees in the field by locating piles of grouse fecal pellets beneath them.
- Ruffed Grouse eat buds of deciduous trees and shrubs. Incorporate deciduous into the retention strategy.
- All native berry plants are important food sources for grouse (flowers and berries). Protect and promote the berry species population on your site.

- Hares have an affinity for dense, unthinned sapling patches. Because hares show an affinity for dense patches of residual forest, any retention of untreated sapling patches may be beneficial for hares.
- Hares benefit in winter months from a connectivity of dense patches of cover. Maintain clumps of natural regeneration during harvest. Larger patches are better for survival from sun exposure.



Figure 5. Snowshoe hare in summer.



Finally, minimize the area occupied by long term roads (reduce length of permanent road, reduce surface width and ROW). All extra road surface reduces available habitat for forage species.

Important Reminders:

- The northern goshawk needs to be managed at a landscape scale. With a declining and now small population, managing individual territories is a critical piece for maintaining a viable population.
- A coordinated management approach to harvest and restoration activities across the remaining individual goshawk territories is critical to the success of maintaining a long-term viable territory.
- Implementing both structure and wildlife assessments pre- and post- harvest supports the science and will allow this BMP to evolve.
- Managing forests for habitat requires a long-term outlook. You are setting up a future forest for certain habitat values.
- A range of treatments and disturbances in the forest is required rather than one similar approach used often. Don't do the same thing everywhere.



Figure 6. Partial cutting in ICH BEC zone. Cover photo: Partial cutting second growth in CWH BEC zone.

References:

British Columbia. Ministry of Forests. Forest Practices Branch. 2003. Silvicultural Systems Handbook for British Columbia. For. Pract. Br., BC. Min. For., Victoria, BC.

<https://www.for.gov.bc.ca/hfp/publications/00085/silvsystemshdbk-print.pdf>

Bunnell, F. L. (2013). Sustaining cavity-using species: patterns of cavity use and implications to forest management. *ISRN Forestry*, 2013, 1– 33. <https://doi.org/10.1155/2013/457698>.

Chase, G. 2021. Foraging Ecology of the Northern Goshawk in Coastal British Columbia. MSc Thesis. SIMON FRASER UNIVERSITY.

Mahon, T. 2008. Mahon, T. 2008. Foraging habitat selection and home range size of Northern Goshawks in northwest British Columbia. Morice and Lakes Innovative Forest Practices Agreement, Houston, B.C. Unpublished report.

McClaren, E.L., T. Mahon, F.I. Doyle, and W.L. Harrower. 2015. Science-Based Guidelines for Managing Northern Goshawk Breeding Areas in Coastal British Columbia. Journal of Ecosystems and Management 15(2):1-91. Published by the Journal of Ecosystems and Management:
<http://jem-online.org/index.php/jem/article/viewFile/576/506>

Price, K. 2023. Habitat thresholds as guidance for forest management and conservation.
<https://www.evergreenalliance.ca/science-alliance-for-forestry-transformation/12/>

Province of British Columbia. Ministry of Forests. Ministry of Environment. 1995. Biodiversity Guidebook. Forest practices code of British Columbia.
<https://www.for.gov.bc.ca/hfd/library/documents/bib19715.pdf>

Province of British Columbia. 2009. Protocol for Stand-level Biodiversity Monitoring: Steps for field data collection and administration. Forest and Range Evaluation Program. B.C. Min. For. and B.C. Min. Environ.
<https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/integrated-resource-monitoring/forest-range-evaluation-program/frep-monitoring-protocols/biodiversity>

Skeena Region Northern Goshawk Population Management Planning Web Application:
<https://governmentofbc.maps.arcgis.com/apps/MapSeries/index.html?appid=feb9d7e2add94cbba54313db59c112a4> UserID – PX.Skeena Password – Skeena1234

Stuart-Smith, A.K., W.L. Harrower, T. Mahon, E.L. McClaren, and F. I. Doyle. (2012). A scientific basis for managing northern goshawk breeding areas in the Interior of British Columbia: Best management practices. FORREX Kamloops, B.C. Series 29.

Links:

Date Creek Research Forest Publications:
<https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/silviculture/silviculture-research/silvicultural-systems-research/date-creek-research-forest>

John Prince Research Forest: <http://www.jprf.ca/research/post>

Stand Level Biodiversity Brochure Side 1: https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/conservation-habitat-management/wildlife-conservation/wildlife-tree-committee/stand_level_biodiversity_brochure_side_1.pdf

Stand Level Biodiversity Brochure Side 2:
https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/conservation-habitat-management/wildlife-conservation/wildlife-tree-committee/stand_level_biodiversity_brochure_side_2.pdf

Wildlife Research Final Report

ABUNDANCE, PREY AVAILABILITY AND DIETS OF AMERICAN MARTENS: IMPLICATIONS FOR THE DESIGN OF OLD-GROWTH RESERVES IN SOUTHEAST ALASKA

Rodney W. Flynn, Thomas V. Schumacher, Merav Ben-David



This project was primarily funded by
THE U.S. FISH AND WILDLIFE SERVICE
Juneau Field Office, Juneau, Alaska
and
THE ALASKA DEPARTMENT OF FISH AND GAME.
Division of Wildlife, Douglas, Alaska

ACKNOWLEDGEMENTS

Kim Hastings, U.S. Fish and Wildlife Service, assisted in arranging the grant, provided peer review of the study plan, and made many useful comments on the manuscript. Joe McClung captained the FWS boat at Point Couverden. Staff of the Tongass National Forest, U.S. Forest Service, assisted with many aspects of the project. Glenn Ith and Jim Brainerd arranged for facilities and vehicles on the Petersburg District. On the Thorne Bay District, Susan Howell and Ray Slayton assisted with logistics and the fieldwork. Dennis Chester assisted with the trapping at Point Couverden. Steve Lewis, Richard Lowell, Paul Converse, Chad Rice, and Mary Mecci from the Alaska Department of Fish and Game, provided field or administrative support. Kimberly Titus provided supervision and project review. Grey Pendleton developed the population estimator and provided statistical review. Becky Strauch computed the variance for the study area estimates. Cathy Brown edited the report.

The Alaska Department of Fish and Game administers all programs and activities free from discrimination on the basis of race, religion, color, natural origin, age, sex, marital status, pregnancy, parenthood, or disability. For information on alternative formats for this and other department publications, please contact the department ADA Coordinator at [voice] 907-465-4120, telecommunications device for the deaf [TDD] 1-800-478-3648, or fax 907-465-6078. Any person who believes she/he has been discriminated against should write to ADF&G, PO Box 25526, Juneau, AK 99802-5526, or OEO, U.S. Department of the Interior, Washington, DC 20240.

Cover photo by Gail Blundell.

ABUNDANCE, PREY AVAILABILITY AND DIETS OF AMERICAN MARTENS: IMPLICATIONS FOR THE DESIGN OF OLD-GROWTH RESERVES IN SOUTHEAST ALASKA

Rodney W. Flynn

Alaska Department of Fish and Game, Division of Wildlife Conservation,
P. O. Box 240020, Douglas, AK 99824

Thomas V. Schumacher

Alaska Department of Fish and Game, Division of Wildlife Conservation,
P. O. Box 240020, Douglas, AK 99824

Merav Ben-David

Department of Zoology and Physiology, 3166, University of Wyoming, 1000 E.
University Ave., Laramie, WY 82071

Final Report

U.S. Fish and Wildlife Service Grant
DCN 70181-1-G133

Alaska Department of Fish and Game

Southeast Regional Office
P.O. Box 240020
Douglas, Alaska
Tel: 907-465-4353

December 2004

Contents

ACKNOWLEDGEMENTS	ii
INTRODUCTION	1
STUDY AREAS	4
General	4
Specific Study Sites	4
Habitat Evaluation	9
METHODS	10
Marten Abundance and Density	10
Landscape Habitat Analysis and Marten Abundance	12
Small Mammal Abundance	12
Marten Diets	13
RESULTS	15
Marten Abundance and Density	15
Habitat Analysis and Marten Density	19
Small Mammal Abundance	19
Marten Diets	21
DISCUSSION	25
MANAGEMENT IMPLICATIONS	30
FUTURE DIRECTION	31
LITERATURE CITED	33
APPENDICES	40

Abstract: Under the Tongass Land Management Plan (TLMP), the U.S. Forest Service is required to leave old-growth reserves that will support viable American marten (*Martes americana*) populations. Specifically, TLMP states that large Old Growth Reserves (OGRs) should support a minimum of 25 female martens. We estimated marten densities at 8 sites throughout Southeast Alaska and projected the number of females in a 16,200 ha OGR. From September 2001 to December 2003, we captured 85 individual martens (50 M, 35 F) from 1–3 times in 8 study areas. Capture rates varied widely among areas with the highest capture rates on Chichagof Island and Thomas Bay, and the lowest capture rates at the Kuiu and Etolin Islands. Marten densities were lower than expected in most areas. Point estimates for numbers of females inhabiting a large OGR were less than the 25 assumed in TLMP at all study areas except Chichagof Island. Point estimates for Point Couverden and Thomas Bay were 19 and 15 females, respectively. Estimates for the remaining 5 study areas ranged from 4–10 females in a large OGR. Although estimates were relatively imprecise, 80% confidence limits included 25 females at only 3 study areas.

Studies of martens conducted on northeast Chichagof Island from 1991-1998 found that marten diets varied seasonally and annually, especially in response to small rodent numbers. On northeast Chichagof martens fed on voles during periods of high abundance, but switched to feed on seasonally available salmon (*Oncorhynchus* spp.) when vole numbers were low. Nonetheless,

on northeast Chichagof Island, the number of potential alternative mammalian foods for martens is relatively limited (i.e., long-tailed vole (*Microtus longicaudus*), Keen's mouse (*Peromyscus keeni*), and red squirrels (*Tamiasciurus hudsonicus*). In this study, we explored whether martens inhabiting geographic areas with higher diversity of potential foods such as other islands and mainland sites in the Alexander Archipelago would exhibit different dietary patterns. Using stable isotope analysis of blood samples taken from live-captured martens and muscle samples concurrently collected from trapped small mammals, we determined that the pattern observed on Chichagof Island applies to other locations in the Tongass. Our results suggested that marten populations on different islands in the Tongass National Forest rely heavily on long-tailed voles. Where vole numbers were low, salmon was the main source of food for martens during fall even in areas where prey diversity was higher than on Chichagof Island. The threshold of vole abundance at which martens switched to feed on salmon was about 1 vole per 100 trap-nights. Also, we determined that when vole numbers were low and both mice and salmon were available, martens fed on salmon. Nonetheless, the low densities of martens in our study areas that included salmon streams suggested that availability of alternative foods at other times of year such as ungulate carrion could also influence survival and reproduction in these carnivores.

Because the assumptions made in TLMP regarding the minimum number of females in OGRs may not be met in most areas, the efficacy of the conservation measures for martens in the Forest Plan needs additional consideration. For populations of martens where OGRs and lands in other non-development land use designations (LUDs) are unlikely to support a sufficient number of females and where further timber harvest is planned, additional conservation measures may be necessary. Increasing the size and proportion of higher quality habitat of OGRs would likely result in higher density of martens in individual OGRs. Because of the apparent importance of salmon as an alternate food in years of low vole abundance, the inclusion of salmon streams within OGRs may increase carrying capacity for martens. Therefore, the U.S. Forest Service should insure the inclusion of salmon-spawning streams in old-growth reserves. Finally, increased connectivity among OGRs would increase the likelihood that populations function as metapopulations and would be repopulated by immigration after local extinctions have occurred. On islands where marten numbers are low, allocating wider corridors between OGRs than required by TLMP may enhance dispersal and therefore viability of marten population. Also, roads through corridors may reduce their effectiveness because fur trappers often use roads to target animals. Finally altering harvest practices may improve the dispersal matrix and facilitate the existence of meta-populations. For example, yarding logs by helicopter would reduce the need to build roads, partial harvest instead of clearcutting could maintain higher habitat value for martens and voles, and clumping timber harvest would reduce the fragmentation of the remaining habitat.

Key words: abundance estimation, American marten, conservation strategy, diet relationships, *Martes americana*, old-growth reserves, small mammals, Southeast Alaska, stable isotope analysis, Tongass National Forest

INTRODUCTION

The conservation strategy of the Tongass Land Management Plan (TLMP) emerged from the principles of metapopulation theory (U.S. Forest Service 1997). A metapopulation is defined as groups of conspecifics (or populations) that are distributed over patches of suitable habitat, spatially isolated by a matrix of unsuitable habitat, which could be crossed but could not support resident animals (McCullough 1996). A metapopulation may persist over time if extinctions of local populations are not synchronized, and extirpated areas can be recolonized from other adjacent populations (Hedrick 1996). Connectivity of suitable habitat patches is important for maintaining the viability of the metapopulation through dispersal (McCullough 1996).

Under the direction of metapopulation theory, the TLMP conservation strategy created a matrix of old-growth reserves (OGRs) of various sizes, shapes, and spacings (Fig. 1). Several species were identified as “design” species based on their dependency on forested habitats and the assumption that their preservation will also facilitate the long-term persistence of other species in the assemblage, including other terrestrial mammals and migratory birds (Buskirk 1992, Suring et al. 1993). Those species included, among others, the northern flying squirrel (*Glaucomys sabrinus*) as an indicator for small (< 4,047 ha) old-growth reserves, American martens (*Martes americana*) as an indicator of medium size reserves (4,047 – 16,200 ha), and wolves (*Canis lupus*) and bears (*Ursus* spp.) as indicators of large old-growth reserves (> 16,200 ha; U.S. Forest Service 1997). In developing the conservation strategy 2 assumptions were made: 1) OGRs will be sufficient to support well-distributed, viable

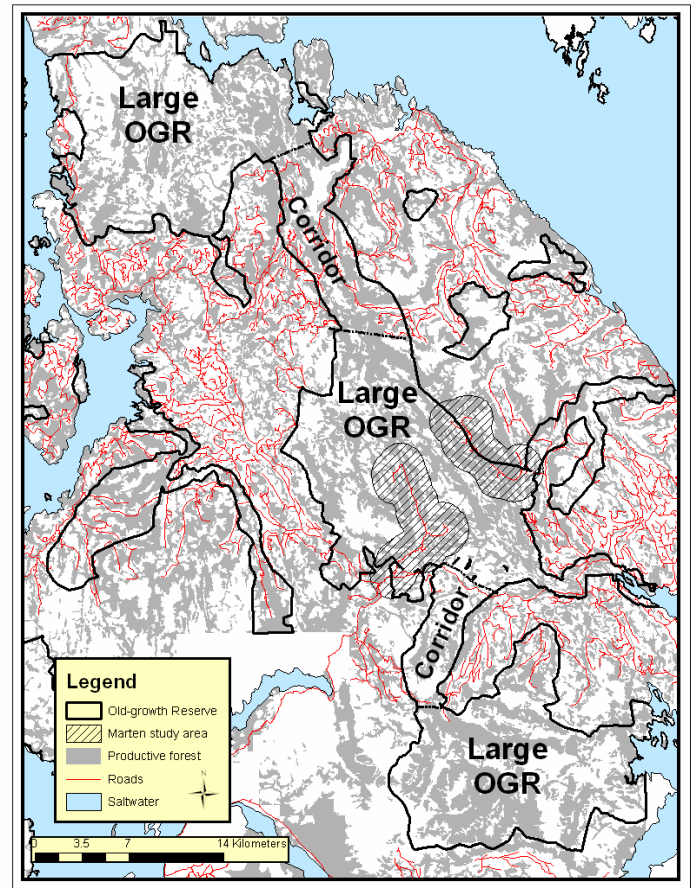


Figure 1. Our interpretation of the old-growth reserve system on central Prince of Wales Island based on an examination of the layout of lands in non-development Land Use Designations (LUDs) (U.S. Forest Service GIS database).

populations and 2) the harvested matrix will provide habitats that will allow for dispersal of individuals among the old-growth reserves. These assumptions, however, were not previously tested.

American martens were chosen as one of the design species in TLMP because they exhibit a consistent close association with mature forests throughout their distributional range (Snyder and Bissonette 1987, Buskirk 1992, Thompson and Curran 1995, Sturtevant et al. 1996). Mature, closed canopy stands confer thermoregulatory advantages that can enhance winter survival (Harlow 1994, Taylor and Buskirk 1996, Wilbert et al. 2000). In addition, the high structural complexity of old-growth forests

influences availability of den and resting sites, food availability, and foraging success (Buskirk and Ruggiero 1994, Sherburne and Bissonette 1994, Taylor and Buskirk 1994, Ben-David et al. 1997, Chapin et al. 1997, Ruggiero et al. 1998, Wilbert et al. 2000), as well as providing protection from predation (Hodgeman et al. 1997, Leiffers and Woodward 1997). Indeed, the strong association between *Martes* species and forested habitats can also be seen in the fossil record (Powell 1981, Clark et al. 1987, Graham and Graham 1994). In addition, marten pelts represent significant economic value to local residents, and thus have added significance for multiple use management of the Tongass National Forest (TNF).

Industrial forestry practices have resulted in fragmentation of mature forests throughout North America (Buskirk and Ruggiero 1994). Timber harvest of old growth high and low volume stands, particularly the clear-cutting method, detrimentally affects martens (Soutiere 1979, Buskirk and Ruggiero 1994, Thompson and Harestad 1994, Hargis et al. 1999). Previous studies have shown that martens avoided open areas that lack overhead cover (Buskirk and Powell 1994) and selected mature forest types over regenerating clear-cuts within their home ranges (Payer 1999). Also, forest fragmentation and the associated increase in second-growth stands on the landscape are associated with alterations in habitat selection by martens and reduced survivorship and reproduction (Thompson and Harestad 1994, Bissonette et al. 1997, Chapin et al. 1998). Therefore, forest management activities on the TNF were expected to affect population abundance of these carnivores (Sidle and Suring 1986).

Densities of martens have been linked to availability of prey, primarily small mammals (Thompson and Colgan 1987). Kartashov (1989) demonstrated that in sables (*M. zibellina*) the percent of breeding

females varies greatly among years. Thompson and Colgan (1987) as well as Strickland and Douglas (1987) observed lower ovulation rates in *M. americana* during years of low prey availability accompanied with declines in population numbers. Similarly, other studies identified small rodents as the most common prey in diets of martens (Buskirk and MacDonald 1984, Douglas et al. 1983, Martin 1987, 1994, Thompson and Colgan 1990). Based on these observations, the TLMP conservation strategy assumed that in years of low prey abundance 25 and 5 resident female martens would inhabit large ($\geq 16,200$ ha) and medium ($\geq 4,047$ ha) OGRs, respectively. These assumptions and relationships were based on the best information available at the time including a review of the current literature and preliminary information from a field study in progress on Chichagof Island (Suring et al. 1993). Subsequent studies (Flynn and Schumacher 2001) on Chichagof Island found lower marten abundance in years of high prey availability than those assumed in the Forest Plan for years of low prey availability (R. W. Flynn, unpublished data). Therefore, the old-growth reserve system, as currently designed, likely will support fewer martens than assumed in the TLMP. If fewer, those populations may not be viable in the long-term unless additional conservation measures are implemented.

Furthermore, TLMP assumed that marten abundance and population dynamics were similar across the TNF. Because the composition and relative abundance of small mammal communities in Southeast Alaska differs substantially by island (Table 1), food availability for insular marten populations likely differs as well. For example, northern flying squirrels occur on the mainland and many islands in southern Southeast, but not on the larger islands of northern Southeast. Red-backed voles

Table 1. Mammalian prey items potentially available to American martens at 8 locations in Southeast Alaska (X = present; - = absent). Species distributions are based on MacDonald and Cook (1996). Actual species abundances will vary by location. Ungulate density index is based on deer pellet-group counts and presence of moose.

Location	Long-tailed voles	Tundra voles	Southern red-backed voles	Northern red-backed voles	Keen's mice	Northern flying squirrels	Red squirrels	Ungulate density index
Chichagof Is.	X	X	-	-	X	-	X	1.00
Etolin Is.	X	-	X	-	X	X	X	0.30
Kuiu Is.	X	-	-	-	X	-	X	0.32
Kupreanof Is.	X	-	-	-	X	-	X	0.56
Point Couverden	X	-	-	X	X	X	X	0.21
Prince of Wales Is.	X	-	-	-	X	X	-	0.69
Thomas Bay	X	-	X	-	X	X	X	0.59
Yakutat	X	X	-	X	X	-	X	0.41

(*Clethrionomys* spp.) occur on much of the mainland and only a few islands in central Southeast. Both species may be important food items. Long-tailed voles (*Microtus longicaudus*; a principal food for martens on Chichagof Island) occur on most islands and the entire mainland, but their abundance appears to vary substantially, especially temporally. For example, long-tailed voles occur on Mitkof Island, but only 4 records exist in the University of Alaska Museum collection (MacDonald and Cook 1996). On northeast Chichagof Island, vole numbers fluctuated between 0.0 and 11.1 captures/100 trap nights from 1991-1998 (Flynn and Ben-David, *in prep*). Studies of diets of martens conducted on Chichagof Island from 1991-1998 found that marten diets varied seasonally and annually, and were correlated with numbers of small rodents (Ben-David et al. 1997). On Chichagof Island martens fed on long-tailed voles year round during periods of high abundance, but switched to feed on salmon (*Oncorhynchus* spp.) during the fall in years when vole numbers were low (Ben-David et al. 1997, Flynn and Ben-David, *in prep*). Although alternative foods existed, marten abundance and productivity were related to an index of abundance of long-tailed voles. Nonetheless, on Chichagof Island the

number of potential foods for martens was relatively limited and the number of potential mammalian prey restricted to 3 species including long-tailed voles, Keen's mice (*Peromyscus keeni*), and red squirrels (*Tamiasciurus hudsonicus*). We assumed that geographic areas with higher diversity of potential foods, such as other islands and mainland sites in the Alexander Archipelago, would support more numerous and stable marten populations.

In this study, we tested the assumption of the TLMP conservation strategy that OGRs on different island and mainland sites will support viable marten populations. Specifically, we estimated the density of martens on 8 island and mainland sites across Southeast Alaska and compared these densities with those listed in the TLMP conservation strategy. Next, we evaluated abundance and diets of martens in relation to the abundance of small mammals in these 8 locations. We expected that on islands with more diverse or stable rodent numbers, marten densities would be greater and populations would fluctuate less. Also, we predicted that in locations with high diversity of small mammals, martens would switch to alternative mammalian prey when vole numbers were low. In contrast, in areas with low diversity of small mammals, we

predicted that martens would switch to feed on salmon when abundance of voles is low. Information from this study will be useful in evaluating the long-term viability of marten populations in the old-growth reserve system of the current Forest Plan.

STUDY AREAS

General

Southeast Alaska (Fig. 2) consists of rugged mountains, numerous islands, and conifer-dominated rain forest. Mountains rise from the sea to over 1,400 m. The maritime climate is cool, and moist throughout the year. In the Juneau area, the annual precipitation ranges from 135 cm at the airport to 236 cm at downtown. Heavy snow accumulations often occur during winter; higher elevations are snow-covered for 7 to 9 months of the year. The natural vegetation is dominated by temperate rain forest, one of the world's most limited ecosystems (Alaback 1988), interspersed with muskegs and alpine tundra. Because of the lack of frequent, large-scale, catastrophic natural disturbance, the rain forests of southeast Alaska are predominantly in an old-growth condition (Alaback and Juday 1989). Sitka spruce (*Picea sitchensis*) or western hemlock (*Tsuga heterophylla*) dominate the overstory of most plant associations on productive sites (Martin 1988, Alaback 1989, Samson et al. 1989). Poorly drained sites often contain mountain hemlock (*Tsuga mertensiana*), Alaska-yellow cedar (*Chamaecyparis nootkatensis*), or western red cedar (*Thuja plicata*). The understory, depending on site conditions, may be dominated by shrubs such as blueberry (*Vaccinium* sp.), rusty menziesia (*Menziesia ferruginea*), or devil's club (*Oplopanax horridum*). Bunchberry (*Cornus canadensis*), trailing raspberry (*Rubus pedatus*), and skunk cabbage (*Lysichitum americanum*) are common forbs.

In order to evaluate habitat composition, we used the timber type (TIMTYP) landcover map available from the U.S. Forest Service. Although developed for timber management purposes at a forest-wide scale (Caouette et al. 2000), this landcover map was the only digital database that encompassed all of our study areas. For this analysis, we used geographic information system (GIS) software to group land cover into 6 categories based on forest condition. Non-forest included alpine, shrub, muskeg, and estuary habitats. Clearcut habitat included those sites logged since 1970 because canopy closure by regenerating forest generally occurs at about 35 years after cutting (Alaback 1982). Scrub forest included unproductive, old-growth forest in volume class 3 (VC3). Volume class 4 (VC4) sites included all old-growth forest in VC4 only. Because we found little volume class 6 or 7 at most study areas or OGRs, we grouped all volume classes ≥ 5 as volume class 5⁺ (VC5⁺). Even-aged forest included stands originating from clearcuts prior to 1970, windthrow, or primary succession after deglaciation (i.e., Yakutat).

Specific Study Sites

We selected 8 geographic areas located across southeast Alaska for study based on geographic distribution, species assemblages and accessibility (Fig. 2). The selected areas represented distinct assemblages of potential marten prey species. Mammal species considered included Keen's mice, long-tailed voles, northern red-backed voles (*Clethrionomys rutilus*), southern red-backed voles (*C. gapperi*), red squirrels, northern flying squirrels, shrews (*Sorex* sp.), and Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) (Table 1, Fig. 3). Moose (*Alces alces*) were present in a few areas, notably Thomas Bay and Yakutat. We based mammal distributions on MacDonald and Cook (1996), but had no prior data on

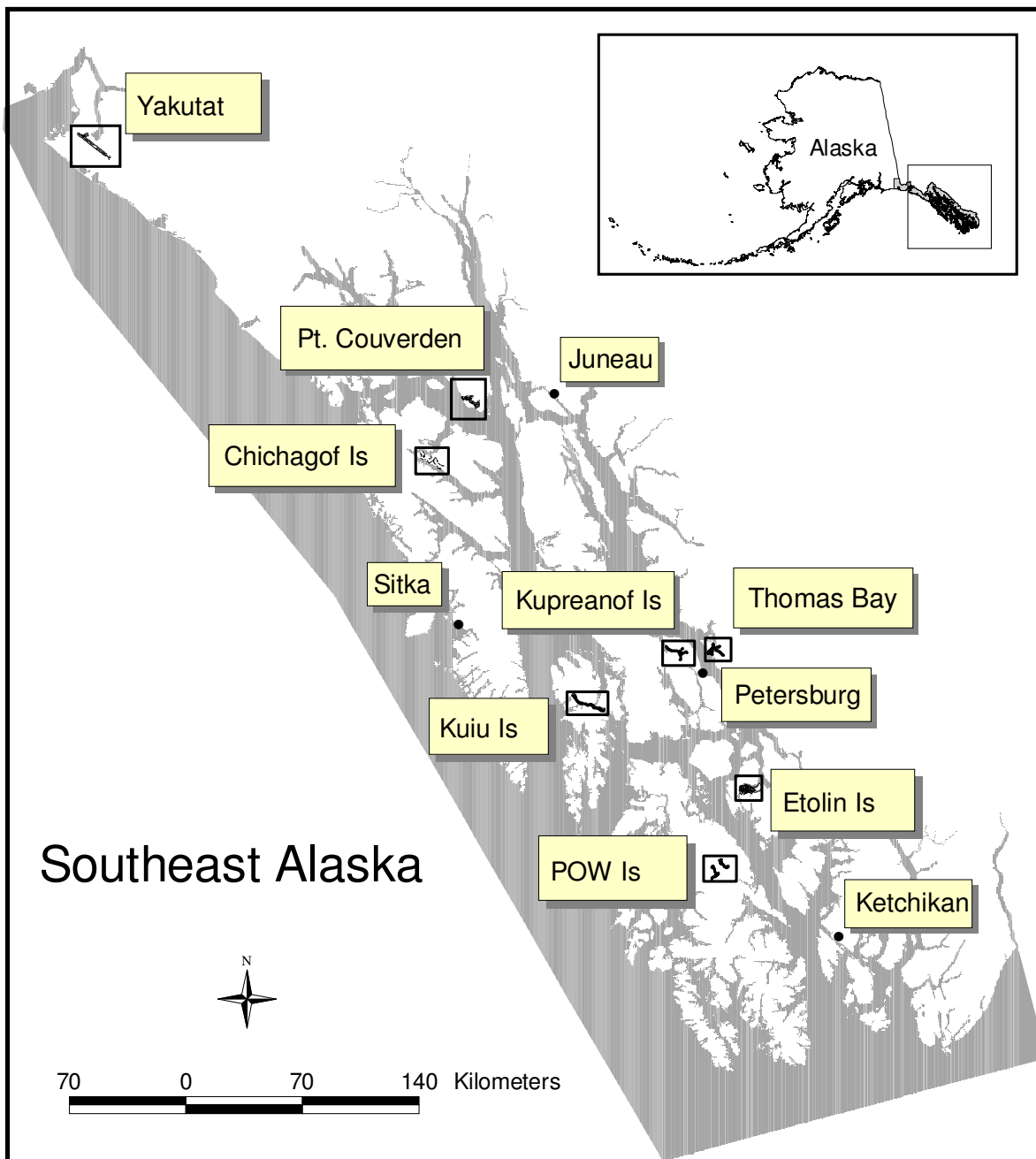


Figure 2. Map of study areas in Southeast Alaska.

species abundance. We expected species abundance to vary among study sites and over time. All sites had spawning Pacific salmon (*Oncorhynchus gorbuscha*, *O. keta*, and *O. kisutch*) available during the late summer and early fall. The resident avian fauna may include Steller's jay (*Cyanocitta*

stelleri), blue grouse (*Dendragapus obscurus*), spruce grouse (*Dendragapus canadensis*), and winter wren (*Troglodytes troglodytes*). Other songbirds such as dark-eyed junco (*Junco hyemalis*), robin (*Turdus migratorius*), varied thrush (*Ixoreus naevius*), hermit thrush (*Catharus guttatus*),

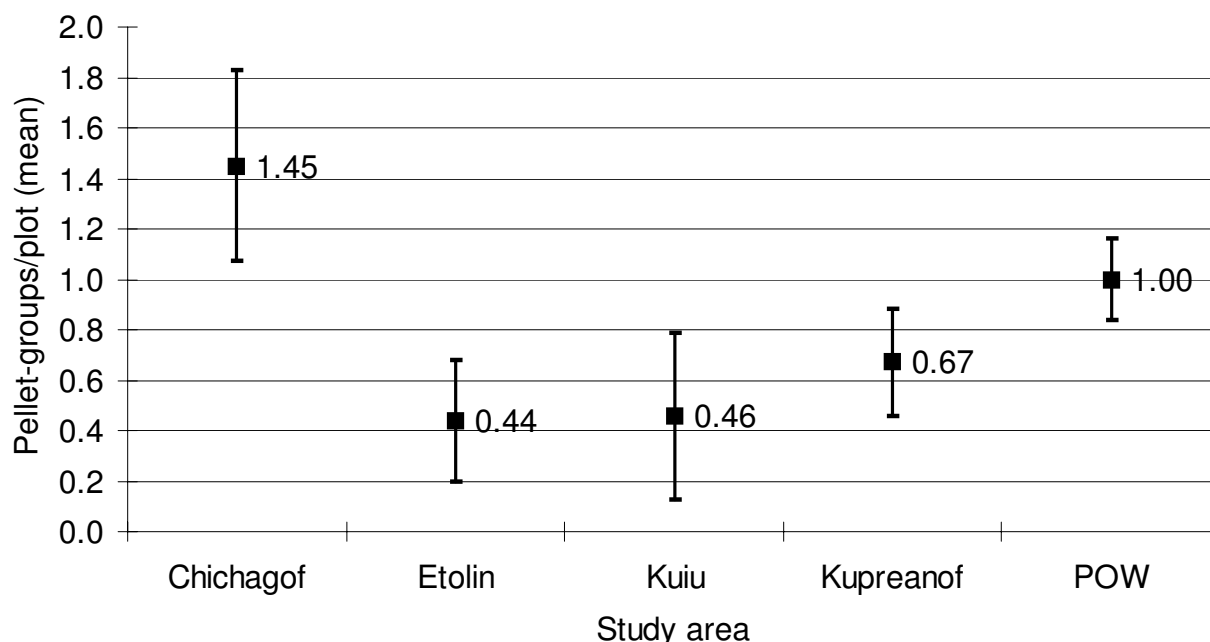


Figure 3. Relative density of black-tailed deer on study sites based on pellet-group transects (Kirchhoff 2003). Means and SEs based on all transects in an area since 1993. The number transects in an area varied from 3 on Kuiu Island to 5 on Chichagof and Prince of Wales Islands. The sample interval for a transect varied from 1 to 9 years. Pellet-group transect data were not available for Point Couverden, Thomas Bay, and Yakutat. At these sites, deer numbers were assumed similar to Etolin Island.

and Swainson's thrush (*Catharus ustulatus*), arrive for the breeding season in early May and depart during September. Although the distributions of grouse and ptarmigan (*Lagopus lagopus*, *L. leucurus*, and *L. mutus*) also vary across the region, we did not consider that these birds contributed significantly to marten diets. At each location, we selected specific study sites based on access and suitable habitat. In order to complete the marten surveys, a site had to be large enough to accommodate a 25-km trapline using logging roads or other access points. Ideally, the study sites contained old-growth reserves, other non-development land use designations (LUDs) with mostly suitable marten habitat, or adequate habitat to meet the minimum composition requirements of an old-growth reserve (at least 50% productive forest and 25% VC5⁺).

