Southeast Alaska by the Numbers 2016

SOUTHEAST CONFERENCE

September 2016

Changes in Southeast Alaska: 2010 to 2015

Regional population increased by **2,731** people to **74,395 +4%**

Labor force increased by **1,950** jobs to **46,145** jobs **+4%**

Government jobs decreased by **650** jobs **-5%**
(excluding military)

Job Earnings Increased by $308 million to **$2.2 billion +16%**

Passenger arrivals via plane, ferry & cruise ship increased by **188,000 +15%**

Southeast Alaska's Economy

If it weren't for state government's fiscal unraveling, the region would be well positioned for a prosperous future.

The last five years have been good to Southeast Alaska. People came here in droves, to visit and to live. Our overall population increased by 4% as 2,730 new people joined our ranks. We broke records in terms of visitors arriving by airplane, and 2016 could be our top year ever for total passenger arrivals by all modes. Since 2010, we added nearly 2,000 jobs and $308 million in total workforce earnings, and 2015 was a record year for regional employment and earnings.

By many indications, our economy should continue to grow. Tourism is growing at 4% per year for the foreseeable future. After three years of declines, mineral prices are on the rise again, which is great news for our local mines. The maritime economy has taken off, and for the first time ever we are building Alaska ferries by Alaskans for Alaskans right here in Southeast Alaska. The seafood industry hit an all-time harvest record in 2013, and although the last couple years have been weak there are indications that next year will be better. The military has gone from being an economic footnote to becoming a key economic driver, as our Coast Guard personnel have grown to more than 800 members in 2016. As our population ages and health care needs grow, the medical industry is poised to expand to meet increasing demand.

Yet, despite so many positive indicators, we are not going to continue to grow. As the capital region for the state we are dependent on state government, both for employment and expenditures, and the economic health of the state government is declining rapidly.

Between 2014 and the first half of 2016, nearly 500 regional state jobs were cut—mostly in Juneau and Ketchikan—with a payroll impact of $28 million. More cuts are on the way. The state capital budget that has funded so many exciting recent projects in our communities has been slashed - from $385 million for our region in FY13 to $47 million in FY17—which will hit our construction sector particularly hard. The University of Southeast Alaska is eliminating programs. State marketing to attract tourists to Alaska has been cut by 92% in the last two years. Annual government payouts to our citizens in the form of the PFD will be reduced moving forward, meaning that fewer dollars will be circulated among local businesses.

As wages and disposable incomes shrink, so will the size of the retail sector. Our private sector is scaling back on hiring as it battens down the hatches and prepares to weather this storm. It will take some time for the full extent of these cuts to be felt across the region. For 2016 and 2017, expect the regional economy to remain mostly flat.

A Message from Southeast Conference

President
Chelsea Goucher

Having been born and raised in Ketchikan, I can attest to the fact that as Southeast Alaskans we often have a difficult time seeing the forest for the trees. Our communities are isolated and geographically distant from one another, and transportation, energy, and telecommunications concern us in ways that individuals living in other parts of the U.S. might have a difficult time understanding. Because of this isolation, it is all too easy for us to look inward and focus on those issues most pressing to our own communities. In a time during which the State of Alaska is facing a severe budget crunch, demographics are shifting, and access to natural resources is dwindling, it may be easy to adopt the attitude of "every man for himself."

I love the publication "Southeast Alaska by the Numbers" because it reminds me every year that this position is weak. We all have much more in common than differences, and these differences—when integrated into the regional picture—are sources of strength which we all can and should celebrate. "Southeast Alaska by the Numbers" reminds us that our communities—while beautifully unique—each share many of the same concerns, and it reinforces the truth that because of these similarities, we are truly stronger when united as a regional force.

We all have a stake in the health of our fishing, mining, mariculture, timber, tourism, and maritime industries. We all benefit from lower energy costs and efficient transportation systems. We all will thrive from improved telecommunications infrastructure, better access to medical care, and the development of value-added manufacturing sectors. "Southeast Alaska by the Numbers" reminds us of this truth and points out where we can, as a region, do better to support both one another and our own communities, tribes, and families.

As stated previously, this is not the time to "go it alone." Though our communities are isolated from one another, often more glaring is our collective isolation from the rest of the state. We are all Alaskans through and through, and now is the time to stand together to ensure that our region prospers through this difficult financial time and far into the future. One important step Southeast Conference has taken to ensure this prosperity is its adoption of the Alaska Marine Highway Reform Project in conjunction with the State of Alaska. I am so proud of this project. It is a perfect example of Southeast Alaskans coming together and joining with other Alaskans from across the state to ensure our collective survival—more than that, our ability to thrive.

I hope you enjoy reading "Southeast Alaska by the Numbers 2016," and I truly hope you enjoy this year's annual meeting—thank you, Petersburg! Most importantly, I hope you are reminded of our incredible diversity and strength as a region and are honestly inspired to do your part to ensure strong economies, healthy communities, and a quality environment in Southeast Alaska.

Executive Director
Shelly Wright

We are in challenging times. State budgets are dwindling and our economies are suffering, but as usual Southeast Alaskans are optimistic and looking for opportunities to get through this. As I visit different communities in Southeast, I find that business owners are cautiously looking forward. We are so lucky to live in Southeast Alaska. Fishermen are still fishing, and with that there is still a need for boat building and repairs. Miners are still mining, and with that there is a need for over 148 occupations that make a mine function. Loggers are still logging, and with that the mill on Prince of Wales is still processing logs and providing support to businesses. Energy projects are being developed to prepare communities for relief from diesel consumption. Gardens are popping up all across Southeast while tribal elders and leaders are passing on the knowledge of traditional food gathering and storing. The University enrollment is growing, and we are still getting thousands of tourists visiting our shores every summer. Everywhere we look there are business opportunities—not always easy opportunities but opportunities nonetheless. Making it work is what we do here. The first Southeast Conference meeting was held in Petersburg 58 years ago, so how appropriate it is that we are back in Petersburg to discuss the reform of the system. At the Annual Meeting many friends come together to share sorrows and joys, projects, and needs. We are excited to be back in Petersburg. We look forward to sharing our message with our members from across the region and enjoying the hospitality of Petersburg.

The mission of Southeast Conference is to **undertake and support activities that promote strong economies, healthy communities and a quality environment in Southeast Alaska**. As the state and federally designated regional economic development organization, Southeast Conference serves as the collective voice for advancing the region's economy. We have 180 member organizations representing 1,200 people from 32 regional communities. We started 58 years ago with a group of people supporting the establishment of a regional transportation system, leading to the formation of the Alaska Marine Highway System. Our members stayed together through more than a half-century to focus on concerns unique to the region.

Credit: Cover photo of Sitka by Jeffrey Wickett. Cover icons created by graphic illustrator Averyl Veliz.

Five Years of Change: 2010 to 2015

The following table tracks key Southeast Alaska indicators over the past 5 years, along with associated changes.

Demographics	2010	2014	2015	Change 2010-15
Population [1]	71,664	74,560	74,395	**4%**
Ages 65 to 79 [2]	5,664	7,603	8,018	**42%**
Under Age Five	4,823	4,622	4,545	**-6%**
Regional Population Excluding Juneau [1]	40,389	41,402	41,118	**2%**
K-12 School District Enrollment [3]	11,388	11,804	11,513	**1%**
General Economic Conditions				
Total Labor Force (jobs, includes self-employed & USCG) [1, 5, 6]	44,195	45,694	46,145	**4%**
Total Job Earnings [1, 5, 6]	$1.9 billion	$2.17 billion	$2.2 billion	**16%**
Total Private Sector Payroll [1, 6]	$1.2 billion	$1.41 billion	$1.44 billion	**20%**
Average Annual Wage [1]	$42,991	$47,593	$47,846	**11%**
Annual Unemployment Rate [1]	7.5%	7.1%	6.5%	**-1%**
Top Economic Sectors	**2010**	**2014**	**2015**	**% Change**
Government	Public Sector: 35% of all employment earnings			
Total Government Employment [1, 5]	13,862	13,602	13,499	**-3%**
Federal Employment [1, 5] (8% of all employment earnings)	2,134	2,110	2,129	**0%**
USDA (Forest Service)	618	521	530	**-14%**
State Employment [1] (14% of all employment earnings)	5,571	5,504	5,282	**-5%**
City and Tribal Employment [1] (13% of all employment earnings)	6,164	5,988	6,088	**-1%**
Total Government Payroll (includes USCG) [1, 5]	$696.7 million	$765.8 million	$769.9 million	**11%**
Commercial Fishing & Seafood Industry	Key Industry: 12% of all employment earnings			
Total Seafood Employment (includes fishermen) [1, 6]	3,966	4,372	4,365	**10%**
Total Seafood Employment Earnings [1, 6]	$209.5 million	$259.0 million	$254.6 million	**22%**
Pounds of Seafood Processed [7]	206,848,075	230,311,924	238,204,188	**15%**
Pounds Landed (commercial seafood pounds by SE residents) [8]	282,947,030	300,899,066	300,733,621	**6%**
Estimated Gross Earnings (ex-vessel value of pounds landed) [8]	$274.4 million	$267.0 million	$224.3 million	**-18%**
Visitor Industry	Key Industry: 9% of all employment earnings			
Total Visitor Industry Employment [1, 6]	5,890	6,923	7,401	**26%**
Total Visitor Industry Wages/Earnings [1, 6]	$158.1 million	$188.5 million	$207.3 million	**31%**
Total Southeast Alaska Passenger Arrivals	1,232,614	1,362,737	1,420,877	**15%**
Cruise Passengers [10]	875,560	967,500	994,000	**14%**
Total Air Passenger Arrivals from Outside Southeast [11]	332,164	372,197	405,554	**22%**
Total AMHS Passengers from Outside Southeast [12]	24,890	23,040	21,323	**-14%**
Total Southeast AMHS Passengers [12]	251,503	242,648	223,000	**-11%**
Health Care Industry (public & private health)	Key Industry: 8% of all employment earnings			
Health Care Employment [1, 6]	3,294	3,323	3,294	**0%**
Health Care Wages [1, 6]	$158.1 million	$174.5 million	$182.0 million	**15%**
Maritime Economy (Includes employment from all industries)	Top Sector: 27% of Private Sector employment earnings			
Private Maritime plus USCG Employment [1,5,6]	5,907	6,768	6,847	**16%**
Private Maritime plus USCG Wages [1,5,6]	$305.9 million	$395.5 million	$399.5 million	**31%**
Other Selected Statistics	**2010**	**2014**	**2015**	**% Change**
Construction Employment [1, 6] (7% of all employment earnings)	2,107	2,168	2,120	**1%**
Mining Employment [1] (5% of all employment earnings)	536	783	795	**48%**
Price of Gold [15]	$1,225	$1,266	$1,160	**-5%**
Consumer Price Index for Anchorage [1]	195.144	215.805	216.909	**11%**
Housing Starts: New Housing Permitted and/or Completed [4,1]	130	321	197	**52%**
Total Megawatt Hours Sold in Southeast [13]	810,205	858,718	853,695	**5%**
Avg. Daily Volume ANS Oil Production (mbbls/day) [14]	619,903	513,318	508,330	**-18%**
Annual Avg. Domestic Crude WTI Oil Prices (in $/Barrel) [16]	$78.90	$52.08	$40.11	**-49%**

Sources: [1]Alaska Department of Labor (ADOL); [2]ADOL Southeast Alaska Population by Age, 2010 to 2015; [3]Alaska Department of Education and Early Development; [4]Based on the quarterly Alaska Housing Unit Survey, a survey of local governments and housing agencies; [5] US Coast Guard; [6] 2014 US Census Nonemployer (self-employment) Statistics; [7]ADF&G Seafood Production of Shorebased Plants in Southeast Alaska, 2000 through 2015; [8]ADF&G Southeast Alaska Commercial Seafood Industry Harvest and Ex-Vessel Value Information, 2012-2015; [9]Alaska Forest Association; [10]McDowell Group & Cruise Line Agencies of Alaska; [11]US Bureau of Transportation Statistics (RITA); [12]Alaska Marine Highway System; [13]Annual Electric Power Industry Report. U.S. Energy Information Administration; [14]Alaska Department of Revenue *Revenue Sources Book;* [15]Kitco Metals Inc.; [13]EIA, *www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm*

The Whole Economy

46,145 Jobs

UP 450 JOBS IN 2015 +1%

$2.1 Billion Workforce Earnings

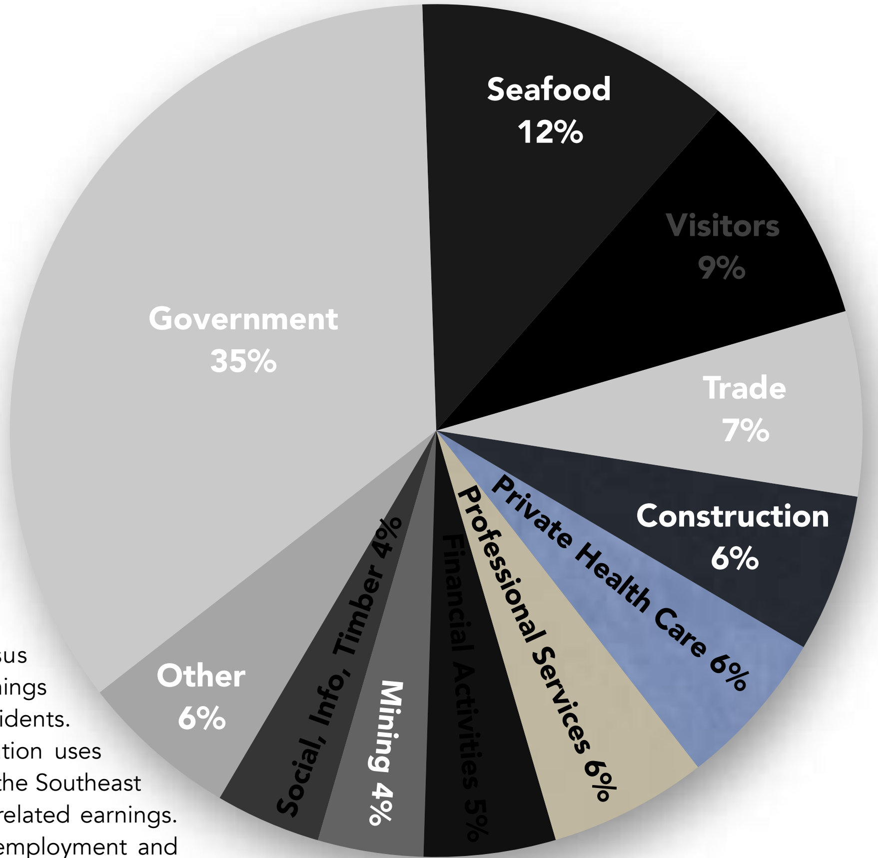
UP $33 MILLION +2%

In 2015, we added 450 job to our economy, along with $33 million in new workforce earnings. Since nearly one-fifth of the workers in the region are either self-employed or military, this publication includes self-employed individuals and active duty Coast Guard personnel. There are important differences in how employment, self-employment, and active duty military data are measured, but combining these data sets with Alaska Department of Labor's Employment and Wage data provides a much clearer and more accurate picture of the regional economy as a whole.

Self-employment is measured using the US Census Nonemployer Statistics, which track self-employment earnings by using tax return data for Southeast Alaska residents. Nonemployer Statistics lag by one year, so this publication uses 2014 self-employment data. The chart to the right shows the Southeast Alaska regional economy as a whole based on all work-related earnings. The data table below provides a detailed breakout of employment and workforce earnings.

2015 Southeast Alaska Employment Earnings

Includes US Coast Guard Payroll & Self-Employment Earnings



2015 Southeast Alaska Employment Related Earnings

	EMPLOYMENT RELATED EARNINGS			EMPLOYMENT NUMBERS		
	Wages (2015)	Self-Employment Earnings (2014)	Total Earnings	Annual Average Employment (2015)	Self-Employed (2014)	Total Employment
Government (includes Coast Guard)	$717,312,157	$52,624,442*	**$769,936,599**	12,841	658*	**13,499**
Seafood Industry	$82,105,036	$172,453,000	**$254,558,036**	1,959	2,406	**4,365**
Visitor Industry	$175,266,760	$32,023,000	**$207,289,760**	6,494	907	**7,401**
Trade: Retail and Wholesale	$123,489,800	$23,139,000	**$146,628,800**	4,159	582	**4,741**
Construction Industry	$102,743,962	$33,760,000	**$136,503,962**	1,513	607	**2,120**
Health Care Industry (private only)	$116,139,379	$11,985,000	**$128,124,379**	2,187	224	**2,411**
Professional and Business Services	$90,527,760	$44,656,000	**$135,183,760**	1,670	1,241	**2,911**
Financial Activities	$52,435,647	$64,023,000	**$116,458,647**	1,137	628	**1,765**
Mining Industry	$81,768,879	$130,000	**$81,898,879**	792	3	**795**
Warehousing, Utilities, & Non-Visitor Transport	$47,337,364	$13,982,000	**$61,319,364**	811	163	**974**
Social Services	$45,171,382	$3,326,000	**$48,497,382**	1,475	187	**1,662**
Information (publishing, broadcasting, telecomm.)	$22,536,036	$1,639,000	**$24,175,036**	515	48	**563**
Timber Industry	$15,067,656	$2,256,000	**$17,323,656**	277	44	**321**
Other	$53,508,920	$26,432,000	**$79,940,920**	1,609	1,008	**2,617**
Total	**$1,725,410,738**	**$482,428,442**	**$2,207,839,180**	**37,439**	**8,706**	**46,145**

Sources: Alaska Department of Labor 2015 Employment & Wage data; 2014 US Census Nonemployer (self-employment) Statistics; 2015 US Coast Guard employment & wage data.
*These cells in Government refer to 2015 active duty Coast Guard personnel employment and wages, and not self-employment data.
Notes: Seafood Industry includes animal aquaculture, fishing & seafood product preparation (NAICS 1125,1141,3117), and Southeast Alaska resident commercial fishermen (nonresident fishermen & crew who did not report income are excluded). **Visitor Industry** includes leisure & hospitality, and visitor transportation (air, water, scenic) (NAICS 71, 72, 481, 487, 483). **Timber** includes forestry and logging support activities for forestry, and wood product manufacturing (NAICS 113, 1153, 321).