Accessibility by vehicle during summer and fall and the availability of lodging facilities were important components in our selection of study areas. Unfortunately, most reserves designated in TLMP did not have adequate access for this project. Also, in order to minimize the effect of fur trapping on density estimates, we looked for study sites where little fur trapping had occurred in recent years. These sites tended to be either remote or under administrative regulations that limited access for marten trapping.

Chichagof Island.—Marten abundance on the Salt Lake Bay area on northeast Chichagof Island has been monitored since 1990 (Flynn and Schumacher 2000). To provide a link between our earlier studies (Ben-David et al. 1997) and this effort, we included the Salt Lake Bay study area as a survey site for this study (Fig. 2). About 80% of the Salt Lake Bay trapline crosses a designated OGR with the remainder in a

timber management LUD. Within the effective trapping area (6,757 ha), the percentage of productive forest (59.3%) and the percentage of VC5⁺ forest (31.8%) exceed the minimums. ADFG has a facility at Salt Lake Bay, and a vehicle was temporarily available for this project. Mammal species of interest on Chichagof Island include long-tailed voles, Keen's mice, red squirrels, and abundant deer. Although restricted to a few species, small mammals on Chichagof Island are some of the largest in the region. We found that long-tailed voles averaged 20 g more than red-backed voles. Although considered the same species now (MacDonald and Cook 1996), Keen's mice on Chichagof Island averaged 7.9 g more than those from all other places. Previously, the deer mice on Chichagof were described as a separate species (*Peromyscus sitkensis*) (Hall 1981) because of their larger size. Now, they are recognized as a subspecies (*P. k. sitkensis*) (MacDonald and Cook 1996) although additional analyses are needed (Lucid and Cook 2004). A larger food packet size may help compensate for situations with less numerous prey.

Based on deer pellet-group surveys (Fig. 2), the relative ungulate density index was rated as high. Marten and small mammal trapping occurred in fall (September to November) 2002 and 2003. Data encompassing our investigations from 1990 – 1998 (Ben-David et al. 1997, Flynn and Schumacher 2001) were also included when appropriate.

Etolin Island.—We selected an area on northern Etolin Island near Anita Bay for a survey site (Fig. 2). Because the designated medium OGR on north Etolin has no road access, we chose a nearby area with road access. Although nearly the entire trapline fell into a timber management LUD, the effective trapping area (7,263 ha) closely resembled the minimum habitat composition requirements of a reserve. The percentage of

productive forest falls 9% short of the minimum standard, but the percentage of VC5⁺ forest exceeds the minimums. A Forest Service facility with housing, vehicle, and fuel exists at Anita Bay. Mammal species of interest on Etolin Island included long-tailed voles, Keen's mice, red-backed voles, red squirrels, northern flying squirrels, deer, and wolves. Sealing records indicated little marten trapping on Etolin Island during recent years. Based on deer pellet-group surveys (Fig. 2), the relative ungulate density index was rated as low. Marten and small mammal trapping occurred in fall 2002.

Kuiu Island.—The selected trapline included 29 km of Forest Service roads (4607, 6402, 6434, and 46095) located east of Rowan Bay on northern Kuiu Island (Fig. 2). About 23.4 km (81%) of the trapline passed through non-development LUDs with about 15 km in a medium OGR. Another 8.5 km of the trapline crossed an area to be managed for remote recreation. Collectively, the 1.6-km buffered trapline included sufficient habitat to meet the minimum requirements of an OGR. Because parts of the trapline passed near the beach, the effective trapping area included a land area of 6,714 ha. Although open to trapping, no marten fur harvest had been reported from the area since 1986. A Forest Service facility with housing, vehicle, and fuel existed at Rowan Bay. Mammal species of interest on Kuiu Island included long-tailed voles, Keen's mice, red squirrels, deer, and wolves. Although present, deer numbers have been low for many years. Based on deer pellet-group surveys (Fig. 2), the relative ungulate density index was rated as low. Marten and small mammal trapping occurred in fall 2001 and 2002.

Kupreanof Island.—We selected an area on northern Kupreanof Island near Portage Bay for a survey site (Fig. 2). Although nearly the entire trapline falls into a timber

management LUD, the effective trapping area (8,425 ha) met the minimum habitat composition requirements of a reserve. A Forest Service facility with housing, vehicle, and fuel existed at Portage Bay. Mammal species of interest on Kupreanof Island included long-tailed voles, Keen's mice, red squirrels, deer, moose, and wolves. Although similar in mammal composition to Kuiu Island, deer numbers on Kupreanof Island are higher. Based on deer pellet-group surveys (Fig. 2), the relative ungulate density was rated as low. Marten and small mammal trapping occurred in fall 2002 and 2003.

Point Couverden.—We added this mainland site, located 54 km west of Juneau, in 2003 (Fig. 2). The trapline included 39.4 km of logging road. Within the effective trapping area (8,128 ha), the percentage of productive forest (56.2%) and the percentage of VC5⁺ forest (27.4%) exceeded the OGR minimums. The small mammal fauna included long-tailed voles, Keen's mice, northern red-backed voles, red squirrels, and northern flying squirrels. Sitka black-tailed deer, moose, and wolves were also present, but in low numbers. Because of low deer numbers, pellet-group surveys had not been done here. Thus, we rated the relative ungulate density index as low. Marten and small mammal trapping occurred in fall 2003.

Prince of Wales Island.—We chose the Honker-Divide area on north-central Prince of Wales Island (POW) as a study site (Fig. 2). This area includes the Honker Divide OGR (Fig. 1) and 2 Forest Service roads penetrate the reserve, including the Cutthroat Road (13.7 km) and the Honker Road (10.8 km). The Cutthroat Road provided access to the western portion of the reserve. On the east, the Honker Road enters the reserve, and then exits for 5 km into a scenic viewshed LUD. The effective live-

trapping area based on a 1.6-km buffer along the trapline was 8,609 ha. Both of these roads had been closed to the general public by a locked gate. Thus, we expected little fur trapping along these roads. Habitat composition within a 1.6-km trapline buffer met the minimum requirements of an OGR. Mammal species of interest on Prince of Wales Island include long-tailed voles, Keen's mice, northern flying squirrels, deer, and wolves. Based on deer pellet-group surveys (Fig. 2), the relative ungulate density index was rated as medium. Marten and small mammal trapping occurred in fall 2001, 2002, and 2003.

Thomas Bay.—For a mainland site, we selected an area near Thomas Bay for a survey site (Fig. 2). The designated OGRs near Thomas Bay have no road access, so we chose an area with road access that closely resembles the minimum composition requirements of OGR. On Forest Service lands, most of the trapline crossed a scenic viewshed LUD. Part of the trapline crossed state lands. Within the effective trapping area (6,440 ha), the percentage of productive forest (42.6%) falls short of the standard (50%), but the percentage of VC5⁺ forest (27.6%) exceeds the minimums. ADFG has a cabin at Thomas Bay and the Forest Service provided a vehicle. Potentially, Thomas Bay had the entire complement of mammal species of interest including long-tailed voles, red-backed voles, Keen's mice, red squirrels, northern flying squirrels, deer, and wolves. Sealing records indicated occasional marten trapping along the shoreline of Thomas Bay, but no recent trapping along the road system. Because not considered an important deer area, adequate deer pellet-group surveys had not been completed to provide a reliable index. In calculating the ungulate index, we assumed that deer numbers were low and similar to nearby Etolin and Kupreanof Islands. We increased the index by 0.2 to account for the

substantial moose population. Marten and small mammal trapping occurred in fall 2001 and 2002.

Yakutat.—We added this mainland site, located 340 km northwest of Juneau, in 2003 (Fig.2). The trapline was 30.0 km long. Within the effective trapping area (10,021 ha), the percentage of productive forest (68.2%) and the percentage of VC5⁺ forest (57.1%) exceed the minimums. The small mammal fauna included long-tailed voles, Keen's mice, northern red-backed voles, red squirrels, and northern flying squirrels. Moose were the primary ungulate and wolves were also present. Deer numbers were believed to be low and no pellet-group data were available. Based on the presence of moose, the relative ungulate density index was rated as low. Marten and small mammal trapping occurred in fall 2003.

Habitat Evaluation

We evaluated whether the composition and spatial distributional patterns of habitats within our study areas were representative of habitats within nearby medium and large OGRs. Because most of the actual OGRs were inaccessible, we used our study areas as surrogates for OGRs. Thus, we wanted to establish whether the habitats within our study areas differed from the established OGRs.

We buffered each marten trapline by 1.6 km to delineate our study areas for the habitat composition analysis. All salt water was considered non-habitat and eliminated from the study areas. Although OGRs were not explicitly mapped in the GIS as a LUD, we used the LUD GIS coverage from TLMP to identify nearby Old-growth Management LUDs that best approximated the composition, size, and distance requirements of medium or large OGRs (U.S. Forest Service 1997). Where the nearest lands with an Old-growth LUD were much smaller than

a study area, we grouped up to 3 of the nearest old growth LUD areas together and considered the combined area as an OGR for the analysis. Five of our study areas overlapped with or were adjacent to OGRs. At 2 sites, Thomas Bay and Point Couverden, OGRs were <2.5 km from our study areas and at Yakutat 1 of the 3 OGRs used was 11.5 km from the study area. We observed no significant barriers to marten dispersal between any pairing of study areas and potential OGRs.

We calculated habitat composition of trapped areas and OGRs and compared 95% confidence intervals around means for proportions of each habitat (Fig. 4). Habitat composition of all study areas and OGRs, except those on Etolin Island, met the minimum forest composition requirements established in TLMP. The Etolin Island study area had 9.4% too little forest in volume classes ≥ 4 and 3.6 % too little forest in VC5⁺, whereas the OGR had 1.1% too little forest in volume classes ≥ 4 , but sufficient VC5⁺ forest. Proportions of lands in each habitat category varied little between study areas and OGRs. The only habitat for which 95% confidence limits did not overlap was clearcut. Study areas had significantly more clearcut habitat than OGRs. Thus, we concluded that the habitat composition of study areas were adequately similar to

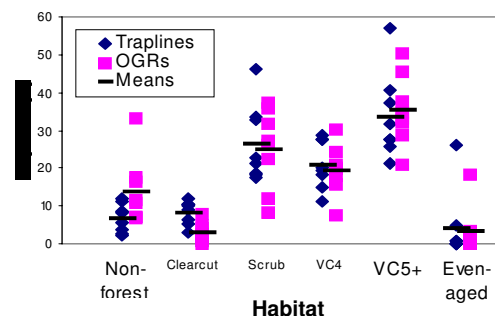


Figure 4. Habitat composition of 8 marten study areas and nearby old growth reserves on the Tongass National Forest, Southeast Alaska, 2001-2003. Habitat classes were derived from the Tongass TIMTYP GIS databases.

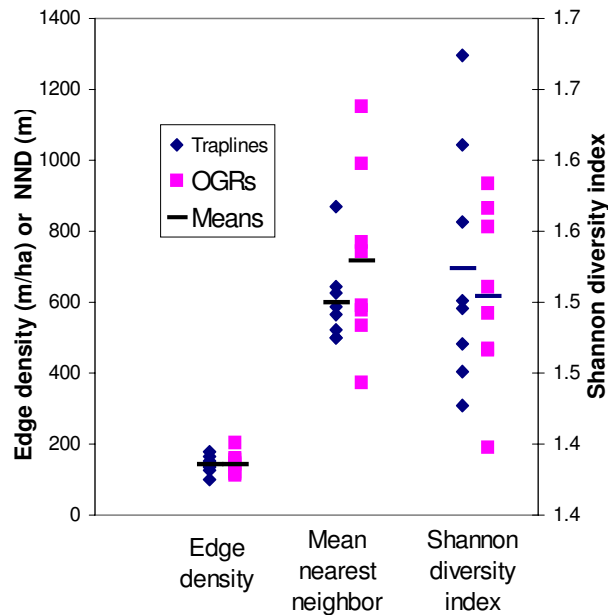


Figure 5. Values of 3 landscape metrics for 8 marten study areas and nearby old growth reserves in Southeast Alaska, 2001-2003.

nearby OGRs

In addition to habitat composition, we compared landscape spatial metrics of the study areas and nearby OGRs. For this analysis, we computed 21 spatial statistics using FRAGSTATS (McGarigal and Marks 1995) as implemented with the Patch Analyst extension for ArcView (Elkie et al. 1999). Similar to the habitat composition evaluation, we compared 95% confidence intervals around means for selected spatial variables. If confidence intervals did not overlap, we considered differences significant.

We selected relevant spatial variables by examining correlations among spatial measures and correlations between measures and mean marten density. Also information on habitat selection provided by Snyder and Bissonette (1987), Chapin et al. (1998), and Potvin et al. (1999) was considered. Of the spatial metrics, edge density (ED), Shannon diversity index (SDI), and mean nearest-neighbor distance (MNN) were poorly

correlated among themselves and correlated with mean marten capture rate. ED is the amount of edge relative to the landscape. SDI, a measure of patch diversity, reflects the number of habitat types and how evenly the study area is distributed among habitat types. MNN, a measure of patch isolation, is the mean edge-to-edge distance between patches of similar habitat. Mean values and ranges for these variables at study areas and OGRs were similar (Fig. 5), and 95% confidence intervals overlapped.

The study areas and adjacent OGRs did differ in road density though. The study areas averaged 3.36 m/ha (SD = 0.52, $n = 8$) of logging road. By design, the road density in OGRs was low (U.S. Forest Service 1997).

METHODS

Marten Abundance and Density

Marten captures.—At each site, a 25-km trapline was established using logging roads or other access points. Along each trapline, trap stations were spaced at about 0.5-km intervals. At each station, a single, wire live trap (Model 203, Tomahawk Live Trap Co., Tomahawk, WI) was covered with a piece of plastic tarp then placed under a log or stump located adjacent (15-40 m) to the logging road or other access point. Traps were set, baited with sardines, or jam, scented with commercial marten lure (Flynn and Schumacher 1996), and checked daily for 5-6 consecutive nights.

For immobilization, captured martens were confined to the end of the trap using a folded blanket and injected with a mixture of 18.0 mg/kg ketamine hydrochloride (Vetalar) and 1.6 mg/kg xylazine hydrochloride (Rompun). All captured martens were sexed, then eartagged (Size 1, Style 1005, National Band and Tag Co., Newport, KY) for individual identification. Animals were left

in the trap until recuperated, then released at the site of capture. Independent Animal Care and Use Committees at the University of Wyoming and the Alaska Department of Fish and Game (ACUC 03-0011) approved all methods of animal handling used in this study.

Marten density.—For each area we first calculated capture rates by dividing the number of captures by total number of trap nights (TN). We then estimated marten abundance on each study site based on the number of unique individuals captured during the trapping session. Previous mark-recapture studies on Chichagof Island found a strong relationship between the number of unique marten captures and the estimated population size (Flynn and Schumacher 2001). During these mark-recapture surveys, the mean capture probability was 0.64 ($n = 16$ trapping sessions, $SE = 0.05$) (ADFG, R. W. Flynn, unpublished data). For this study, we assumed that the mean probability of capture at any time during the survey was similar to that of Chichagof Island. In addition, Flynn and Schumacher (1993) found that female martens on Chichagof Island have an average home range size (95% minimum convex polygon) of 5.3 km² ($n = 13$, $SE = 0.7$) and males to have a mean home range size of 7.8 km² ($n = 28$, $SE = 1.1$). We estimated the effective trapping area by assuming that all martens with a home range intersecting a trapline had a capture probability equal to the average measured on Chichagof Island (Flynn and Schumacher, *in prep.*). We estimated the effective trapping area by buffering the trapline by the mean radius of home ranges. Because of different home range sizes, we computed the buffer distances separately for males ($\bar{x} = 1.51$ km, $SE = 0.1$) and females ($\bar{x} = 1.25$ km, $SE = 0.1$). We separately estimated variance of the effectively trapped areas for males and females at each study site based on means of 300 bootstrap

samples of actual home range diameters from Chichagof Island.

We estimated male and female marten density separately by using:

$$\hat{d} = \frac{C}{(p * A)},$$

where:

d = density of male or female martens per hectare,

C = number of unique males or females captured,

p = probability of capture (0.64),

A = the mean effectively trapped area for either sex,

with variance estimated by:

$$\text{var}(\hat{d}) \cong (\hat{d})^2 \left[\frac{1}{C} + \frac{\text{var}(A)}{A^2} + \frac{\text{var}(p)}{(p)^2} \right]$$

This variance estimation included the combined variances of the capture probability and home range size (G. Pendleton, ADFG, personal communication). We estimated the number of male and female martens that would likely inhabit a 16,200 ha OGR associated with a given study area by multiplying the estimated density in the study area by 16,200 ha. We scaled the variance of the estimated density of martens per hectare to the magnitude of a large OGR by multiplying the variance by 16,200 ha and used standard methods to calculate confidence intervals.

Marten sex and age ratios and body condition.—In order to gather additional information on population status, we sexed, aged, weighed and measured each animal. We used deviations from body mass predicted by linear regressions between body mass and total body length as a measure of body condition (BCI) for captured martens. These relationships were developed using all martens live-captured in Southeast Alaska since 1991 (Flynn and

Ben-David, *in prep.*). First, the mean total length was computed for each animal with multiple captures. We assumed that individuals had reached their full length when first captured, and any subsequent differences in body length were attributed to measurement error. Because of strong sexual dimorphism, we computed regression equations for males and females separately (males: $y = 2.544x - 455.8$, $r^2 = 0.139$; females: $y = 1.9929x - 347.3$, $r^2 = 0.198$, where y = body mass (g) and x = total body length (mm). We used the standardized residuals from the regressions as our BCI. We pulled 2 first premolar teeth for age determination by cementum analysis (Matson's Laboratory, Milltown, MT). Age ratios were expressed as juveniles: adult and juveniles: adult female. Martens aged older than 1 year were considered adults. For all the population parameters, we compared means and 95% CIs among study areas and years.

Effect of fur trapping.—We examined the reported marten catch to gain insight into whether recent fur trapping had likely influenced marten abundance. To minimize the potential effect of fur trapping on our estimates of marten density, we selected study areas that had experienced little recent marten trapping. We gauged trapping activity using ADFG fur sealing records. Since 1984 trappers have been required to submit marten pelts harvested in all game management units (GMU) in Southeast Alaska for sealing by a Department designated sealer. We summarized harvest in two ways. First we calculated mean and peak harvest over a 12-year period for landscapes surrounding each study area. Then we summarized harvest from 1999-2002 for only the immediate vicinity of our study areas where animals residing on the study area were likely to be trapped. Also, trapping records provided insight on historic population trends in the larger area.

Landscape Habitat Analysis and Marten Abundance

To examine whether habitat features at our different study sites affected our estimation of density, we attempted to correlate landscape habitat features with marten density. Although we assumed the study areas met the minimum habitat composition requirements for an OGR, we examined correlations among the amount of productive old-growth forest habitat (VC4, VC4⁺, and VC5⁺) and marten density. Because the study areas were selected based on similar habitat composition, we did not expect marten density to be correlated with habitat composition.

As previously discussed, we used the Patch Analyst extension for ArcView (Elkie et al. 1999) to produce 21 metrics of landscape pattern for each study area (McGarigal and 1995). In order to select variables to compare with marten density, we examined correlations among these spatial measures. We then chose variables that were poorly correlated with each other and thought related to marten habitat ecology (Hargis and Bissonette 1997, Chapin et al. 1998, Potvin et al 2000). We explored the relationships among 4 of the spatial statistics and marten density using multiple regression. For this analysis, we weighted each observation by the number of repeated observations per study area using weighted least squares. In the regression model, we attempted to predict mean marten density using number of patches (NP), edge density (ED), SDI, and MNN as explanatory variables.

Small Mammal Abundance

The relative abundance of small mammals, excluding squirrels, was estimated using a snap-trap index similar to Calhoun (1948). We did not collect information on squirrel or berry abundance because of time and effort

limitations. We established transects in at least 2 old-growth forest stands at each study site: a productive western hemlock stand and a mixed conifer/blueberry stand (Marten 1989). At some sites, 2 transects were placed in each habitat. Each transect consisted of 25 trap stations placed at 15-m intervals. During the early fall, we placed 2 Museum Special snap traps at each station, baited them with a mixture of peanut butter and rolled oats, and set for 3 consecutive nights (450 trap nights). Traps were checked once daily. The number of animals captured by species was recorded and expressed as the number of captures per 100 trap nights. We calculated means and CIs for each habitat and year by study area. All specimens were weighed and sent to the University of Alaska Museum, Fairbanks.

Similar to the marten density analysis, we explored the relationships among 4 of the spatial statistics and small mammal abundance using multiple regression. For this analysis, we weighted each observation by the number of repeated observations per study area using weighted least squares. In the regression model, we attempted to predict the abundance of each small mammal species using NP, ED, SDI, and MNN as explanatory variables.

Marten Diets

Diet composition.—We determined autumn marten diets on each study site using stable isotope analysis (SI; Ben-David et al. 1997, Szepanski et al. 1999). Applying SI analysis to tissues, such as blood, allowed repeated sampling of known individuals (Ben-David et al. 1997, 2001), enabling us to investigate individual diets and the factors underlying feeding habits of individuals among study areas and years. In this analysis, comparisons of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of potential prey and predator provided information on the dietary composition of the predator

during the proceeding 3-4 weeks (Ben-David et al. 1997, 1998a).

To determine the isotopic signatures of marten prey, muscle tissue samples were collected from all small mammals captured in this study (see section on Small Mammal Abundance). Data for other potential food items such as squirrels, berries, and salmon were adopted from our earlier studies on Chichagof Island (Ben-David et al. 1997). To determine the isotopic signatures of martens, a 3.0 cc blood sample was drawn from the jugular vein of all captured martens. The blood was allowed to clot, the serum separated, and the remaining material was frozen for storage. All samples from captured martens and small mammals were sent to the Department of Zoology and Physiology at the University of Wyoming for SI analysis.

Tissues (clotted blood cells and muscle samples) were kept frozen until preparation for determination of stable isotope ratios. Although lipid contents may deplete values of $\delta^{13}\text{C}$ of tissues (DeNiro and Epstein 1978, Kelly 2000), samples were not defatted because clotted blood cells, hair, and vegetation contain low amounts of lipids and no difference was detected in $\delta^{13}\text{C}$ in salmon fat and defatted muscle tissues (Ben-David 1996). Samples of blood and muscle were dried at 60° - 70° C for 48 h and then ground to fine powder using a dry tissue grinder (Glenn Mills Inc., Clifton, NG). Subsequently, all samples were weighed into a miniature tin cup (4 by 6mm) for combustion. We analyzed sub-samples with a Carlo-Erba series 2 C/N analyzer attached to a VG Optima mass spectrometer to obtain the stable isotope ratios as well as values of percent C and N (Ben-David et al. 1998a, 1998b). Each sample was analyzed in duplicate and results accepted only if the variance between the duplicates did not exceed that of the peptone standard ($\delta^{13}\text{C}_{\text{std}}$

= -15.8, $\delta^{15}\text{N}_{\text{std}} = 7.0$, CV = 0.1). Samples were analyzed at the mass-spectrometry facility at the University of Wyoming.

We used a K nearest-neighbor randomization test (Rosing et al. 1998) to determine whether isotopic signatures of small mammals differed between the study areas and through time. To establish whether martens switched to alternative prey when vole numbers were low, we used the program IsoSource (Phillips and Gregg 2003) to calculate an index of the proportion of each food item in the diet of martens. For each study area, we used the end-members from that site except for those islands and mainland sites for which we had no samples of prey. For those locations and periods, we used the values of the nearest location and the closest time period. Values for salmon, berries, and squirrels were only available for Chichagof Island from 1992-1994. We used diet-tissue enrichment of 2% for carbon when mammalian prey, avian prey, and berries were consumed, and 1% when salmon or invertebrates were consumed, based on results from feeding experiments in captivity on mink (*Mustela vison*) and black bears (Ben-David 1996, Ben-David and Schell 2001, Hilderbrand et al. 1996). Also, based on the captive experiments we used fractionation values of 3% for nitrogen (Ben-David 1996, Hilderbrand et al. 1996).

To explore the relation between abundance of voles and diet of martens, we used non-linear curve estimation (SPSS 11.5 for Windows) with number of vole captures per 100 trap-nights as the independent variable and $\delta^{15}\text{N}$ as the dependent one. We repeated the analysis with number of vole captures per 100 trap-nights as the independent variable and percent salmon in the diet derived from the output of IsoSource as the dependent one.

We used multiple regression analysis to investigate which measures of food

abundance might best predict abundance of martens. We used marten density as the dependent variable and measures of ungulate density and estimated biomass of 3 small mammal species as the independent variables. For this analysis, we weighted each observation by the number of repeated observations per study area using weighted least squares. In this regression model, food variables were added in a step-wise manner ($P < 0.1$).

We estimated relative abundance of ungulates based on annual deer pellet group survey data (Kirchhoff 2003) gathered near our study areas (Fig. 3). Mean deer-pellet counts were scaled to range from 0-1. No recent deer surveys had been completed at Point Couverden, Thomas Bay, and Yakutat because of believed low deer numbers. A lack of field sign indicated that deer were scarce at Point Couverden and Yakutat, but populations appeared higher at Thomas Bay. For this analysis, we assumed that deer numbers at Point Couverden and Yakutat were similar to Kuiu Island. For Thomas Bay, we assumed that deer numbers were mid-way between nearby Kupreanof and Etolin Islands. For study areas where significant moose or elk populations were present, we adjusted the ungulate index slightly upward (+0.1 for Kupreanof and +0.2 for Thomas Bay and Yakutat). We estimated relative biomass of long-tailed and red-backed voles and Keen's mice on each study area each year by multiplying the capture rate for each species by the mean body weight of each species (i.e., g per 100 TNs). Because we found that Keen's mice on Chichagof Island averaged 7.9g ($t = 15.6$, $P < 0.001$) more than those from the other study sites, we used the measured value for that location (27.1g).

Finally, we tried to predict marten density using a combination of food and habitat variables. In this regression model, food and habitat variables were added stepwise ($P <$

0.1), and each observation was weighted by the number of repeated observations per study area using weighted least squares. The predictive ability of this combined model was compared with the previous food only model.

RESULTS

Marten Abundance and Density

Marten captures.—From September 2001 to December 2003, we captured 85 individual martens (50 M, 35 F) from 1–3 times in the 8 study areas. Usually, trapping effort in each area ranged from 250–300 trap nights (TN) per year. However, we had as few as 178 TN at Chichagof Island in 2003 and as many as 338 TN at POW in 2001. Reduced

trapping effort in some areas resulted from logistical difficulties including logs temporarily blocking roads, vehicle problems, and bad weather delaying air travel.

The highest numbers of individuals were captured on Chichagof Island (22) and at Thomas Bay (19, Table 2). Even with only 178 TN of effort, we caught the third highest number of martens (10) on Chichagof Island in 2003. The actual number of female martens captured was low at most sites. We captured only 1 female on Etolin and Kuiu islands in 2002. The highest numbers of female martens caught were 7 on Chichagof Island in 2002 and 4 at Point Couverden.

Table 2. Age and gender classifications of marten live-trapping surveys at 8 study areas in Southeast Alaska during fall 2001–2003. Juvenile (Juv.) martens = age class 0. Adult martens are ≥ 1 year old.

Study area	Year	Males		Females		TN	Captures/100TN		Juv per adult female
		Juv ^a	Adult ^a	Juv ^a	Adult ^a		Males	Females	
Chichagof Is.	2002	5	2	4	3	239	2.9	2.9	3.
	2003	3	1	2	4	178	2.2	3.4	1.3
Etolin Is.	2002	0	0	0	1	223	0	0.4	0
Kuiu Is.	2001	1	0	0	2	279	0.4	0.7	0.5
	2002	0	1	0	1	298	0.3	0.3	0
Kupreanof Is.	2002	0	4	1	0	272	1.5	0.4	--
	2003	4	1	1	0	249	2.0	0.4	--
Point Couverden	2003	2	2	1	3	291	1.4	1.4	1.0
Prince of Wales Is.	2001	2	1	0	2	338	0.9	0.6	1.0
	2002	2	2	1	0	225	1.8	0.4	--
	2003	2	1	1	1	212	1.4	0.9	3.0
Thomas Bay	2001	3	3	0	3	281	2.1	1.1	1.0
	2002	6	3	1	2	266	3.4	1.1	3.5
Yakutat	2003	0	2	2	1	294	0.7	1.0	2.0

^a Ages determined using counts of cementum annuli.

Capture rates varied widely among areas (Table 2). The highest capture rates were on

Chichagof Island and at Thomas Bay, and the lowest capture rates were at Kuiu and

Etolin islands. The highest capture rate on Chichagof Island (5.8/100TN) was over 14 times greater than the lowest capture rate on Etolin Island (0.4/100TN). Capture rates for female martens varied from 3.4 captures/100TN on Chichagof Island in 2003 to 0.3 captures/100TN on Kuiu Island in the same year (Table 2). Capture rates for areas visited in consecutive years were similar at Chichagof Island and POW between 2002 and 2003. Differences in capture rates between years at other areas mostly resulted from capturing one more or fewer martens than during the previous year. Thomas Bay was an exception where with 15 TN less effort we caught 3 more martens in 2002 than in 2001. We visited 5 of the study areas in 2 consecutive years (POW 3 consecutive years), but recaptured few previously marked martens (Table 2). In these 5 areas, 69 martens were marked but we recaptured only 5 (7.2%). We had no indication that any of these individuals were harvested prior to subsequent surveys.

Marten density.—We estimated densities of female and male martens on our study areas during each trapping session (Table 3). Based on these densities, we calculated the likely number of females and males present in a large (16,200 ha) OGR in the same area (Table 3). The point estimates for numbers of females inhabiting a large OGR were less than the 25 assumed in TLMP at all study areas except Chichagof Island. Point estimates for Point Couverden and Thomas Bay were 19 and 15 females, respectively. Estimates for the remaining 5 study areas ranged from 4–10 females in a large OGR. In all cases, variance associated with these estimates was large, resulting in relatively broad confidence limits. Still, 80% confidence limits at only 3 of 8 study areas included 25. Patterns in abundance of male

martens were similar to females with the highest estimates at Chichagof Island, Thomas Bay, and Point Couverden. However, the point estimate for males on Kupreanof Island was also similar to Chichagof Island and Point Couverden.

Marten sex and age ratios and body condition.—In most areas we caught similar numbers of males and females, but at Thomas Bay and Kupreanof Island we caught mostly males (Table 2). The capture rate for females on Chichagof Island (2.9 and 3.4/100TN) was more than double that of other sites. The number of juveniles captured per adult female varied among areas, with no consistent pattern. For example, we found similar ratios of juveniles to adult females at Chichagof Island and Thomas Bay where martens were relatively abundant and at POW where martens were relatively scarce. We caught juvenile martens, but no adult females on Kupreanof Island in 2002 and 2003 and on POW in 2002.

Mean body condition index varied greatly among areas and years ranging from -0.31 in Thomas Bay in 2002 to 1.50 on Kuiu in 2002 (Table 4). When grouped by study area by year, marten BCI did not differ by sex ($t = 0.78$, $df = 12$, $P = 0.45$) and averaged 0.53 ($n = 13$, $SD = 0.86$) for males and 0.24 ($n = 14$, $SD = 0.75$) for females. We found no significant relationship between BCI and marten density ($r = -0.34$, $P = 0.120$). Similarly, we found no relationships among marten BCI and rodent biomass (long-tailed voles $r = -0.181$; $P > 0.268$; Keen's mice $r = 0.062$, $P = 0.416$; and red-backed voles $r = 0.154$, $P = 0.120$).

Table 3. Estimated densities and numbers of female and male martens in 16,200 ha old growth reserves (OGR) on 8 study sites in the Tongass National Forest, Southeast Alaska, 2001-03.

Study area	Year	Number captured	Marten density per 1000 ha (var)	Martens in 16,200 ha OGR	Confidence limits (80%)	
					Lower	Upper
Females						
Chichagof Is.	2002	7	1.7 (0.67)	31	14	48
	2003	6	1.6 (0.56)	27	11	42
Etolin Is.	2002	1	0.3 (0.09)	5	0	11
Kuiu Is.	2001	2	0.6 (0.20)	10	1	19
	2002	1	0.3 (0.09)	5	0	11
Kupreanof Is.	2002	1	0.3 (0.08)	5	0	10
	2003	1	0.3 (0.08)	5	0	10
Point Couverden	2003	4	1.2 (0.39)	19	6	32
Prince of Wales Is.	2001	2	0.5 (0.14)	8	1	16
	2002	1	0.3 (0.07)	4	0	9
	2003	2	0.5 (0.14)	8	1	16
Thomas Bay	2001	3	0.9 (0.30)	15	3	26
	2002	3	0.9 (0.30)	15	3	26
Yakutat	2003	3	0.6 (0.15)	10	2	18
Males						
Chichagof Is.	2002	7	1.7 (0.53)	28	13	43
	2003	4	1.0 (0.28)	16	5	27
Etolin Is.	2002	0	--	--	--	--
Kuiu Is.	2001	1	0.2 (0.06)	4	0	9
	2002	1	0.2 (0.06)	4	0	9
Kupreanof Is.	2002	4	0.9 (0.26)	15	5	26
	2003	5	1.2 (0.34)	19	7	31
Point Couverden	2003	4	1.0 (0.29)	16	5	26
Prince of Wales Is.	2001	3	0.6 (0.14)	10	2	18
	2002	4	0.8 (0.20)	13	4	23
	2003	3	0.6 (0.14)	10	2	18
Thomas Bay	2001	6	1.6 (0.49)	25	10	40
	2002	9	2.3 (0.81)	38	19	56
Yakutat	2003	2	0.3 (0.06)	6	0	11

Table 4. Body condition indices (BCI; mean and SE) for marten captured during surveys 2001-2003 at 8 study areas, Southeast Alaska.

Location	Year	Males			Females			All		
		<i>n</i>	$\bar{X}$	SE	<i>n</i>	$\bar{X}$	SE	<i>n</i>	$\bar{X}$	SE
Chichagof Is.	2002	6	-0.33	0.37	6	-0.14	0.40	12	-0.24	0.26
	2003	5	0.57	0.13	6	1.03	0.55	11	0.82	0.30
Etolin Is.	2002	0	-	-	1	0.01	-	1	0.01	-
Kuiu Is.	2001	1	0.45	-	2	0.4	0.3	3	0.59	1.17
	2002	1	2.63	-	1	0.37	-	2	1.50	1.13
Kupreanof Is.	2002	4	1.43	0.24	1	-0.45	-	5	1.06	0.42
	2003	6	-0.29	0.41	1	2.11	-	7	0.05	0.49
Point Couverden	2003	4	1.15	0.21	4	-0.03	0.39	8	0.56	0.30
Prince of Wales Is.	2001	3	0.43	0.52	1	-0.49	-	4	0.20	0.44
	2002	4	-0.24	0.31	1	0.25		5	-0.14	0.26
	2003	2	0.84	0.69	2	-0.60	0.68	4	0.12	0.57
Thomas Bay	2001	6	-0.34	0.34	3	-0.27	0.46	9	-0.31	0.26
	2002	9	-0.01	0.32	3	-0.08	0.21	12	-0.03	0.24
Yakutat	2003	2	0.60	0.09	3	1.03	0.7	5	0.86	0.17

Fur trapping.—Populations of martens surrounding all study areas experienced trapper harvest between 1991 and 2002 (Table 5). Mean annual harvest ranged from 224 martens/year on north central POW and 165 martens/year on Chichagof Island to 3 martens/year on northern Kuiu Island. Marten harvest was reported in all 12 years at POW and Chichagof Island and for 11 of 12 years at Yakutat and Kupreanof Island. However, most harvest occurred away from our study areas. In all but 2 cases, <10 martens were harvested in the immediate vicinity of study areas during winters preceding our surveys. Fur trappers caught 16 marked martens in 3 study areas. All but 1 of these martens were trapped after our

final visit to an area, so fur trapping concurrent with our study had little influence on recaptures among years. A trapper caught 8 marked martens from the Thomas Bay road system during December 2002. We had captured 7 of those 8 martens during our October 2002 survey. A trapper caught 6 marked martens from the Kupreanof Island study area road system in January 2003. Of those 6 martens, we had captured 4 during our November 2002 survey, but not 2 other martens marked during 2001. The single marked marten harvested on POW was trapped away from the study area, about 22 km south of its original capture site.

Table 5. Trapper harvest of martens around 8 study areas in Southeast Alaska. Regional harvest indicates harvest for the population of which the study area was a part. Harvest in the vicinity of a study area represents harvest where martens residing on the study area were likely to be caught. Harvest data are from Alaska Department of Fish and Game fur sealing records.

Study areas	Regional marten harvest				Marten harvest in vicinity of study areas			
	Mean 1991-2002	Years with reported harvest	Peak harvest		1999	2000	2001	2002
			No.	Year				
Chichagof Is.	165	12	362	1996	0	0	1	3
Etolin Is.	11	6	55	1996	0	4	9	1
Kuiu Is.	3	2	17	2000	0	17	0	0
Kupreanof Is.	22	11	51	1999	19	24	0	0
Point Couverden	16	7	92	1998	0	18	0	0
Prince of Wales	224	12	377	2000	1	0	3	0
Thomas Bay	19	8	69	1998	30	0	3	25
Yakutat	68	11	211	1994	0	42	11	21 ^a

^a Residents of Yakutat indicated that 50 – 60 martens were actually trapped during the 2002-03 season.

Habitat Analysis and Marten Density

As expected, we found no significant correlations among marten density and variables representing the composition of forested habitats ($P > 0.21$). Of the spatial metrics, NP and SDI best predicted marten density ($r^2 = 0.58$, $df = 11$, $P = 0.003$) according to the model: $y = 3.21 - 0.007x_1 + 7.909x_2$, where $x_1 = NP$ and $x_2 = SDI$. Although also correlated with marten density, MNN didn't enter into the regression model ($P < 0.1$) because of its correlation with NP ($r = -0.4273$, $P = 0.07$). Thus, landscapes with higher marten densities had fewer patches and a more even distribution of habitat patch types.

Small Mammal Abundance

Catch rates.—We sampled populations of small mammals in all study areas (Table 6). We caught voles, long-tailed or red-backed, at all sites except Kupreanof Island.

Although long-tailed voles have been reported from all study areas (MacDonald and Cook 1996), we found them moderately abundant only on Chichagof Island, especially in 2002. By 2003, the catch rate declined there by about 60% (Table 7). Long-tailed voles were quite scarce in all other areas with only 1 captured on POW in 526 TN, 1 captured on Kuiu Island, and only 2 captured at Yakutat. Although long-tailed voles have been documented on the mainland near Point Couverden and on Kupreanof Island, we did not catch any there. Red-backed voles were abundant at all 3 mainland sites and Etolin Island, but they were not captured on the other islands.

Keen's mice were very scarce on the mainland. We caught only 1 Keen's mouse at Yakutat, few at Thomas Bay (0.3 and 1.0 captures/100TN), and none at Point Couverden. On the islands, catch rates of

Table 6. Mean capture rates for mice and voles in old-growth forest at all study areas in Southeast Alaska, fall 2001-2003. For each transect at each location, 2 Museum Special snap traps were set at 25 stations evenly spaced along a 360 m-long line and checked for 3 consecutive nights (150 trap nights). Captures are expressed as number per 100 trap nights.

Location	Year	n	Keen's mice		Long-tailed voles		Red-backed voles	
			$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Chichagof Island	2002	2	4.7	0.0	9.3	0.6	-	-
	2003	3	3.3	1.0	3.8	1.2	-	-
Etolin Island	2002	2	3.7	3.6	0.0		3.4	3.4
Kuiu Island	2001	2	4.7	0.7	0.4	0.3	-	-
	2002	2	7.7	2.3	0.0		-	-
Kupreanof Island	2002	2	4.7	4.6	0.0		-	-
	2003	3	3.5	1.0	0.0		-	-
Point Couverden	2003	4	0.2	0.2	0.0		16.9	2.9
Prince of Wales Island	2001	2	6.7	2.7	0.0		-	-
	2002	2	3.7	0.3	0.0		-	-
	2003	4	7.0	1.7	0.2	0.2	-	-
Thomas Bay	2001	2	0.4	0.3	0.4	0.3	4.4	2.3
	2002	2	1.0	0.3	0.0		6.7	1.4
Yakutat	2003	2	0.0		0.7	0.7	12.7	2.0

Keen's mice ranged from 2.3 to 7.7 captures/100 TN. Compared to 2002, capture rates for mice on the islands were 30% and 25% lower on Chichagof Island and Kupreanof Island, respectively, but up by about 33% on POW.

Body mass.—The Keen's mice on Chichagof Island ($\bar{x}$ = 27.1 g, SE = 0.68) were significantly (t = 15.6, P < 0.001) greater in body mass compared with the other study sites ($\bar{x}$ = 19.2 g, SE = 0.18). Northern red-backed voles ($\bar{x}$ = 22.4 g, SE = 0.61) were slightly larger (t = 2.3, P = 0.02) than Southern red-backed voles ($\bar{x}$ = 21.0, SE = 0.30). Long-tailed voles ($\bar{x}$ = 40.7 g, SE = 0.93) were significantly (t = 22.1, P < 0.001) larger than red-backed voles ($\bar{x}$ = 21.4 g, SE = 0.29).

Habitat relationships.—We found no differences in mean rodent catch rates by habitat (t = -0.049, df = 31, P = 0.31). The mean catch rate for large/medium old-growth forest did not differ from intermediate-sized for any species. Mean catch rates did not differ by habitat for Keen's mice (t = -0.042, df = 13, P = 0.484); long-tailed voles (t = -0.082, df = 13, P = 0.214), or red-backed voles (t = -0.62, df = 3, P = 0.288). We found no correlation between mean capture rate of long-tailed voles and Keen's mice (r = 0.064, P = 0.827).

In a regression model, the catch rate of long-tailed voles was best predicted by the landscape variable MNN: $y = -410 + 0.749x_1$ (1), (r^2 = 0.71, df = 13, P < 0.001). In contrast, the biomass of Keen's mice was

best predicted by the multiple regression model: $y = -44.82 + 1.0x_1 + 0.203x_2 - 198.0x_3$ (2), where $x_1 = \text{ED}$, $x_2 = \text{MNN}$, and $x_3 = \text{SDI}$ ($r^2 = 0.58$, $\text{df} = 11$, $P = 0.003$). Red-backed vole abundance was best predicted by the multiple regression model: $y = 1056 - 4.6280x_1 - 0.483x_2$ (3), where $x_1 = \text{ED}$, ($P = 0.001$) and $x_2 = \text{MNN}$ ($P = 0.038$) ($r^2 = 0.606$, $\text{df} = 13$, $P = 0.038$). Thus, long-tailed voles were more numerous in a landscape with more diverse and evenly sized habitat patches. Red-backed voles were also most numerous in landscapes with less fragmentation and evenly spaced habitat patches. The biomass of Keen's mice was greater in more fragmented landscapes.

Marten Diets

Prey isotope values.—Isotope values of small mammals exhibited some spatial and temporal variation (Figs. 6-8). Isotopic values for red-backed voles in Yakutat were different from those captured on Point

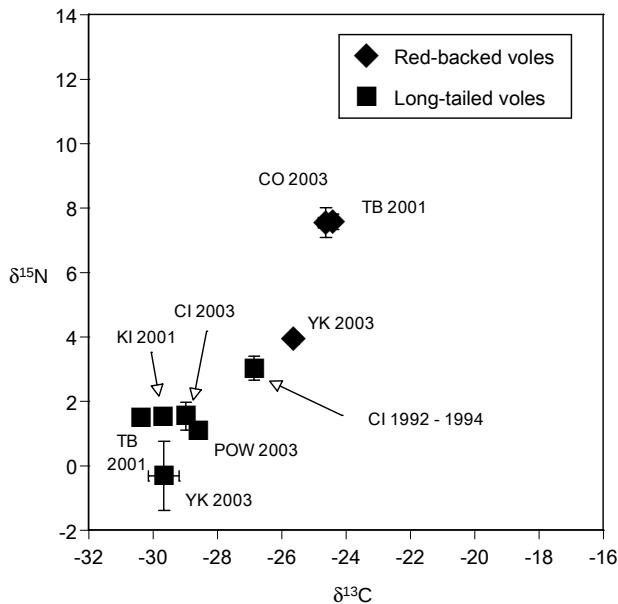


Figure 6. Values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (mean $\pm$ SE) for red-backed and long-tailed voles in Southeast Alaska. CI is Chichagof Island, CO is Point Couverden, KI is Kuiu Island, POW is Prince of Wales Island, TB is Thomas Bay, and YK is Yakutat.

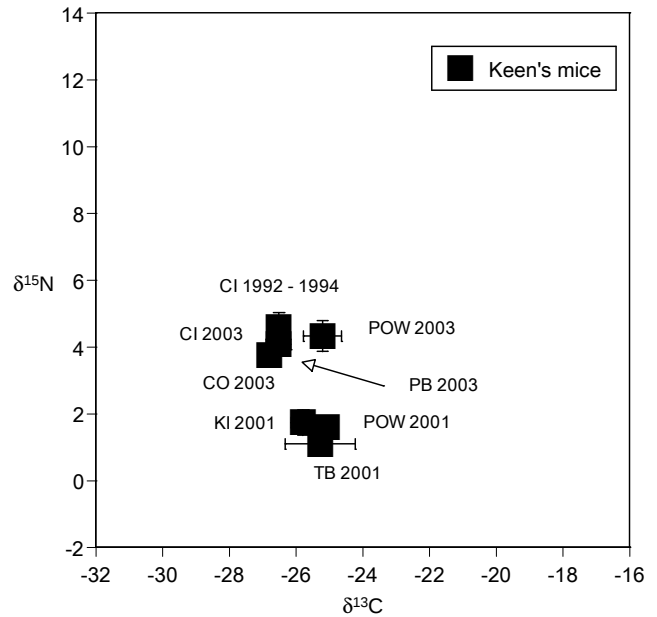


Figure 7. Values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (mean $\pm$ SE) for Keen's mice in Southeast Alaska. CI is Chichagof Island, CO is Point Couverden, KI is Kuiu Island, PB is Portage Bay on Kupreanof Island, POW is Prince of Wales Island, and TB is Thomas Bay.

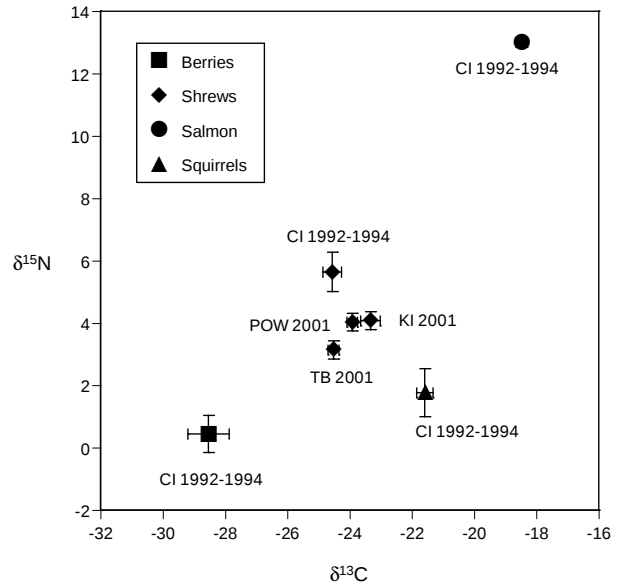


Figure 8. Values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (mean $\pm$ SE) for salmon, squirrels, berries, and shrews in Southeast Alaska. CI is Chichagof Island, CO is Point Couverden, KI is Kuiu Island, PB is Portage Bay on Kupreanof Island, POW is Prince of Wales Island, and TB is Thomas Bay.

Couverden and Thomas Bay (K nearest-neighbor randomization test; $P < 0.001$) but the latter two were not ($P = 0.313$). Long-tailed voles did not significantly differ among locations (K nearest-neighbor randomization test; $P = 0.543$). However, long-tailed voles captured on Chichagof Island in 1992-1994 did differ from those caught during this study (Fig. 6; $P < 0.001$). Isotopic values of long-tailed voles were different than those of red-backed voles as well as from those of Keen's mice ($P < 0.001$). Keen's mice exhibited two clusters, which differed from each other ($P < 0.001$) (Fig. 7). One cluster included Chichagof Island (both 1992-1994 and 2002), POW in 2003, Kupreanof Island (PB) and Point Couverden (CO), whereas the second cluster included POW in 2001, Thomas Bay (TB), and Kuiu Island (KI; Fig. 7). In addition, Keen's mice from the first cluster did not significantly differ from red-backed voles from Yakutat (Fig. 6, 7). Shrews in all locations had similar isotopic signatures except for Thomas Bay (CI-TB $P = 0.0004$; KI-TB $P = 0.038$; POW-TB $P = 0.035$) (Fig. 8).

Diet composition.—We collected blood or small tissue samples for stable isotope analysis from 77 of 89 (87%) martens captured including individuals caught in >1 year. The proportion of prey items in the diet of martens differed among the sampling locations and through time (Table 7). The average proportion of long-tailed and red-backed voles in the diet of martens ranged between 0.07 to 0.46 and 0.07 to 0.36 respectively (Table 7). For Chichagof Island, the consumption of long-tailed voles appeared to track their abundance ($r = 0.76$, $P = 0.008$). The same relationship was clear when all sites and sampling years were included in the analysis ($r = 0.64$, $P = 0.01$). The average proportion of Keen's mice in the diet of martens ranged from 0.02 to 0.28 even in locations or periods where voles

were low (Table 7). For Chichagof Island, the consumption of Keen's mice did not appear to track vole abundance ($r = 0.006$, $P = 0.98$). Similarly, when all sites and times were included in the analysis, we found no correlation between the abundance of voles and the consumption of Keen's mice ($r = -0.11$, $P = 0.89$). Usually martens consumed a higher proportion of voles than Keen's mice, and more Keen's mice than squirrels. The exception was Etolin Island where about 30% of the diet was squirrels. We could not separate the proportions of red and flying squirrels in the diet, so where their ranges overlap, the squirrel portion of the diet likely includes both species. The proportion of squirrels in the diet averaged 0.127 for all sites and ranged between 0.009 and 0.3. We found no correlation between vole abundance and proportion of squirrels in the diet ($r = 0.08$, $P = 0.78$). Berries were consumed on all study areas (average of 0.179 for all sites with a range of 0.067 – 0.344), but usually in greater proportion in areas where voles were abundant than where they were scarce. When all sites were considered together, we found a marginal positive correlation between vole abundance and proportion of berries in the diet ($r = 0.494$, $P = 0.07$).

On study areas where voles were scarce, salmon was the dominant food item in fall (Table 7). Where salmon was the most common food item, martens also ate mammalian prey, but Keen's mice usually made up a greater proportion of the diet than voles or squirrels (Table 7). Both the values of $\delta^{15}\text{N}$ (Fig. 9) and proportion of salmon in the marten diets (Fig. 10) were related to the abundance of voles. When vole numbers were lower than 1 animal per 100 trap-nights, martens appeared to consume large amounts of salmon. The relationship between values of $\delta^{15}\text{N}$ and number of vole captures per 100 trap-nights was best

Table 7. Proportions of prey items in the diet of martens in different locations and years in Southeast Alaska. Proportions were determined from stable isotope values and the program IsoSource. Vole abundance is presented as number of captures of both long-tailed and red-backed voles per 100 trap-nights.

Location	Year	Vole numbers	Long-tailed voles		Red-backed voles		Keen's mice		Salmon		Squirrels		Berries	
			$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Chichagof Island	1991	0.33	0.101	0.075			0.136	0.100	0.579	0.030	0.074	0.019	0.111	0.082
	1992	0.00	0.089	0.067			0.121	0.089	0.592	0.028	0.096	0.018	0.098	0.073
	1993	0.33	0.173	0.126			0.234	0.169	0.148	0.053	0.225	0.029	0.190	0.138
	1994	3.00	0.291	0.189			0.181	0.119	0.049	0.039	0.120	0.038	0.344	0.196
	1995	7.67	0.463	0.196			0.086	0.064	0.027	0.022	0.470	0.037	0.227	0.195
	1996	3.00	0.204	0.144			0.255	0.180	0.125	0.057	0.193	0.032	0.224	0.157
	1997	0.67	0.153	0.112			0.206	0.149	0.213	0.047	0.261	0.026	0.167	0.122
	2002	9.33	0.251	0.167			0.211	0.142	0.071	0.040	0.186	0.037	0.282	0.177
	2003	4.67	0.232	0.167			0.276	0.148	0.131	0.053	0.107	0.041	0.253	0.182
Etolin Island	2001	4.30	0.202	0.139	0.070	0.053	0.131	0.103	0.040	0.031	0.297	0.029	0.259	0.145
Kuiu Island	2001	0.20	0.094	0.070			0.192	0.139	0.379	0.007	0.237	0.066	0.098	0.072
	2002	0.00	0.295	0.111			0.022	0.020	0.529	0.008	0.009	0.010	0.145	0.115
Kupreanof Island	2002	0.00	0.153	0.100			0.223	0.152	0.324	0.009	0.144	0.071	0.156	0.105
	2003	0.00	0.065	0.049			0.085	0.063	0.626	0.018	0.158	0.013	0.067	0.050
Point Couverden	2003	16.30	0.128	0.097	0.200	0.143	0.199	0.154	0.156	0.078	0.147	0.040	0.170	0.126
Prince of Wales Island	2001	0.00	0.138	0.100			0.240	0.173	0.402	0.049	0.056	0.033	0.165	0.120
	2002	0.00	0.124	0.090			0.215	0.156	0.461	0.044	0.057	0.030	0.148	0.108
	2003	0.20	0.165	0.112			0.273	0.197	0.283	0.055	0.099	0.038	0.189	0.137
Thomas Bay	2001	4.60	0.107	0.078	0.232	0.165	0.162	0.112	0.234	0.092	0.130	0.069	0.134	0.103
	2002	6.70	0.188	0.109	0.213	0.134	0.155	0.104	0.134	0.074	0.099	0.065	0.211	0.145
Yakutat	2003	13.40	0.322	0.130	0.355	0.210	0.124	0.076	0.137	0.081	0.062	0.029	0.229	0.163

described by the regression: $y = 7.306x^{-0.048}$ (4), where $y = \delta^{15}\text{N}$ of marten diets, and $x =$ vole abundance ($r^2 = 0.527$, $P < 0.001$, Fig. 9). The relation between percent salmon in the diet and number of vole captures per 100 trap-nights was best described by the regression: $y = 0.187x^{-0.137}$ (5), where $y =$ percent salmon in marten diets and $x =$ vole abundance ($r^2 = 0.657$, $P < 0.001$, Fig. 10).

We found that the biomass of long-tailed voles and Keen's mice best predicted marten density according to the regression model: $y = 1.777 + 0.007x_1 - 0.008x_2$ (6); where $y =$ marten density (per 1000 ha), $x_1 =$ biomass of long-tailed voles (per 100TN) ($P = 0.006$), and $x_2 =$ biomass of Keen's mice (per 100TN) ($P = 0.082$) ($r^2 = 0.44$, $P = 0.016$). Of the other food variables, the ungulate index nearly entered the model ($t = 1.40$, $P = 0.19$). The abundance of red-backed voles

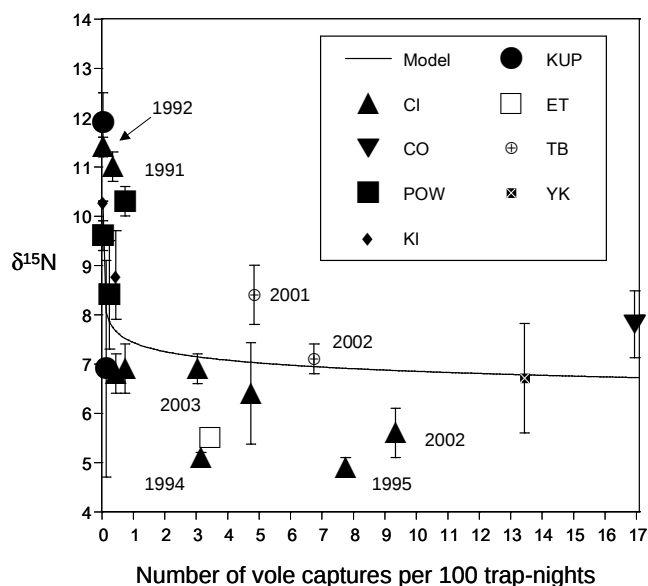


Figure 9. Relation between values of $\delta^{15}\text{N}$ (mean $\pm$ SE) and number of voles captured per 100 trap-nights in Southeast Alaska. Vole numbers are calculated as the sum of both long-tailed and red-backed voles. CI is Chichagof Island, CO is Point Couverden, ET is Etolin Island, KI is Kuiu Island, KUP is Kupreanof Island, POW is Prince of Wales Island, TB is Thomas Bay and YK is Yakutat.

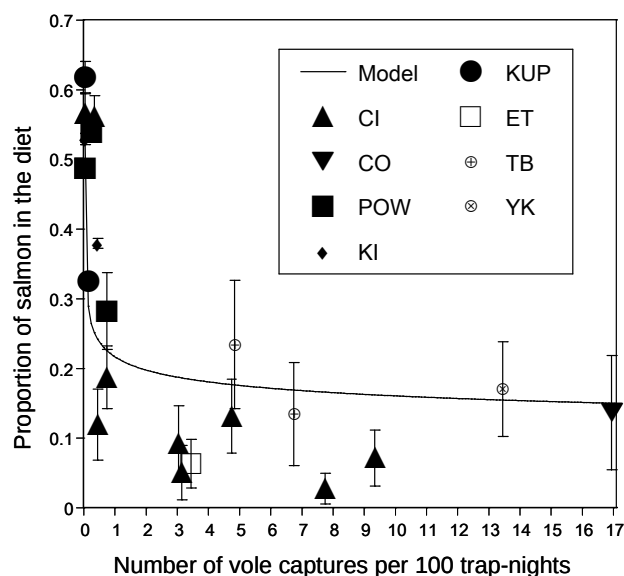


Figure 10. Relation between percent salmon in the diet, as determined with the program IsoSource (mean $\pm$ SE) and number of voles captured per 100 trap-nights in Southeast Alaska. Vole numbers are calculated as the sum of both long-tailed and red-backed voles. CI is Chichagof Island, CO is Point Couverden, ET is Etolin Island, KI is Kuiu Island, KUP is Kupreanof Island, POW is Prince of Wales Island, TB is Thomas Bay and YK is Yakutat.

was not a significant predictor of marten abundance ($t = -0.509$, $P = 0.62$).