SOUTHEAST MARITIME: 6,850 Jobs

Private and US Coast Guard Maritime Employment & Workforce Earnings

Fishing & Seafood Processing
Jobs: **4,365**
Wages: **$254.6 M**
Change in jobs 2010-15: **+10%**

Marine Tourism
Jobs: **971**
Wages: **$30.7 M**
Change in jobs 2010-15: **+27%**

US Coast Guard
Jobs: **829** (Active Duty and Civilian)
Wages: **$69.7 M**
Change in jobs 2010-16: **+62%**

Marine Transportation
(Excluding Tourism)
Jobs: **409**
Wages: **$31.4M**
Change in jobs 2010-15: +**2%**

Ship Building, Repair, Marinas
Jobs: **280**
Wages: **$12.3 M**
Change in jobs 2010-15: **+19%**

Marine-Related Construction
Jobs: **34**
Wages: **$3.1 M**
Change in jobs 2010-15: **+17%**

Southeast Private & USCG Maritime Economy 2010-2015

Total Jobs 2015: **6,850**
Total Wages 2015: **$400 Million**
Change in jobs since 2010: **+940**
Change in jobs by percent: **+16%**
Change in earnings since 2010: **+$94 Million**
Change in earnings by percent: **+31%**

Maritime icons created by graphic illustrator Averyl Veliz.
For methodology, notes, and sources, see *www.raincoastdata.com/sites/default/files/Maritime by the Numbers.pdf*

Southeast Seafood Industry 4,365 Jobs

Down 7 Jobs in 2015 0%

Our all-time record seafood harvest in Southeast Alaska was set in 2013, and the numbers have been a bit lackluster since then. The total Southeast Alaska seafood harvest in 2015 was 301 million pounds with a total ex-vessel value of $224 million—a 40% decline in value from two years earlier, and 14% below the 10-year average. The harvest for 2016 is threatening to be the lowest in years.

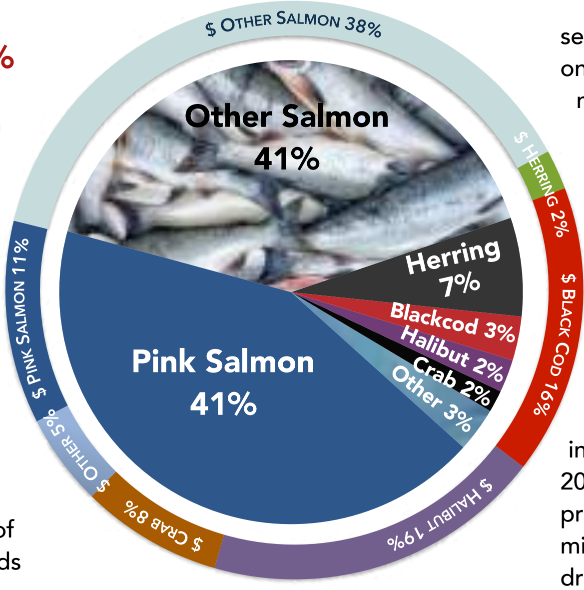
The Seafood Industry is a Key Economic Driver

Seafood harvests have been a critical part of the Southeast Alaska economy for thousands of years, and it was over Southeast Alaska salmon that statehood itself was fought. The regional seafood industry (including commercial fishermen and seafood processors) generated 4,365 annual regional jobs in 2015, making up **12% of all regional employment earnings** and **9% of all jobs**.

Those working in our region's seafood industry earned $254 million last year, which represents a $45 million increase since 2010. Nonresident commercial fishermen and crew members are excluded from these figures. The majority of the statewide catch of the Chinook, coho, chum, shrimp, Dunguness, and the dive fisheries occurs in Southeast Alaska.

Seafood Landed in SE Alaska by Species, 2015

Outer ring = % of harvest by dollar value.
Inner pie = % of harvest by pounds landed.



Regional Seafood Facts 2010-2015

- Since 2010, **2 billion pounds of seafood** were harvested from Southeast Alaska waters with a catch value to fishermen of **$1.8 billion.**
- More than a **third of all Alaska salmon** were caught in Southeast Alaska, along with **three-quarters of all Alaska King Salmon**.
- Seafood earnings increased by **22%**, a **$45 million** rise since 2010.

In 2015, the five salmon species represented 82% of the overall regional seafood catch in terms of the volume—but only half of total ex-vessel value ($112 million). Halibut and blackcod—while just five percent of the total pounds landed—accounted for more than one-third of the total catch value in 2015. (See double pie chart to the left).

Seafood Processing

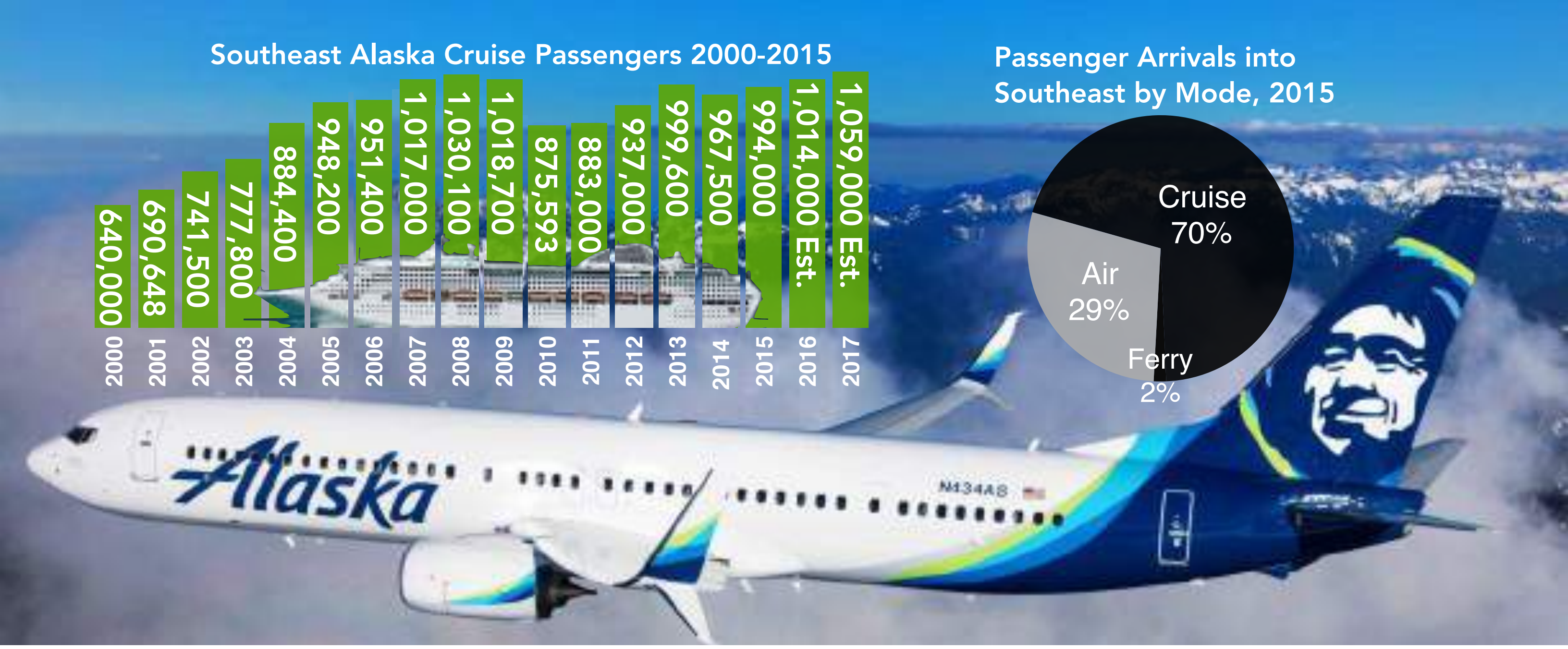
In 2015, shore-based seafood facilities in Southeast Alaska processed 238 million pounds of seafood, with a wholesale value of $466 million, a 3% increase in seafood pounds processed over 2014. State-shared fisheries taxes for processing activity in FY15 generated $3.9 million for regional communities, a 32% drop from the year before.

Seafood Industry Outlook

The preseason forecast for 2016 predicted 34 million pink salmon and 49 million salmon altogether. As of August 2016, only about half of these harvest levels had been realized, bringing the catch far below expectations, which were low to begin with.

Regardless of the final 2016 count, expect the volume of the 2017 seafood harvest to be well above 2016 levels. The two-year pink salmon life cycle, which spikes in odd-numbered years, will drive the regional harvest up in 2017.

Sources: Combination of ADOL 2015 Employment and Wage data; 2014 US Census Nonemployer (self-employment) Statistics; ADF&G Seafood Production of Shorebased Plants in Southeast Alaska; ADF&G Southeast Alaska Commercial Seafood Industry Harvest and Ex-Vessel Value Information; Run Forecasts and Harvest Projections for 2016 Alaska Salmon Fisheries and Review of the 2015 Season; ADF&G April 2015; ADF&G 2016 Preliminary Alaska Commercial Salmon Harvest - Blue Sheet Updated August 29, 2016; Shared Taxes and Fees Annual Report FY15, ADOR; Alaska Commercial Salmon Harvests and Ex-vessel Values, ADF&G. **Seafood Industry** includes animal aquaculture, fishing, & seafood product preparation (NAICS 1125,1141,3117) and Southeast Alaska resident commercial fishermen (nonresident fishermen & crew who did not report income are excluded).
Photo credit: Chris Miller.



Southeast Visitor Industry 7,400 Jobs

Up 480 Jobs in 2015 +7%

Visitors have been coming to Southeast Alaska since John Muir wrote about the area in 1879. Today this sector is the region's fastest growing industry. In 2015, 1.4 million air, ferry, and cruise passengers came to Southeast Alaska from outside the region, a 4% increase over 2014. Airline passenger traffic was up 9%, and cruise passenger traffic to the region increased by 3%. Ferry passenger traffic was down by 8% due to service cuts. Most (70%) visitors to the region come by cruise ship.

Key Economic Driver

The visitor industry is one of the region's largest private sector employers in terms of jobs, accounting for 16% (7,400) of all regional employment and 23% of all private sector jobs. Since 2010, visitor industry employment grew by 26%, with 1,500 new jobs. Those working in the visitor industry earned $207 million in 2015—or nine percent of all regional employment income.

One-third of all Alaska visitor spending occurs in Southeast, where visitors spent $622 million in 2015 (excluding transportation to and from Alaska). The total 2015 economic impact of the industry to the region was $1.2 billion.

Increased Jet Service

Southeast Alaska saw a record-breaking number of airline passengers in 2015, topping the peak number of arrivals previously set in 2007. A total of 405,554 passengers arrived from outside the region. But it doesn't look like that record will last long. As of July 2016, airline passenger arrivals were up 8% over the first half of 2015, meaning that 2016 will likely be another record year for aviation visitors. Delta Airlines began summer flight services between Juneau and Seattle in 2014 for the first time since 1996, driving prices down and flight activity up.

Cruise Ship Traffic

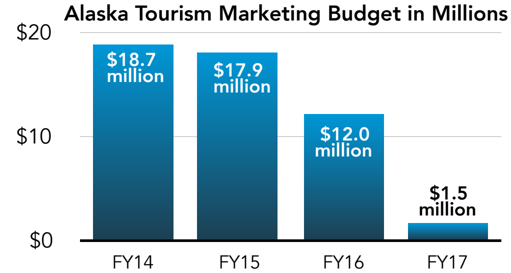
Cruise passengers are also nearing record numbers, topping a million passengers for the first time since 2009. In 2016, a projected 1,014,000 cruise ship passengers will visit the region, making 480 voyages on 31 cruise ships. Southeast Alaska is continuing to see larger ships replacing smaller vessels. To handle this change Juneau has built a panamax dock that opened in 2016 and is in the process of building a second so that Juneau will have the capacity to host four 1,000-foot vessels at a time. Icy Strait Point completed a 400-foot floating dock, Adventure Center, and restaurant in 2016. Southeast Alaska received 4.5% of all global cruise ship passengers in 2015. Despite the fact that cruise ridership is increasing, the region's global share of passengers is expected to decrease to 4.1% in 2016.

Visitor Outlook

The visitor industry has the strongest outlook of all Southeast Alaska industries, and 2016 is looking like it could be the best year ever for this sector. It tends to follow national trends, which are projected to grow around 4% annually through 2020. As the national economy grows stronger, and perceived security risks for international travel destinations increase, Southeast Alaska becomes even more attractive to visitors.

Cruise passenger arrivals are likely to hit a new record in 2017—with 45,000 more passengers—finally surpassing the current record set in 2008. While the number of voyages is likely to remain the same, expect the number of cruise passengers coming to the region to rise as larger ships visit the region. Airline passenger numbers are also expected to grow. Along with increased visitors, the number of jobs and related income in this sector should continue to improve. However, a deep reduction in the Alaska Tourism Marketing budget by the state could impact growth in the longer term. It was $17.9 million in FY2015 but will only be $1.5 million in 2017, a 92% cut. In comparison, Hawaii spent $84 million in tourism marketing last year.

Alaska Tourism Marketing Budget in Millions



Sources: Combination of ADOL 2015 Employment and Wage data and 2014 US Census Nonemployer (self-employment) Statistics; McDowell Group; US Bureau of Transportation Statistics (RITA); Alaska Marine Highway System; Cruise Line Agencies of Alaska; Cruise Market Watch; Juneau International Airport Passenger Statistics; Economic Impact of Alaska's Visitor Industry. Forecast 2020 U.S. Department of Commerce, US Office of Travel and Tourism Industries. OMB budgets. **Note:** In this analysis, the visitor industry includes leisure and hospitality businesses, along with air, water & scenic transportation companies. Photo credit: Alaska Airlines.


Southeast Healthcare Industry 3,300 Jobs

Down 30 Jobs in 2015 -1%

When both private and local hospital healthcare services are taken into account, Southeast Alaska's 3,294 healthcare workers earned 8% ($182 million) of all regional wages in 2015. Albeit by a small margin, regional healthcare employment fell for the third year in a row in 2015. This in spite of the fact that the health care industry is projected to be the fastest growing in the state through 2022, that health care needs in our region have been increasing due to an aging populace and a (slightly) growing population, and that there have been increasing patient volumes for some major regional providers.

There appear to be several reasons for this. The healthcare sector continues to face uncertainty due to the state's budget shortfall and questions regarding longer-term Medicaid expansion decisions, which is leading medical institutions to not replace departing staff as they wait to see how the state will resolve its budget distress. Also, as healthcare becomes more expensive, providers are pressured to contain costs and consolidate "shared services"—meaning that jobs like accounting, payroll, and human resources that used to be local are increasingly being done outside of Southeast Alaska in places where the cost of living is less. Another contributing factor is the influence of medical tourism, as travel to Anchorage and the lower-48 for medial care becomes more common. Finally, with implementation of the Affordable Care Act, there has been intense demand for medical workers at all levels nationwide, which makes local retention and recruitment for regional medical industry jobs more difficult than it had been in the past, leading to fewer hires.

Healthcare Industry Outlook

These pressures that have limited the growth of healthcare in the region show no signs of abating any time soon, and indeed, early employment numbers for 2016 show job losses continuing. The forecast is for this industry to essentially remain flat in 2016 and 2017.

Sources: ADOL 2015 Employment and Wage data; Kitco Metals Inc; Coeur Mining Inc. 2015 Annual Report; Hecla Mining Company 2015 Annual Report. Photo credits: Michael Penn.

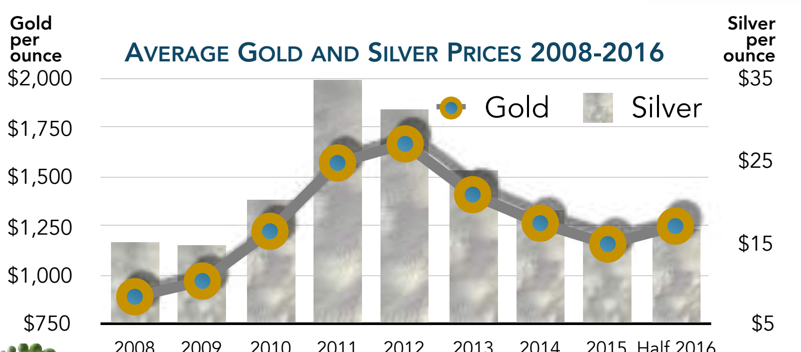
Southeast Mining Industry 800 Jobs

Up 12 Jobs in 2015 +2%

In 2015, there were 795 annual average mining jobs in Southeast Alaska, with a payroll of $82 million. The two large mines operating in the region account for nearly all mining employment. In August 2016 Hecla Greens Creek employed 418 full-time permanent employees, while Kensington had a staff of 325. With an average annual wage of $103,000, mining jobs pay the highest wages in the region of any sector.

Hecla Greens Creek is one of the largest silver mines in the world, with an orebody that also contains zinc, gold, and lead, while the Coeur owned Kensington is exclusively a gold mine. In 2015, the production at both mines was up. Kensington increased its production by 7% over 2014 with 126,266 ounces of gold in 2015. At Hecla Greens Creek silver production was up by 9% to 8.5 million ounces of silver, 61,934 tons of zinc, 60,566 ounces of gold, and 21,617 tons of lead.

After several years of downward trends, metal prices are up in 2016. Gold rose 22% in 2016 to $1,344 in August 2016. Silver rose 40% and zinc rose 52% in the same time period. Precious metal prices tend to increase when there is a lack of confidence in global financial markets. Much of the 2016 gold and silver rise (50 to 60%) has been credited to the UK's Brexit vote to leave the European Union. Mineral exploration has remained dormant, with the exception of the copper-zinc-silver-gold Palmer Project near Haines.