In a combined food and landscape habitat model, marten density was best predicted by the regression: $y = 1.381 + 0.005x_1 + 5.14x_2$ (7); where $y =$ marten density (per 1000 ha), $x_1 =$ biomass of long-tailed voles (per 100TN) ($P = 0.025$), and $x_2 =$ SDI ($P = 0.075$) ($r^2 = 0.65$, $P = 0.015$). In this combined model, the biomass of Keen's mice dropped out ($P = 0.123$) and was replaced with SDI ($P = 0.075$). As previously reported, SDI was a significant predictor of Keen's mice. Thus, marten density was best predicted by the abundance of long-tailed voles and the more proportional distribution of habitat patches.

DISCUSSION

We found that marten densities in Southeast Alaska, as previously documented for Chichagof Island (Flynn and Schumacher 1996), depended on the abundance of long-tailed voles in areas of similar habitat composition. In addition, we demonstrated that a greater biomass of Keen's mice clearly did not contribute to increased marten abundance. Marten density also appeared greater in less fragmented landscapes based on several spatial variables. These observations were consistent with other studies that demonstrated that at least 3 factors can strongly influence the density of martens on a landscape: amount and distribution of older forest (Thompson and Colgan 1987, Hargis and Bissonette 1997, Chapin et al. 1998, Potvin et al. 2000), prey abundance (Weckwerth and Hawley 1962, Thompson and Colgan 1990), and fur trapping (Strickland and Douglas 1987, Katnik et al. 1994). In contrast with our predictions, however, we did not find a relation between marten densities and the diversity of the prey fauna.

Despite the observation that our traplines were similar in habitat characteristics to the planned OGRs at each location, it appeared that those large OGRs would likely not support the 25 females assumed in TLMP (U.S. Forest Service 1997), even in years of high abundance of long-tailed voles. Although our estimates of marten densities may be imprecise, the upper 80% CIs for Etolin, Kuiu, Kupreanof, POW, and Yakutat did not include 25 females. Thus, OGRs in these areas would likely not support the 25 females assumed in TLMP. Additionally, the TLMP conservation strategy referred to resident, adult females, whereas our estimates included all females including juveniles. Similarly, male martens were only slightly more abundant in our study areas, with projected numbers ranging from 4

(Kuiu Island) to 38 (Thomas Bay in 2002). Again, the upper 80% CIs for several study areas, including POW, Etolin, Kuiu, and Yakutat, did not include 25 individuals. Nonetheless, whether 25 resident females are required or sufficient for the maintenance of viable populations in OGRs as well as to ensure the persistence of metapopulations is unclear.

Our density estimates may be imprecise because we assumed that the probability of capture previously observed on Chichagof Island was appropriate for other areas in Southeast Alaska. On Chichagof Island, trap habituation may have resulted in an upward bias in capture probabilities. In that case, our density estimates for other study areas would be slightly low. Unfortunately, we had too few recaptures in this study and are unable to test the effects of habituation on capture probabilities. Nonetheless, by incorporating the error terms associated with both capture probability and home-range size observed in Chichagof Island, we probably obtained a robust estimate of marten densities for our other study areas.

Two lines of evidence suggested that our density estimates for all 8 study areas were reasonable. Although number of captures per 100 trap nights (capture rate) varied greatly among study areas (from 0.4 captures/100TN on Etolin Island in 2002 to 5.8 captures/100TN on Chichagof Island in 2002) and among years, this capture rate was relatively consistent within each area where we trapped in subsequent years and the ranking of capture rates among study sites was similar. For example, capture rates for Chichagof Island and Thomas Bay were consistently the highest and Kuiu Island and Kupreanof Island the lowest. POW was usually intermediate, but only slightly higher than Kupreanof. This observation is especially important given the low recapture rates and suggests that capture rates represented abundance rather than

habituation of a few individuals. In addition, ADFG marten fur sealing records were generally consistent with our density estimates after accounting for the distribution of road systems and the location of population centers (such as permanent communities and temporary logging camps) as a measure of effort. For example, over the last 12 years trapper harvest on Chichagof Island, where we estimated a high density of martens, has often been quite high despite a ban on use of motorized land vehicles for trapping on federal lands. Despite extensive road systems, we found few records of high harvests on Kuiu, Kupreanof, or Etolin islands where we estimated low densities of martens. In contrast, we estimated relatively high densities of martens at Thomas Bay and Point Couverden, but harvest in these areas has been relatively low. Both areas have limited road systems and can be difficult to access in winter. Although we also estimated relatively low densities of martens on POW, the north-central portion of the island has often produced relatively high harvests. POW is the largest island in Southeast Alaska, and it has over 5000 residents and ~5000 km of roads. We believe that high harvest there results from high trapper effort.

We believe fur trapping had little influence on our capture success at most study sites because few martens were trapped in the vicinity of those sites during the winters prior to and during our surveys. A few exceptions, however, merit discussion. In Yakutat, conversations with residents during our live-trapping survey indicated that 50-60 martens were harvested there during the previous winter instead of the 21 martens reported in ADFG sealing records. Despite occurring on the mainland, the population of martens in Yakutat is isolated by mountains and glaciers, and therefore may respond more like an island population. Such level of harvest could have reduced our capture

success and depressed the density estimate for this area. Harvest also occurred on the Kuiu Island study area during the winter before our 2001 survey when 17 martens were taken. Nonetheless, there was no harvest during the next winter, and our 2002 survey resulted in fewer captures than in 2001. Therefore we feel it is unlikely that the harvest that occurred in 2001 greatly influenced our results. Finally, despite no trapping of martens on our study area, marten harvest on north-central POW during 2000 exceeded the mean harvest for that area by 155 animals. Although this high level of harvest should not have affected the number of martens residing on the study area, it could have reduced the number of transient martens present during our 2001 survey. If that was the case, our density estimate for 2001 may be biased low.

Although our traplines did not always completely overlap the designated OGRs, we found only minor differences in habitat composition and spatial patterns between them. We anticipated greater proportions of clearcut habitat in our study areas than in OGRs because one of the criteria for study areas was that they have ≥ 25 km of drivable road; and roads are built to access areas for logging. In contrast, guidelines for designing OGRs specify that they contain a minimum of clearcut habitat (U.S. Forest Service 1997). Although our study areas often had about twice the amount of clearcuts as nearby OGRs, this habitat type was a relatively small proportion of landcover at all sites ($< 12\%$). For example, the Chichagof Island and Kuiu Island study areas had about the same proportion of clearcut habitat, but much different marten capture rates. Therefore, we believe the greater proportions of clearcuts in study areas compared to OGRs likely did not bias our estimates of marten density in OGRs.

Our observations suggested that marten densities did not vary by composition of

forested-habitats within the narrow range sampled. By design the OGRs, and thus the study areas, have minimum habitat composition requirements for productive old-growth forest, i.e., 50% productive old-growth forest and 25% VC5⁺. These minimums were developed based on previous studies in other forests that described habitat requirements for martens (U.S. Forest Service 1997). Our data suggested that these minimums are probably appropriate.

The measures of spatial patterns of habitat that emerged from our analysis were representative of what has been established elsewhere as high quality habitat for martens. The prevailing view is that the highest densities of martens are associated with areas of continuous late-successional forest (reviewed by Buskirk and Ruggiero 1994). Working in landscapes heavily fragmented by logging, Snyder and Bissonette (1987) and Chapin et al. (1998) found that both size and isolation of residual forest stands influenced the use of those stands by martens. Hargis and Bissonette (1997) reported that naturally fragmented landscapes and landscapes fragmented by logging supported lower densities of martens than landscapes with continuous forest. Potvin et al. (2000) found that forest fragmentation was lower in actual marten home ranges than in randomly placed home ranges on an industrial forest landscape. In our study, the number of habitat patches was negatively correlated with marten density. Thus, marten densities were greater in less fragmented study areas. In contrast, SDI was positively correlated with marten densities. We interpret these variables to collectively indicate that study areas with larger and more evenly distributed patches of forest supported higher densities of martens than areas with more fragmented forest. Insufficient amounts of productive forest in the Etolin Island study area likely had little

influence on the low marten capture rate experienced there. The proportions of forest in volume classes ≥ 4 and VC5⁺ on the Etolin Island study area differed by only 1.8% (67 ha) and 6.1% (374 ha), respectively, from proportions at the Thomas Bay study area, which was of similar size and had among the highest marten densities.

We were surprised that marten densities were not clearly influenced by the diversity of the small mammals fauna in the different study areas. We expected that a more diverse fauna would result in a consistently greater quantity of available food that would enhance reproduction and survival in martens. A more diverse prey base should provide alternative foods when preferred foods were less available. Our multiple-regression model (equation 3), however, only identified the biomass of long-tailed voles as a positive predictive variable of marten densities. Our ungulate index was positively correlated with marten density, but didn't enter into the regression model at $\alpha = 0.1$, probably because our ungulate index was correlated with long-tailed vole abundance. Although Keen's mice were a significant negative variable in the regression model, we do not believe that the abundance of Keen's mice actually impacted marten populations, but their abundance was correlated with other factors. Our data did show that the abundance of red-backed voles had no relationship with marten densities. Unfortunately, we were unable to assess the availability of red- and northern flying squirrels to martens because of financial and logistical constraints. Nonetheless, the relatively low proportion of squirrels (of either or both species) in the diet of martens as calculated from stable isotope ratios, and the lack of relation between voles abundance and the relative consumption of squirrels suggest that they too may play a lesser role in determining the abundance of martens in Southeast Alaska.

Because isotope values of small mammals exhibited some spatial and temporal variation in Southeast Alaska, our ability to extrapolate from one area to another may be limited. Even in the same location (Chichagof Island), isotopic values changed between sampling years. These differences were not consistent though. For example, isotopic values of long-tailed voles on Chichagof Island in 1992 – 1994 were different than those in 2003, but that pattern was not detected in values of Keen's mice. Ben-David et al. (2001) cautioned that an isotopic value observed in primary and secondary consumers is an emergent property of multiple ecological processes that can vary with changing environmental conditions (e.g., nutrient and water availability for plants; community composition of plants and plant quality; nutritional condition of the animal, etc.). Thus, future studies into the nutritional ecology of martens (as well as other animals) will require full sampling of all possible foods during the entire duration of the study. In this study, we used isotopic values of squirrels, berries, and salmon from Chichagof Island for all other locations. Our use of data for salmon is likely appropriate because salmon acquire most of their biomass at sea (Heard 1991), and the values we obtained for fish caught on Chichagof Island were comparable to other studies in other locations in the Pacific Northwest and Alaska (Kline et al. 1989, 1993, Hilderbrand et al. 1999, Naiman et al. 2002, Reimchen et al. 2002). Our use of isotopic values for berries and squirrels from Chichagof Island, however, as well as values of other prey items from different sites and periods may have biased our results. Nonetheless, because the spatial and temporal variation was sporadic we feel that the broad conclusions we draw from our data are valid.

Results from the isotope analysis, combined with the observation that biomass of long-tailed voles was a predictive variable of marten density, suggest that similar to our previous findings from Chichagof Island (Ben-David et al. 1997), martens in different locations and across time relied heavily on voles. Unfortunately, because we had only 3 locations with both vole species, our ability to unequivocally establish the relative importance of each vole species was limited. Other studies found that martens preferred *Microtus* species to *Clethrionomys* spp. (Weckwerth and Hawley 1962, Buskirk and MacDonald 1984). Whether this preference relates to habitat association of the 2 species, their behavior, or energetic profitability is unclear. Red-backed voles are usually significantly smaller (28 – 34 g) than long-tailed voles (37 – 57 g; Burt and Grossenheider 1976, this study), and thus may provide lower energetic returns. Interestingly, our results suggested that the consumption of Keen's mice by martens remains relatively low even when vole numbers are low. The lack of correlation between capture rates of Keen's mice and long-tailed voles suggested that martens could have switched to feed on Keen's mice when numbers of long-tailed voles were low, but did not necessarily do so. As with the result from our multiple regression model (equation 6), this observation indicated that Keen's mice might not constitute an important alternative prey for martens in Southeast Alaska. That marten body condition (BCI) was not correlated with rodent biomass may be, in part, a result of the fact that most of the rodent biomass in our study was derived from the mean capture rates of Keen's mice. Unfortunately, our low capture rates of long-tailed voles precluded evaluation of the effects of the biomass of this species alone on the BCI of martens.

Similar to our earlier finding from Chichagof Island (Ben-David et al. 1997), when vole numbers were low, salmon was the main source of food for martens during fall. In this study we were able to identify a threshold of vole abundance at which martens switched to feed on salmon. This threshold is about 1 vole per 100 TN. The model of proportion salmon in the diet relative to vole abundance (equation 2), explained more of the variation than the one with values of $\delta^{15}\text{N}$ (equation 1) probably because the calculation of proportion of salmon in the diet (with the program IsoSource, Phillip and Gregg 2003) accounted for the variation in isotopic values of voles. Although both models were highly significant and explained 53 – 66% of the variance in the data, other factors could have influenced the consumption of salmon by martens in the different locations and years. Those factors can be the distribution of salmon streams in the study areas, the abundance of other foods such as squirrels, and berries, as well as potential differences in isotopic values of foods (see discussion above). Although the effects of consumption of salmon on survival and reproduction of martens remains unclear, planning of OGRs should ensure the inclusion of salmon streams within their boundaries.

The role of ungulate carrion in supporting populations of martens in Southeast Alaska is poorly understood. In this study, ungulate density was nearly a significant predictor of marten density (equation 6), but because ungulate carrion is scarce at the time of our sampling we did not include this variable in our diet estimation. We suspect that ungulates may be more important in late winter and spring when carrion from winter-killed animals is available. Indeed, our study on Chichagof Island (Ben-David et al. 1997) revealed that deer composed up to 32% of the diet of martens in that season. We suspect that the availability of ungulate

carrion affects marten densities through reproduction rather than survival. In spring, blastocysts, which are embryos in diapause since the previous summer, implant in the uterus and begin to develop (Mead 1989). Because active pregnancy is an energetically demanding time for mammals (Robbins 1993), nutrition from ungulate carrion may enhance reproductive rates in martens. The effects of ungulate carrion on reproduction in martens merits further investigation.

In our original study design, we did not fully consider the difference in size of the different small mammal populations on the island and mainland sites. Long-tailed voles weigh twice as much as red-backed voles, and Keen's mice on Chichagof Island were significantly heavier than mice from other study areas. Consequently, at similar densities, islands inhabited by the larger-bodied small mammals could provide a greater biomass of prey for martens than islands or mainland sites with smaller individuals. This observation could explain why a high diversity of potential prey items alone did not ensure higher numbers of martens. Our marten trapping results generally support this idea. Chichagof Island had the most numerous and productive population of martens of the 8 areas sampled, and it also was populated by the largest bodied small mammals, which were relatively numerous. Therefore, body mass and abundance must both be considered when interpreting the value of small mammals as prey for martens. Where long-tailed voles were abundant, we caught high numbers of martens. Where long-tailed voles were scarce, but red-backed voles abundant, we caught moderate numbers of martens, and where voles were scarce, we caught few martens.

MANAGEMENT IMPLICATIONS

In Southeast Alaska, populations of martens on islands and areas of the mainland, isolated by glaciers and major rivers, are demographically independent because martens generally do not cross water barriers (Buskirk and Ruggiero 1994). These populations also show genetic isolation (Stone et al. 2002, Small et al. 2003). Because the demographic characteristics of populations of martens appeared related to the abundance of prey (Thompson and Colgan 1987, this study) and because assemblages and abundances of potential prey differ by island (MacDonald and Cook 1996, this study) and through time (Flynn and Schumacher 2001), conservation measures for martens should be tailored to specific populations, not for the TNF as a whole.

Our findings indicated that on most study areas, even in years of high abundance of long-tailed voles, large OGRs would likely not support the 25 female martens assumed in TLMP (U.S. Forest Service 1997). Therefore, for populations of particular concern, it will be important to understand the range of these fluctuations when developing future conservation plans. The conservation strategy in TLMP recognized the importance of managing for periodic lows in marten populations. Nonetheless, until more information becomes available on the nature of these fluctuations in different parts of the TNF, such conservation plans will be deficient. Although our study captured some of the spatial and temporal variation in marten densities in the Alexander Archipelago, we only visited sites in 1 – 3 consecutive years, and therefore did not capture the full range of fluctuations in marten population. In addition, whether 25 resident females are required or sufficient for the maintenance of viable populations in

OGRs as well as to ensure the persistence of metapopulations remains unclear.

Our findings also suggested that the habitat suitability model used to evaluate the effects of timber management on martens probably overestimates the number of martens. The current model, developed over a decade ago from data collected on Chichagof Island, assigns densities of martens to habitat types based only on vegetative features and does not take into account the differing assemblages and abundances of prey found throughout the TNF. Our data illustrates the need to include information on the dynamics of prey populations, especially long-tailed voles, and the distribution of salmon streams on the landscape in future improvements of this habitat suitability model.

Based on our findings, the efficacy of the conservation measures for martens in the Forest Plan will require additional consideration. For populations of martens where OGRs and lands in other non-development LUDs are unlikely to support a sufficient number of females and where further timber harvest is planned, additional conservation measures may be necessary. We suggest that an increase of the size and proportion of higher quality habitat of OGRs would likely result in increase in the number of martens in individual OGRs. As an initial step in re-evaluating the conservation strategy for martens on the TNF, we recommend mapping all large and medium OGRs, determining their size and forest composition, and applying marten density estimates for locations with available data. Many planned large OGRs will likely be larger than the minimum size of 16,200 ha. Therefore, even with low densities, larger than required OGRs may support the minimum number of female martens. Because of the apparent importance of salmon as an alternate food in years of low vole abundance (Ben-David et al. 1997, this study), the inclusion of salmon streams

within OGRs may also increase carrying capacity for martens.

Finally, increased connectivity among OGRs would increase the likelihood that populations will function as metapopulations and OGRs would be repopulated by immigration after local extinctions have occurred. Little information exists on the proper design of corridors or their use by martens. However, we suspect that wider forested corridors would be more likely used by martens for dispersal. On islands where marten numbers are low, designating wider corridors between OGRs than required by TLMP may enhance viability of the population. Also, roads through corridors may reduce their effectiveness because fur trappers often use them.

Management of matrix lands may hold the greatest potential for enhancing conservation of martens. On a forest-wide basis, about 57% of the timber production land is unsuitable for harvest (U.S. Forest Service 1997). Mapping the distribution and vegetative cover of these lands would be an initial step in providing information about potential habitat for populations of martens when TLMP is fully implemented. For populations where marten numbers are low and planned logging will threaten viability, several changes to forest management could minimize the effects of logging. Yarding logs by helicopter would reduce the need to build roads and thereby maintain refugia from fur trapping. Using partial harvest instead of clearcutting could also maintain habitat value for martens while allowing some timber harvest. To most benefit martens, the goal of partial harvesting should be to maintain productivity for small mammals, especially voles, within harvested stands. To do this the productivity of plants beneath the forest canopy must be maintained as a food source for small mammals. On study plots throughout Southeast Alaska, Deal (2001) found that

partial harvesting prescriptions retaining >50% of the basal area of a stand including trees in all size classes prevented establishment of a new tree cohort and retained understory plant communities similar to old-growth forest. Widespread use of partial harvesting prescriptions instead of clearcutting on lands managed for timber production could significantly enhance conservation of martens. Finally, because unfragmented forest supports the highest densities of martens (Snyder and Bissonette 1987, Chapin et al. 1997, 1998, Hargis and Bissonette 1997, Potvin et al. 2000), we recommend clumping timber harvest to maintain the largest possible blocks of uncut forest.

FUTURE DIRECTION

The past 3 years of research has documented that densities of most marten populations in the TNF were lower than assumed in the TLMP conservation strategy for this design species. Our data indicated that by consuming seasonally available salmon, martens in areas where voles are scarce could maintain body condition similar to martens in areas with abundant voles. However, the low densities of martens in these areas suggest that availability of food at other times of year could affect the dynamics of these populations through survival and reproduction. Therefore, understanding the relation between diet, body condition, reproduction and survival in martens in relation to the availability of small mammal and other prey at other times of the year may provide insight into the frequency and amplitude of fluctuations in the marten numbers.

Because of the high spatial and temporal variability in marten densities that we found across the TNF, more study sites should be sampled in the future to better clarify the effects of habitat and diversity of prey

assemblages on marten population dynamics. Two large islands in northern Southeast (Admiralty and Baranof islands) should be surveyed to increase sample sizes for islands with relatively simple prey fauna. These islands are inhabited by other vole species, i.e. tundra (*Microtus oeconomus*) and meadow voles (*Microtus pennsylvanicus*). ADFG fur sealing records indicate that martens may reach similar densities on northern Baranof Island as they occur on Chichagof Island, suggesting that these voles may function like long-tailed voles. Also, ADFG deer pellet-group survey data indicates that northern Baranof and Admiralty islands support densities of deer similar to Chichagof Island. Abundances of tundra vole populations and their contribution to marten diets have not been studied. Admiralty Island, where martens appear less abundant than on Chichagof or Baranof Islands, also supports high numbers of deer, but is populated by meadow voles. These islands are in close proximity, have similar topography, and aside from species of voles, support similar assemblages of prey species. An investigation of marten abundance, diets, and prey availability on these islands would enhance our understanding of the relative value of the 3 species of voles for martens. Also, the Southeast Mainland showed large variability in marten numbers, suggesting that expansion of sampling is also merited there.

On Chichagof Island during the 1990's, populations of small mammals and martens peaked at about 6-year intervals. On other island and mainland sites, small mammals and thus martens may fluctuate at different intervals. Additional years of data in each study area would allow better estimates of the range of temporal fluctuations in marten densities.

Because marten densities were best predicted by catch rates of long-tailed vole and Keen's mice along with ungulate

abundance, surveys of these species would provide useful information on the likely status of marten populations. Long-tailed voles might be considered a keystone species (Simberloff 1998) because of their influence on other species, particular small predators. For areas with significant future timber harvest planned, monitoring of small mammals would provide insight into possible marten population status and trends. Generally, the abundance of small mammals is easier to estimate than other mammals, but more research into cost-effective sampling approaches would be important. Our small mammal sampling effort was quite modest, but still provided useful results. In addition, the effects of partial harvesting, which may cause little change to the understory vegetation compared to unharvested stands (Deal 2001), on small mammal communities merits further investigation.

Finally, if OGRs do not support the minimum number of females as stated in TLMP, unrestricted movement among OGRs may ameliorate the effects of local extirpation. Marten populations in harvested landscapes probably behave as metapopulations where individuals disperse among adjacent reserves. Such dispersal through connecting corridors would maintain gene flow, ensure maintenance of genetic variability, and reduce the risk of local extinction. The ability of martens to disperse across open spaces, however, is unclear. Future work should concentrate on estimating dispersal rates of martens through the harvested matrix. In such studies, martens could be tagged and their movements monitored to study dispersal. Alternately or in conjunction, DNA analysis could be used to explore dispersal patterns in relation to fragmented landscapes by evaluating gene flow, number of migrant per generation, as well as dispersal distances with assignment tests (Cornuet et al. 1999,

Blundell et al. 2002). This investigation of dispersal and gene flow in populations of martens would also allow for the determination of corridor characteristics necessary for maintaining connectivity of marten populations.

LITERATURE CITED

- ALABACK, P. B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. *Ecology* 63:1932-1948
- _____. 1988. Endless battles, verdant survivors. *Natural History* 97:45-48.
- _____, AND G. P. JUDAY. 1989. Structure and composition of low elevation old-growth forests in research natural areas of southeast Alaska. *Natural Areas Journal* 9:27-39.
- BEN-DAVID, M. 1996. Seasonal diets of mink and martens: effects of spatial and temporal changes in resource abundance. Ph.D. Dissertation, University of Alaska Fairbanks. Fairbanks.
- _____. 1997. Diet analysis of northern goshawks using stable isotope ratios. Pages 17-23 in K. Titus, C. Flatten, and R. Lowell, eds. *Goshawk ecology and habitat relationships on the Tongass National Forest*. Federal Aid in Wildlife Restoration Progress Report, Study SE-4-2. Alaska Department of Fish and Game, Douglas.
- _____, D. M. SCHELL, AND R. W. FLYNN. 1997. Annual and seasonal changes in diets of martens: evidence from stable isotope analysis. *Oecologia* 111:280-291.
- _____, R. T. BOWYER, L. K. DUFFY, D. ROBY, AND D. M. SCHELL. 1998a. Social behavior and ecosystem processes: river otter latrines and nutrient dynamics of terrestrial vegetation. *Ecology* 79:2567-2571.
- _____, T. A. HANLEY, AND D. M. SCHELL. 1998b. Fertilization of terrestrial vegetation by spawning Pacific salmon: the role of flooding and predator activity. *Oikos* 83:47-55.
- _____, AND SCHELL, D. M. 2001. Mixing models in analyses of diet using multiple stable isotopes: a response. *Oecologia* 127:180-184.
- _____, E. SHOCHAT, AND L. ADAMS. 2001. Utility of stable isotope analysis in studying foraging ecology of herbivores: examples from moose and caribou. *Alces* 37: 421-434.
- BISSONETTE, J. A., D. J. HARRISON, C. D. HARGIS, AND T. G. CHAPIN. 1997. The influence of spatial scale and scale-sensitive properties on habitat selection by American marten. Pages 368-385 in J. A. Bissonette, ed. *Wildlife and Landscape Ecology*. Springer-Verlag, New York, New York, USA.
- BLUNDELL, G. M., M. BEN-DAVID, P. GROVES, R. T. BOWYER, AND E. GEFFEN. 2002. Characteristics of sex-biased dispersal and gene flow in coastal river otters: implications for natural recolonization of extirpated populations. *Molecular Ecology* 11:289-303.
- BURT, W. H., AND R. P. GROSSENHEIDER. 1976. *A field guide to the mammals of North America*. Houghton Mifflin Company. Boston, Massachusetts, USA.
- BUSKIRK, S. W. 1992. Conserving circumboreal forests for martens and fishers. *Conservation Biology* 6:318-320.

- _____, AND S. O. MACDONALD. 1984. Seasonal food habits of martens in Southcentral Alaska. *Canadian Journal of Zoology* 62:944-950.
- _____, AND R. A. POWELL. 1994. Habitat ecology of fishers and American martens. Pages 283-296 in S.W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds. *Martens, Sables, and Fishers: Biology and Conservation*. Cornell University Press, Ithaca, New York, USA.
- _____, AND L. F. RUGGIERO. 1994. American marten. Pages 7-37 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, L. J. Lyon, and W. J. Zielinski, eds. *The scientific basis for conserving forest carnivores*. U.S. Forest Service. General Technical Report. RM-254.
- CALHOUN, J. B. 1948. North American census of small mammals. Rodent ecology project, release 1. John Hopkins University, Baltimore.
- CAOUCETTE, J. P., M. G. KRAMER, AND G. J. NOWACKI. 2000. Deconstructing the timber volume paradigm in management of the Tongass National Forest. U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-482.
- CHAPIN, T. G., D. J. HARRISON, AND D. D. KATNIK. 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. *Conservation Biology* 12:1327-1337.
- _____, D. J. HARRISON, AND D. M. PHILLIPS. 1997. Seasonal habitat selection by marten in an untrapped forest preserve. *Journal of Wildlife Management* 61:707-717.
- CLARK, T. W., E. ANDERSON, C. DOUGLAS, AND M. STRICKLAND. 1987. *Martes americana*. *Mammalian Species*, American Society of Mammalogists 289:1-8.
- CONOVER, W. J., AND R. L. IMAN. 1988. Rank transformations as a bridge between parametric and non-parametric statistics. *American Statistician* 35:24-130.
- CORNUET, J., S. PIRY, G. LUIKART, A. ESTOUP, AND M. SOLIGNAC. 1999. New methods employing multilocus genotypes to select or exclude populations as origins of individuals. *Genetics* 153:1989-2000.
- DEAL, R. L. 2001. The effects of partial cutting on forest plant communities of western hemlock - Sitka spruce stands in southeast Alaska. *Canadian Journal of Forest Research* 31:2067-2079.
- DENIRO, M. J., AND S. EPSTEIN. 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42:495-506.
- DOUGLAS, R. J., L. G. FISHER, M. MAIR. 1983. Habitat selection and food habits of marten, *Martes americana*, in the Northwest Territories. *Canadian Field-Naturalist* 97:71-74.
- ELKIE, P. C., R. S. REMPEL, AND A. P. CARR. 1999. Patch Analyst User's Manual. A tool for quantifying landscape structure. NWST Technical Manual TM-002. Northwest Science and Technology. Thunder Bay, Ontario, Canada.
- FLYNN, R. W. AND T. V. SCHUMACHER. 1993. Ecology of martens in Southeast Alaska. *Federal Aid in Wildlife Restoration Progress*

- Report, Grant W-24-1, Study 7.16. Alaska Department Fish and Game, Juneau.
- _____, AND _____. 1996. Ecology of martens in Southeast Alaska. Federal Aid in Wildlife Restoration Progress Report, Grant W-24-4, Study 7.16. Alaska Department Fish and Game, Juneau.
- _____, AND _____. 2000. Ecology of martens in Southeast Alaska. Federal Aid in Wildlife Restoration Progress Report, Grant W-27-3, Study 7.16. Alaska Department Fish and Game, Juneau.
- _____, AND _____. 2001. Marten abundance on northeast Chichagof Island, Southeast Alaska, during 1991-1998. Unpublished report. Alaska Department of Fish and Game, Douglas.
- _____, AND M. BEN-DAVID. In prep. Body condition, blood chemistry, and diet relationships in martens on northeast Chichagof Island, Southeast Alaska. Unpublished manuscript. Alaska Department of Fish and Game, Douglas.
- GRAHAM, R. W. AND M. A. GRAHAM. 1994. Late quaternary distribution of *Martes* in North America. Pages 26-58 in S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds. *Martens, Sables, and Fishers: Biology and Conservation*. Cornell University Press, Ithaca, New York, USA.
- HARGIS, C. D. AND J. A. BISSONETTE. 1997. Effects of forest fragmentation on populations of American martens in the intermountain west. Pages 437-451 in G. Proulx, H. N. Bryant and P. M. Woodward, eds. *Martes: taxonomy, ecology, techniques, and management*. Provincial Museum of Alberta, Edmonton, Alberta.
- _____, J. A. BISSONETTE, AND D. L. TURNER. 1999. Influence of forest fragmentation and landscape pattern on American martens. *Journal of Applied Ecology* 36:157-172.
- HARLOW, H. J. 1994. Trade-offs associated with the size and shape of American martens. Pages 391-403 in S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds. *Martens, Sables, and Fishers: Biology and Conservation*. Cornell University Press, Ithaca, New York, USA.
- HEARD, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pages 118-230 in C. Groot and L. Margolis, eds. *Pacific Salmon Life Histories*. University of British Columbia Press, Vancouver.
- KARTASHOV, L. M. 1989. Age changes in fertility of sables (*Martes zibellina* L.) in the central OB' region. *Soviet Journal of Ecology* 20:120-124.
- HEDRICK, P. W. 1996. Genetics of metapopulations: aspects of a comprehensive perspective. Pages 29-51 in D. R. McCullough, ed. *Metapopulations and wildlife conservation*. Island Press, Washington, D.C., USA.
- HILDERBRAND, G. V., S. D. FARLEY, C. T. ROBBINS, T. A. HANLEY, K. TITUS, C. SERVHEEN. 1996. Use of stable isotopes to determine diets of living and extinct bears. *Canadian Journal Zoology* 74:2080-2088.
- _____, T. A. HANLEY, C. T. ROBBINS, AND C. C. SCHWARTZ. 1999. Role of brown bears (*Ursus arctos*) in the flow of marine nitrogen into

- terrestrial ecosystems. *Oecologia* 121:546-550.
- HODGMAN, T. P., HARRISON, D. J., PHILLIPS, D. M., AND K. D. ELOWE. 1997. Survival of American marten in an untrapped forest preserve in Maine. Pages 86-99 in G. Proulx, H. N. Bryant, and P.M. Woodard, eds. *Martes: taxonomy, ecology, techniques, and management*. Provincial Museum of Alberta, Edmonton, Canada.
- KARTASHOV, L. M. 1989. Age changes in fertility of sables (*Martes zibellina* L.) in the central OB' region. *Soviet Journal of Ecology* 20:120-124.
- KATNIK, D. D., D. J. HARRISON, AND T. P. HODGMAN. 1994. Spatial relations in a harvested population of martens in Maine. *Journal of Wildlife Management* 58:600-607.
- KELLY, J. F. 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. *Canadian Journal Zoology* 78:1-27.
- KIRCHHOFF, M. J. 2003. Deer pellet-group surveys in Southeast Alaska. Unpublished report. Alaska Department of Fish and Game. Douglas.
- KLINE, T. C., J. J. GOERING, O. A. MATHISEN, AND P. H. POE. 1989. Recycling of elements transported upstream by runs of Pacific salmon: I. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ evidence in Sashin creek, Southeastern Alaska. *Canadian Journal of Fisheries and Aquatic Science* 47:136-144.
- _____, _____, _____, AND _____. 1993. Recycling of elements transported upstream by runs of Pacific salmon: II. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ evidence in the Kvichak River, Bristol Bay, Southwestern Alaska. *Canadian Journal of Fisheries and Aquatic Science* 50:2350-2365.
- LEIFFERS V. J., AND P. M. WOODWARD. 1997. Silvicultural systems for maintaining marten and fisher in the boreal forest. Pages 407-418 in G. Proulx, H. N. Bryant, and P. M. Woodard, eds. *Martes: taxonomy, ecology techniques and management*. The Provincial Museum of Alberta, Edmonton.
- LUCID, M. K. AND J. A. COOK. 2004. Phylogeography of Keen's mouse (*Peromyscus keeni*) in a naturally fragmented landscape. *Journal of Mammalogy* 85:1149-1159.
- MACDONALD, S. O. AND J. A. COOK. 1996. The land mammal fauna of Southeast Alaska. *Canadian Field-Naturalist* 110:571-598.
- MARTIN, J. R. 1989. Vegetation and environment in old-growth forests of northern southeast Alaska: a plant association classification. M.S. Thesis. Arizona State University, Tempe.
- MARTIN, S. K. 1987. The ecology of the pine marten (*Martes americana*) at Sagehen Creek, California. Ph.D. Dissertation. University of California, Berkeley.
- _____. 1994. Feeding ecology of American marten and fishers. Pages 297-315 in S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds. *Martens, sables, and fishers: biology and conservation*. Cornell University Press, Ithaca, New York.
- MCCULLOUGH, D. R. 1996. Introduction. Pages 1-10 in D. R. McCullough, ed. *Metapopulations and wildlife*

- conservation. Island Press, Washington, D.C., USA
- MCGARIGAL, K. AND B. J. MARKS. 1995. Fragstats: spatial pattern analysis program for quantifying landscape structure. U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-351.
- NAIMAN, R. J., R. E. BILBY, D. E. SCHINDLER, AND J. M. HELFIELD. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. *Ecosystems* 5:399-417.
- PAYER, D. C. 1999. Influences of timber harvesting and trapping on habitat selection and demographic characteristics of American marten. Ph.D. Dissertation, University of Maine, Orono, Maine, USA.
- PHILLIPS, D. L. AND J. W. GREGG. 2003. Source partitioning using stable isotopes: coping with too many sources. *Oecologia* 136:261-269.
- POTVIN, F., L. BELANGER, AND K. LOWELL. 2000. Marten habitat selection in a clearcut boreal landscape. *Conservation Biology* 14:844-857.
- POWELL, R. A. 1981. *Martes pennanti*. Mammalian Species, American Society of Mammalogists 156:1-6.
- REIMCHEN, T. E., D. MATHEWSON, M. D. HOCKING, AND J. MORAN. 2002. Isotopic evidence for enrichment of salmon-derived nutrients in vegetation, soils, and insects in riparian zones in coastal British Columbia. American Fisheries Society Symposium
- ROSING, M. N., M. BEN-DAVID, AND R. BARRY. 1998. Analysis of stable isotope data: a K nearest-neighbor randomization test. *The Journal of Wildlife Management* 62:380-388.
- RUGGIERO, L. F., D. E. PEARSON, AND S. E. HENRY. 1998. Characteristics of American marten den sites in Wyoming. *Journal of Wildlife Management* 62:663-673.
- SAMSON, F. B. AND OTHERS. 1989. Conservation of rain forests in southeast Alaska: report of a working group. Transactions 54th North American Wildlife and Natural Resource Conference 54:121-133.
- SHERBURNE, S. S., AND J. A. BISSONETTE. 1994. Marten subnivean access point use: response to subnivean prey levels. *Journal of Wildlife Management* 58:400-405.
- SIDLE, W. S. AND L. H. SURING. 1986. Management indicator species of the national forest lands of Alaska. U.S. Forest Service Technical Publication R10-TP-2, Juneau.
- SIMBERLOFF, D. 1998. Flagships, umbrellas and keystones: is single species management passé in the landscape era? *Conservation Biology* 83:247-257.
- SMALL, M. P., K. D. STONE, AND J. A. COOK. 2003. American marten (*Martes americana*) in the Pacific Northwest: population differentiation across a landscape fragmented in time and space. *Molecular Ecology* 12:89-104.
- SNYDER, J. E. AND J. A. BISSONETTE. 1987. Marten use of clearcuttings and residual forest stands in western Newfoundland. *Canadian Journal of Zoology* 65:169-174.
- SOUTIERE, E. C. 1979. Effects of timber harvesting on marten in Maine.

- Journal of Wildlife Management 43:850-860.
- STONE, K. D., R. W. FLYNN, AND J. A. COOK. 2002. Post-glacial colonization of northwestern North America by the forested associated American martens (*Martes americana*, Mammalia: Carnivora: Mustelidae). *Molecular Ecology* 11:2049-2063.
- STRICKLAND, M. A., AND C. W. DOUGLAS. 1987. Marten. Pages 531-546 in M. Novak, J. Baker, M. E. Obbard, and B. Molloch, eds. *Wild Furbearer Management and Conservation in North America*. Ontario Trappers Association, North Bay, Ontario.
- STURTEVANT, B. R., J. A. BISSONETTE AND J. N. LONG. 1996. Temporal and spatial dynamics of boreal forest structure in western Newfoundland: silvicultural implications for marten habitat management. *Forest Ecology and Management* 87:13-25.
- SURING, L. H., D. C. CROCKER-BEDFORD, R. W. FLYNN, C. S. HALE, G. C. IVERSON, M. D. KIRCHHOFF, T. E. SCHENCK, L. C. SHEA, AND K. TITUS. 1993. A proposed strategy for maintaining well-distributed, viable populations of wildlife associated with old-growth forests in Southeast Alaska. U.S. Forest Service, Alaska Region, Juneau.
- SZEPANSKI, M. M., M. BEN-DAVID, AND V. VAN BALLEMBERGHE. 1999. Assessment of salmon resources in the diet of the Alexander Archipelago wolf using stable isotope analysis. *Oecologia* 120: 327-335.
- TAYLOR, S. L., AND S. W. BUSKIRK. 1994. Forest microenvironments and resting energetics of the American marten *Martes americana*. *Ecography* 17:249-256.
- _____, AND S. W. BUSKIRK. 1996. Dynamics of subnivean temperature and wind speed in subalpine forests of the Rocky Mountains. *Journal of Thermal Biology* 21:91-99.
- THOMPSON, I. D, AND P. W. COLGAN. 1987. Numerical responses of martens to a food shortage in northcentral Ontario. *Journal Wildlife Management* 51:824-835.
- _____, AND P. W. COLGAN. 1990. Prey choice by marten during a decline in prey abundance. *Oecologia* 83:443-451.
- _____, AND W. J. CURRAN. 1995. Habitat suitability for marten of second-growth balsam fir forests in Newfoundland. *Canadian Journal of Zoology* 73:2059-2064.
- _____, AND A. S. HARESTAD. 1994. Effects of logging on American martens, and models for habitat management. Pages 355-367 in S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds. *Martens, Sables, and Fishers: Biology and Conservation*. Cornell University Press, Ithaca, New York, USA.
- U.S. FOREST SERVICE. 1997. Land and resource management plan-Tongass National Forest. U.S. Forest Service R10-MB-338dd, Alaska Region, Juneau.
- WECKWERTH, R. P. AND V. D. HAWLEY. 1962. Marten food habits and population fluctuations in Montana. *Journal of Wildlife Management* 26:55-74.
- WILBERT, C. J., S. W. BUSKIRK, AND K. G. GEROW. 2000. Effects of weather and snow on habitat selection by

American martens (*Martes americana*). Canadian Journal of Zoology 78:1691-1696.

APPENDICES

Appendix A. Summary of martens live-captures at 8 study sites in Southeast Alaska, 2001-2003.

Study area	Marten number	Age first capture ^a	Sex	Year(s) captured			Mo./Yr. harvested
				2001	2002	2003	
Chichagof Is.	CI-188	8	F			X	
	CI-312	3	M		X		
	CI-313	0	F		X		
	CI-314	0	M		X		
	CI-315	0	M		X		
	CI-316	0	F		X		
	CI-317	1	F		X		
	CI-318	0	M		X		
	CI-319	0	F		X		
	CI-320	0	M		X		
	CI-321	1	F		X	X	
	CI-322	4	F		X		
	CI-323	0	F		X		
	CI-324	0	M		X		
	CI-325	2	M		X		
	CI-326	2	F			X	
	CI-327	0	M			X	
	CI-328	0	M			X	
	CI-329	Ad	M			X	
	CI-330	1	F			X	
	CI-331	0	F			X	
	CI-332	0	M			X	
	CI-333	9	F			X	
Etolin Is.	ET-01	4	F		X		
Kuiu Is.	KI-01	0	M	X	X		
	KI-02	4	F	X			
	KI-03	5	F	X			
	KI-04	1	F		X		
Kupreanof Is.	KUP-01	1	M		X		1/03
	KUP-02	0	F		X		
	KUP-03	1	M		X		1/03
	KUP-04	1	M		X		
	KUP-05	3	M		X	X	1/03
	KUP-06	0	M			X	1/03
	KUP-07	0	M			X	1/03
	KUP-08	0	M			X	
	KUP-09	0	F			X	
	KUP-10	0	M			X	1/03

Appendix A. Continued.

Study area	Marten number	Age first capture ^a	Sex	Year(s) captured			Mo./Yr. harvested
				2001	2002	2003	
Point Couverden	C-01	1	F	X			
	C-02	Ad	M	X			
	C-03	1	F	X			
	C-04	0	M	X			
	C-05	4	M	X			
	C-06	2	F	X			
	C-07	0	F	X			
	C-08	0	M	X			
Prince of Wales Is.	POW-01	0	M	X			
	POW-02	Ad	F	X			
	POW-03	0	M	X			
	POW-04	Ad	F	X			
	POW-05	1	M	X			
	POW-06	0	M		X		
	POW-07	1	M		X		
	POW-08	1	M		X		
	POW-09	0	F		X		
	POW-10	0	M		X		12/02
	POW-12	6	F			X	
	POW-28	3	M			X	
	POW-29	0	M			X	
	POW-30	0	F			X	
	POW-31	0	M			X	
Thomas Bay	TB-01	2	M	X	X		12/02
	TB-02	0	M	X			
	TB-03	7	F	X			
	TB-04	4	M	X			
	TB-05	4	F	X			12/02
	TB-06	0	M	X			12/01
	TB-07	0	M	X			
	TB-08	2	F	X	X		
	TB-09	1	M	X			
	TB-10	0	M		X		12/02
	TB-11	0	M		X		
	TB-12	2	M		X		12/02
	TB-13	0	M		X		
	TB-14	0	F		X		12/02
	TB-15	1	M		X		
	TB-16	0	M		X		12/02
	TB-17	0	M		X		12/02
	TB-18	0	M		X		
	TB-19	1	F		X		12/02
Yakutat	Y-01	1	M			X	
	Y-02	4	F	X			
	Y-03	0	F	X			
	Y-04	0	F	X			
	Y-05	1	M	X			

^a Ages were determined by cementum annuli analysis. Adult/juvenile classifications based on skull characteristics examined in the field.

Appendix B. Mean captures/100 trap nights of mice and voles at 8 study sites around Southeast Alaska, fall 2001-2003. In each habitat category at each location, 2 Museum Special snap traps were set at 25 stations evenly spaced along a 360m-long transect and checked for 3 consecutive nights (150 trap nights). In some habitats, multiple transects were completed (n = number of transects).

Location	Year	Habitat							
		Large/Medium MS Forest				Intermediate MS Forest			
		n	Keen's mice	Long-tailed voles	Red-backed voles	n	Keen's mice	Long-tailed voles	Red-backed voles
Chichagof Island	2002	1	4.7	8.7	--	1	4.7	10.0	--
	2003	1	2.0	3.3	--	2	4.0	4.0	--
Etolin Island	2002	1	0	0	6.7	1	7.3	0	0
Kuiu Island	2001	1	5.3	0	--	1	4.0	0.7	--
		1	4.7	0	--	1	10.7	0	--
Kupreanof Island	2002	1	9.3	0	--	1	0	0	--
	2003	2	4.3	0	--	1	2.0	0	--
Point Couverden	2003	2	0.3	0	13.0	2	0	0	19.7
Prince of Wales Island	2001	1	9.3	0	--	1	4.0	0	--
	2002	1	3.3	0	--	1	4.0	0	--
	2003	2	4.4	0	--	2	9.7	0.3	--
Thomas Bay	2001	1	0.7	0.7	2.0	1	0	0	6.7
	2002	1	0.7	0	5.3	1	1.3	0	8.0
Yakutat	2003	2	0	0.7	12.7				

Appendix C. Habitat composition of 8 marten study areas and nearby OGRs in Southeast Alaska, 2001-2003. Habitat classes were derived from the U. S. Forest Service TIMTYP landcover GIS database.

Habitat	Study Areas							
	Chichagof Island	Etolin Island	Kuiu Island	Kupreanof Island	Point Couverden	Prince of Wales Is.	Thomas Bay	Yakutat
Marten study areas								
Non-forest	8.6	2.5	3.9	2.2	12.0	5.5	11.3	8.2
Clearcut	10.2	10.5	11.8	10.3	8.9	6.2	2.9	5.4
Scrub forest	21.3	46.4	18.7	33.5	22.9	32.7	17.4	18.3
VC 4	27.5	19.3	20.0	27.6	28.8	18.2	14.9	11.1
VC 5 ⁺	31.8	21.4	40.7	25.8	27.4	37.4	27.5	57.1
Even-aged	0.6	0	4.8	0.6	0	0	26.1	0
Totals	100	100	100	100	100	100	100	100
OGRs								
Non-forest	17.6	16.2	6.6	10.9	33.3	7.2	7.7	11.7
Clearcut	4.8	1.7	7.7	0.9	4.3	0.6	2.6	0.1
Scrub forest	22.3	31.6	26.0	37.2	8.2	27.4	35.9	12.1
VC 4	15.7	20.3	24.3	30.2	20.7	17.7	19.6	7.6
VC 5 ⁺	37.5	28.6	32.0	20.7	33.1	45.5	34.8	50.2
Even-aged	2.1	1.6	4.8	0.1	0.3	1.6	0	18.3
Totals	100	100	100	100	100	100	100	100



American martens and habitats in the Salt Lake Bay study area, Southeast Alaska.

Above photos by R. Flynn. Back cover photo by T. Schumacher.





Global maps of twenty-first century forest carbon fluxes

Nancy L. Harris¹✉, David A. Gibbs¹, Alessandro Baccini^{2,10}, Richard A. Birdsey², Sytze de Bruin³, Mary Farina^{2,11}, Lola Fatoyinbo⁴, Matthew C. Hansen⁵, Martin Herold³, Richard A. Houghton², Peter V. Potapov⁵, Daniela Requena Suarez³, Rosa M. Roman-Cuesta⁶, Sassan S. Saatchi^{7,8}, Christy M. Slay⁹, Svetlana A. Turubanova⁵ and Alexandra Tyukavina⁵

Managing forests for climate change mitigation requires action by diverse stakeholders undertaking different activities with overlapping objectives and spatial impacts. To date, several forest carbon monitoring systems have been developed for different regions using various data, methods and assumptions, making it difficult to evaluate mitigation performance consistently across scales. Here, we integrate ground and Earth observation data to map annual forest-related greenhouse gas emissions and removals globally at a spatial resolution of 30 m over the years 2001–2019. We estimate that global forests were a net carbon sink of $-7.6 \pm 49 \text{ GtCO}_2\text{e yr}^{-1}$, reflecting a balance between gross carbon removals ($-15.6 \pm 49 \text{ GtCO}_2\text{e yr}^{-1}$) and gross emissions from deforestation and other disturbances ($8.1 \pm 2.5 \text{ GtCO}_2\text{e yr}^{-1}$). The geospatial monitoring framework introduced here supports climate policy development by promoting alignment and transparency in setting priorities and tracking collective progress towards forest-specific climate mitigation goals with both local detail and global consistency.

Climate change must be addressed by various actors including scientists, policymakers, companies, investors and civil society, all of whom operate under different mandates and capabilities. Both IPCC reports^{1,2} and the Paris Agreement³ recognize that climate change mitigation goals cannot be achieved without a substantial contribution from forests but monitoring the extent to which forests impact atmospheric greenhouse gas (GHG) concentrations is challenging. Opposing fluxes (emissions from sources (+) and removals by sinks (-)) occur simultaneously within regions on the basis of where and when disturbance and management take place, interannual variability can be high and land-use patterns are more dynamic and operate on finer spatiotemporal scales than reflected in most global models⁴. Furthermore, ability to distinguish anthropogenic from non-anthropogenic effects is limited on the basis of direct observation² and most estimation methods offer few details about where, when and why forest fluxes occur. Yet understanding the magnitude, drivers and spatial distribution of carbon fluxes across the world's forests, and how they can be managed both to reduce emissions and enhance removals, is increasingly important for climate policy and the various actors developing nature-based solutions⁵.

Current estimates of terrestrial GHG fluxes vary with respect to scope, definitions, assumptions and level of transparency and completeness. At the global scale, the net annual carbon dioxide (CO₂) flux from anthropogenic land-use and land-cover change—driven mainly by tropical deforestation—is estimated in IPCC reports^{1,2} and the Global Carbon Project⁶ by a bookkeeping model^{7,8} or by dynamic global vegetation models⁶. The remaining

non-anthropogenic sink of atmospheric carbon on land—predominantly forests⁹—is then inferred as the residual of the other terms of the global carbon budget¹. Another approach compiles national GHG inventories (GHGIs), which reflect methodologies developed by the IPCC and agreed to under the United Nations Framework Convention on Climate Change^{10,11}. The quality, methodological complexity and sources of data used by each country vary, as do the completeness and frequency of reporting. These approaches produce dissimilar global net forest fluxes; GHGI estimates compiled from country reports are 4.3 GtCO₂ yr⁻¹ lower than global estimates from models summarized in IPCC reports—a discrepancy larger than the total annual emissions of India, the world's third highest emitter¹². A substantial part of this discrepancy (about 3.2 GtCO₂ yr⁻¹) can be explained by conceptual differences in what is counted in the anthropogenic forest sink. Beyond this large disparity in global estimates, data and methodological mismatches also exist across project, subnational and national forest GHG measurement systems, leading to complications around integrating smaller-scale activities into larger national or subnational monitoring programmes¹³ and around the potential international transfer of forest-related emission reductions versus those achieved as part of a country's own nationally determined contribution¹⁴. In sum, the complexity and lack of spatial detail in GHG measurement systems contributes to confusion about the role forests play in climate mitigation targets and discourages the transformational action and ambition needed in the forest sector to achieve global climate goals.

Here, we introduce a transparent, independent and spatially explicit global system for monitoring the collective impact of

¹World Resources Institute, Washington DC, USA. ²Woodwell Climate Research Center, Falmouth, MA, USA. ³Laboratory of Geo-Information Science and Remote Sensing, Wageningen University and Research, Wageningen, the Netherlands. ⁴Biospheric Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA. ⁵Department of Geographical Sciences, University of Maryland, College Park, MD, USA. ⁶Center for International Forestry Research (CIFOR), Bogor, Indonesia. ⁷Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA. ⁸Institute of Environment, University of California, Los Angeles, CA, USA. ⁹The Sustainability Consortium, University of Arkansas, Fayetteville, AR, USA. ¹⁰Present address: Department of Earth and Environment, Boston University, Boston, MA, USA. ¹¹Present address: Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, USA. ✉e-mail: nharris@wri.org

forest-related climate policies implemented by diverse actors across multiple scales. We complement existing global forest carbon flux estimation approaches of large area vegetation models and aggregation of national inventories with a third approach that capitalizes on recent advances in Earth observation. Using recently revised IPCC guidelines as a methodological framework^{10,11}, we separately map GHG emissions (sources) and carbon dioxide removals (sinks) from global forest lands at 30-m resolution between 2001 and 2019 (Methods). Areas of forest extent, loss and gain from the Global Forest Change product of Hansen et al.¹⁵ form the basis of the activity data. By co-locating activity data with spatially explicit emission and removal factors developed from integrating ground and Earth observation monitoring data on land use and management type, forest type, forest age class, fire history and biomass and soil carbon stocks, we separately map gross annual carbon removals occurring within natural, seminatural and planted forests and gross annual emissions arising from five dominant drivers of forest disturbance. We then map the difference between gross emissions (+) and gross removals (−) as the net annual forest-related GHG flux, which may be positive or negative in an area depending on the balance of gross fluxes. Tracking gross emissions and removals separately, rather than solely the net balance between the two, underscores the dual role of forests as sources and sinks in the global carbon cycle and facilitates more complete and transparent accounting of the individual pathways involved in forest-based mitigation (reducing emissions and increasing removals).

Global distribution of forest emissions and removals

Between 2001 and 2019, deforestation and other satellite-observed forest disturbances resulted in global gross GHG emissions of $8.1 \pm 2.5 \text{ GtCO}_2\text{e yr}^{-1}$ (mean $\pm$ s.d.). Carbon dioxide (CO_2) was the dominant GHG; methane (CH_4) and nitrous oxide (N_2O) emissions from stand-replacing forest fires and drainage of organic soils in deforested areas accounted for 1.1% of gross emissions ($0.088 \text{ GtCO}_2\text{e yr}^{-1}$). Over the same period, gross carbon removals by forest ecosystems were $-15.6 \pm 49 \text{ GtCO}_2\text{e yr}^{-1}$. Taken together, the balance of these opposing fluxes (gross emissions and gross removals) yields a global net GHG forest sink of $-7.6 \pm 49 \text{ GtCO}_2\text{e yr}^{-1}$ (Table 1 and Fig. 1). The large uncertainties in global gross removals and net flux are almost entirely due to extremely high uncertainty in removal factors from the IPCC Guidelines¹¹ applied to old secondary temperate forests outside the United States and Europe (Supplementary Table 1).

Tropical and subtropical forests contributed the most to global gross forest fluxes, accounting for 78% of gross emissions ($6.3 \pm 2.4 \text{ GtCO}_2\text{e yr}^{-1}$) and 55% of gross removals ($-8.6 \pm 7.6 \text{ GtCO}_2\text{e yr}^{-1}$) (Table 1). While these forests removed more atmospheric carbon than temperate and boreal forests on a gross basis (-8.6 versus -4.4 and $-2.5 \text{ GtCO}_2\text{e yr}^{-1}$, respectively), tropical and subtropical forests contributed just 30% to the global net carbon sink; about two-thirds of the global net sink was in temperate (47%) and boreal (21%) forests, resulting from substantially lower gross emissions there than in the subtropics and tropics (0.87 and 0.88 versus $6.3 \text{ GtCO}_2\text{e yr}^{-1}$, respectively).

Just six large forested countries (Brazil, Canada, China, Democratic Republic of the Congo, Russia and the United States) accounted for 51% of global gross emissions, 56% of global gross removals and 60% of net flux. Forests in nearly all countries were net carbon negative, that is, gross carbon removals from established and regrowing forests exceeded gross emissions from land-use change and other forest disturbances. The main exceptions were in Indonesia, Malaysia, Cambodia and Laos, where annual gross emissions across these countries ($1.36 \text{ GtCO}_2\text{e yr}^{-1}$), including peat drainage and burning ($0.14 \text{ GtCO}_2\text{e yr}^{-1}$), exceeded gross removals ($-0.83 \text{ GtCO}_2\text{e yr}^{-1}$) (Fig. 2). Globally, 72% of gross removals were concentrated in older (>20 yr) secondary natural and seminatural

forests, 12% in tropical primary forests, 10% in plantations, 3.5% in young (<20 yr) forest regrowth, 1.3% in mangroves and 0.34% in boreal and temperate intact forest landscapes (Table 1).

Fluxes for specific localities and drivers of forest change

Our analysis enables consistent evaluation of forest GHG dynamics across scales and in custom geographies beyond national or climate domain boundaries (Fig. 1). For example, $\sim 27\%$ of the global net forest GHG sink occurred within protected areas¹⁶. Forests in the Brazilian Amazon were a net carbon source of $0.22 \text{ GtCO}_2\text{e yr}^{-1}$ between 2001 and 2019, whereas forests across the larger Amazon River basin—encompassing 514 Mha of forests across nine countries—were a net carbon sink of $-0.10 \text{ GtCO}_2\text{e yr}^{-1}$. Although smaller in extent than the Amazon, the net sink in forests of Africa's Congo River basin (298 Mha) was approximately six times stronger ($-0.61 \text{ GtCO}_2\text{e yr}^{-1}$), reflecting nearly identical gross removals (-1.1 versus $-1.2 \text{ GtCO}_2\text{e yr}^{-1}$) but gross emissions that were half those of the Amazon basin (0.53 versus $1.1 \text{ GtCO}_2\text{e yr}^{-1}$).

From overlaying forest GHG flux maps in Fig. 1 with a global map of dominant drivers of forest disturbance¹⁷, we estimate that commodity-driven deforestation was the largest source of gross forest-related emissions between 2001 and 2019 ($2.8 \text{ GtCO}_2\text{e yr}^{-1}$) and occurred primarily in the rainforests of South America and Southeast Asia. Forests in shifting agriculture landscapes, a dominant land use in the tropics characterized by cycles of small-scale forest clearing of both primary and secondary forests followed by secondary regrowth, contributed another $2.1 \text{ GtCO}_2\text{e yr}^{-1}$ to gross emissions and $-3.3 \text{ GtCO}_2\text{e yr}^{-1}$ to gross removals, leading to a net sink in these areas of $-1.2 \text{ GtCO}_2\text{e yr}^{-1}$. Gross emissions from stand-replacing forest fires, occurring primarily in temperate and boreal forests, averaged $0.69 \text{ GtCO}_2\text{e yr}^{-1}$. Forestry-dominated landscapes, comprised of both plantations and natural and seminatural forests, were a net sink of $-3.3 \text{ GtCO}_2\text{e yr}^{-1}$ between 2001 and 2019. This reflects $2.4 \text{ GtCO}_2\text{e yr}^{-1}$ of gross emissions from harvest offset by $-5.5 \text{ GtCO}_2\text{e yr}^{-1}$ of gross removals from forest management and regeneration and $-0.16 \text{ GtCO}_2\text{e yr}^{-1}$ of increased carbon storage in harvested wood products.

A flexible data integration framework

The IPCC Guidelines used as the overarching methodological framework in this analysis^{10,11} provide three tiers of methods, parameters and data sources for GHG flux estimation, where progression from Tier 1 to Tier 3 generally results in more accurate and precise estimates at the expense of more analytical complexity and larger data requirements. For forests, Tier 3 estimates are characterized by the incorporation of repeated, country-specific measurements over time but the land-use definitions and the spatial scale of data sources chosen can impact the resulting estimates. Therefore, in addition to estimating uncertainty in GHG estimates within geographies for which information was available to do so (climate domains), we also conducted sensitivity analyses to demonstrate how estimates change as data inputs and model assumptions are varied within our spatial data integration framework (Supplementary Information). At the global scale, GHG flux estimates were relatively insensitive to changes in model assumptions; estimates for most pixels changed less than 15% in either direction and sources stayed sources while sinks stayed sinks.