Southeast Timber Industry 320 Jobs

Down 7 Jobs in 2015 -2%

Despite a slight uptick in 2014, regional timber jobs were down again in 2015 by 2%. This comes on top of significant recent job losses. Since 2010, employment in this industry has been reduced by 24%. In 1991, there were 3,543 year-round timber jobs in the region, peaking in August with 4,200 timber workers. In 2016 dollars, those job losses represent $257 million in annual direct wages, or roughly all the earnings of the regional seafood industry combined. The number of board feet harvested annually has fallen by 96% from peak levels in the 1990s.

Today, most of the regional timber jobs are divided between two organizations: Sealaska, the regional Alaska Native corporation, and Viking Lumber on Prince of Wales Island—the last remaining mid-sized sawmill in the region. Alcan Forest Products is another key employer. Timber workforce earnings were $17.3 million for 2015.

Timber Outlook

Timber industry employment is likely to continue to decline into 2016 and beyond for the following reasons:

- The Forest Service's pending Tongass Transition Plan to young growth will reduce, and then terminate, access to old-growth timber which has been the mainstay of industry sales;
- Litigation over nearly every timber sale has made log deliveries to Viking Lumber uncertain and is a barrier to potential new mills obtaining the financing needed to join the Southeast industry;
- Timber available for sale is often uneconomic, thereby constraining supply to Viking Lumber and potential new mills; and
- The poor outlook for future economic timber is a disincentive for continued participation in the Southeast timber industry.

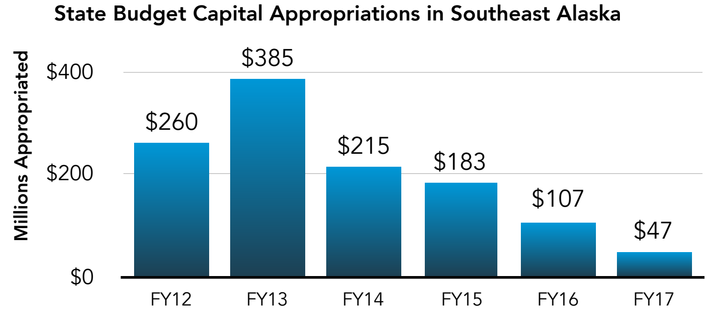
Southeast Construction Industry 2,120 Jobs

Down 50 Jobs in 2015 -2%

For the second year in a row construction employment is down. Jobs fell by 50 last year to 2,120, and early employment data from 2016 indicates that construction related employment will drop another 100 jobs this year. Construction workers in the region earned $136.5 million in 2015—or 6% of all Southeast Alaska employment earnings.

Construction outlook

Over the last five years, new homes, commercial buildings, and high-profile publicly-funded projects have created a construction boom. Unfortunately, the contraction of the State capital budget and decreased federal spending means that future projects are no longer being added to the lists of planned activity. As large-scale endeavors are unable to obtain funding, construction projects will be put on hold, and employment levels will drop. Legislative capital appropriations in the region have already dropped 88% from $385 million in FY13 to just $47 million in the FY17 budget.



Home construction was also down 39% from the year before, with just 197 new housing units permitted or completed in 2015. While single family home construction was up slightly, multi-family unit construction was down significantly.

Sources: Combination of Alaska Department of Labor 2015 Employment and Wage data and 2014 US Census Nonemployer (self-employment) Statistics; State of Alaska Capital Budget FY12-17. **Photo credits:** Timber by Ansley Dahlstrom. Construction by Michael Penn.

Southeast Alaska **Government**

Government
13,500 Jobs

Down 100 Jobs in 2015 -1%

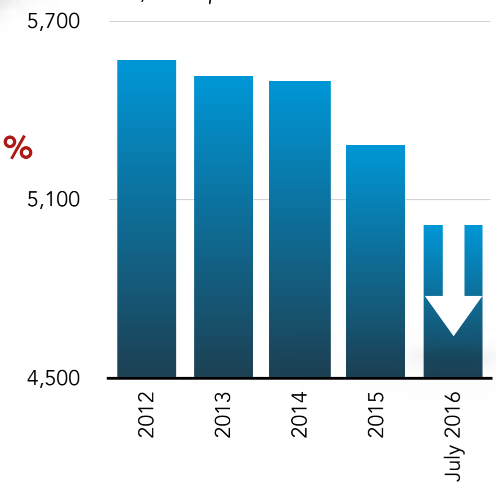
Government wages made up 35% of all regional employment earnings ($766 million) and 29% of the region's jobs (13,500) in 2015, but this sector is on the decline, with job losses occurring in every area of government—state, federal, local, and tribal—with the exception of the US Coast Guard.

State Government Losses

In Southeast Alaska, 14% of all direct wages come from the State. From 2014 through July 2016, nearly 500 State of Alaska jobs were lost with associated annual wages of $28 million. Three-quarters of these jobs came out of Juneau, with Ketchikan losing most of the rest. Declining oil production and prices have devastated the State of Alaska budget and are poised to create a significant downward drag on the regional economy. The state is facing budget gaps of more than $3 billion a year. State spending is down 44 percent since 2013, but even with this reduction, state savings will be depleted in less than two years without legislative action. Reduced state spending also has a direct negative impact to the private sector, since many local businesses provide the majority of their services to the public sector, and reduced government employment will eventually decrease demand for goods and services across the region.

Southeast State Jobs

State jobs in the region are down 260 in 2016 so far, and nearly 500 jobs since 2014, a drop of 9%



Federal Government Losses

Southeast has lost 300 federal jobs since 2010

Federal government employment losses are compounding state job cuts. Since 2010, federal jobs (excluding active duty Coast Guard, which has been growing) fell by 300. Since 2004, jobs in this sector have fallen by 28%, translating into a loss of $48 million in wages across the region annually. Federal spending declines also mean fewer projects and programs that support the region.

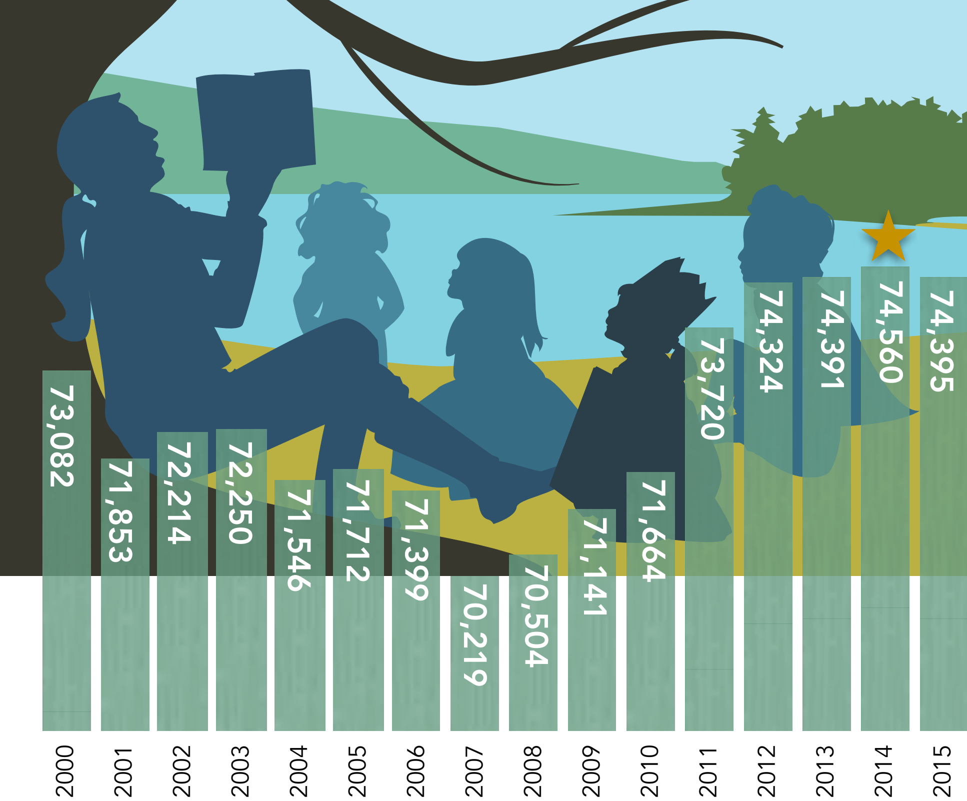
Local Government Losses

Changes in local government employment have been less dramatic. However, declining State revenue and federal budget cuts continue to result in payment reductions to municipal and tribal governments. Communities across the region are struggling financially, and relying on savings to cover unexpected shortfalls stemming from state budget cuts. Most municipalities are sending the same message—they can make up the differences from rainy day accounts this year, but not next year.

Government Outlook

Early job reports from 2016 are grim. Local and federal employment levels are down by 1% each. State employment is down by 260 jobs in the first half of the year, and according to the Office of Management and Budget, further cuts will result in approximately 200 additional Southeast jobs cut by June 2017. As for making projections regarding the future, Policy Analyst Sylvan Robb explains: "Ideally the legislature will act this coming session and pass the Governor's proposals to implement a sustainable budget, thus stemming job losses. Until we know the outcome of the next session, it is impossible to project what might happen beyond next year."

Sources: ADOL 2015 Employment and Wage data; U.S. Coast Guard; Alaska Department of Revenue. Photo Credit: Michael Penn.



Demographics

Population 74,395

Down 165 People in 2015 -0.2%

Between 2010 and 2015 Southeast Alaska's population increased by 2,730 people, or 4%, hitting record population levels for four years in a row. However, for the first time in eight years the population shrank, albeit by a tiny margin. Between 2014 and 2015, we lost 165 people (-0.2%). These losses were not centered in any particular place, with half of our communities recording a handful of fewer people.

Five Years of Shifting Trends

Despite five years of relatively flat trends, there were some interesting shifts in the region during this period. The number of people in their 40s shrank by 1,500, and we ended up with 300 fewer babies and toddlers—a 6% drop for kids four and under. But the most pronounced five-year shift was the continued explosion of baby boomers into their older years. Those aged 65 to 80 grew by 42% (2,350 people). By 2017, the Alaska Department of Labor projects that a quarter of our population will be 60 or older.

Gustavus was the biggest mover and shaker since 2010, growing by 21% for a gain of nearly 100 people. Significant population growth (of 19% or higher) was experienced by some of our smaller communities, including Kasaan, Whale Pass, and Port Alexander.

Among communities with over 1,000 residents, Skagway grew by the most, a 7% gain. Juneau added 2,000 new people to its ranks, a growth of six percent. The island of Prince of Wales grew by nearly 6%, thanks to strong growth in places like Klawock, Thorne Bay, and Coffman Cove. Most of these new residents came from outside Alaska, and not from neighboring communities. The number of people moving within Southeast has steadily declined during the past 15 years.

Places with double-digit percentage population losses since 2010 included Pelican and Elfin Cove.

Population Outlook

Alaska Department of Labor projects an additional increase of less than one percent by 2017 (580 new people), but with the public sector continuing to shed jobs, any upward population trends appear unlikely.

Population Change 2010 to 2015

	2010	2015	Change
Juneau Borough	31,275	33,277	6%
Ketchikan Borough	13,477	13,778	2%
Sitka Borough	8,881	8,929	1%
Petersburg Borough	3,203	3,199	0%
Haines Borough	2,508	2,493	-1%
Wrangell Borough	2,369	2,442	3%
Metlakatla	1,405	1,472	5%
Craig	1,201	1,180	-2%
Skagway Municipality	968	1,040	7%
Klawock	755	820	9%
Hoonah	760	783	3%
Yakutat City & Borough	662	613	-7%
Kake	557	620	11%
Thorne Bay	471	510	8%
Gustavus	442	533	21%
Angoon	459	426	-7%
Hydaburg	376	402	7%
Coffman Cove	176	194	10%
Tenakee Springs	131	142	8%
Naukati Bay	113	107	-5%
Hollis	112	113	1%
Hyder	87	82	-6%
Klukwan	95	93	-2%
Pelican	88	79	-10%
Kasaan	49	86	76%
Port Protection	48	54	13%
Edna Bay	42	47	12%
Port Alexander	52	62	19%
Whale Pass	31	46	48%
Game Creek	18	21	17%
Elfin Cove	20	15	-25%
Point Baker	15	14	-7%
Balance (POW, H/A CA)	801	723	-10%
Total	**71,664**	**74,395**	**4%**

Sources: Alaska Department of Labor (ADOL); ADOL Southeast Alaska Population by Age, Sex and Borough/Census Area, 2010 to 2013; Alaska Department of Education and Early Development; Alaska Population Projections 2012 to 2042, April 2012; 2010 US Census. Image credit: Avery Veliz.

Southeast Alaska Regional Overview

Southeast Alaska Land Ownership

Circle size = Number of Acres

78%

The Federally-Managed Tongass Makes up nearly 4/5th of ALL Southeast Alaska

16% Other Federal Holdings make up nearly all the rest (mostly Glacier Bay)

3.4% Alaska Native Organizations are the region's next largest land owner

2.5% State of Alaska Lands include those managed as part of the Mental Heath Trust

0.25% Municipal Land Holdings

0.05% ← Private land owners

Sources: Personal communications with Kyle Moselle, State of Alaska; Susan Jennings, US Forest Service; Brian Kleinhenz, Sealaska. *Economies in transition: An assessment of trends relevant to management of the Tongass National Forest, USDA 1998.*
Photo Credit: Canoe by Annie Caufield.

The Region

The Southeast Alaska Panhandle extends 500 miles along the coast from Metlakatla to Yakutat, encompassing approximately 33,500 square miles of land and water. The full saltwater shoreline of Southeast Alaska is approximately 18,500 miles. More than 1,000 islands make up 40 percent of the total land area. The region is home to 34 communities. The three largest communities—Juneau, Ketchikan, and Sitka—together are home to 75 percent of the regional population. Alaska Natives make up nearly a quarter (22%) of the region's population. The Tlingit, Haida, and Tsimshian have resided in the region for thousands of years.

Land Ownership

Southeast Alaska's land ownership is dominated by the federal government, which manages 94 percent of the land base. Most of this (78%, or 16.75 million acres) is the Tongass National Forest. The remaining federal lands are mostly in Glacier Bay National Park. The State manages 2.5 percent of the total land base (511,500 acres), including the Alaska Mental Health Trust Authority and University of Alaska lands. Boroughs and communities own 53,000 acres—a quarter of one percent of the entire regional land base. Alaska Native organizations, including village, urban, and regional corporations and the Annette Island Reservation, own 3.4 percent (728,100 acres) of the land base. Other private land holdings account for 0.05 percent of the remaining land base. The lack of privately owned land and land available for development is unique in Southeast Alaska and impedes the ability of the region to nurture the private sector. (See infographic on the left.)

Economic Trends

Beginning in the 1880s, the economy of Southeast Alaska experienced a century of growth that intensified after statehood in 1959. From statehood into the 1990s, population and employment levels in Southeast more than doubled as the workforce expanded in the areas of mining, government, fishing, tourism, and timber. However, the later 1990s and early 2000s were difficult years for the Southeast Alaska people. At the beginning of the 1990's seafood and timber directly accounted for a fifth of the regional economy. Over that next decade pulp mills and sawmills in the region closed, laying off 3,200 workers. During the same period, the value of salmon declined, and catch values fell by two-thirds. Total Southeast Alaska wages hit bottom in 1997. It would be another ten years before the adverse economic consequences of timber industry losses worked their way through the regional economy. Population levels continued to decline through 2007. Between 2008 and 2015 the region staged a recovery, gaining people and jobs; however, the recent state budget crisis is poised to change the economic trajectory of the region, where state jobs and expenditures are key drivers.

Southeast 2020 Strategic Plan Summary

In May 2016, Southeast Conference released the Southeast Alaska 2020 Economic Plan, a new five-year strategic plan for the region. The membership worked together to develop an overall vision statement, 47 objectives, and 8 priority objectives, along with regional and industry specific SWOT analyses. More than 400 people representing small businesses, tribes, Native organizations, municipalities, and nonprofits were involved in various elements of the planning process. The Plan's objectives are listed below.

Transportation

★ **Priority** Minimize Impacts of Budget Cuts to AMHS and Develop Sustainable Operational Model.
Road Development.
Move Freight to and from Markets More Efficiently.
Ensure the Stability of Regional Transportation Services Outside of AMHS.

Energy

★ **Priority** Work with Federal and State Government to Promote Regional Energy Projects.
★ **Priority** Diesel Displacement.

Support Community Efforts to Create Sustainable Power Systems That Provide Affordable/Renewable Energy.
Complete Regional Hydrosite Evaluation for Southeast Alaska.

Maritime

Maritime Industrial Support

★ **Priority** Maritime Industrial Support Sector Talent Pipeline: Maritime Workforce Development Plan.
Continue to Grow the Regional Maritime Sector.
Increase Access to Capital for the Regional Maritime Industrial Support Sector.

Support Capital Investments in Expanded Marine Industry Support Infrastructure.
Harbor Improvements.
Examine Arctic Exploration Opportunities That the Region as a Whole Can Provide.

Seafood Industry

★ **Priority** Mariculture Development.
★ **Priority** Full Utilization and Ocean Product Development.

Increase Energy Efficiency and Reduce Energy Costs.
Regional Seafood Processing.
Seafood Markets.
Sea Otter Utilization and Sustainable Shellfish.
Maintain Stable Regulatory Regime.
Seafood Workforce Development.

Visitor Industry

★ **Priority** Market Southeast Alaska to Attract More Visitors.
Improve Access to Public Lands.
Increase Flexibility in Terms of Permit Use.
Increase Yacht and Small Cruise Ship Visitations.
Improve Communications Infrastructure.
Advocate for Funding to Maintain Existing Recreational Infrastructure.
Grow Cultural and Arts Tourism.

Timber Industry

★ **Priority** Provide an Adequate, Economic and Dependable Supply of Timber from the Tongass National Forest to Regional Timber Operators.
Stabilize the Regional Timber Industry.
Work with USFS to Direct Federal Contracts Toward Locally-Owned Businesses.
Support Small-Scale Manufacturing of Wood Products in Southeast Alaska.
Continue Old-Growth Harvests Until Young-Growth Supply is Adequate.
Community-Based Workforce Development.
Update Young Growth Inventory.

Other Objectives

Housing: Support Housing Development.
Food Security: Increase Production, Accessibility, and Demand of Local Foods.
Communications: Improved Access to Telemedicine in Southeast Alaska.
Marketing: Market Southeast Alaska as a Region.
Solid Waste: Regional Solid Waste Disposal.
Education: Partner with University & K-12 to Meet Workforce Needs
Arts: Increase Recognition of Southeast Alaska's Thriving Arts Economy.
Mining: Minerals & Mining Workforce Development.
Research: Attract Science and Research Jobs to Southeast Alaska.
Cultural Wellness: Support Activities and Infrastructure That Promote Cultural Wellness
Healthcare: Meet Regional Needs.

2020 Plan Priority Objective #1:
Minimize Impacts of Budget Cuts to AMHS and Develop Sustainable Operational Model

PROJECT STEERING COMMITTEE

Chair: Dennis Watson - Craig
Dave Kensinger - Petersburg
Greg Wakefield - Anchorage
Elizabeth Bolling - Ketchikan
Shannon Adamson - Juneau
Josh Howes - Anchorage
Will Ware - Juneau
Sharon Hildebrand - Fairbanks
John Whiddon, SWAMC - Kodiak
Dan Kelly - Ketchikan
Michael Anderson - Cordova
Dennis Bousson - Skagway
Staff: Robert Venables

PROJECT TIMELINE

STEP I: The "AMHS Reform Project"

Phase I: Mission, goals and governance recommendations.
Completion expected by December 2016

Phase II: Twenty-five Year Ferry System Operating Plan.
January 2017 through December 2017

STEP II: AMHS Value Outreach
Ongoing through 2020

STEP III: Address Decreased State Funding Impacts
Ongoing through 2020

Photos were provided by the AMHS.

Southeast Conference's eight priority objectives were ranked in order of importance. The top priority objective of the organization is to secure the long-term viability of the ferry system.

PROJECT BACKGROUND

Southeast Alaska is dependent on marine transportation linkages for nearly every facet of its economic existence. Because of this, the health of the Alaska Marine Highway System (AMHS) is vital to economic development in the region, and the AMHS is at a critical juncture. The impact of declining oil production and prices on the state budget means that the ferry system must determine a way to maintain services while decreasing costs. In May 2016, Governor Bill Walker signed a Memorandum of Understanding with Southeast Conference to undertake a statewide comprehensive planning process aimed at improving the long-term viability of AMHS. Southeast Conference is working on a two-phase approach that will identify structural changes to improve the operability and financial health of the state ferry system.

STEP I: Design New Strategic Operating Plan for AMHS: The "AMHS Reform Project"

Steering Committee Led: A steering committee comprised of Alaskans from across the state will oversee development of the plan, and the process will involve broad public engagement and multiple stakeholder meetings.

Phase I: Mission goals and governance recommendations. The first phase of the project will identify alternative governance models for the state ferry system, recommend the model best suited to operate the system in an economically optimal way that meets user needs, and explore options to install an empowered governance board. Elliott Bay Design Group and McDowell Group have teamed together to work on this phase.

Phase II: Comprehensive Operations and Business Plan: A new ferry system operating plan will be developed using the findings and recommendations from phase I in order to ensure a financially sustainable Alaska Marine Highway System for at least the next 25 years. Phase II includes a fleet renewal plan.

STEP II: AMHS Value Outreach

Communicate the significance and large scale economic importance of the ferry system to the public as well as to lawmakers. Southeast Conference recently published *The Value of Alaska Marine Highway in 25 Stories* in collaboration with five Alaska Regional Development Organizations.

STEP III: Address the Impacts of Decreased State Funding

Work with AMHS and Administration to minimize service cuts to communities, while developing revenue sources beyond the farebox.

Participate in creating the vision for Alaska's marine highway

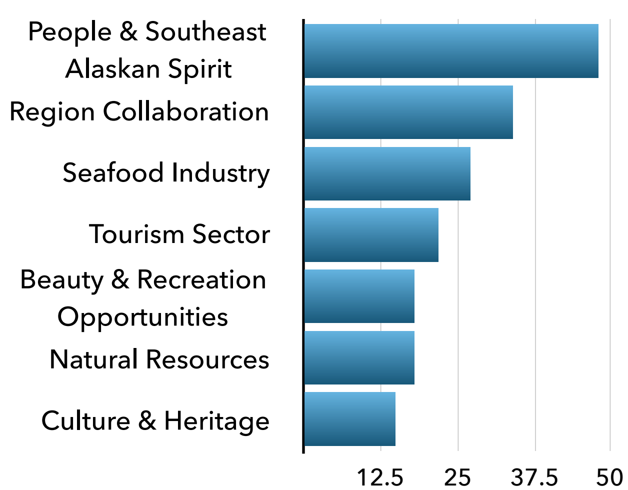
Find out more at *www.seconference.org/transportation-issues*

Southeast Alaska SWOT Analysis: *Strengths, Weaknesses, Opportunities & Threats*

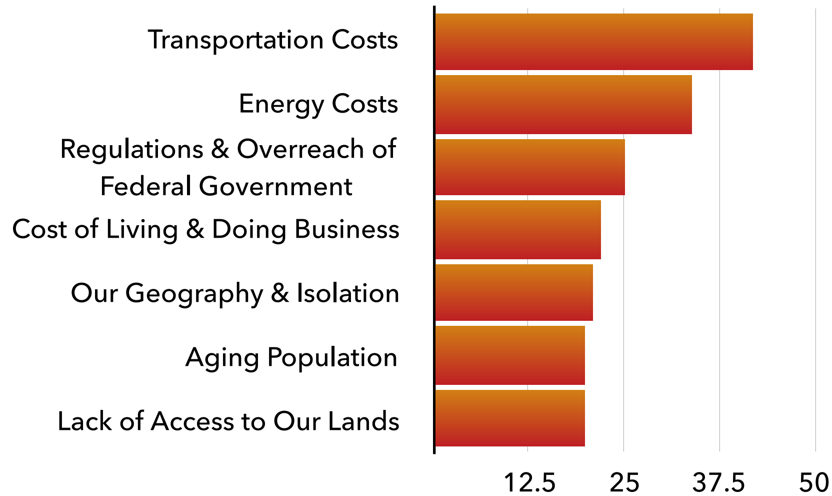
At Southeast Conference's March 2015 Mid-Session Summit, 180 people representing small businesses, tribes, native corporations, municipalities, and community organizations generated nearly **1,200 individual written comments** that became part of this analysis.

- Top Strength: **Our people & our Southeast Alaskan spirit**
- Top Weakness: **Transportation costs**
- Top Opportunity: **Seafood & product development**
- Top Threat: **Federal government regulations & overreach**

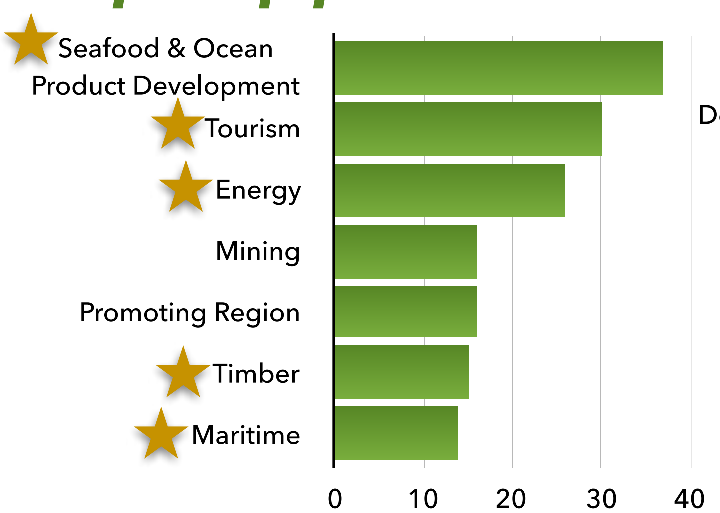
Top Strengths



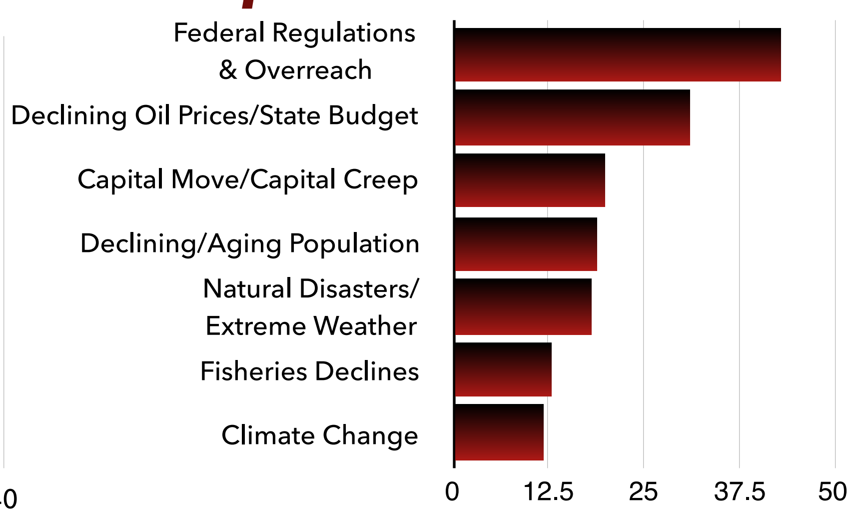
Top Weaknesses



Top Opportunities



Top Threats



Industry specific SWOT analyses for each of Southeast Alaska's key economic sectors can be found in the 2020 Economic Plan.

★ A star signifies that one of the eight priority objectives in the regional economic plan addresses this "top opportunity."

Map of Southeast Alaska and the AMHS Ferry Route 2016

SOUTHEAST CONFERENCE

Southeast Conference Board

Garry White – President
Executive Director, Sitka Economic Development Association

Chelsea Goucher – Vice President
Sales Representative, Alaska Marine Lines

Patricia Phillips – Past President
Mayor, City of Pelican

Joe Jacobson – Secretary
Vice President of Business Development, Huna Totem Corp

Shelia Kleinschmidt – Treasurer
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Vice President, Viking Lumber

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Mayor, Haines Borough

Gordy Wrobel – Director
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Glen Thompson – Director
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Robert Venables *- Energy Coordinator*

Rain Coast Data

Publication developed by
www.raincoastdata.com

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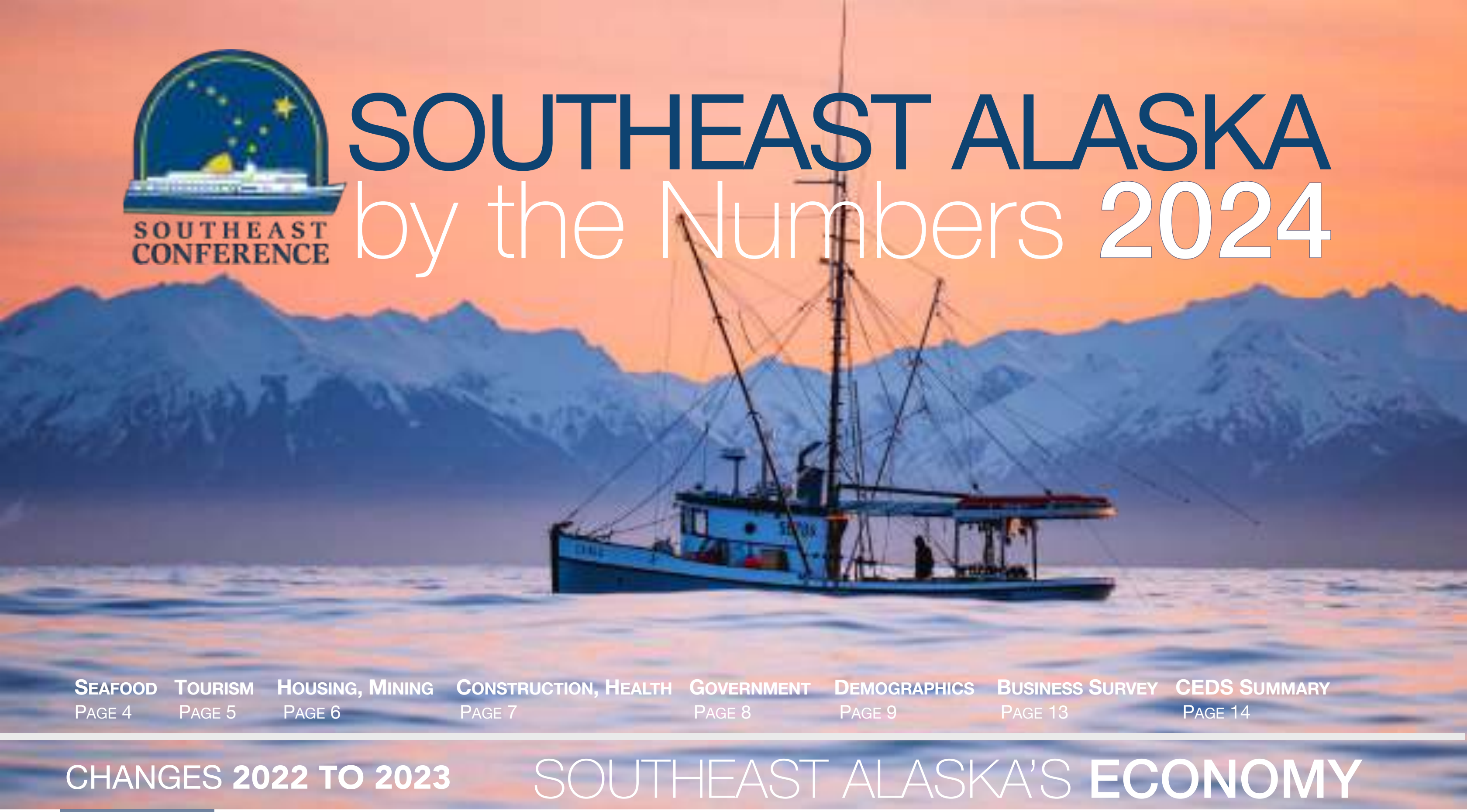


SOUTHEAST ALASKA by the Numbers 2024

SOUTHEAST CONFERENCE

CHANGES **2022 TO 2023**

The **Labor force** increased by **1,428 jobs** to **45,883** **+3%**

Total wages increased by **$120 million** to $2.76 billion, **+5%**

Tourism jobs increased by **26%**, **wages** increased by **44%, +$105 million**

Value of Seafood Landed in the region decreased by **20%, -$66 million** catch was up by **74 million pounds**

Regional **population** decreased by **796 people** to **71,077**

Healthcare jobs increased by 88, **wages** increased by **$24 million**

SOUTHEAST ALASKA'S **ECONOMY**

2023 Southeast Alaska's economy is growing. In 2023 jobs were up by 3% and wages were up by 5% over 2022. All but two communities gained workers as 1,400 new jobs were added across the region. However, the region's two top private sector industries, seafood and tourism, experienced very different outcomes.

In 2023, tourism became the largest sector in the region, with a lot more jobs, and more wages than any other sector, including local or state government. Tourism jobs flooded back, growing by 26%, an increase of 1,700 year-round-equivalent jobs. Workers earned $105 million more than the year before, a 44% increase.

Seafood was the top private sector industry in 2022 and brought in a massive harvest in 2023. But while the catch was the largest in more than a decade, it had one of the lowest catch values on record, $66 million less than the smaller catch from the year before. Wages fell by 26%, as global markets drove down prices.

Other sectors were mostly up. The government, healthcare, retail, construction, finance, and mining sectors all added workers to their payrolls. Tribal government grew by 9%. Regional GDP was up by 31%. Nine communities saw double digit wage growth. But not all indicators were up. State jobs continued to decline, social services were down, along with professional & business services. Population and school enrollment declined.

2024 The economy of 2024 is strong and diversified. Two-thirds of Southeast business leaders are optimistic looking forward, with 30% saying their prospects will be even better over the next year. The regional economy has finally fully recovered from the pandemic.

Tourism is having another strong year as 1.68 million cruise passengers are expected to visit. The construction industry is responding to $334 million in infrastructure bill investments in Southeast. Inflation has normalized. Wages are on the rise.

Seafood continues to be a concern. While prices are up slightly from 2023 levels, the catch is down significantly, although the season is ongoing.

While jobs continue to grow in 2024, so do concerns about the lack of a sufficient workforce in the region. Compared to 2010, when the population was nearly identically sized, the region now has 1,700 more jobs and 5,600 fewer workforce-aged residents. In 2024, regional business leaders were asked where the focus needs to be over the next five years. The top two answer were clear:

1. Housing initiatives, and
2. Attracting and retaining a workforce-aged population.

We need more young people in the region, and in order to attract them, we need more housing and more affordably-priced homes.

Photo by Rafe Hanson Photography

A **SOUTHEAST CONFERENCE** PUBLICATION BY RAIN COAST DATA

The Whole **Southeast Alaska Economy** 2023

In 2023, Southeast Alaska gained more than 1,400 year-round equivalent jobs and $120 million in workforce earnings compared to 2022.