However, estimates were more affected by changes in data sources, particularly at local scales. For example, replacing the global 30-m biomass map developed in this study as the basis of emission factors (Extended Data Fig. 1) with a coarser (1-km) resolution biomass map produced by Saatchi et al.¹⁸ for the tropics produced 12% lower gross GHG emissions there than our original estimate. Replacing the 30-m annual tree cover loss data from Hansen et al.¹⁵ in the Brazilian Amazon with annual forest loss data from Brazil's national forest monitoring system¹⁹, which

Table 1 | Forest-related GHG fluxes by climate domain and forest type

Climate domain	Forest type	Forest extent 2000 (Mha)	GtCO ₂ e yr ⁻¹ , 2001–2019					
			Gross emissions	Percentage of global total	Gross removals	Percentage of global total	Net GHG flux	Percentage of global total ^d
Boreal	Primary ^a	38	0.26	3.2	−0.044	0.28	0.22	
	Old secondary (>20 yr)	1,030	0.60	7.4	−2.4	15	−1.8	
	Young secondary (≤20 yr)	22	0.015	0.19	−0.037	0.24	−0.022	
	Plantations/tree crops ^b	0.21	0.000056	0.00070	−0.0027	0.017	−0.0027	
	Total boreal	1,090	0.88 ± 0.42	11	−2.5 ± 0.96	16	−1.6 ± 1.1	21
Temperate	Primary ^a	2.3	0.036	0.45	−0.0092	0.059	0.027	
	Old secondary (>20 yr)	560	0.71	8.8	−4.2	27	−3.5	
	Young secondary (≤20 yr)	16	0.049	0.60	−0.039	0.25	0.0092	
	Plantations/tree crops ^b	12	0.071	0.88	−0.14	0.92	−0.073	
	Total temperate	590	0.87 ± 0.60	11	−4.4 ± 48	28	−3.6 ± 48	47
Subtropical	Primary ^a	3.6	0.0062	0.076	−0.0058	0.037	0.00035	
	Old secondary (>20 yr)	270	0.46	5.7	−0.84	5.4	−0.38	
	Young secondary (≤20 yr)	13	0.11	1.3	−0.067	0.43	0.040	
	Plantations/tree crops ^c	54	0.40	5.0	−0.71	4.6	−0.31	
	Mangroves	0.070	0.000066	0.00082	−0.0040	0.026	−0.0040	
	Total subtropical	340	1.0 ± 0.59	12	−1.6 ± 0.56	10	−0.65 ± 0.81	8.6
Tropical	Primary ^a	1,010	1.8	22	−1.9	12	−0.12	
	Old secondary (>20 yr)	880	1.9	23	−3.8	24	−1.9	
	Young secondary (≤20 yr)	47	0.76	9.5	−0.40	2.5	0.37	
	Plantations/tree crops ^c	47	0.89	11	−0.73	4.7	0.16	
	Mangroves	7.2	0.010	0.12	−0.16	1.0	−0.15	
	Total tropical	1,990	5.3 ± 2.4	66	−7.0 ± 7.6	45	−1.7 ± 8.0	22
Global	Primary	1,060	2.1	26	−2.0	13	0.13	
	Old secondary (>20 yr)	2,750	3.7	45	−11	72	−7.7	
	Young secondary (≤20 yr)	99	0.9	12	−0.54	3.5	0.39	
	Plantations/tree crops	113	1.4	17	−1.6	10	−0.23	
	Mangroves	8.7	0.012	0.14	−0.20	1.3	−0.19	
	Total global	4,029	8.1 ± 2.5	100	−16 ± 49	100	−7.6 ± 49	100

Average annual gross GHG emissions, gross GHG removals and net GHG fluxes across global forest lands between 2001 and 2019. Estimates reflect forest ecosystem fluxes only; harvested wood products are excluded. Uncertainties are expressed as s.d. Large uncertainties in net flux estimates should be interpreted with caution; s.d. are very large relative to the estimates in part because net flux estimates reflect the sum of negative (removals) and positive (emissions) terms, complicating the combination of their error terms. ^aThe extent of primary forests was delineated differently for tropical and extratropical regions (Methods). ^bFluxes occurring within seminatural managed forests are reported in the relevant secondary forest category (old or young). ^cFluxes reported in the plantation/tree crop category include those associated with conversion of natural forests to plantations or tree crops (for example, oil palm) over the 2001–2019 analysis period. ^dCalculating percentages of net flux by forest type is complicated by the mixture of sources and sinks among forest types, and is thus omitted.

excludes deforestation events smaller than 6.25 ha, reduced average gross emissions there from 1.1 to 0.74 GtCO₂e yr⁻¹. This difference arises from increased detection of emissions from small forest clearings. Both examples highlight the value of our spatially detailed approach in capturing more changes and larger fluxes occurring at small scales where many human-induced forest changes are occurring. In the United States, replacing Tier 3 removal factors estimated specifically for US forest types and age classes from repeated inventory measurements with generalized Tier 1 defaults from the updated IPCC Guidelines¹¹ led to a 38% stronger net carbon sink there than the original estimate. (See Supplementary Table 2 and Extended Data Figs. 2–8 for additional examples.) These analyses quantitatively and spatially demonstrate tradeoffs between globally consistent analyses and locally derived values that are difficult to aggregate globally and may not be available or comparable across regions. The flexible spatial data integration framework introduced here enhances science-policy coordination by providing a more

systematic, structured, transparent and verifiable system for exploring differences in data, assumptions and resulting estimates than what has been available previously.

Forest fluxes in the global carbon budget

Our results are not directly comparable to other global estimates because other estimates typically reflect all terrestrial fluxes (versus forests only), report only net fluxes (versus gross and net fluxes), include only CO₂ (versus all relevant GHGs) and make assumptions to partition between anthropogenic and non-anthropogenic net fluxes^{2,12}. While the spatial, observation-based framework introduced here permits estimation of fluxes for any forest definition and the inclusion (or exclusion) of any geographic area of interest, it cannot distinguish between anthropogenic versus non-anthropogenic effects or between managed versus unmanaged land until the requisite spatial data become available to differentiate them²⁰. When considering only CO₂ fluxes to improve comparability with the

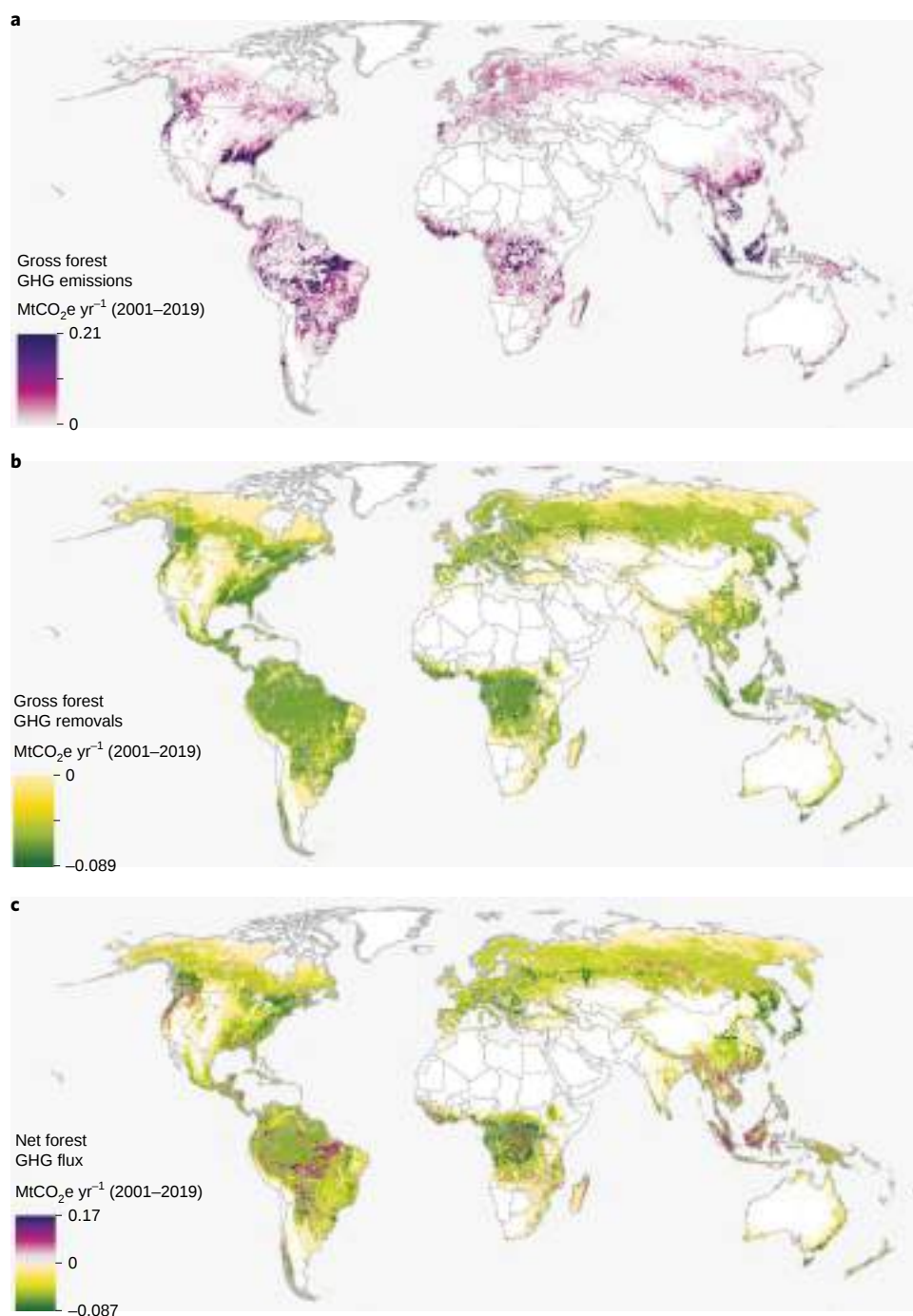


Fig. 1 | Forest-related GHG fluxes (annual average, 2001–2019). **a**, Gross annual GHG emissions. **b**, Gross annual GHG removals. **c**, Net annual GHG flux. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04° geographic grid. Values in the legend reflect the average annual GHG flux from all forest dynamics occurring within a grid cell, including emissions from all observed disturbances and removals from both forest regrowth after disturbance as well as removals occurring in undisturbed forests.

Global Carbon Budget, we estimate a larger net CO₂ sink by forest ecosystems ($-7.8 \text{ GtCO}_2 \text{ yr}^{-1}$) than its estimate of $-5.2 \text{ GtCO}_2 \text{ yr}^{-1}$ for all terrestrial fluxes over the same time period⁶. One potential reason for this difference is that our model underestimates gross forest-related emissions due to the exclusion of forest disturbances that go undetected and unquantified in the medium resolution satellite observations that underpin our analysis. Gross emissions from tropical forest degradation have been estimated as $2.1 \text{ GtCO}_2 \text{ e yr}^{-1}$, with selective logging, fuelwood harvest and non-stand-replacing

fires accounting for 53, 30 and 17% of the total, respectively²¹. Adding this (non-spatial) estimate of gross degradation emissions to our satellite-based gross carbon emission and removal estimates occurring within forest ecosystems, as well as $-0.16 \text{ GtCO}_2 \text{ yr}^{-1}$ of net removals in harvested wood products, yields a revised net forest-atmosphere CO₂ flux of $-5.8 \text{ GtCO}_2 \text{ yr}^{-1}$ (Table 2). Taken together, these estimates of gross removals ($-15.6 \text{ GtCO}_2 \text{ yr}^{-1}$) and gross emissions related to forests (including degradation: $10 \text{ GtCO}_2 \text{ yr}^{-1}$) appear to nearly balance the global carbon budget

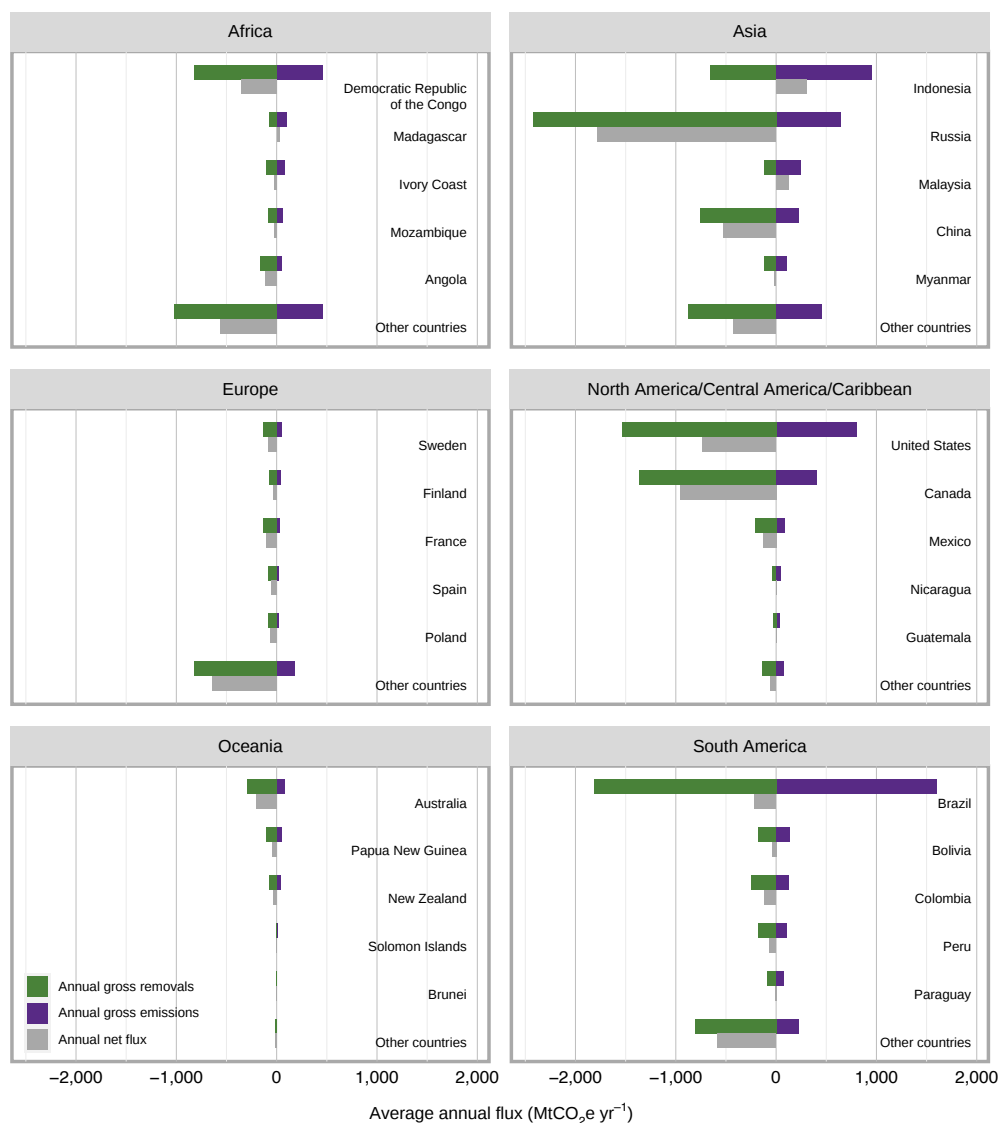


Fig. 2 | Gross and net GHG fluxes from forests by region (annual average, 2001–2019). Net forest-related fluxes (grey bars) are shown with their two component gross fluxes: gross emissions from land-use change and other forest disturbances (purple) and gross removals occurring in undisturbed forests as well as removals from forest regrowth after disturbance (green). The top five countries per region are ranked high to low on the basis of gross emissions, with all other countries in the region grouped into ‘other countries’.

(Table 2) but other important fluxes are omitted from our analysis such as those occurring within grasslands, semi-arid savannas and shrublands²² (due to the 30% per 5 m of tree cover definition used in our analysis), non-stand-replacing fires²³, degradation outside the tropics and other terrestrial fluxes not previously included in any global budget to date²⁴. We include Table 2 to highlight how our gross estimates of forest-related fluxes fit within the context of the global carbon budget but our research is geared towards highlighting forest emission and removal hotspots for policy-relevant applications and stakeholders (Fig. 1), not towards producing a comprehensive and precise accounting of the full terrestrial carbon budget.

Limitations and future improvements

All forest monitoring systems reflect a balance between data availability, scale of applicability, measurement costs, reducing uncertainties and other constraints. Given the urgency of addressing climate change, the time and costs required to develop monitoring systems that reduce uncertainties as far as practicable²⁵ must be balanced

against the potential benefits of publicly accessible, operational and fit-for-purpose systems that provide enough spatial detail to incentivize real, near-term and sustained investment in nature-based climate solutions on the ground. In this study, we combined publicly available data into a global monitoring framework that generates consistent information on forest carbon fluxes cost-effectively over large spatial scales. However, this approach encounters limitations that should be addressed as research progresses.

First, the global forest change data used as the basis of activity data in our analysis are spatially detailed but contain temporal inconsistencies. While the forest loss product is updated annually through 2019, gain has not been updated past 2012 and represents a cumulative total (2000–2012). Therefore, although gross emissions can be estimated annually (Extended Data Fig. 9), estimating annual trends in gross removals and net flux is limited by a lack of a consistent time series on forest regrowth. Globally, GHG flux estimates were relatively insensitive to this limitation; we estimate that expansion of forest extent observed after 2000 accounted for less than 5% of global gross carbon removals, with the vast majority occurring

Table 2 | Comparison of results from this study to the Global Carbon Project, 2001–2018

Global carbon budget, 2001–2018 (GtCO ₂ yr ^{−1})			
Global Carbon Project		This study	
Sources			
Fossil fuel and cement	32.0	Fossil fuel and cement	32.0
Land-use change (net, anthropogenic) ^a	5.3	Forests (gross, all observed disturbances) ^b	7.9
		Forests (gross, unobserved emission sources) ^c	2.1
Total sources	37.3		42.0
Sinks			
Atmosphere	16.9	Atmosphere	16.9
Ocean	8.7	Ocean	8.7
Terrestrial (net, non-anthropogenic) ^d	10.5	Forests (gross, all forests) ^e	15.6
		Harvested wood products	0.16
Total sinks	36.1		41.4
Land (net, all land)	−5.2	Forests (net, all forests) ^f	−5.8
Budget imbalance ^g	1.2		0.6

Estimates from the Global Carbon Project (GCP)²⁸ and this study are not directly comparable due to differences in scope (all land versus forests, respectively), data, methodologies and reporting structure. In GCP reporting, land-use change emissions (sources) reflect the net balance between anthropogenic emissions (+) and removals (−), thus the net emission estimate is lower than gross emissions reported in this study. Similarly, gross removals reported in this study reflect removals across all forest lands, including removals implicit (but unreported) in the net land-use change estimate of GCP. ^aEstimates only net direct anthropogenic effects, including deforestation, afforestation/reforestation and wood harvest. Gross fluxes higher but not reported. ^bGross emissions from all forest disturbances (anthropogenic and non-anthropogenic) observed from Landsat data. Estimate includes CO₂ only for comparability with GCP; non-CO₂ emissions are 0.086 GtCO₂e yr⁻¹. ^cGross emissions from forest degradation in 74 developing countries covering 2.2 billion hectares of forest, from Pearson et al.²¹. ^dIn IPCC's Fifth Assessment Report¹, calculated as the residual of all other terms in the carbon budget. ^eGross removals from all forest processes (direct, indirect and natural). ^fCalculated as the net balance between gross forest ecosystem emissions and removals (7.9 + 2.1 = 10.0 GtCO₂ yr⁻¹) plus an additional net removal of −0.16 GtCO₂ yr⁻¹ in harvested wood products. ^gBudget imbalance is the difference between total sources and total sinks.

instead in forests established before 2000. However, accurate monitoring of the timing of recent regrowth becomes more important in local contexts where rapid forest loss/gain dynamics are occurring, such as in plantations with short rotation cycles and other dynamic areas dominated by intensive forestry or short-fallow shifting cultivation systems (Extended Data Fig. 5). Temporal inconsistencies are also present within the global loss product; one algorithm covers years 2001–2010 and another covers 2011–2019, with later years of loss likely to be more sensitive to changes related to small-scale agriculture, fires and other forms of forest degradation. For these reasons, we report only long-term averages and not annual trends in forest GHG fluxes. A forthcoming ‘version 2’ global tree cover loss product and an improved global gain product, already piloted for the lower Mekong region of Southeast Asia²⁶, will improve temporal consistency. Incorporating these improvements into the forest GHG flux model will more accurately capture interannual variability in emissions and removals over time and will thus provide a consistent basis for more temporally detailed monitoring of the long-term net impact of forests on atmospheric GHGs²⁷.

Second, information is currently lacking to develop globally consistent and spatially detailed maps of forest carbon removals. In our analysis, uncertainty in gross removals is substantially higher than uncertainty in gross emissions, driven primarily by high uncertainty in removal factors for established forests in temperate regions (Table 1 and Supplementary Table 1). Through the integration of

ground and Earth observation data, several biomass and soil carbon maps have been developed that inform spatially explicit emission factors. However, accurate and precise estimation of forest carbon removal factors requires information derived from long-term forest inventories applied consistently and repeatedly through time across different forest types and age classes. For many of the world's forests, this information does not exist²⁸. Many developing countries have not completed their first forest inventory, let alone repeated inventories. Efforts to combine georeferenced plot networks with other spatially explicit data inputs to create maps over large scales of forest carbon accumulation rates over time, similar to what has been done to develop biomass density maps at a single point in time, have begun but are still in their infancy²⁹. We therefore applied removal factors using a stratification approach, where each forest pixel is assigned a removal factor on the basis of its geographic region, forest type and age class (Methods). Removal factors reflect both ecological forest dynamics (tree growth, mortality and recruitment through natural regeneration) and indirect effects (long-term increases in atmospheric CO₂ concentrations and temperature, nutrient fertilization). Going forward, new satellite missions such as GEDI, ICESAT-2 and BIOMASS will provide repeated measurements of forest height and biomass over time that should improve understanding of spatial variation in rates of carbon removal across heterogeneous forest landscapes.

The global forest carbon monitoring framework introduced here, and the main improvements identified above, allow for efficient prioritization and evaluation of how data updates and improvements influence GHG flux estimates and their uncertainties. As satellite- and ground-based forest monitoring improve, so too will the associated forest GHG flux estimates.

Conclusions

Our analysis reinforces the need to reduce gross emissions from tropical deforestation as a climate change mitigation strategy, while also highlighting the substantial but often underappreciated contribution of intact primary and older secondary forests to carbon dioxide removals. Quantifying gross emissions and removals separately and consistently across all forest lands—and producing maps in addition to tabular statistics—improves transparency in the accounting of factors and geographies contributing to the global net forest GHG flux. It also provides a framework to integrate new and improved data sources over time. Governments interested in spatially prioritizing implementation and tracking of national and subnational forest mitigation targets can increasingly make use of such data. Non-government actors, such as companies aiming to reduce emissions from deforestation associated with commodity supply chains and emerging market mechanisms considering the inclusion of forests for carbon offset programs, could benefit from a globally consistent and spatially explicit forest monitoring system developed using the same internationally accepted methods as national governments use but based on independent observations and with GHG estimates that can be linked to individual actions and generated at scales relevant to diverse climate-related policies, programmes and stakeholders.

The goals of the Paris Agreement—primarily, net zero anthropogenic emissions in the second half of this century—create an imperative to track forest-related emissions and removals transparently and at scales that link more closely to mitigation activities on the ground. As the capacity of national governments to collect, process and analyse data continues to improve, the global forest carbon monitoring framework introduced here can help to enhance transparency, inform forest-related climate policy and implementation initiatives, underpin independent technical assessments, reconcile differences between national reports and scientific studies, and provide a more consistent and comparable basis for tracking progress at local scales and for assessing atmospheric

impacts of global forest change under the Paris Agreement's forthcoming Global Stocktake³⁰.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at <https://doi.org/10.1038/s41558-020-00976-6>.

Received: 15 May 2020; Accepted: 3 December 2020;

Published: 2 January 2021

References

1. IPCC *Climate Change 2014: Synthesis Report* (eds Core Writing Team, Pachauri, R. K. & Meyer L. A.) (IPCC, 2014).
2. IPCC *Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (IPCC, 2019).
3. *Adoption of the Paris Agreement FCCC/CP/2015/10/Add.1* (UNFCCC, 2015).
4. Klein Goldewijk, K., Beusen, A., Doelman, J. & Stehfest, E. New anthropogenic land use estimates for the Holocene: HYDE 3.2. *Earth Syst. Sci. Data* **9**, 927–953 (2017).
5. Griscom, B. W. et al. National mitigation potential from natural climate solutions in the tropics. *Philos. Trans. R. Soc. B* **375**, 20190126 (2020).
6. Friedlingstein, P. et al. Global carbon budget 2019. *Earth Syst. Sci. Data* **11**, 1783–1838 (2019).
7. Houghton, R. A. & Nassikas, A. A. Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Glob. Biogeochem. Cycles* **31**, 456–472 (2017).
8. Hansis, E., Davis, S. J. & Pongratz, J. Relevance of methodological choices for accounting of land use change carbon fluxes. *Glob. Biogeochem. Cycles* **29**, 1230–1246 (2015).
9. Pan, Y. et al. A large and persistent carbon sink in the world's forests. *Science* **333**, 988–993 (2011).
10. IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Vol. 4 (eds Eggleston, S. et al.) (IGES, 2006).
11. IPCC. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* Vol. 4 (eds Buendia, E. C. et al.) (IPCC, 2019).
12. Grassi, G. et al. Reconciling global-model estimates and country reporting of anthropogenic forest CO₂ sinks. *Nat. Clim. Change* **8**, 914–920 (2018).
13. Lee, D., Llopis, P., Waterworth, R., Roberts, G. & Pearson, T. *Approaches to REDD+ Nesting: Lessons Learned from Country Experiences* (World Bank, 2018).
14. Streck, C. et al. *Options for Enhancing REDD+ Collaboration in the Context of Article 6 of the Paris Agreement* (Meridian Institute, 2017).
15. Hansen, M. C. et al. High-resolution global maps of 21st-century forest cover change. *Science* **342**, 850–853 (2013).
16. *World Database on Protected Areas User Manual* (UNEP, 2016); <https://www.protectedplanet.net/en/resources/wdpa-manual>
17. Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A. & Hansen, M. C. Classifying drivers of global forest loss. *Science* **361**, 1108–1111 (2018).
18. Saatchi, S. S. et al. Benchmark map of forest carbon stocks in tropical regions across three continents. *Proc. Natl Acad. Sci. USA* **108**, 9899–9904 (2011).
19. *PRODES Deforestation* (INPE, 2019); <http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes>
20. Ogle, S. M. et al. Delineating managed land for reporting national greenhouse gas emissions and removals to the United Nations framework convention on climate change. *Carbon Balance Manag.* **13**, 9 (2018).
21. Pearson, T. R., Brown, S., Murray, L. & Sidman, G. Greenhouse gas emissions from tropical forest degradation: an underestimated source. *Carbon Balance Manag.* **12**, 3 (2017).
22. Ahlström, A. et al. The dominant role of semi-arid ecosystems in the trend and variability of the land CO₂ sink. *Science* **348**, 895–899 (2015).
23. Van Der Werf, G. R. et al. Global fire emissions estimates during 1997–2016. *Earth Syst. Sci. Data* **9**, 697–720 (2017).
24. Kirschbaum, M. U., Zeng, G., Ximenes, F., Giltrap, D. L. & Zeldis, J. R. Towards a more complete quantification of the global carbon cycle. *Biogeosciences* **16**, 831–846 (2019).
25. Global Forest Observations Initiative. *Integration of Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests* 2nd edn (FAO, 2016).
26. Potapov, P. et al. Annual continuous fields of woody vegetation structure in the Lower Mekong region from 2000–2017 Landsat time-series. *Remote Sens. Environ.* **232**, 111278 (2019).
27. Federici, S., Lee, D. & Herold, M. *Forest Mitigation: A Permanent Contribution to the Paris Agreement?* (Climate and Land Use Alliance, 2017).
28. Romijn, E. et al. Assessing change in national forest monitoring capacities of 99 tropical countries. *Ecol. Manag.* **352**, 109–123 (2015).
29. Cook-Patton, S. Mapping potential carbon capture from global natural forest regrowth. *Nature* **585**, 545–550 (2020).
30. *The Global Stocktake* (UNFCCC, 2015); <https://unfccc.int/topics/science/workstreams/global-stocktake-referred-to-in-article-14-of-the-paris-agreement>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© The Author(s), under exclusive licence to Springer Nature Limited 2021

Methods

Study design and scope. We mapped gross and net GHG emissions by sources and removals by sinks from global forest lands by synthesizing information collected from more than 637,000 ground plots, 707,561 waveform lidar observations and other satellite data into a spatial forest carbon monitoring framework. The analysis covers 2001 to 2019 but can be extended to include later years as data are updated. To the extent possible, we adhered to IPCC Guidelines developed for the agriculture, forestry and other land use (AFOLU) sector^{10,11}. In the context of IPCC land-use categories, our analysis covers only forest-related transitions (forest to non-forest, non-forest to forest and forest remaining forest). We applied the IPCC gain-loss method (versus the stock-difference method¹⁰), in which forest carbon (C) stocks in five ecosystem pools were estimated for a base year (2000) after which changes in C stocks were estimated by considering both annual C losses from land-use change and disturbance (conventionally represented by a + sign) as well as annual C gains from forest regrowth (represented by a – sign). We included harvested wood products as a sixth (human-created) carbon pool. We also included methane (CH₄) and nitrous oxide (N₂O) emissions from stand-replacement forest fires and drainage of organic soils associated with a loss of tree cover. We summarized GHG fluxes across all relevant gases and reported in units of CO₂ equivalents (CO₂e) using 100-yr Global Warming Potentials (without climate feedbacks) from the IPCC Fifth Assessment Report¹.

We set all data inputs to a common resolution of 0.00025° × 0.00025° to match the resolution of Landsat-based tree cover change data of Hansen et al.¹⁵. Gross emissions and removals were modelled at this common resolution across approximately 90 billion individual pixels of global forest cover (defined below). We resampled all input layers to this resolution so that outputs can be flexibly aggregated to larger scales. Extended Data Fig. 10 summarizes the overall conceptual approach and Supplementary Table 3 provides a list of data inputs.

Forest definition and extent. Initially, we defined forest extent in the year 2000 similarly to Hansen et al.¹⁵, that is, any 30-m Landsat pixel that met a tree canopy threshold of at least 30% with trees taller than 5 m in height. This initial definition included natural and seminatural forests, plantations and agricultural tree crops such as oil palm and agroforestry systems where minimum height and cover thresholds were met. On the basis of available data, we made four modifications to the original tree cover map to refine our global map of forest extent:

1. We included pixels of tree cover gain since 2000 in addition to tree cover already present in the year 2000.
2. We included only tree cover pixels that also had a corresponding value in the aboveground biomass density map (0.031% of tree cover pixels lacked a biomass value).
3. We excluded all areas of tree cover falling within oil palm plantation boundaries mapped for the year 2000 in Indonesia and Malaysia^{31–34}.
4. We replaced tree cover extent from Hansen et al.¹⁵ with mangrove forest extent using data from Giri et al.³⁵; in areas of geographic overlap, mangroves had priority.

Forest aboveground live biomass density in 2000. We created a year 2000 map of aboveground live biomass density (AGB, in Mgha⁻¹) at 30-m resolution by combining two maps: one developed specifically for mangroves³⁶ and the other developed to cover all woody vegetation globally (Supplementary Data 1). In areas of geographic overlap, the mangrove biomass map had priority. The basic approach is the same as that used to map tropical biomass at 500-m (ref. ³⁷) and 30-m (ref. ³⁸) resolution; published height–biomass equations were applied to estimate biomass over specific regions and forest types around the world (Extended Data Fig. 1a). These equations, developed by linking observations from airborne or spaceborne lidar to 20,347 ground-measured biomass plots, were applied to estimate aboveground biomass density from spaceborne lidar observations across 707,561 locations globally. To create a continuous biomass map (Extended Data Fig. 1b), separate random forest models were trained for each of six biogeographic realms using predictor variables of Landsat imagery (bands 3, 4, 5 and 7), normalized difference vegetation index (NDVI), normalized difference infrared index (NDII), mean percentage tree cover, mean elevation, mean slope and monthly mean precipitation, temperature and bioclimatic data. Additional details are provided in Supplementary Data 1.