Annual Average Jobs

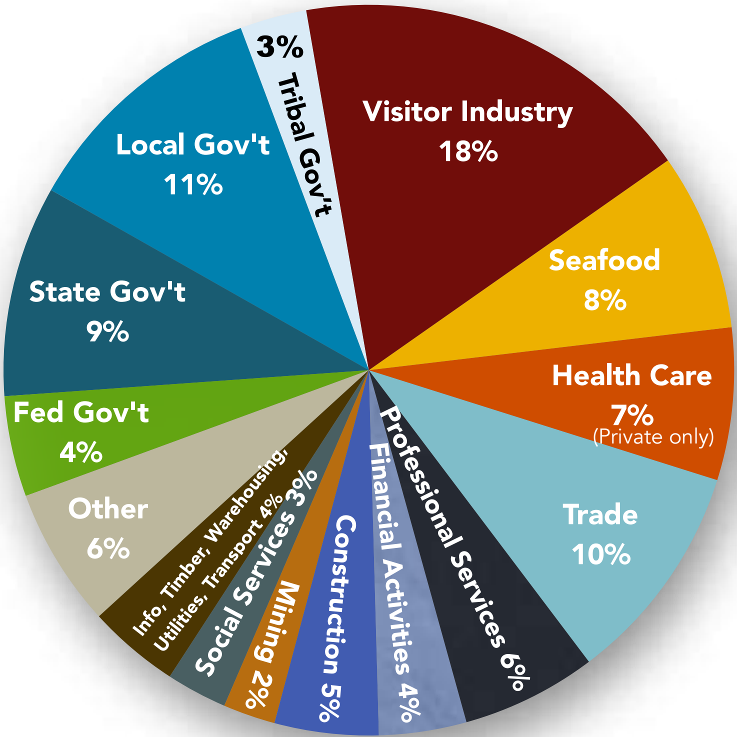
45,883 Jobs

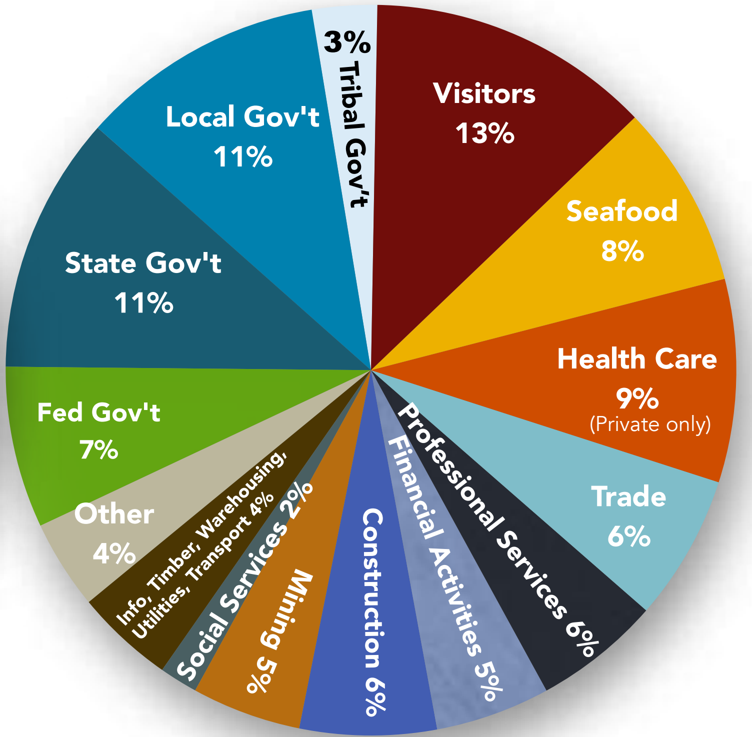
UP 1,428 JOBS IN 2023 +3%

Employment Earnings

$2.76 Billion Workforce Earnings

UP $120 MILLION +5%





2023 Southeast Alaska Employment Earnings

	Employment Related Earnings			Employment Numbers			
	Wages (2023)	Self-Employment Earnings (est.)	Total Earnings	Annual Average Employment (2023)	Self-Employed (est.)	Total Employment	Change 2022 to 2023
Government (includes Coast Guard)	$832,280,274	$60,120,000	**$892,400,274**	12,110	668	**12,778**	**134**
Visitor Industry	$308,869,594	$38,487,214	**$347,356,808**	7,212	1,050	**8,263**	**1,694**
Seafood Industry	$104,743,179	$120,094,157	**$224,837,336**	1,453	2,151	**3,604**	**-49**
Trade: Retail and Wholesale	$152,775,223	$25,737,565	**$178,512,788**	3,950	566	**4,515**	**261**
Health Care Industry (private only)	$231,396,548	$17,181,417	**$248,577,965**	2,815	279	**3,095**	**72**
Construction Industry	$119,487,289	$47,894,644	**$167,381,933**	1,479	632	**2,110**	**72**
Financial Activities	$61,963,111	$78,305,008	**$140,268,119**	1,015	761	**1,776**	**30**
Professional and Business Services	$101,092,563	$53,776,335	**$154,868,898**	1,526	1,220	**2,746**	**-191**
Mining Industry	$133,345,932	$462,762	**$133,808,694**	1,054	7	**1,061**	**59**
Social Services	$42,641,296	$4,188,024	**$46,829,320**	1,049	190	**1,238**	**-27**
Information	$16,259,923	$1,025,356	**$17,285,279**	325	47	**372**	**-107**
Timber Industry	$16,939,861	$2,301,703	**$19,241,564**	239	52	**291**	**-4**
Warehousing, Utilities & Non-Visitor Transportation	$71,535,757	$12,717,397	**$84,253,154**	955	245	**1,200**	**-768**
Other	$70,534,248	$38,567,492	**$109,101,740**	1,734	1,099	**2,833**	**251**
Total	**$2,263,864,798**	**$500,859,075**	**$2,764,723,873**	**36,914**	**8,968**	**45,883**	**1,428**

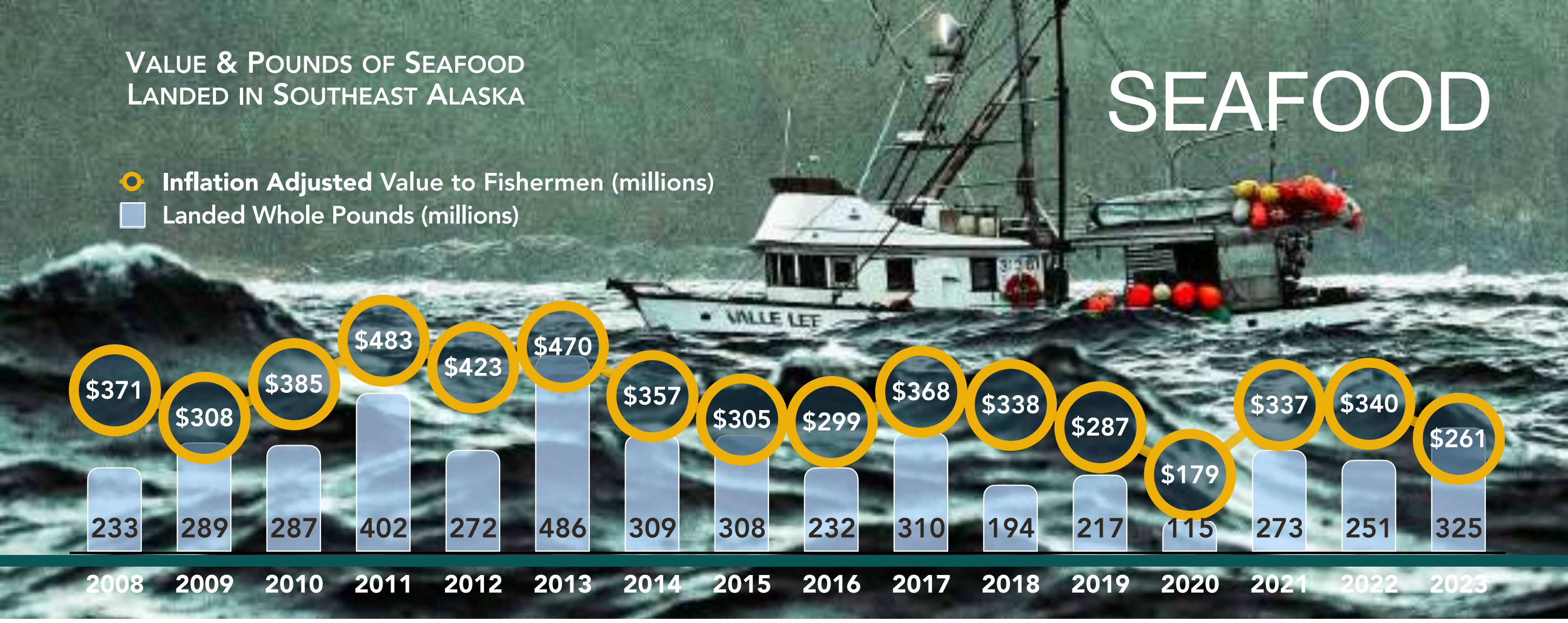
Sources: Alaska Department of Labor Employment & Wage data; (latest available) US Census Nonemployer (self-employment) Statistics; Active Duty Military Population, ADOL. *These cells in Government refer to active duty Coast Guard personnel employment and wages, and not self-employment data. **Notes: Seafood Industry** includes animal aquaculture, fishing & seafood product preparation, and Southeast Alaska resident commercial fishermen (nonresident fishermen & crew who did not report income are excluded). **Visitor Industry** includes leisure & hospitality, and visitor transportation (air, water, scenic). **Timber** includes forestry and logging support activities for forestry, and wood product manufacturing.

Change in the Last Year: 2022 to 2023

Table tracks key Southeast indicators over the past year, along with associated changes.

Demographics	2022	2023	% Change 2022-2023	Change 2022-2023
Total Population [1]	71,873	71,077	-1%	-796
Under Age 15 [2]	12,422	11,993	-3%	-429
Twenty-somethings [2]	7,824	8,038	3%	214
Ages 65 and older [2]	13,462	13,698	2%	236
UAS Enrollment (fall enrollment)	2,148	2,177	1%	29
K-12 School District Enrollment [3]	10,803	10,697	-1%	-106
General Economic Conditions				
Total Labor Force (jobs, includes self-employed & USCG) [1,5,6]	44,455	45,883	3%	1,428
Total Job Earnings [1, 5, 6]	$2.64 billion	$2.76 billion	5%	$120 million
Total Private Sector Payroll [1, 6]	$1.8 billion	$1.97 billion	9%	$166.7 million
Average Annual Wage [1]	$59,493	$60,257	1%	$763
Annual Unemployment Rate [1]	3.6%	3.9%	0.3%	0.3%
Top Economic Sectors	**2022**	**2023**	**% Change**	**Change**
Government	Public Sector: 32% of all employment earnings			
Total Government Employment [1, 5]	12,644	12,778	1%	134
Federal Employment [1, 5] (8% of all employment earnings)	2,019	2,044	1%	25
State Employment [1] (14% of all job earnings)	4,334	4,287	-1%	-47
City and Tribal Employment [1] (14% of all job earnings)	6,291	6,446	2%	155
Total Government Payroll (includes USCG) [1, 5]	$842.7 million	$892.4 million	6%	$49.7 million
State of Alaska Payroll [1]	$289.1 million	$315 million	9%	$25.9 million
Visitor Industry	Key Industry: 13% of all employment earnings			
Total Visitor Industry Employment [1, 6]	6,569	8,263	26%	1,694
Total Visitor Industry Wages/Earnings [1, 6]	$241.9 million	$347.4 million	44%	$105.5 million
Total Southeast Alaska Passenger Arrivals	**1,652,223**	**2,145,049**	30%	492,826
Cruise Passengers [10]	1,178,123	1,670,000	42%	491,877
Total Air Passenger Arrivals from Outside SE [11]	465,299	467,738	1%	2,439
Total AMHS Passengers from Outside SE [12]	8,801	7,311	-17%	-1,490
Commercial Fishing & Seafood Industry	Key Industry: 8% of all employment earnings			
Total Seafood Employment (includes fishermen) [1, 6]	3,653	3,604	-1%	-49
Total Seafood Employment Earnings [1, 6]	$301.8 million	$224.8 million	-26%	-$77 million
Commercial Fishing Boats Homeported in SE [15]	2,647	2,661	1%	14
Value of Seafood Processed [7]	$765.7 million	$508.2 million	-34%	-$257.5 million
Pounds (whole seafood landed pounds by SE residents) [8]	251.4 million	325.2 million	29%	73.7 million
Estimated Gross Earnings (ex-vessel value of pounds landed) [8]	$326.8 million	$260.7 million	-20%	-$66.1 million
Health Care Industry (public & private health)	Key Industry: 11% of all employment earnings			
Health Care Employment [1, 6]	3,811	3,899	2%	88
Health Care Wages [1, 6]	$287.2 million	$311.5 million	8.5%	$24.4 million
Maritime Economy (Includes employment from all industries)	Key Industry: 14% of all employment earnings			
Private Maritime plus USCG Employment [1,5,6]	5,558	5,567	0%	9
Private Maritime plus USCG Wages [1,5,6]	$482.2 million	$380.2 million	-21%	-$102 million
Other Selected Statistics	**2022**	**2023**	**% Change**	**Change**
Construction Employment [1, 6] (6% of all employment earnings)	2,038	2,110	4%	72
Mining Employment [1] (5% of all employment earnings)	1,002	1,061	6%	59
Price of Gold [7]	$1,802	$1,928	7%	126
Total Southeast AMHS Ridership [12]	113,868	127,461	12%	13,593
Cost of Living: Consumer Price Index [1]	256.4	260.4	2%	4
Housing Units Permitted/Completed [4,1]	169	258	53%	89
Avg. Daily Volume ANS Oil Production (mbbls/day) [14]	485,193	468,445	-3%	-16,748
Annual Avg. Domestic Crude WTI Oil Prices (in $/Barrel) [14]	$100	$83	-17%	-17

Sources: [1]Alaska Department of Labor (ADOL); [2]ADOL Southeast Alaska Population by Age; [3]Alaska Department of Education and Early Development; [4]Based on the quarterly Alaska Housing Unit Survey, a survey of local governments and housing agencies; [5] US Coast Guard; [6] US Census Nonemployer (self-employment) Statistics and estimates based on business climate surveys; [7]Kitco Metals Inc.; [8]ADF&G Southeast Alaska Commercial Seafood Industry Harvest and Ex-Vessel Value Information; [10]Cruise Line Agencies of Alaska; [11]US Bureau of Transportation Statistics (RITA); [12]Alaska Marine Highway System data; [14]Alaska Department of Revenue Crude Oil and Natural Gas Prices; [15]Commercial Fisheries Entry Commission.



Seafood Industry

3,604 Annualized Jobs 2023

Earnings Down $77 million in 2023

2023 While seafood was the top private sector wage provider in the region in 2021 and 2022, the value of seafood dropped precipitously in 2023, but not for lack of fish.

In 2023, regional fishermen caught 325 million pounds of seafood (measured in whole pounds) the largest catch since 2013. Yet it was one of the lowest catch values on record with a value of $261 million. Only 2020 was lower in recent history. The overall gross value of the catch was down 20%, a $66 million decrease over 2022. Total earnings across the seafood sector dropped by $77 million.

The overall harvest was huge. Fishermen caught 74 million more pounds of seafood in 2023 than they did in 2022. This includes 78 million more pounds of pink salmon — due to it being an odd year — and 27 million more pounds of chum. But the per pound value of species were down considerably, up to 49%. The pandemic and the Russia-Ukraine war had contributed to an over-abundant global salmon supply, leading to depressed prices across all species. Overall jobs were basically flat, down by 1%, so workers simply earned a lot less than they had in 2022, after working more.

In 2023, the five salmon species represented 82% of the regional seafood catch by pounds landed, and slightly more than half the overall value (54%). Halibut, black cod, crab, and the dive fisheries accounted for just 10% of pounds landed, but 41% of the total harvest value. The majority of the statewide catch of Chinook, coho, chum, shrimp, Dungeness crab, and the dive fisheries typically occurs in Southeast Alaska.

Key Economic Driver

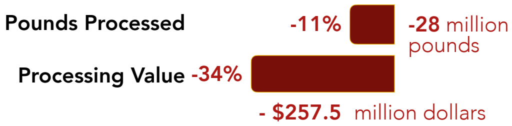
The regional seafood industry (including commercial fishing and seafood processing) generated 3,604 annual regional jobs and $225 million in earnings in 2023, making up 8% of earnings and jobs in the region.

The 10-year Southeast seafood harvest averages are 253 million whole pounds, and an inflation adjusted value of $307 million.

Seafood Processing

Seafood processing values were also down significantly. In 2023, shore-based seafood facilities in Southeast Alaska processed 229 million pounds of seafood in the region, with a wholesale value of $508 million, including shorebased processors and direct marketers. This represents a 34% decrease in value over 2022 as 28 million fewer pounds of seafood were processed.

SE Seafood Processing: 2022 vs. 2023

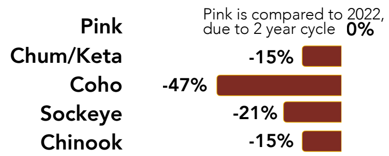


The 2023 Southeast Catch
Compared to the 2022 Catch in Millions

Species	2023 Pounds Landed	2022 Pounds Landed	2023 Catch Value	22-23 Change in Value
Pink Salmon	146.5	68.3	$40.0	10%
Chum Salmon	102.3	74.9	$68.3	-30%
Herring	22.6	51.8	$11.0	28%
Black Cod	15.6	17.1	$39.6	-28%
Coho Salmon	10.4	9.3	$12.2	-15%
Halibut	8.0	8.9	$38.3	-30%
Sockeye Salmon	5.3	6.9	$6.5	-54%
Chinook	2.5	3.4	$14.0	-22%
Geoduck, Sea Cucumbers, Urchins	2.2	2.0	$13.6	52%
Crab	5.2	4.2	$14.4	-24%
All Other	4.7	4.8	$3.0	-2%
Pounds	325 million	251 million	$261 million	-$66 million

2024 The 2024 harvest-to-date is down, and fish prices remain low. Southeast has seen a solid pink salmon return, in contrast with the rest of Alaska, which has been reporting abysmal pink harvests. In ASMI's September 2024 update is below:

SE Salmon Catch: 2023 vs. 2024
Year over year: week 36



2024 continues to be a challenge for regional fishermen and processors, although prices appear to be up slightly from 2023's deflated levels.

Sources: Combination of ADOL Employment and Wage data; US Census Nonemployer (self-employment) Statistics; ADF&G Seafood Production of Shorebased Plants in Southeast Alaska; ADF&G Southeast Alaska Commercial Seafood Industry Harvest and Ex-Vessel Value Information; Alaska Commercial Salmon Harvests and Ex-vessel Values, ADF&G. Weekly Alaska Salmon Harvest Updates are produced for ASMI by McKinley Research. **Seafood Industry** includes animal aquaculture, fishing, & seafood product preparation and Southeast Alaska resident commercial fishermen (nonresident fishermen & crew who did not report income are excluded). **Photo by Rafe Hanson Photography.**

VISITOR INDUSTRY

Visitor Industry

8,263 Annualized Jobs

$347 Million in Wages in 2023

Jobs up 1,694 Jobs in 2023

Earnings up by 44% +$106m

2023 Nearly 2.2 million passengers arrived in Southeast Alaska by air, ferry, and cruise ship in 2023.

Record Breaking Cruise Ship Season

Cruise passenger numbers grew by a nearly a half million passengers, a 42% increase from 2022, as the pandemic's impact on tourism was finally erased. The 2023 season's 1.67 million cruise ship passengers marked a new regional record, breaking the previous record of 1.33 million cruise passengers set in 2019. Airline passengers increased by more than 2,400. Although total ferry passenger traffic arriving from outside the region was down by about 1,500 passengers due to scaled back marketing.

In 2023, visitor sector jobs increased by 26% over 2022, as nearly 1,700 new year round equivalent jobs were added, and wages grew by $105.5 million, a 44% increase. Those working in the visitor industry earned $347 million in 2023, comprising 13% of all regional employment income, making tourism the top economic sector in the region.

2024

Business Leaders Survey

By all accounts 2024 has been a very good year for tourism businesses, and by extension, the regional economy. In spring 2024, business leaders from the tourism, food, and beverage sectors reported a strong economic climate with 81% calling the business climate good or very good for their business. Nearly half (43%) expected their business operations to be even stronger headed into 2024 and 2025.

Similar-Sized Cruise Season in 2024

After 3 years of cruise passenger number volatility, 2024 offers a stable supply of cruise passengers. The City and Borough of Juneau (CBJ) is working with the cruise industry on passenger abatement strategies to ensure a holding pattern on growth. In 2024, ships are expected to carry 1.68 million passengers by the end of this summer.

Tourism businesses are reporting record revenues, and are becoming competitive with other sectors for workers, as visitor sector wages increase. Between 2022 and 2023, the average tourism wage increased 14%.

"Sales are definitely up, but so are expenses."
Tourism business leader in August 2024

Workforce and Housing Challenges

With the most visitor sector jobs the region has ever had, attracting a workforce sufficient to serve visitors has remained a challenge for regional businesses, and business leaders place the primary blame on housing. In a visitor industry SWOT, leaders say the top tourism weakness in the region is limited housing, the top opportunity is workforce housing development, and the top threat is a shortage of housing.

Jet Passengers

Total air passenger arriving from outside Southeast was up by 1% in 2023 to just under a half million. In the first half of 2024 total air passenger arrivals for the region was 2% above 2023 levels.

2025 2026

Visitor Stability Expected in 2025/2026

Moving into 2026, regional cruise ship passenger numbers are expected to be slightly smaller than the 2023 and 2024 seasons. This is due to three significant agreements between local communities and the larger cruise industry:

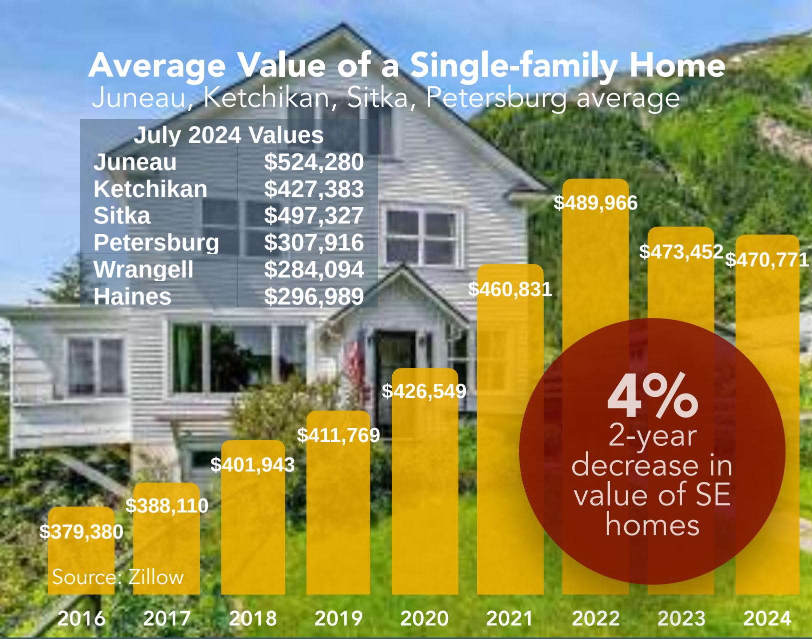
1) 5-Ship Limit: In 2024, the CBJ started enforcing a 5-ship-per-day limit, a recommendation of the community's Visitor Industry Task Force, and agreed to by the industry.

2) Daily Caps: CBJ worked with the cruise lines to set a daily agreed upon limit of 16,000 on weekdays and 12,000 on weekends, which will be enacted in 2026.

3) Shorter Season: Also in 2026, the cruise season will be significantly shorter. Instead of starting in early April, the 2026 cruise season is currently slated to begin on April 28th, and instead of running through the end of October, the season will end on October 6th.

These three changes are intended to cap significant overall cruise passenger growth and includes an agreement to meet annually to balance the schedule.

Sources: CLIA Alaska & Cruise Line Agencies of Alaska. Combination of ADOL Employment and Wage data and US Census Nonemployer (self-employment) Statistics; Alaska Visitors Statistics Program (AVSP) VII; US Bureau of Transportation Statistics (RITA); Alaska Marine Highway System; Juneau International Airport Passenger Statistics; Juneau Docks & Harbors capacity figures. **Note:** In this analysis, the visitor industry includes leisure and hospitality businesses, along with air, water & scenic transportation companies.



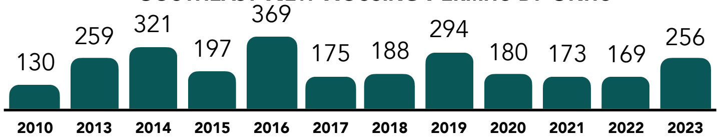
Kensington Mine

Housing Indicators

Southeast business leaders say that housing is the top obstacle to economic development in the region, with 61% of business leaders saying it is **critically important** for their local community to focus on housing over the next five years. Southeast has 28,854 occupied housing units.

New Housing: In the past 10 years, Southeast communities added more than 2,300 new permitted housing units, a 9% increase, including nearly 1,300 single-family homes, 400 multi-family homes (2-4 units), and 600 apartment units. 2023 marked the highest year of new housing development since 2019.

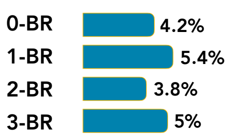
Southeast New Housing Permits by Units



Growth in Single-Person Households: Southeast continues to experience a housing crisis, but the core cause has shifted. The rise of single occupancy households — from a quarter of all regional households to a third — has erased many inventory gains. This is primarily due to a demographic shift. There are more residents aged 65 and older, a segment that is more likely to live alone, generating more than 1,400 new single-occupancy households in the past eight years.

Rental Housing: The region has more than 10,000 rentals. Based on a 2023 survey of 2,100 rental units in the region by the Alaska Department of Labor, the overall rental vacancy rate was 4.5%, similar to 2022. Two bedroom units have the lowest vacancy rates, at 3.8%. A healthy vacancy rate is considered to be approximately 8%. The average adjusted rent in Southeast Alaska was $1,392 in 2023, a 6.8% increase over 2022. Sitka has the lowest increase at 1.6%, while Ketchikan rent increased by 9.4%.

2023 SE Rental Vacancy Rates



Short-Term Rentals: Use of short-term rentals, like Airbnb and Vrbo, have risen by 7% from 912 active listings in the summer of 2023 to 979 active listings in August of 2024. Just 140 of these regional listings are available all or most of the year (more than 270 days), making the overall impact on the housing market relatively low.

Sources:Air DNA, ADOL Quarterly Alaska Housing Unit Survey, a survey of local governments and housing agencies; US Census; Zillow. Kitco Metals Inc; Coeur Mining Inc. Annual Report; Hecla Mining Company Annual Report.

Mining Industry

1,061 Annualized Jobs in 2023

Up 59 Jobs in 2023, Wages up by 12%, +$14m

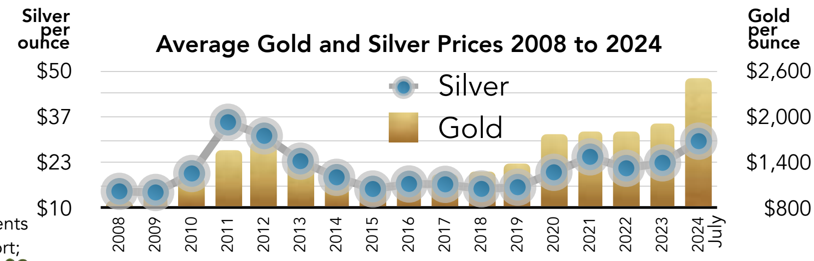
2023 The mining sector continues to grow. Mining jobs in Southeast Alaska were up by 6% and wages were up by 12% in 2023. The average annual mining wage was $126,100 in 2022, more than twice the overall regional wage of $60,226. Three mines in the region account for nearly all mining employment.

- **Hecla Greens Creek** is one of the largest silver mines in the world. In August 2024, Hecla Greens Creek had 520 full-time permanent employees (+14 from 2023) and continues to ramp up production and employment. Greens Creek is the largest private sector employer in Juneau as well as the highest taxpayer. In 2023, Greens Creek produced 9.1 million ounces of silver, similar to 2022.
- **Coeur Alaska's Kensington** is exclusively a gold mine. Kensington had a production of 84,789 ounces of gold in 2023, a 22% decrease from 2022. In 2024, Coeur Alaska Kensington had a full-time permanent staff of 369 (-14 from 2023).
- **Dawson** is a smaller gold and silver project on Prince of Wales. Dawson Mine reported 48 full-time workers in 2024.

Additional mining exploration projects are active in the region, including the Palmer Project in Haines, Herbert Gold in Juneau, Bokan Mountain, and Niblack, both on Prince of Wales.

The forecast for mining in the near term is positive with high metals prices and solid production from the areas producing mines. However, the industry continues to be challenged by the shortage of skilled labor.

Gold and silver have surged in 2024, and are up by 21+% since the start of the year. Gold reached a new peak of $2,500 in August 2024.



Construction Industry

2,110 Annualized Jobs in 2023

Jobs up 72, Wages up by $14 million

2023 For the fourth year in a row, construction employment was up. Construction jobs increased by 4% (72 jobs), while wages grew by 9% in 2023. Construction workers in the region earned $167 million, representing 6% of all regional workforce earnings in 2023. Early data shows construction jobs increased by another 300 jobs in the first half of 2024.

Sector growth is limited by a lack of workers, not projects. The Federal Infrastructure Investment and Jobs Act (IIJA) has led to large construction projects across Southeast, but local firms must compete statewide and nationally for workers as similar investments into infrastructure projects are occurring across the US. Local business leaders say that the workforce shortage makes it difficult to develop projects.

By June 2024, IIJA awards totaling $334 million for work across Southeast communities had been announced to support the region's roads, bridges, ports, airports, energy grids, communication systems, and ferries (note that ferry funding that was not Southeast specific is excluded from this list).

In Southeast in 2024, grants for federal infrastructure act funding, by community, include:

Infrastructure Act Awards in SE

Area	Millions
Juneau Borough	$37.1
Ketchikan Borough	$18.2
Sitka Borough	$9.5
Petersburg Borough	$10.9
Haines Borough/Klukwan	$6.7
Wrangell Borough	$29.5
Skagway Borough	$20.5
Yakutat Borough	$13.3
Prince of Wales Island	$22.0
Hoonah	$43.1
Metlakatla	$19.7
Angoon	$11.7
Kake	$5.2
Gustavus	$3.6
Hyder, Tenakee, Elfin Cove, Pelican, Port Alexander	$2.1
Other Regional	$80.6
Total SE Investment	**$334 Million**

Health Care Industry

3,900 Annualized Jobs in 2023

Jobs up 88, Wages up by $24 million

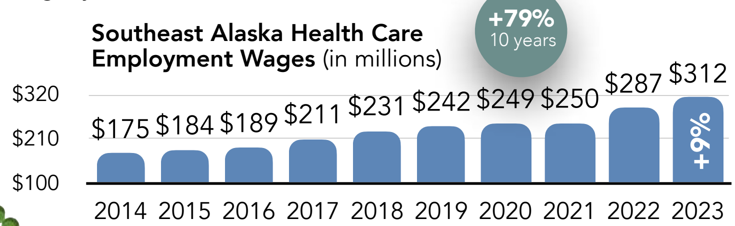
2023 Southeast Alaska's 3,900 public and private healthcare workers comprised 8% of the regional workforce in 2023, earning 11% of all wages, $312 million.

Healthcare is the biggest economic sector in Alaska — both in terms of jobs and wages — accounting for 13% of all workforce earnings and 11% of jobs statewide, having outpaced Alaska's historically-dominant sectors years ago. Through growth and turnover more than 7,500 new healthcare workers need to be hired across Alaska every year to keep up with staffing needs. Since there are too few Alaska healthcare workers to fill the demand for services in Alaska, job vacancies in the industry are increasing. Southeast Alaska medical facilities must compete statewide and nationally for high-demand healthcare workers.

In 2023, the region added 88 healthcare jobs, amidst growing demand for services as the population ages. Southeast providers have repeatedly increased wages to remain competitive in attracting and retaining workers. Regional healthcare wages increased by 9% between 2022 and 2023 in an effort to compete for workers. Over the last 10 years total regional healthcare wages grew by $137 million, a 79% increase.

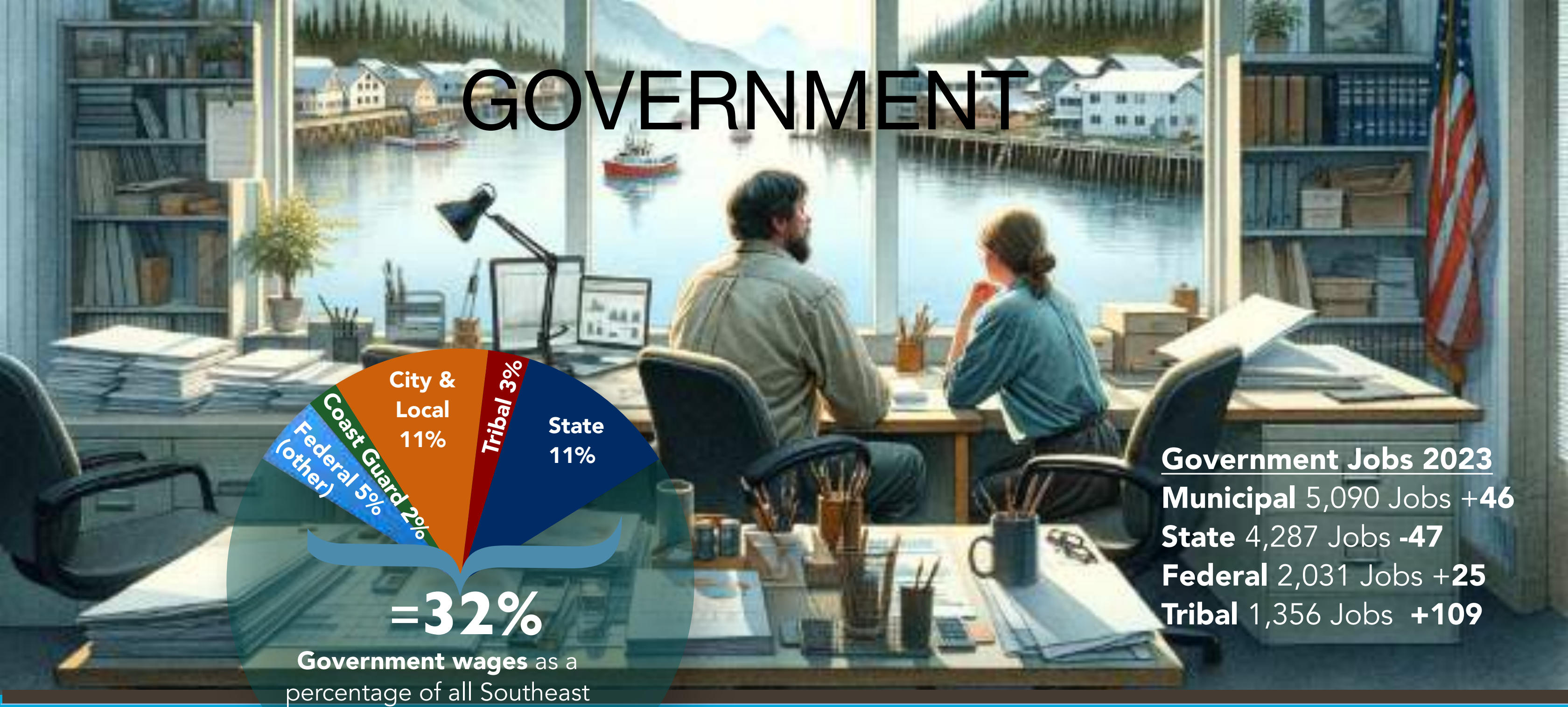
The SouthEast Alaska Regional Health Consortium (SEARHC) is the region's largest healthcare provider with 1,222 staff in 27 communities in 2023 and a payroll (including benefits) of $186 million. The next largest employer, Bartlett Regional Hospital, has a staff of 770, while PeaceHealth, the third largest, has a staff of approximately 500.