Forest ecosystem carbon pools in 2000. From the 30-m global AGB map, we mapped belowground live biomass density (BGB) using a forest root-to-shoot ratio³⁹ with mangrove-specific ratios based on defaults provided in Table 4.5 of the 2013 IPCC Wetlands Supplement⁴⁰. AGB and BGB values were converted to C density values using a biomass-to-carbon ratio of 0.45 for mangroves⁴⁰ and 0.47 for all other forest types^{10,11}. From the final 30-m AGB map we estimated dead wood and litter biomass densities per pixel as constant fractions of AGB using a lookup table based on global ecological zone, elevation and precipitation regime⁴¹ (Supplementary Table 4). Dead wood and litter biomass densities were converted to C densities using IPCC conversion factors¹⁰.

Soil organic carbon density in the top 30 cm of mineral soils was mapped using SoilGrids250 (v.2.0)⁴² after resampling from its original spatial resolution of 250 m

to match the common 30-m resolution of our analysis. For mangrove forests, we used a 30-m soil carbon map developed specifically for mangroves⁴³. We delineated locations of organic (peat) soils using maps summarized in Supplementary Table 3.

We used these five forest carbon pool maps as the basis for estimating emission factors associated with various forest disturbances (see below).

Activity data. Activity data were defined using the global forest change product of Hansen et al.¹⁵ with loss updated annually on Global Forest Watch. In the model, all pixels defined as forest were classified into one of four categories: (1) loss only; (2) gain only; (3) both loss and gain; or (4) no change over the period 2001–2019. Loss is defined by Hansen et al. as a stand-replacement disturbance and includes all disturbances (natural and anthropogenic) observable in Landsat imagery. Gain is defined as a non-forest to forest change, which includes tree cover gain observed after harvest and other disturbance. The loss product is annual, while the gain product represents a cumulative total (2000–2012). Loss and gain can co-occur on pixels undergoing forest management or other forms of disturbance and regrowth. Lack of annually updated gain data is addressed through the sensitivity analysis (Extended Data Fig. 5). Due to a lack of information about tree cover gain after 2012, we assumed no additional areas of gain from 2012 to 2019. Areas of no change reflect forest areas established before 2000 that showed no observable disturbance in Landsat imagery between 2000 and 2019.

Emission factors. We assigned emission factors to tree cover loss pixels following an IPCC land-use classification framework, on the basis of whether each pixel maintained its land use or was converted to a new use over the analysis period. Since forest may remain in the same use despite a temporary loss of tree cover, we used the global 10-km map of Curtis et al.¹⁷ (updated through 2019) to attribute tree cover loss to one of five dominant drivers; these influence the C pools affected (Supplementary Table 5) and thus the emission factors assigned to each individual loss pixel. Supplementary Table 6 summarizes emission factors by forest type within each climate domain.

Commodity-driven deforestation and shifting agriculture. The initial change in C stocks was estimated as a full loss of C in aboveground, belowground, dead wood and litter pools. In addition to CO₂ emissions resulting from a loss of C stocks, we used IPCC equation 2.27 (ref. ¹⁰) and a 1-km global burned area map⁴⁴ to calculate CH₄ and N₂O emissions in loss pixels that overlapped with areas that burned the same year or the year before (to account for lag effects between fire occurrence and observed tree cover loss). For deforestation on mineral soils, soil C loss was estimated using IPCC equation 2.25 (ref. ¹⁰); default soil stock change factors vary by ecological zone and were assigned spatially using ecozone boundaries⁴⁵. Per IPCC guidelines, 1/20th of the total soil C stock change was apportioned annually from the year of loss through the last year of the analysis period (2019) but assigned to the year of observed tree cover loss. Due to lack of information in the driver attribution map¹⁷ about the specific land use established after forest clearing, we assumed for the purposes of soil emission accounting that all deforested land on mineral soils for commodity-driven deforestation was converted to annual cropland with full tillage and medium inputs. A different factor was used to estimate loss of soil C on mineral soils (Table 5.10 in the IPCC Guidelines¹⁰) in areas of shifting agriculture, which were assumed to represent transient land-use conversions to cropland under shortened fallow, where vegetation recovery is not attained before re-clearing. Soil emissions were not estimated for areas of loss on mineral soils that overlapped with forest and wood fibre plantations, even if they fell within the broader commodity-driven deforestation or shifting agriculture classes, consistent with the assumption that loss of tree cover within tree plantations follows the forestry assumptions listed in Supplementary Table 5 (see emissions from Forestry below). For loss on organic soils that overlapped with tropical plantations and tree crops planted since 2000, GHG emissions associated with drainage were estimated using CO₂ and CH₄ emission factors provided in the IPCC Wetlands Supplement⁴⁰. Like emissions from mineral soils, emissions from peat drainage were assumed to continue in each year after loss up through the last year of the analysis period (2019) but were assigned to the year of observed tree cover loss. Emissions (CO₂, CH₄ and N₂O) from peat burning were also calculated on the basis of methods provided in the IPCC Wetlands Supplement⁴⁰ where a loss pixel overlapped with areas burned the same year, or the year before, the loss event (on the basis of global burned area data).

Urbanization. The same assumptions and calculations were used for calculating gross emissions from urbanization as for commodity-driven deforestation and shifting agriculture, except a different factor was used to estimate the loss of soil C on mineral soils. We assumed that forest land converted to settlement was paved over and applied the IPCC default assumption¹¹ that 20% of the soil C relative to the previous land use was lost as a result of disturbance, removal or relocation.

Forestry. Emission factors for loss attributed to forestry were estimated as the loss of C in live biomass only, following assumptions outlined in Supplementary Table 5 that there is no net change to the dead organic matter or soil C pools in the case of mineral soils. Emissions from peat drainage and burning associated with forestry activities, as well as non-CO₂ emissions in the case of forest fires, were included in

the same way as for deforestation and shifting agriculture above. Emission factors for loss pixels within the 'zero or minor loss' category of the driver attribution map also followed assumptions for forestry (Supplementary Table 5).

Wildfire. Within 10-km grid cells of the drivers map labelled wildfire, wildfire emission factors were applied only for 30-m pixels where loss occurred in the year of, or year after, a fire event in the 1-km burned area map. In these cases, we used IPCC equation 2.27 (ref. ¹⁰) to estimate both CO₂ and non-CO₂ emissions from forest fire. The AGB map determined the mass of fuel available for combustion and a lookup table (Table 2.6 of the IPCC Guidelines¹⁰) provided default combustion and emission factors that were applied on the basis of forest type (primary versus secondary). For boreal and temperate forests, combustion factors were applied on the basis of the assumption of a land-clearing fire, given that forest loss is defined in Hansen et al.¹⁵ as a stand-replacement disturbance. In cases where organic soils overlapped with burned areas, emissions from peat burning (CO₂, CH₄ and N₂O) were estimated following guidance in the IPCC Wetlands Supplement⁴⁰. Forestry emission factors, rather than wildfire factors, were applied where loss did not overlap with a fire event in the 1-km burned area map.

Removal factors. We developed removal factors spatially by linking information about each pixel's geographic region, ecological zone, forest type and age class to corresponding growth rates on the basis of best available information. Supplementary Table 6 summarizes removal factors by forest type in each climate domain. In areas of geographic overlap, the priority of assigning removal factors to a given pixel reflects the order of data sources listed below. Removal factors include accumulation in live biomass only and reflect the net increase, accounting for both productivity and mortality. We assumed no change to the dead organic matter and soil organic carbon pools, consistent with the IPCC Tier 1 assumption of no net change to non-biomass pools in forest land remaining forest land. The number of years of carbon accumulation was assigned as 19 yr for undisturbed forest, 6 yr for areas of new tree cover gain and one less than the year in which tree cover loss occurred for loss-only forest.

Mangroves. We applied mangrove-specific growth rates and root-to-shoot ratios from IPCC Tables 4.4 and 4.5 of the Wetlands Supplement⁴⁰, respectively.

Europe. We assigned removal factors spatially according to a map of dominant tree species developed from 260,000 national inventory plot locations⁴⁶. For each species, we estimated mean annual increment (MAI) values from Table 4.11 of the updated IPCC Guidelines¹¹, FAO Planted Forest Assessment⁴⁷ and national inventories⁴⁸ (Supplementary Table 3). These were converted to aboveground biomass growth rates using species-specific biomass conversion and expansion factors and belowground biomass increment was added on the basis of a root-to-shoot ratio⁴⁹.

Plantations and tree crops. Outside Europe, we assigned removal factors for plantations and tree crops using a variety of published data sources⁴⁹. For common plantation species, we used MAI and biomass conversion and expansion factors summarized in the updated IPCC Guidelines¹¹ to estimate aboveground biomass increment and added belowground biomass increment on the basis of a root-to-shoot ratio⁴⁹. Rates in plantations were assigned on the basis of mapped species when known or, when unknown, the most common mix of plantation species grown in the region. Removal factors for tree crops such as oil palm and rubber as well as various types of agroforestry systems were estimated for areas mapped as such on the basis of regionally specific values derived from the published literature and from Tables 5.1 and 5.3 of the updated IPCC Guidelines¹¹. All removal factors used for plantations and tree crops, along with data sources and assumptions applied, are provided in the companion spatial attribute file associated with the global compilation of planted tree maps used in this analysis⁴⁹.

United States. We developed removal factors for three age classes (0–20, 20–100 and >100 yr) for forest types across 11 geographic regions using methods broadly similar to those of Smith et al.⁵⁰, except that we included more forest types in each region, as well as more recent and comprehensive data from the US Forest Inventory and Analysis database. Removal factors were developed from approximately 130,000 inventory plot locations. Pixels were assigned removal factors on the basis of dominant forest type⁵¹, age class⁵² and geographic inventory region.

Young secondary forests. Outside the United States and Europe, areas of tree cover gain that fell outside boundaries of mangroves³⁵ and planted trees⁴⁹ were assumed to be secondary natural forest regrowth <20 years old. We assigned natural forest regrowth removal factors to these areas using the 1-km map of Cook-Patton et al.²⁹.

Primary forests. We used removal factors by ecological zone and continent from IPCC Table 4.9 of the 2019 IPCC Refinement¹¹ and assigned them spatially between 30°N and 30°S within a tropical primary humid forest map⁵³. Outside 30°N and 30°S, we used a map of intact forest landscapes⁵⁴ as a proxy for primary forests, which is likely to be highly conservative due to the relatively large extent

criterion applied but represents the best available information by which to spatially delineate primary from old secondary forests in boreal and temperate regions.

Old secondary forests. We assigned removal factors from IPCC Table 4.9 (>20 yr) to all forest areas that fell outside the types identified above. Given no observed disturbance occurred in these areas since the year 2000, we assumed they were secondary natural forests at least 20 years old.

Harvested wood products. We used statistics reported in FAOSTAT and methods outlined in the 2019 Refinement¹¹ to estimate emissions and/or removals arising from harvested wood products. Losses of harvested wood products in use were assumed to result in CO₂ emissions to the atmosphere, with no explicit representation of the subsequent retention of disposed wood in solid waste disposal sites (SWDS) and eventual CO₂ emissions from SWDS. Calculations rely on statistics reported by countries on production, import and export volumes for three aggregate semifinished wood product commodity classes: sawnwood, wood-based panels and paper and paperboard.

Uncertainty analysis. We estimated uncertainty in GHG flux estimates globally and at the scale of climate domains by combining uncertainties in the activity data and emission/removal factors following a Taylor series statistical approach as in Roman-Cuesta et al.⁵⁵ and Carter et al.⁵⁶. This approach underlies the IPCC Approach 1 (simple error propagation)¹⁰ and produces similar results but reflect exact calculations of variances and s.d., whereas IPCC Approach 1 is an approximated approach that yields 95% confidence intervals.

Uncertainties of all major components of the flux model were included (activity data, affected C pools of the emission/removal factors, combustion and emission factor uncertainties for fire-related emissions). Errors were assumed to be statistically independent (uncorrelated), normally distributed and without bias. Supplementary Table 1 shows the contribution of each uncertainty component for domain and global gross emissions, removals and net flux, reported as the percentage reduction in output variances as each of the uncertainty components were assumed to have no variance. Variance of the net GHG flux was reduced the most when removing variance of the removal factor for temperate forests older than 20 yr. Variances are likely to be lower when estimated across smaller geographic regions. Estimation of uncertainty is currently limited to the global and biome scales based on available data for estimating uncertainty in the activity data.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Geospatial data generated from the current study are publicly available on Global Forest Watch's Open Data Portal (<http://data.globalforestwatch.org/>) and from the corresponding author upon request. Summary geospatial statistics are available from the corresponding author upon request. All data inputs used in the current study are publicly available or were obtained by the corresponding author.

Code availability

To ensure full reproducibility and transparency of our research, we provide all of the scripts used in our analysis. Codes used for this study are permanently and publicly available on GitHub (<https://github.com/wri/carbon-budget>).

References

- Austin, K. et al. Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments. *Land Use Policy* **69**, 41–48 (2017).
- Gaveau, D. L. et al. Four decades of forest persistence, clearance and logging on Borneo. *PLoS ONE* **9**, e101654 (2014).
- Miettinen, J., Shi, C. & Liew, S. C. Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990. *Glob. Ecol. Conserv.* **6**, 67–78 (2016).
- Gunarso, P., Hartoyo, M., Agus, F. & Killeen, T. in *Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil* (eds Killeen, T. J. & Goon, J.) 29–64 (RSPO, 2013).
- Giri, C. et al. Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob. Ecol. Biogeogr.* **20**, 154–159 (2011).
- Simard, M. et al. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nat. Geosci.* **12**, 40–45 (2019).
- Baccini, A. et al. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nat. Clim. Change* **2**, 182–185 (2012).
- Zarin, D. J. et al. Can carbon emissions from tropical deforestation drop by 50% in 5 years? *Glob. Change Biol.* **22**, 1336–1347 (2016).
- Mokany, K., Raison, R. J. & Prokushkin, A. S. Critical analysis of root: shoot ratios in terrestrial biomes. *Glob. Change Biol.* **12**, 84–96 (2006).

40. IPCC *Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (eds Hiraishi, T. et al.) (IPCC, 2014).
41. *Methodological Tool: Estimation of Carbon Stocks and Change in Carbon Stocks in Dead Wood and Litter in A/R CDM Project Activities* (UNFCCC, 2013); <https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-12-v3.0.pdf>
42. Hengl, T. et al. SoilGrids250m: global gridded soil information based on machine learning. *PLoS ONE* **12**, e0169748 (2017).
43. Sanderman, J. et al. A global map of mangrove forest soil carbon at 30 m spatial resolution. *Environ. Res. Lett.* **13**, 055002 (2018).
44. Giglio, L., Boschetti, L., Roy, D. P., Humber, M. L. & Justice, C. O. The Collection 6 MODIS burned area mapping algorithm and product. *Remote Sens. Environ.* **217**, 72–85 (2018).
45. *Global Ecological Zones for FAO Forest Reporting: 2010 Update* (FAO, 2012).
46. Brus, D. et al. Statistical mapping of tree species over Europe. *Eur. J. Res.* **131**, 145–157 (2012).
47. Del Lungo, A., Ball, J. & Carle, J. *Global Planted Forests Thematic Study: Results and Analysis* (FAO, 2006); <http://www.fao.org/forestry/12139-03441d093f070ea7d7c4e3ec3f306507.pdf>
48. *Portugal National Greenhouse Gas Inventory submitted to the UNFCCC, 1990–2018* (UNFCCC, 2020).
49. Harris, N. L., Goldman, E. D. & Gibbs, S. *Spatial Database on Planted Trees Version 1.0* <https://www.wri.org/publication/spatialdatabase-planted-trees> (WRI, 2019).
50. Smith, J. E., Heath, L. S., Skog, K. E. & Birdsey, R. A. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States* General Technical Report (USDA, Forest Service, 2006); <https://doi.org/10.2737/NE-GTR-343>
51. Ruefenacht, B. et al. Conterminous US and Alaska forest type mapping using forest inventory and analysis data. *Photogramm. Eng. Remote Sensing* **74**, 1379–1388 (2008).
52. Pan, Y. et al. Age structure and disturbance legacy of North American forests. *Biogeosciences* **8**, 715–732 (2011).
53. Turubanova, S., Potapov, P. V., Tyukavina, A. & Hansen, M. C. Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. *Environ. Res. Lett.* **13**, 074028 (2018).
54. Potapov, P. et al. The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013. *Sci. Adv.* **3**, e1600821 (2017).
55. Roman-Cuesta, R. M. et al. Hotspots of gross emissions from the land use sector: patterns, uncertainties, and leading emission sources for the period 2000–2005 in the tropics. *Biogeosciences* **13**, 4253–4269 (2016).
56. Carter, S. et al. Agriculture-driven deforestation in the tropics from 1990–2015: emissions, trends and uncertainties. *Environ. Res. Lett.* **13**, 014002 (2017).

Acknowledgements

We thank S. Gibbs for her work on preliminary model development and T. Maschler for his contributions to workflows enabling efficient data processing and generation of summary statistics. Support for this research was funded in part by the Norwegian Ministry of Foreign Affairs (18/2721 Global Forest Watch Achieving Sustainability and Scaling Impact), the UK Department for International Development (DFID FGMC grant no. FGMC2018-21-WRI) and the US Agency for International Development (cooperative agreement no. 7200AA19CA00027 Global Forest Watch 3.0) in support of the Global Forest Watch Partnership convened by the World Resources Institute, by National Aeronautics and Space Administration Earth Science Division NNH12ZDA001 NICESAT2: studies with ICESAT and CryoSat-2 grant no. 12-ICESAT212-0022 to the Woods Hole Research Center and by the NASA Carbon Monitoring System Program Project 'Estimating Total Ecosystem Carbon in Blue Carbon and Tropical Peatland Ecosystems' (16-30 CMS16-0073) to NASA Goddard. The contribution of M.H., S.deB. and D.R.S. was supported by CIFOR's global comparative study on REDD+ (funded by NORAD), the European Space Agency CCI-Biomass project and the European Commission Horizon 2020 projects VERIFY (grant no. 776810) and REDD-Copernicus (grant no. 821880). Data used in part of this publication were made possible, in part, by an agreement from the United States Department of Agriculture's Forest Service. This publication may not necessarily express the views or opinions of the Forest Service.

Author contributions

N.L.H. was involved in conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, visualization and writing. D.A.G. contributed to data curation, formal analysis, investigation, methodology, software, validation, visualization and writing. A.B., R.A.B., R.R.C., M.F., L.F., M.C.H., R.A.H., P.V.P., C.M.S., D.R.S., S.S.S. and S.A.T. contributed to data curation, formal analysis, methodology and writing. M.H. contributed to data curation, visualization and writing. S.deB. and A.T. contributed to formal analysis and methodology.

Competing interests

The authors declare no competing interests.

Additional information

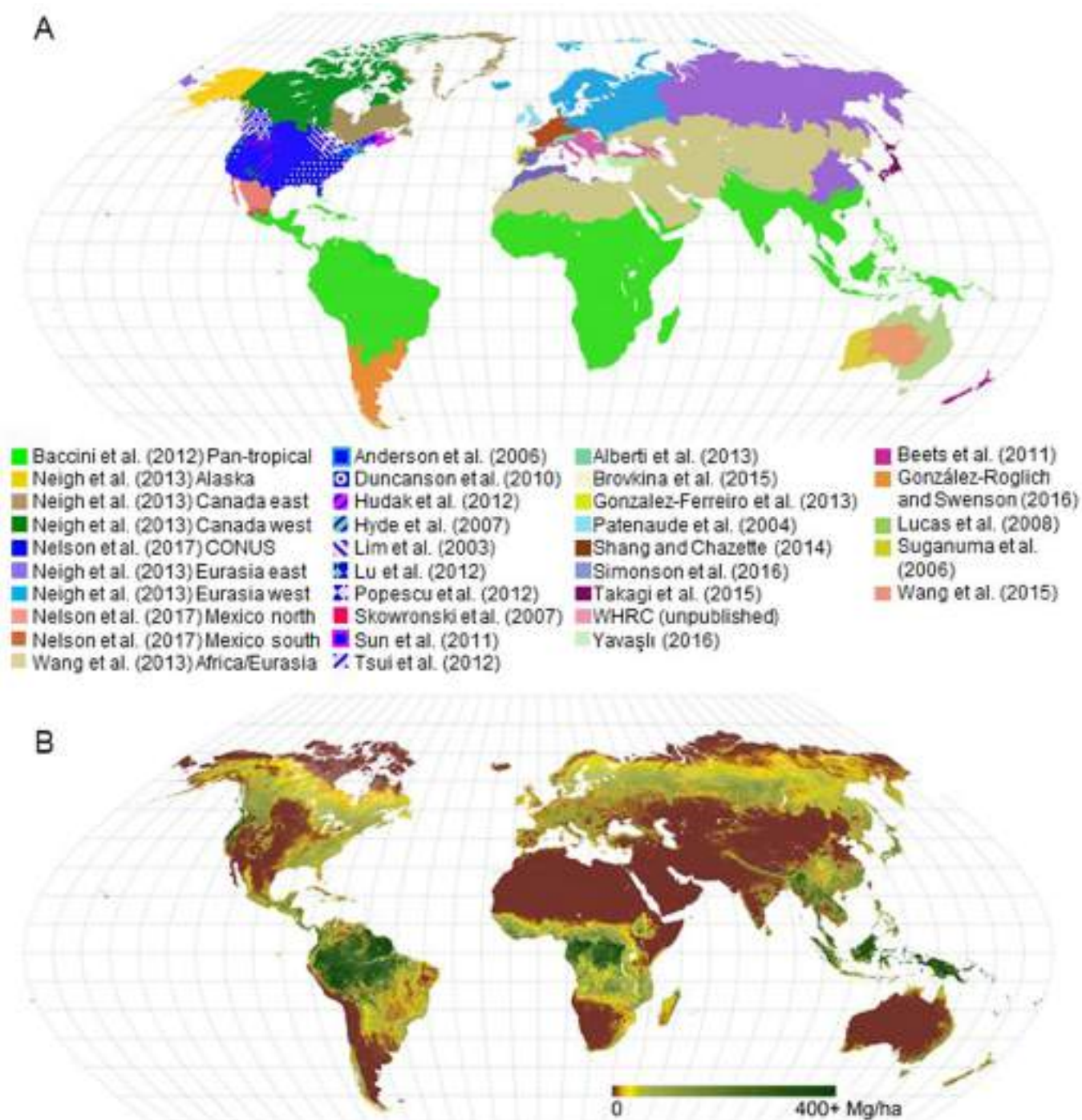
Extended data is available for this paper at <https://doi.org/10.1038/s41558-020-00976-6>.

Supplementary information is available for this paper at <https://doi.org/10.1038/s41558-020-00976-6>.

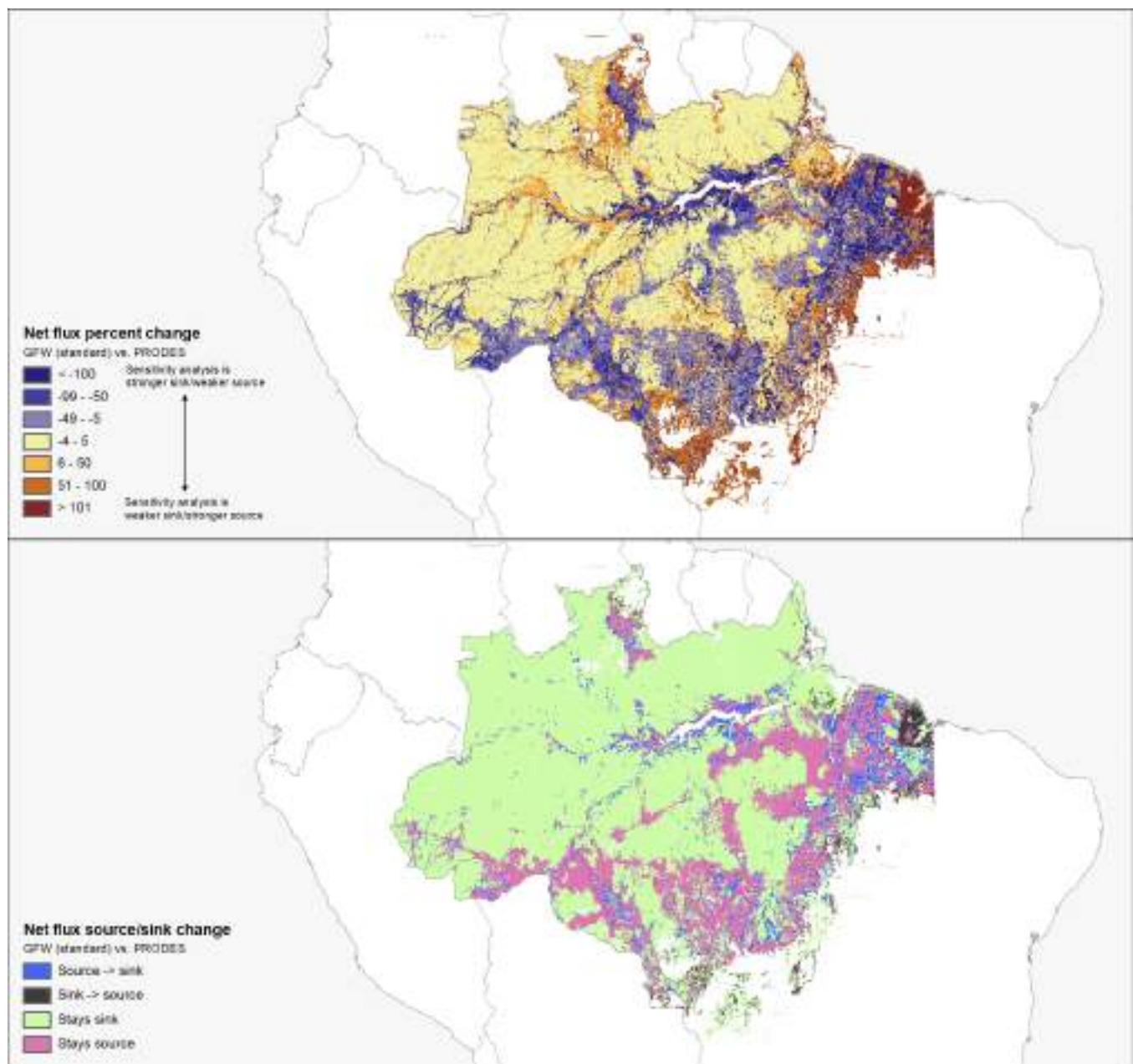
Correspondence and requests for materials should be addressed to N.L.H.

Peer review information *Nature Climate Change* thanks Gert-Jan Nabuurs, Seth Spawn and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

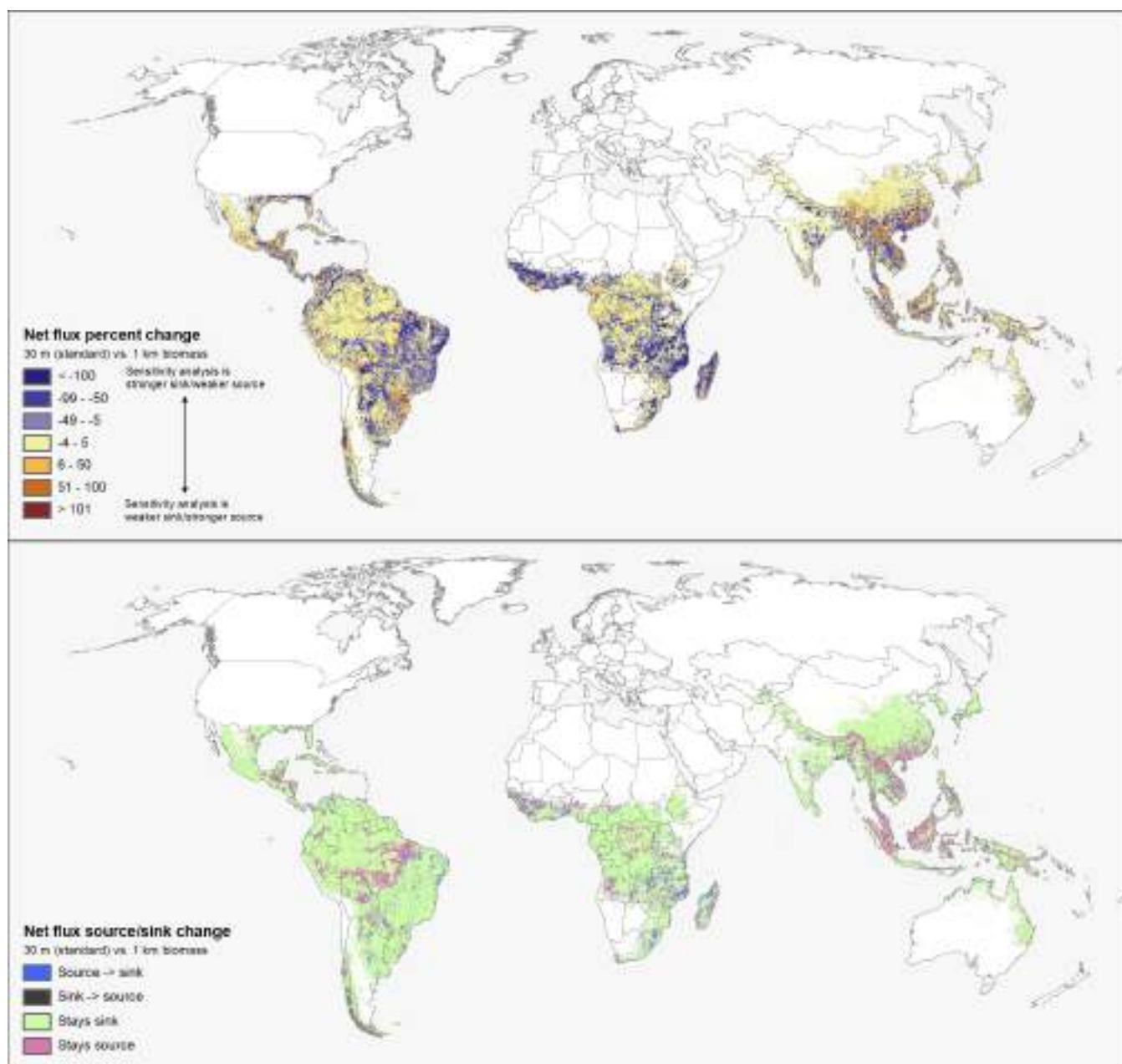
Reprints and permissions information is available at www.nature.com/reprints.