Early data indicates that regional healthcare jobs have declined slightly in the first half of 2024.



Sources: Combination of Alaska Department of Labor Employment and Wage data and US Census Nonemployer (self-employment) Statistics; State of Alaska.
Photography credit: Petersburg Medical Center

GOVERNMENT



Government Jobs 2023

Municipal 5,090 Jobs +**46**
State 4,287 Jobs **-47**
Federal 2,031 Jobs +**25**
Tribal 1,356 Jobs **+109**

Government

12,778 Annualized Jobs in 2023

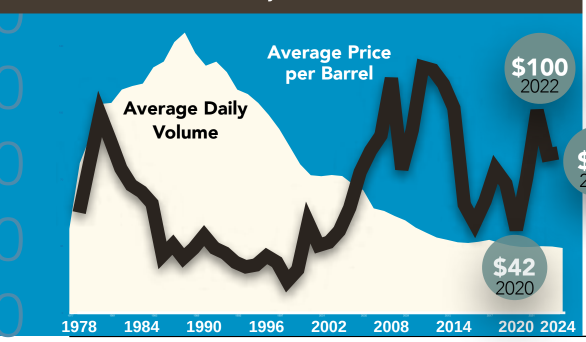
Up 134 Jobs in 2023
Wages up by 6%, $50 million

2023 Government workers made up 32% of all regional employment earnings ($892 million) in 2023, and 27% (12,778) of the region's jobs. Overall public sector wages grew by $50 million in 2023, an increase of 6%, while government jobs grew by 3%.

State Government Losses

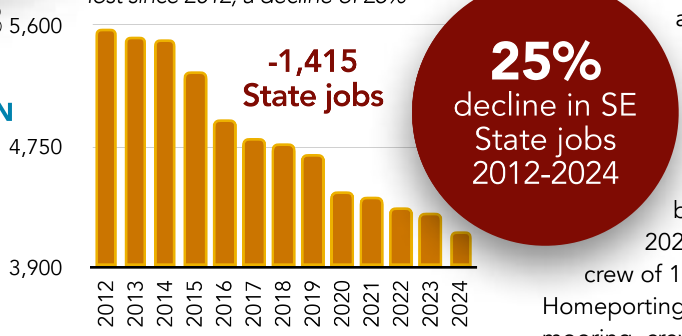
Despite being home to the State Capital, the region's State government sector has been cut for 12 years in a row. From 2012 to 2024, State jobs have been reduced by a quarter, a decline of 1,415 annualized workers. Outside the region State jobs are down just 6% over the same period. Since 2022, the State added more than 1,000 new jobs outside of Southeast Alaska.

Avg. Daily Volume of the Trans Alaska Pipeline System and Inflation Adjusted Price Per Barrel, 1978-2023



Southeast State Jobs

State jobs in the region are down for the 12th year in a row, for a total of 1,415 jobs lost since 2012, a decline of 25%



Permanent Fund Challenges

Alaska's revenue structure is dependent on oil prices and permanent fund earnings. The $81 billion Alaska Permanent Fund, which contributes more than half of the State's general fund revenue, has been posting negative returns. More money is being spent from the fund than is being deposited or earned through investments. Without sufficient earnings the fund could be unable to contribute to state services or pay dividends within the next several years.

Federal Government

Federal jobs were up by 1% in 2023 to 2,031, with associated earnings of nearly $200 million. Early jobs data indicate that federal employment numbers will be up again in 2024.

Federal investments have been critical for restoring the regional economy post-pandemic, as more than a billion dollars have been spent in, or pledged to, the region.

US Coast Guard

The federal job count includes 668 active duty US Coast Guard (USCG) personnel. The USCG announced in August that the port of Juneau will serve as an icebreaker homeport base. The hope is that the 360-ft Aiviq will be ready with a limited crew by 2026, but deployment with the full crew of 190 is expected to take longer. Homeporting preparations, such as improved mooring, crew facilities and increased housing, will boost the local and regional economy.

Local Government

Because the local government has to absorb some public services reduced by the state, employment has increased. In 2023, local governments added 46 jobs, a 1% increase. Employment is also up in the first half of 2024. Local government workers consists of the following: 44% public administration, 40% public education, just over 2,000 workers in Southeast; and 16% public health care workers.

Tribal Government Prospers

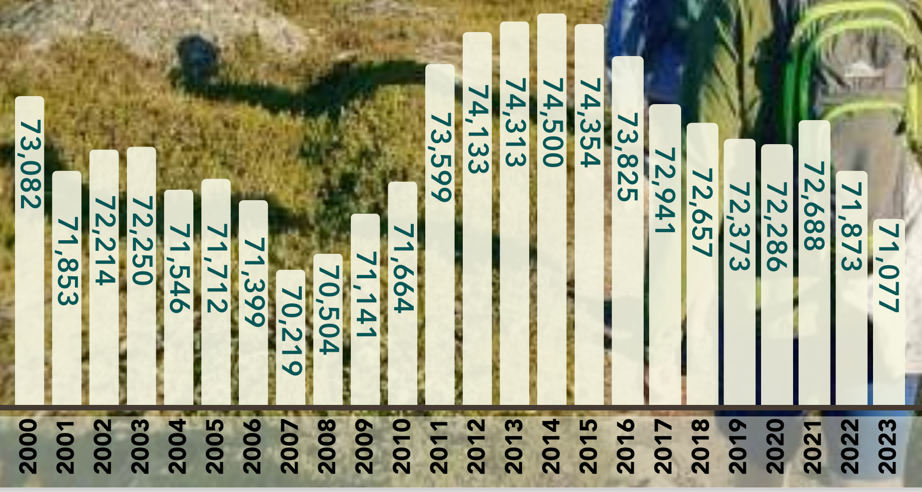
Tribal government staff grew by 9% to 1,356 annualized workers in 2023, while wages grew by 13% to $79.5 million — making it one of the fastest growing sectors in the region. In the past 7 years, tribal government jobs increased by 51%, and now make up 11% of all government jobs in the region, along with 3% of all Southeast jobs.

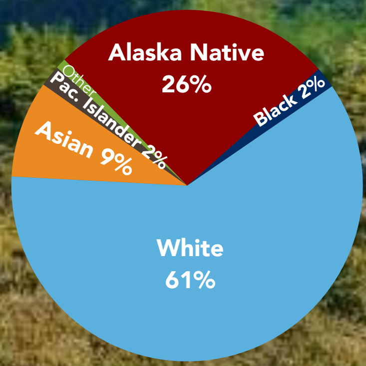
Sources: ADOL Employment and Wage data; Alaska Department of Revenue Crude Oil Prices. Alaska Office of Management Budget.

DEMOGRAPHICS

Population 71,077

-796, -1.1%





2023 The region's population was down in 2023, declining by more than one percent to 71,077 residents, a loss of nearly 800 people. Although 15 communities saw population gains.

School Enrollment

K-12 enrollment was down by 1%, as school numbers fell by 106 students in 2023. However, losses were primarily experienced by Juneau and Ketchikan schools, and mostly at grade school level. Enrollment for K-5th grade in those two communities alone fell by 150 students. Ten of the region's smallest school districts gained students, for a combined 117 enrollment increase.

A Changing Workforce

Southeast continues to have the state's oldest residents. Since 2010 — a year with a similar resident count to 2023 — the region lost more than 2,000 kids, while the 60-plus population grew by more than 7,000 older residents, from 17% of the overall population to 27%. Those of prime working age, aged 19 to 59, shrank by more than 5,600 residents. While many work well into their senior years, this demographic shift has resulted in a declining regional workforce.

Great Summer Job Market

In 2023, Juneau was named the 3rd best city in the US for summer jobs (out of 180), highlighting the ample high-quality seasonal work opportunities for the region's teens and those in their 20s.

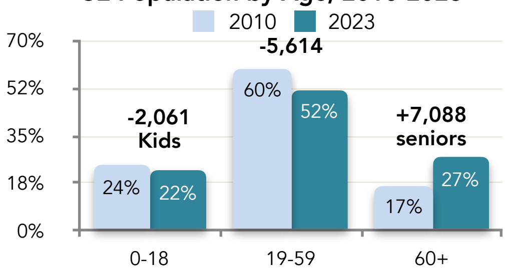
Workforce Residency

In 2022, 7% of the Southeast workforce were Alaskans from other areas of the state, and 28% were non-Alaskans. Non-Alaskans earned 19% of all regional wages in 2022. Southeast's largest numbers of nonresidents work in seafood processing (68%). The sector with the most residents is utilities (89%).

Out Migration

In 2023, nearly 800 more people moved away from Southeast Alaska than those who moved here, and deaths slightly outnumbered births. The majority of those who moved away left Alaska entirely.

SE Population by Age, 2010-2023



Population Change 2022 to 2023

Community	2022	2023	Change
Juneau Borough	31,834	31,549	-1%
Ketchikan Borough	13,776	13,475	-2%
Sitka Borough	8,354	8,231	-1%
Petersburg Borough	3,358	3,367	0.3%
Haines Borough	2,576	2,530	-2%
Wrangell Borough	2,085	2,039	-2%
Metlakatla	1,444	1,446	0%
Skagway Borough	1,147	1,127	-2%
Craig	993	1,019	3%
Hoonah	917	885	-3%
Klawock	694	696	0.3%
Yakutat Borough	673	677	1%
Gustavus	658	655	-0.5%
Kake	530	530	0%
Thorne Bay	447	478	7%
Angoon	340	343	1%
Hydaburg	348	337	-3%
Coffman Cove	201	191	-5%
Hollis	139	145	4%
Naukati Bay	131	130	-1%
Tenakee Springs	126	123	-2%
Whale Pass	84	91	8%
Pelican	83	90	8%
Klukwan	86	87	1%
Port Alexander	57	51	-11%
Kasaan	49	50	2%
Edna Bay	42	49	17%
Hyder	46	47	2%
Elfin Cove	38	38	0%
Port Protection	33	36	9%
Game Creek	18	18	0%
Point Baker	10	10	0%
Remainder	556	537	-3%
Total	**71,873**	**71,077**	**-1.1%**

Sources: Alaska Department of Labor (ADOL); ADOL Southeast Alaska Population by Age, Sex and Borough/Census Area; Alaska Population Projections; US Census. WalletHub. Nonresidents Working in Alaska (ADOL).

Jobs by Community

Looking at all communities across Southeast in 2023, job counts were up in nearly every community compared to 2022.

The largest 2022 to 2023 job gains percentage-wise included **Skagway** (+16%), **Wrangell** (+11%), **Haines/Klukwan** (+11%), **Hoonah** (+9%), and **Gustavus** (+9%). Two communities experienced continued job losses in 2023 compared to 2022. **Metlakatla** and **Angoon** each lost 2-3% of all jobs.

Wages were up in every community, and more than half saw double digit wage increase percentages. The largest increases in total wages were seen in **Klukwan** (+25%), **Skagway** (+22%), **Wrangell** (+18%), and **Gustavus** (+18%).

Regional job rates remained below 2019 levels for many communities in 2023. Five communities had more jobs in 2023 than they did in 2019, including **Gustavus** (+37%), **Hoonah** (+21%), and **Yakutat** (+21%).

Approximately half of all regional jobs (49%) and wages (52%) are in **Juneau**.

***Note:** This analysis **excludes self-employment data**, which is not made available below the borough/census area level. Still, tracking change in labor figures is an important way to track overall workforce changes in a community.*

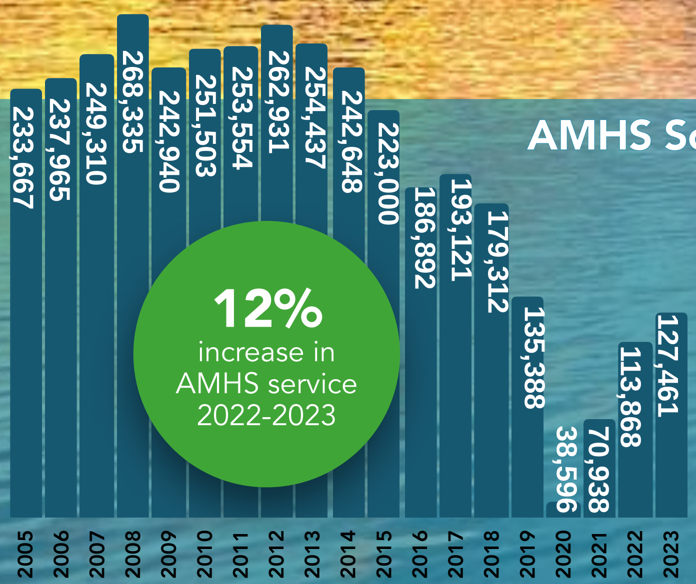
Annual Employment Change by Community 2022 to 2023

Community	2022 Annual Average Employment	2023 Annual Average Employment	2023 Wages in millions	Wages Change 2022-2023	Employment Change 2022-2023	Employment Change 2019-2023
Juneau	17,323	17,722	$1,170.5	8%	2%	-1%
Ketchikan	6,963	7,281	$432.6	9%	5%	-2%
Sitka	4,267	4,341	$265.1	9%	2%	1%
Prince of Wales	1,393	1,436	$73.0	10%	3%	-6%
Petersburg	1,244	1,253	$67.4	10%	1%	-2%
Haines	913	1,017	$46.9	16%	11%	-1%
Wrangell	673	749	$41.3	18%	11%	-9%
Skagway	879	1,017	$54.9	22%	16%	-6%
Metlakatla	503	493	$27.9	4%	-2%	-2%
Hoonah SSA	476	520	$26.5	15%	9%	21%
Yakutat	341	340	$21.9	8%	0%	21%
Gustavus SSA	255	279	$14.7	18%	9%	37%
Kake	161	166	$6.1	5%	3%	-1%
Angoon SSA	138	134	$4.7	3%	-3%	-13%
Hyder	38	42	$2.6	13%	11%	-19%
Klukwan	48	54	$1.3	25%	13%	6%

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section.
Notes: The Hoonah sub-subarea (SSA) includes Pelican and Elfin Cove. The Angoon SSA includes Tenakee Springs. Prince of Wales includes the Hollis SSA, Thorne Bay SSA and Hydaburg. An SSA is the smallest unit for which the Quarterly Census of Employment and Wages is analyzed.

Southeast Alaska GDP 2022 = $5.5 billion
Change 2021 to 2022 = 31%
Source: BEA

AMHS Southeast Ridership



Ferry connectivity, long identified as the most vulnerable element of the regional economy, has been cut dramatically over the past decade. However, ridership was up by 12% between 2022 and 2023, as pandemic recovery continues. Although ridership of those coming to Southeast from outside the region is down by 17%, as marketing to the lower-48 market has been paused.

Ferry service in 2024 continues to be plagued by maintenance needs and a lack of workers. The Tazlina, Columbia, and Matanuska were out of service due to significant maintenance needs. The smaller fleet and just one operating mainliner meant another year without cross gulf service. The Kennicott is heading to the shipyard in November. Lack of qualified crew continues to limit service.

The State continues to work with federal agencies to get three new ferries to replace the Tustumena, Matanuska, and Lituya — including one hybrid model and an electric ferry — constructed and ready for operations by 2027.

Source: AMHS.

SOUTHEAST ALASKA REGIONAL OVERVIEW

VIRTUALLY ALL OF THE REGIONAL LAND BASE IS FEDERAL. THE FEDERALLY-MANAGED TONGASS NATIONAL FOREST MAKES UP NEARLY 4/5TH OF ALL SOUTHEAST ALASKA LANDS.

Southeast Alaska Land Ownership

Circle size = Number of Acres

78% TONGASS

94% FEDERAL LANDS

16% OTHER FEDERAL HOLDINGS MAKE UP NEARLY ALL THE REST (MOSTLY GLACIER BAY)

3.4% ALASKA NATIVE ORGANIZATIONS ARE THE REGION'S NEXT LARGEST LANDOWNER

2.5% STATE OF ALASKA LANDS INCLUDE THOSE MANAGED AS PART OF THE MENTAL HEALTH TRUST

0.25% MUNICIPAL LAND HOLDINGS

0.05% ← PRIVATE LANDOWNERS

Sources: State of Alaska; US Forest Service; Sealaska. *Economies in transition: An assessment of trends relevant to management of the Tongass National Forest, USDA 1998. Image Credits: Mike Dangeli and Mike Russ Photography*

THE REGION

The Southeast Alaska panhandle extends 500 miles along the coast from Metlakatla to Yakutat, encompassing approximately 33,500 square miles of land and water. The saltwater shoreline of Southeast Alaska totals approximately 18,500 miles. More than 1,000 islands make up 40 percent of the total land area. The region is home to 34 communities. The three largest communities – Juneau, Ketchikan, and Sitka – together are home to 75 percent of the regional population.

CULTURE

The dominant culture in the region is indigenous. Alaska Natives – the Tlingit, Haida, and Tsimshian – make up more than a quarter (26%) of the region's population. Alaska's Native peoples have resided in the region for at least 11,000 years. The region's mild climate, abundant food and raw materials supported the development of highly-organized and culturally-advanced societies with extensive trade routes and rich artwork.

ECONOMIC TRENDS

Starting in the 1880s, the economy of Southeast Alaska experienced a century of growth that intensified after statehood in 1959. From statehood into the 1990s, population and employment levels in Southeast more than doubled as the workforce expanded in the areas of mining, government, fishing, tourism, and timber. In the early 1990's seafood and timber directly accounted for a fifth of the regional economy. Over the next decade pulp mills and sawmills in the region closed, laying off 3,200 workers. During the same period, the value of salmon declined and catch levels fell. The population continued to decline through 2007. Between 2008 and 2015, the region experienced a significant economic recovery, rebounding to record numbers of jobs, wages, and residents. However, the loss of a quarter of all State of Alaska jobs in the region stymied recovery. The regional economy was decimated in 2020 as the pandemic wiped out the tourism season and an extremely poor 2020 salmon season exacerbated the economic losses. By 2024 the jobs, tourists, fish, and wages are back, but low seafood prices, and a declining workforce, are creating new economic challenges.

LAND OWNERSHIP

A lack of privately-owned land and accessible land available for development is unique to Southeast Alaska and impacts the ability of the region to nurture the private sector. (See infographic on the left.) Southeast Alaska's land ownership is dominated by the federal government, which manages 94 percent of the land base. Most of this (78%, or 16.7 million acres) is the Tongass National Forest. The remaining federal lands are mostly in Glacier Bay National Park. Alaska Native organizations, including village, urban, regional corporations, and the Annette Island Reservation, own 3.4 percent (728,100 acres). The State manages 2.5 percent of the total land base (511,500 acres). Boroughs and communities own 53,000 acres — a quarter of one percent of the regional land base. Other private land holdings account for 0.05% of the regional land base.

JULY 2024 ECONOMIC SNAPSHOT

Change in July 2024 Jobs compared to July 2023 Levels: +400 jobs

July 2024 jobs up **1.2%** Over 2023 levels

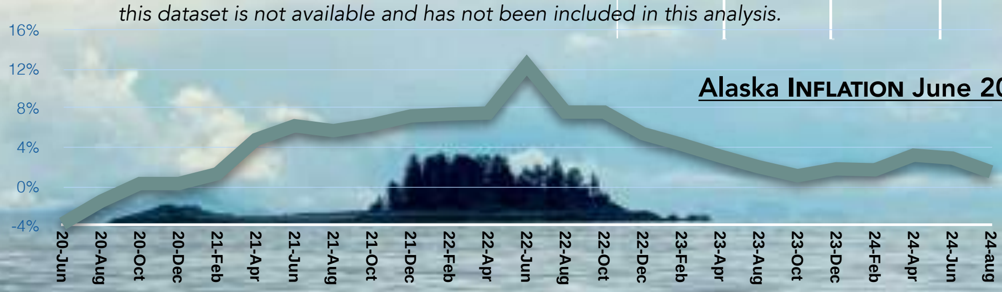
In July 2024 the regional job numbers were 400 above July 2023 levels, a 1% jobs increase. These early estimates can change, but as expected tourism and construction job counts have continued to grow, while seafood processing and state government jobs are down in July of 2024, compared to 2023.

State government is the only sector that continue to cut jobs following peak pandemic losses. By July of 2024, state jobs were down by 12% over July of 2019, a loss of 550 jobs.

Seafood processing jobs are always down in even years, so the losses in the seafood sector are expected to continue.

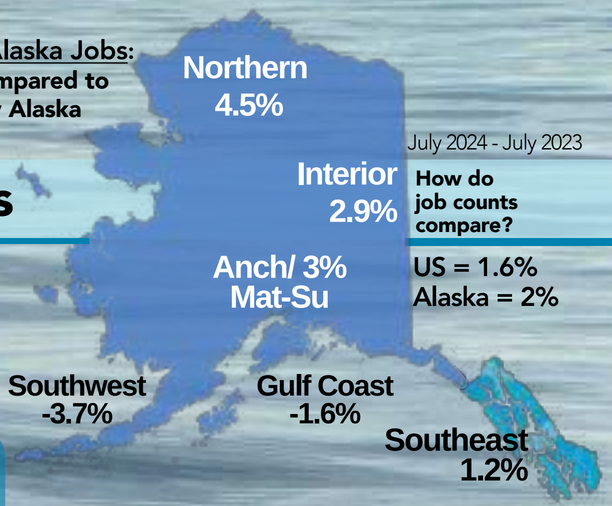
Note that 2024 numbers are preliminary. Self-employment data for this dataset is not available and has not been included in this analysis.

Alaska INFLATION June 2020 to August 2024: % change by



After rising post-2020, Alaska's urban inflation levels have normalized. Between August 2023 to August 2024, CPI rose 1.5%. Food prices rose 0.5%, energy prices increased 4.6%, and medical costs rose 9.4% according to the Bureau of Labor Statistics.

Change in Alaska Jobs: July 2024 compared to July 2023, by Alaska region



July 2024 - July 2023

How do job counts compare?

US = 1.6%
Alaska = 2%

Southeast **Employment Changes**

SE jobs compared to 2019 Pre-pandemic Levels in the Same Month

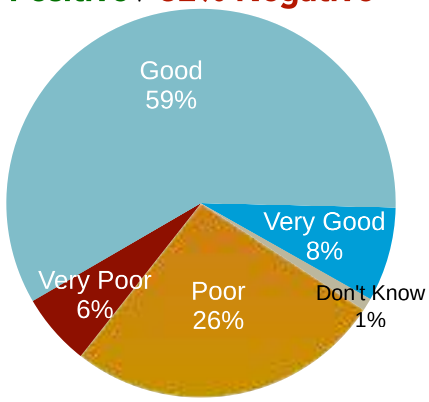
Jobs in the Southeast region were down sharply in the wake of the pandemic, especially in the summer months. It took 43 months — April 2020 until November of 2023 — for Southeast Alaska to make a full recovery to pre-pandemic workforce levels.

Source: Alaska Department of Labor

SOUTHEAST **ECONOMIC OUTLOOK** SURVEY

"How do you view the overall business climate right now?"

67% Positive / 32% Negative



2nd Best Business Climate Since Survey Began in 2010

In April 2024, 440 Southeast Alaska business owners and top managers from 25 communities responded to Southeast Conference's Business Climate Survey.

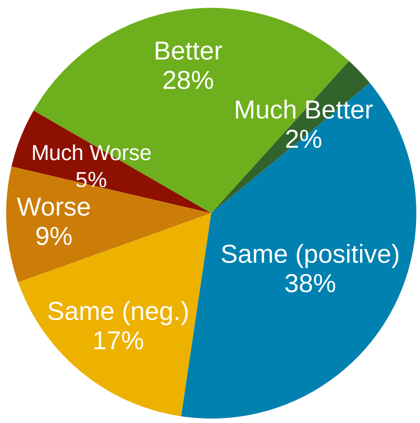
Approximately two-thirds (67%) have a positive view of the Southeast business climate, **making it the 2nd highest rated business climate since surveying began in 2010.** Only 2023 was better.

While many sectors have a positive perspective on the current economy, those leading **financial** organizations, **tourism** enterprises, and **construction** or **engineering**—focused businesses were the most positive; along with business leaders in **Skagway**, **Yakutat**, **Sitka**, and **Hoonah.**

The **seafood** sector was most likely to call the 2024 economy poor or very poor, along with business leaders in **Petersburg**.

"What is the economic outlook for your business or industry over the next year (compared to the previous year)?"

68.5% Positive / 31.5% Negative



The Outlook is Solid

Business leaders are also optimistic about the future. Almost a third of respondents expect their prospects to be better or much better over the next year, with an overall positivity rating of 68%.

The economic outlook for **Alaska Native** organizations, **tourism**, **nonprofits**, and **healthcare** are most positive moving into 2024. Communities with the most positive outlooks include **Hoonah**, **Skagway**, and **Ketchikan**.

Seafood and **timber** have the most negative outlooks, along with community leaders in **Wrangell** and **Petersburg**.

Southeast Alaska Industry Strengths, Weaknesses, Opportunities, and Threats 2024

Seafood

- *Top Strength*: High quality product
- *Top Weakness*: High costs
- *Top Opportunity:* Increase value-added processing
- *Top Threat:* Low seafood prices

Visitor Industry

- *Top Strength*: Natural beauty of region
- *Top Weakness*: Limited seasonal housing
- *Top Opportunity:* Workforce housing development
- *Top Threat:* Housing shortages

Transportation

- *Top Strength:* Connecting communities
- *Top Weakness*: Lack of qualified workforce
- *Top Opportunity:* Improve ferry service
- *Top Threat:* Demise of AMHS

Energy

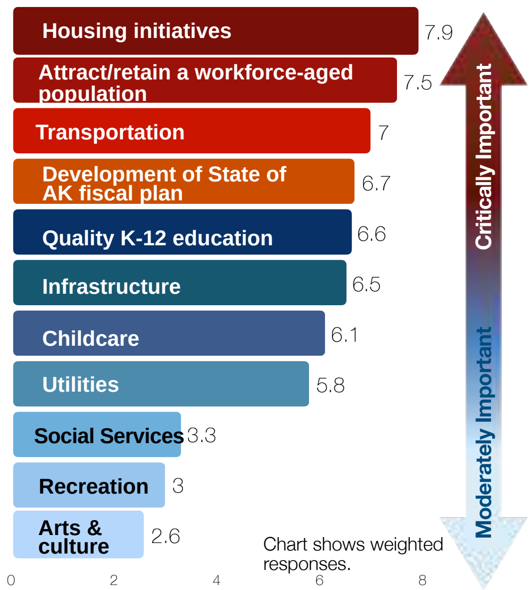
- *Top Strength:* High % renewable/hydropower
- *Top Weakness*: High costs of infrastructure
- *Top Opportunity*: Heat pump installation
- *Top Threat:* Inadequate workforce

Creating A Vibrant Business Climate: "How important is it to focus on these factors over the next five years?"

Housing, Workforce, Transportation Solutions are Needed for a Vibrant Southeast Alaska Business Climate

Southeast Alaska business leaders were asked to rank the importance of focusing on 11 key element necessary for creating a vibrant business climate. **Business leaders continue to identify housing as the top obstacle to economic development** and critical for creating a vibrant business climate in the region, with 61% of business leaders saying it is *critically important* to focus on housing over the next five years. The housing shortage is deterring young families and workers from relocating to, or remaining in, the region. Half of regional business leaders say that **finding better ways to attract and retain workforce-aged residents to the region is *critically important*.** This is most strongly expressed by Juneau, Wrangell, Petersburg, and Ketchikan businesses leaders, where three-fifths of respondents say the need to attract young professionals over the next five years is critical.

Nearly half of business leaders say a continued focus on transportation remains a critical area of focus, a percentage that rises sharply in communities like Kake, Pelican, Gustavus, and Haines. The reduction of Alaska Marine Highway ferry service and lack of ferry reliability negatively impacts regional businesses.



SOUTHEAST **2025 STRATEGIC PLAN** SUMMARY

These initiatives were finalized in 2021. The 2030 Strategic Plan is currently being developed.

In April 2021, Southeast Conference released the Southeast Alaska 2025 Economic Plan, a five-year strategic plan for the region. The membership worked together to develop an overall vision statement, more than 50 objectives, and 3 priority objectives, along with regional and industry specific SWOT analyses. More than 400 people representing small businesses, tribes, Alaska Native organizations, municipalities, and nonprofits were involved in various elements of the planning process. The Plan's prioritized objectives are listed below.

Transportation

1. **Priority** Sustain and support the Alaska Marine Highway System
2. Develop a long-term, strategic, multi-modal, regional transportation plan
3. Ensure the stability of regional passenger transportation services
4. Move freight to and from markets more efficiently
5. Ports and harbors infrastructure improvements
6. Road Development

Seafood & Maritime

Seafood

1. **Priority** Mariculture development
2. Work to promote a year-round seafood economy
3. Further develop seafood markets
4. Maintain a stable regulatory regime
5. Research the effects of changing ocean conditions on the marine environment
6. Support regional processors becoming economically competitive
7. Communicate the importance of salmon hatcheries
8. Seafood sector workforce development
9. Full resource utilization & ocean product development

Maritime

1. Increase employment & training opportunities for Southeast Alaska residents in the Marine Industrial Support Sector
2. Increase energy efficiency & reduce energy costs
3. Expand marine industrial support capacity

Energy Sector

1. **Priority** Promote beneficial electrification
2. Continue to support rural Southeast communities with high-cost electric rates without access to lower-cost hydroelectricity
3. Work with communities to create energy systems that provide sustainable, affordable, renewable thermal energy
4. Implement regional energy plan with a focus on "committed units" and deployment of renewables
5. Energy workforce development

Visitor Industry

1. Market Southeast Alaska to attract more visitor spending and visitor opportunities
2. Grow cultural and arts tourism opportunities
3. Increase access to public lands and expand trail network
4. Increase yacht and small cruise ship visitation
5. Educate public on the economic value of tourism

Mining Industry

1. Proactively support mining operations and mineral exploration projects
2. Support efforts to increase access to minerals and energy sources for mining on state and federal lands
3. Mining and exploration workforce development
4. Preserve access to reliable, year-round transportation for miners living in rural Southeast Alaska
5. Attract mining capital

Health Care

1. Plan for a post COVID-19 health care system
2. Retain Alaska-trained health care students
3. Meet the health care needs of an aging population
4. Increase health care training within the region and state

Timber Industry

1. Provide an economically viable and dependable supply of timber from the Tongass National Forest to regional timber operators
2. Revise the Tongass National Forest Land Management Plan
3. Support an integrated timber industry that includes harvest of young growth and old growth
4. Community-based timber workforce development
5. Work with USFS to direct federal contracts and timber sale opportunities toward eligible locally-owned businesses

Other Objectives

1. **Housing:** Support the sustainable development of housing
2. **Childcare:** Increase childcare capacity
3. **Communications:** Improve communications access
4. **Education Objective:** Partner with University of Alaska Southeast and K-12 school districts to build career pathways and meet employer needs for a skilled workforce
5. **Natural Disaster Planning:** Support disaster preparation and relief efforts
6. **Solid Waste:** Support regional solid waste management solutions
7. **Food Security:** Increase supply, demand and equitable access and distribution of local foods and regional food system opportunities
8. **Arts:** Increase the recognition of Southeast Alaska's thriving Northwest Coast arts economy
9. **Cultural Wellness:** Support the development of activities and infrastructure that promotes cultural wellness and multicultural wellness

A Message from **Southeast Conference**

Executive Director **Robert Venables**

The secret to our success? You! Your partnerships and participation in our planning efforts continue to lead to millions of dollars in new investments in our region. Since the pandemic, Southeast Alaska has seen a billion dollars in federal investment. Those funds have stabilized economies while working to revitalize communities by creating infrastructure improvements to our basic needs of roads, ports, harbors and facilities. It has also provided technical assistance and empowerment for business startups from broadband to mariculture.

While we are ecstatic about the large federal investments in mariculture and now heat pumps, we are even more pleased to see the future of AMHS come into focus. While AMHS continues to struggle with an aging fleet and crew shortages which has left communities with limited service, a new, long-range plan is emerging that will guide the ferry system's operations and investment decisions to 2045. This plan promotes a modernized AMHS with increased standardization and needed system efficiencies.

This year, the Southeast Conference board revamped SEC's mission, vision and values statement to acknowledge SEC's role in addressing the challenges and opportunities faced, dubbing this year's theme, Navigating the Changing Tides. Our mission is to undertake and support activities that promote strong economies, sustainable communities and a healthy environment in Southeast Alaska. Our vision is to facilitate enduring connections that enable dynamic, diverse, and thriving economies across Southeast Alaska as we:

- **Position** Southeast Alaska as an economic leader in the global economy.
- **Engage** community leaders to develop solutions which will enhance the economic sustainability of our region.
- **Catalyze** change and prosperity for our diverse region.
- **Facilitate** visionary and adaptive solutions to sustain our region in perpetuity.
- **Build** trust among our partners.
- **Respect** and celebrate the diversity of our region.
- **Develop** capacity internally and externally to accomplish our mission.

Incoming President **Zak Kirkpatrick**

Zak Kirkpatrick is the Chief Marketing Officer for Allen Marine/Alaskan Dream Cruises

In the mid-1950s my great grandparents immigrated from the mountains of Sweden to Haines with their three children in tow. Upon arrival, they built a small fishing boat and lived out the rest of their lives providing for the family through the bounty of the sea. Compelled by a relative's promise of Alaska as a superlative "land of opportunity" they left everything familiar behind to make the journey across the Atlantic (and the United States).

As a born and raised Alaskan, I've found that promise to my great grandparents remains true. For me, opportunity has largely come through the visitor industry. In high school, work as a fishing guide and for the United States Forest Service at the Mendenhall Glacier provided me spending money to put gas in my skiff's outboard. Later, marine tour deckhanding led to the ability to get my captain's license and helped pay for my advertising degree at Brigham Young University in Utah. While most of my classmates chased marketing jobs in large, metropolitan marketing firms after graduation, I wanted to return home. The visitor industry offered the chance to live in the place I was raised, and had grown to love, while offering compelling, year-round work in my field.

Advancement within the Allen Marine organization has enabled us to raise our young family and put down roots. For me, tourism equaled big opportunity! For others in my family, great opportunities have come in the form of fishing, mining, transportation, healthcare, state government, and other fields.

As we go about our daily lives and unique work tasks, it can be easy to get a certain measure of tunnel vision as we focus on our own niches, which is why I enjoy Southeast Conference. This fantastic organization brings together a wide array of industries and sectors, helping all of us learn from the experience of others and providing us with knowledge to support one another. Hopefully we ultimately realize we're all united under a common goal of supporting activities that lead to strong economies, sustainable communities, and a healthy environment for our beautiful corner of the world.

The mission of Southeast Conference is to **undertake and support activities that promote strong economies, sustainable communities, and a healthy environment in Southeast Alaska**. As the state- and federally-designated regional economic development organization, Southeast Conference serves as the collective voice for advancing the region's economy. We have 200 member organizations representing 1,200 people from 32 regional communities. We started 66 years ago with a group of people supporting the establishment of a regional transportation system, leading to the formation of the Alaska Marine Highway System. Our members stayed together through more than a half-century to focus on concerns unique to the region.

SOUTHEAST CONFERENCE

Southeast Conference Board

Lacey Simpson – President
Ketchikan Assistant City Manager,
Assistant KPU General Manager

Zak Kirkpatrick – 1st Vice President
Chief Marketing Officer
Allen Marine/Alaskan Dream Cruises

Katie Koester – 2nd Vice President
City Manager, City & Borough of Juneau

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