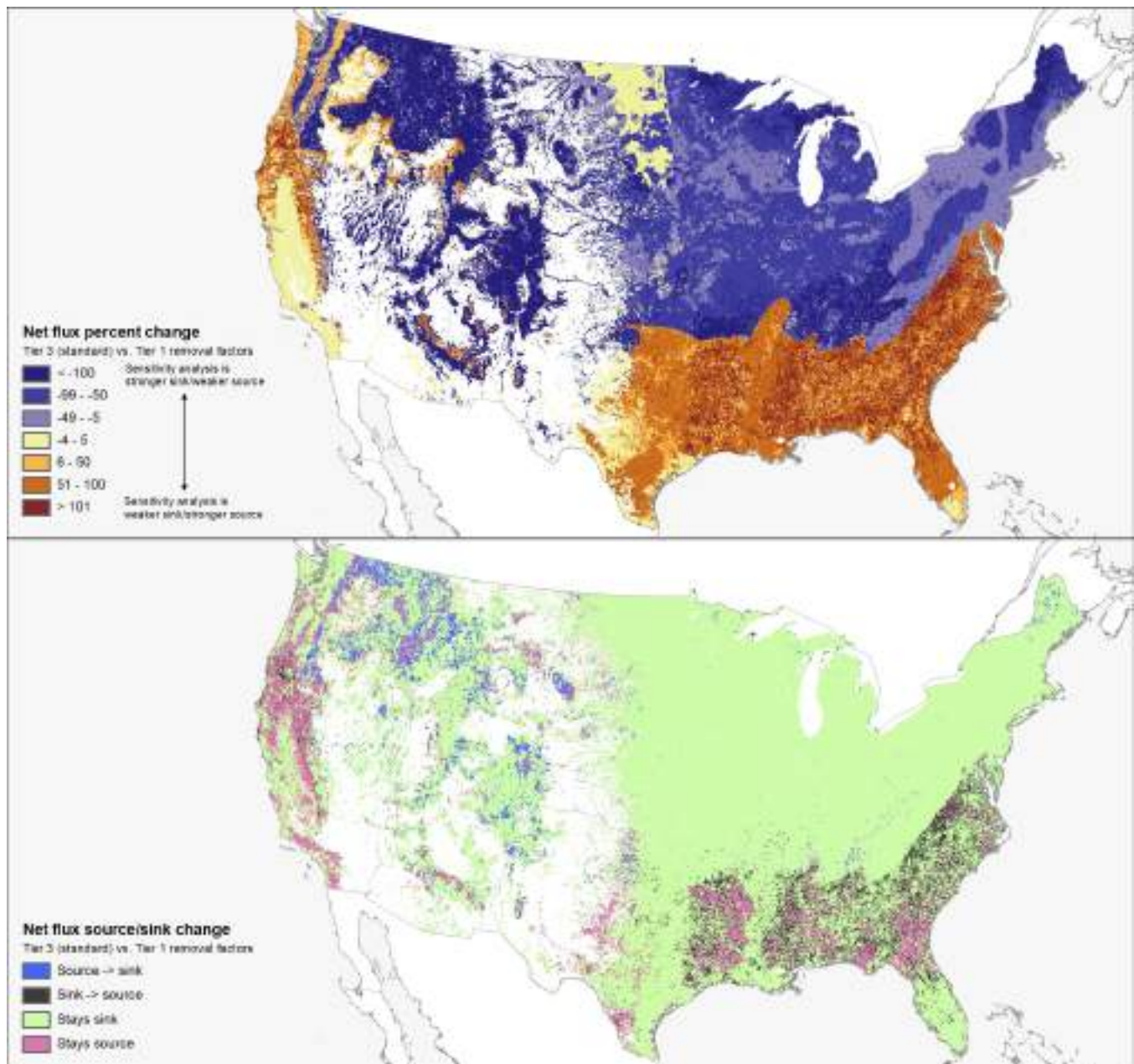
Extended Data Fig. 1 | Aboveground live woody biomass density in the year 2000. a, Subsets of ecoregions over which different height-biomass equations were applied. Patterned shading indicates equations that were only applied to conifer GLAS shots within the specified ecoregion. **b**, Global 30-m map of aboveground live woody biomass density in the year 2000.



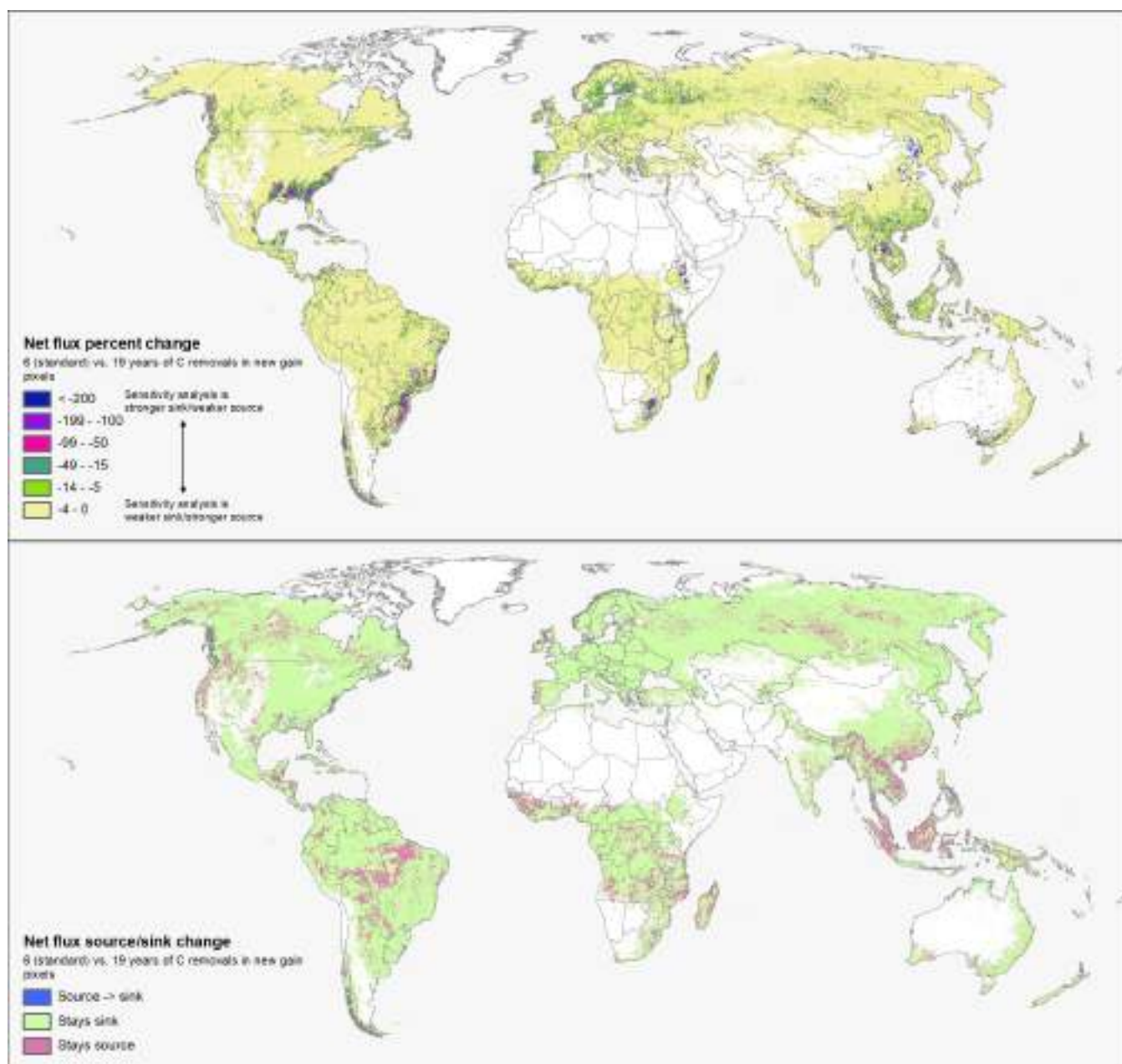
Extended Data Fig. 2 | Results of sensitivity analysis when the source of tree cover loss data used in the forest GHG flux model is changed from the 30-m tree cover loss product of Hansen et al.¹⁵ in the standard model to PRODES, Brazil's 250-m forest loss monitoring product for the Brazilian Amazon¹⁹, in the alternative model. Top panel: Percent change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



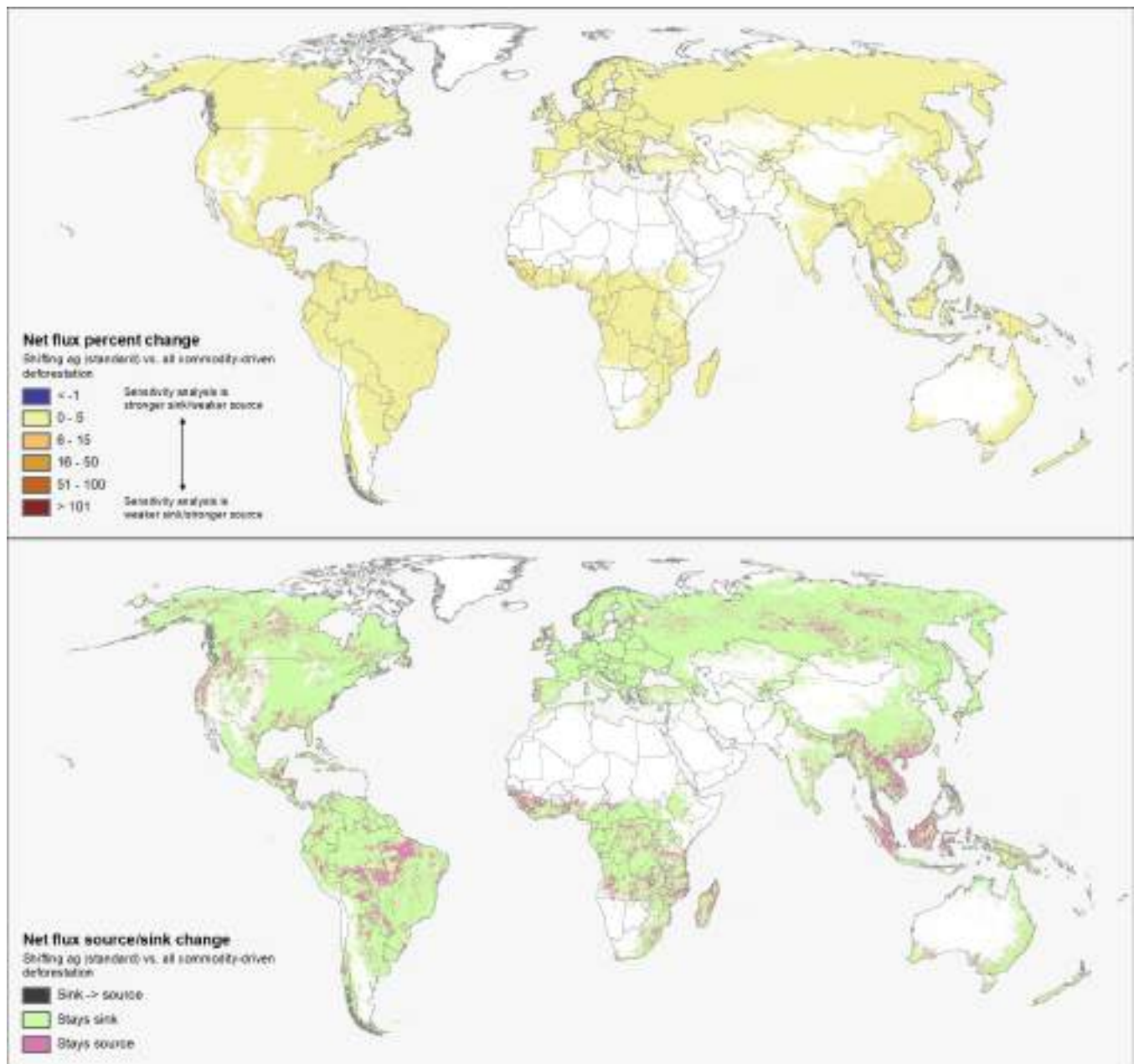
Extended Data Fig. 3 | Results of sensitivity analysis when the source of biomass data used in the forest GHG flux model is changed from a 30-m global AGB map in the standard model to a 1-km tropical AGB map in the alternative model. Top panel: Percent change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



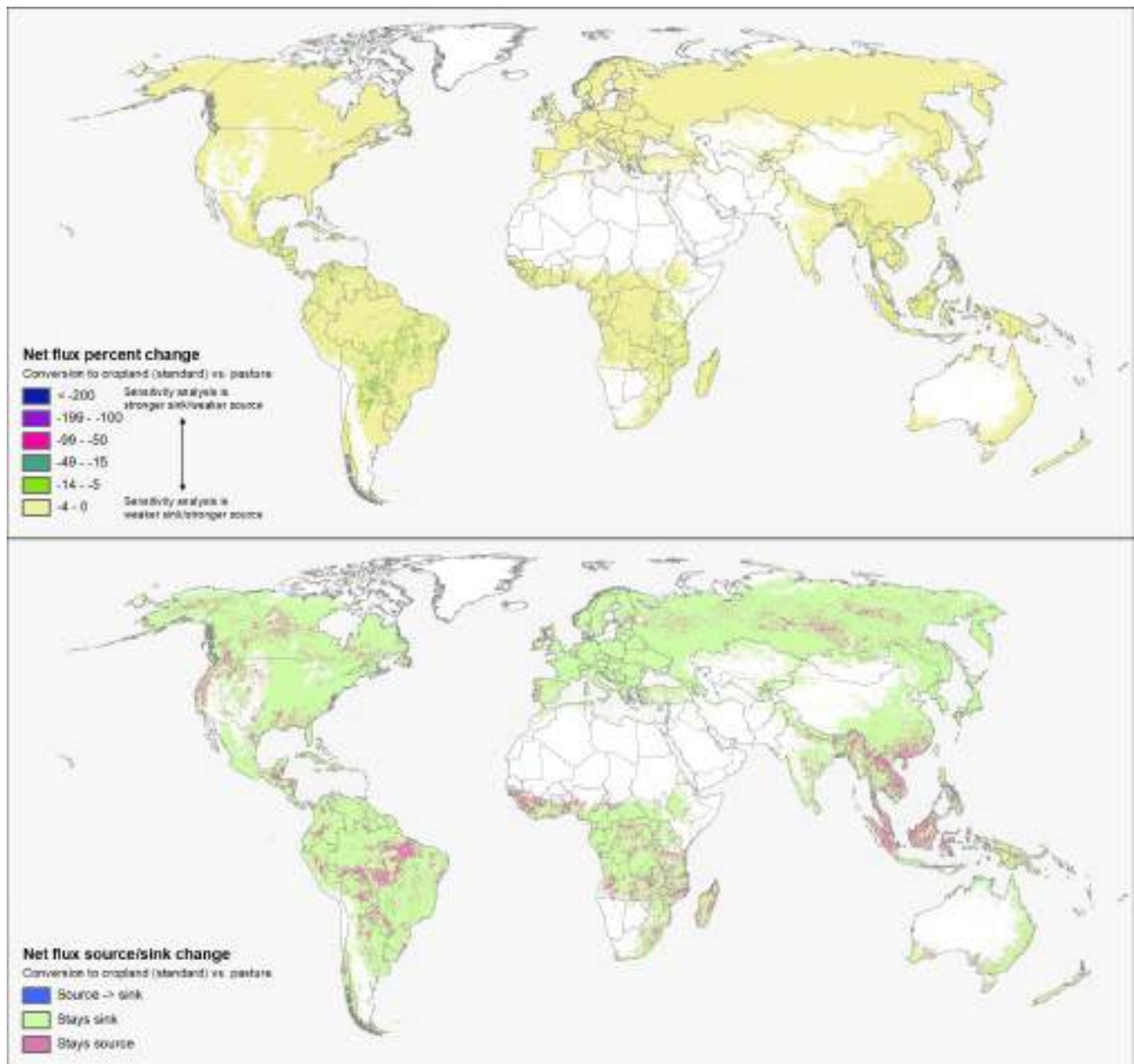
Extended Data Fig. 4 | Results of sensitivity analysis when rates of AGB accumulation derived from inventory data for different forest types of the United States in the standard model are replaced by IPCC Tier 1 default rates in the alternative model. Top panel: change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



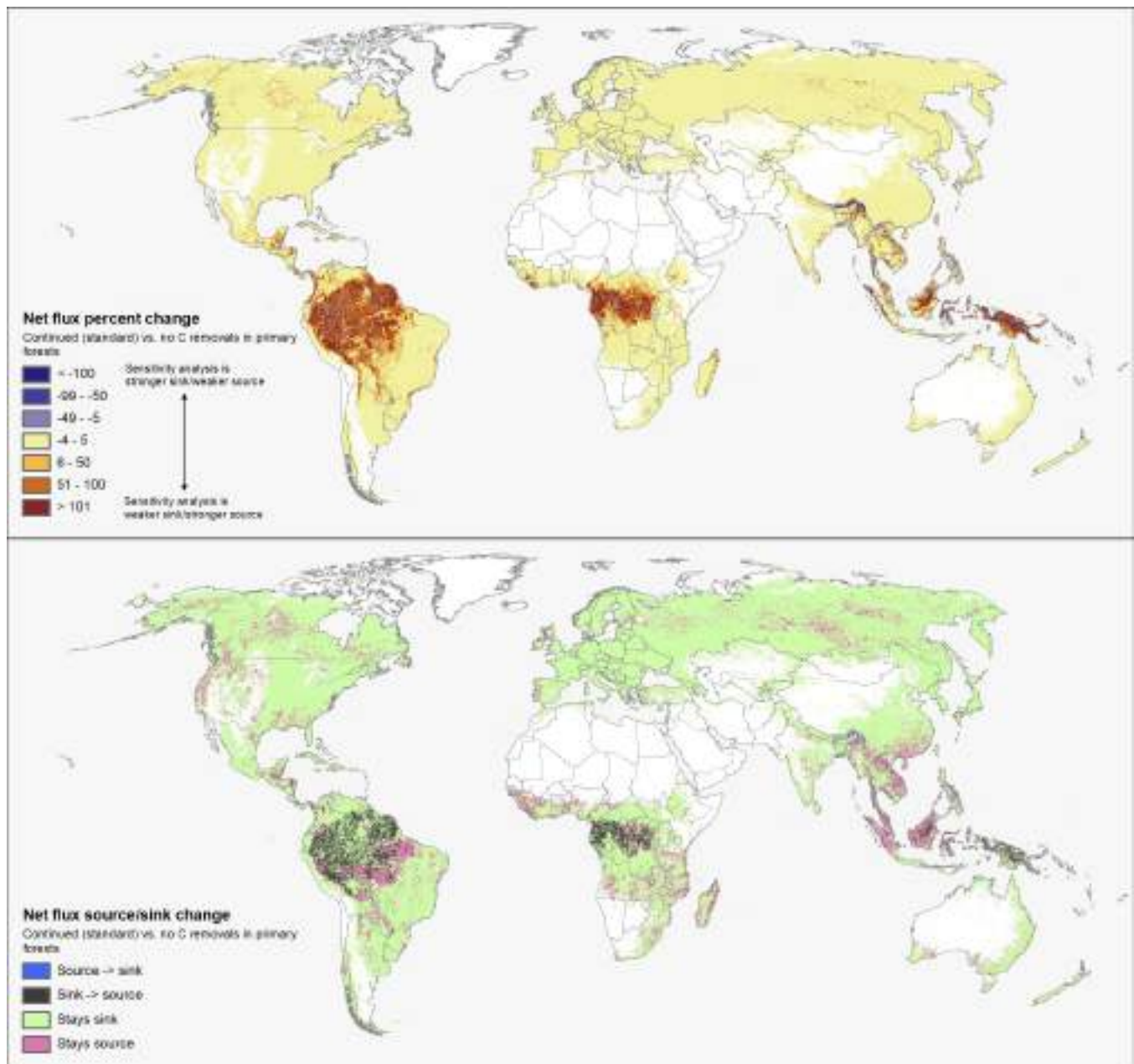
Extended Data Fig. 5 | Results of sensitivity analysis when the number of years of growth in the GHG flux model is assumed to be 19 in the alternative model vs. 6 in the standard model for pixels of tree cover gain since the year 2000. Top panel: Percent change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



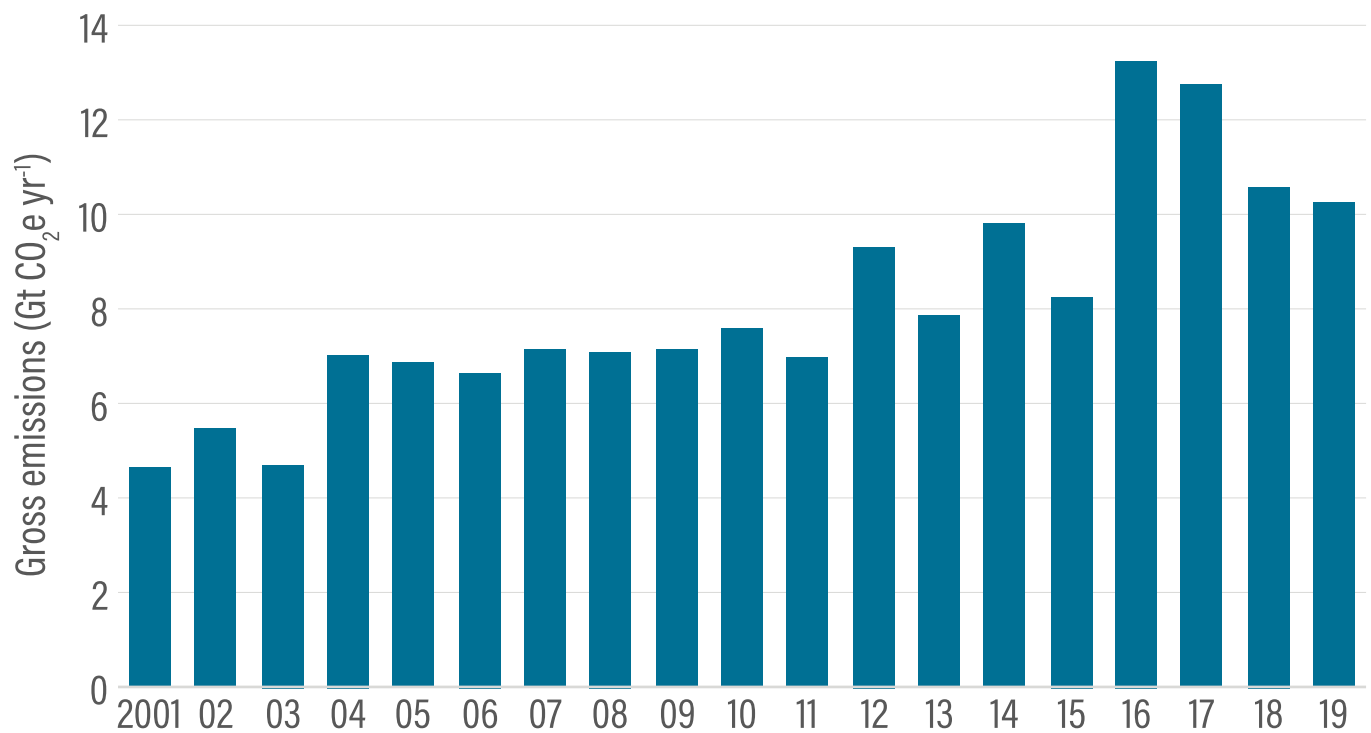
Extended Data Fig. 6 | Results of sensitivity analysis when tree cover loss in the GHG flux model is attributed to commodity-driven deforestation in the alternative model vs. shifting agriculture in the standard model. Top panel: Percent change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



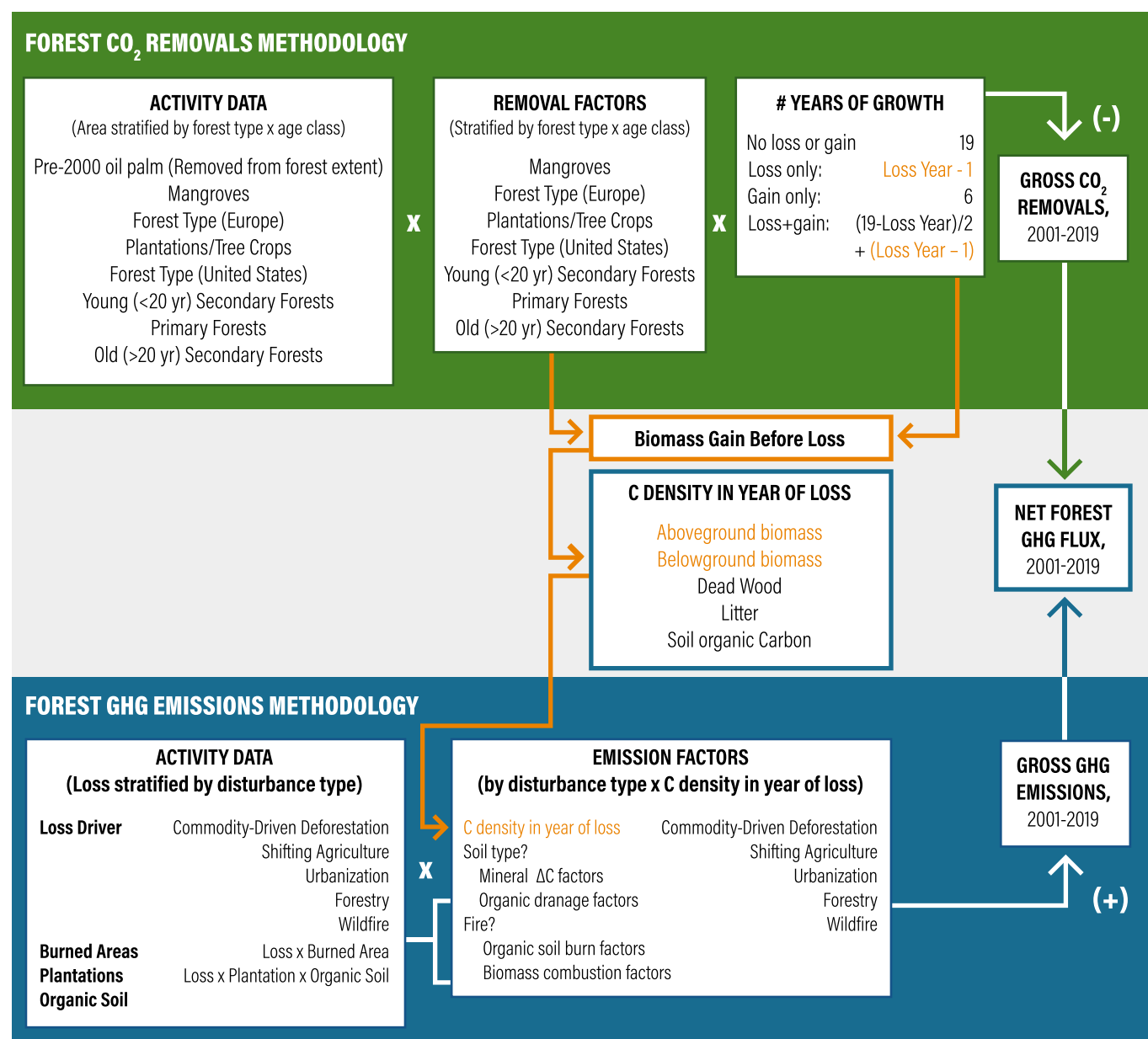
Extended Data Fig. 7 | Results of sensitivity analysis when the post-deforestation land-use assumption in the GHG flux model is changed from cropland in the standard model to grassland in the alternative model. Top panel: Percent change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



Extended Data Fig. 8 | Results of sensitivity analysis when assumptions about carbon uptake in primary forests and intact forest landscapes are changed to zero carbon uptake in the alternative model vs. positive carbon uptake in the standard model. Top panel: Percent change in net GHG flux between standard model and sensitivity analysis model; Bottom panel: Delineation of areas that remain a net GHG source or sink in the sensitivity analysis model vs. those that switch from being a net source or sink to a net sink or source as a result of the changes applied. For display purposes, maps have been resampled from the 30-m observation scale to a 0.04-degree geographic grid.



Extended Data Fig. 9 | Gross forest-related emissions, 2001–2019. Emissions reflect all stand-replacement disturbances (natural and anthropogenic) observable in Landsat imagery.



Extended Data Fig. 10 | Conceptual framework for modelling forest-related GHG fluxes. For each 30-m pixel included in the model, gross forest-related emissions and removals are estimated as the product of activity data and emission/removal factors. Net forest GHG flux is the sum of gross fluxes. Text and arrows in orange are portions of the removals methodology that are passed into the emissions methodology.

Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- | | | |
|-------------------------------------|-------------------------------------|--|
| ☐ | ☒ | The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☒ | ☐ | A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☐ | ☒ | The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ | A description of all covariates tested |
| ☐ | ☒ | A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ | A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☒ | ☐ | For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ | For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ | For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ | Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection No software was used to collect data in this study.

Data analysis Code for developing the model and summarizing geospatial statistics in this study are available on GitHub at <https://github.com/wri/carbon-budget> and https://github.com/wri/gfw_forest_loss_geotrellis, respectively. Figure 2 was generated using R v3.5.0 and package ggplot2 v3.3.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

Geospatial data generated from the current study will be made publicly available on Global Forest Watch's Open Data Portal (<http://data.globalforestwatch.org/>) and from the corresponding author upon request. Summary geospatial statistics will be available from the Global Forest Watch dashboards and a publicly accessible API, as well as from the corresponding author upon request. All data analyzed as part of the current study are either publicly available or were obtained by the corresponding author upon request.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see [nature.com/documents/nr-reporting-summary-flat.pdf](https://www.nature.com/documents/nr-reporting-summary-flat.pdf)

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	The study design is structured as a geographic information system (GIS) model and is based on a synthesis of spatially explicit data sources to map gross and net greenhouse gas emissions and removals from global forest lands at 30-m resolution between 2001 and 2019.
Research sample	Results of this study are not based on a statistical sampling design but on published wall-to-wall maps of global tree cover and tree cover change generated by Hansen et al. (2013) as well as other published geospatial data sets. The study area includes all global land except Antarctica and some small oceanic and Arctic islands. Table S3 documents the dozens of data sources we combined for this analysis. The model includes greenhouse gases CO ₂ , CH ₄ , and N ₂ O, and six carbon pools.
Sampling strategy	Results of this study are not based on a statistical sampling design, although quantification of uncertainty in this study is based in part on results from a probability-based stratified random sample of 1,500 blocks (120x120 m) to validate map-based estimates of global forest change. Three sub-strata were created per biome: no change, loss and gain. The sample allocation for each biome was 150 blocks for no change, 90 for change and 60 for gain (1,500 blocks total). For more information, refer to Hansen et al. (2013).
Data collection	Results of this study are based on a synthesis of published datasets, not on original data collection. The datasets are combined using existing frameworks for calculating GHG emissions and removals (IPCC guidelines for national GHG inventory reporting).
Timing and spatial scale	The time period of analysis covers 2001 to 2019. The starting and ending years were determined by the ranges of key data sources available during model development. The spatial scale of this study's results is 30-m resolution with full coverage of all continental land.
Data exclusions	No data were excluded from this analysis.
Reproducibility	The reproducibility of this study's results is facilitated by providing all model code used in a public repository (GitHub). Various data sources used as inputs into the study are publicly accessible and freely available.
Randomization	This is not relevant to our study because results are not based on a statistical sampling design.
Blinding	This is not relevant to our study because results are not generated based on a statistical sampling design.
Did the study involve field work?	☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging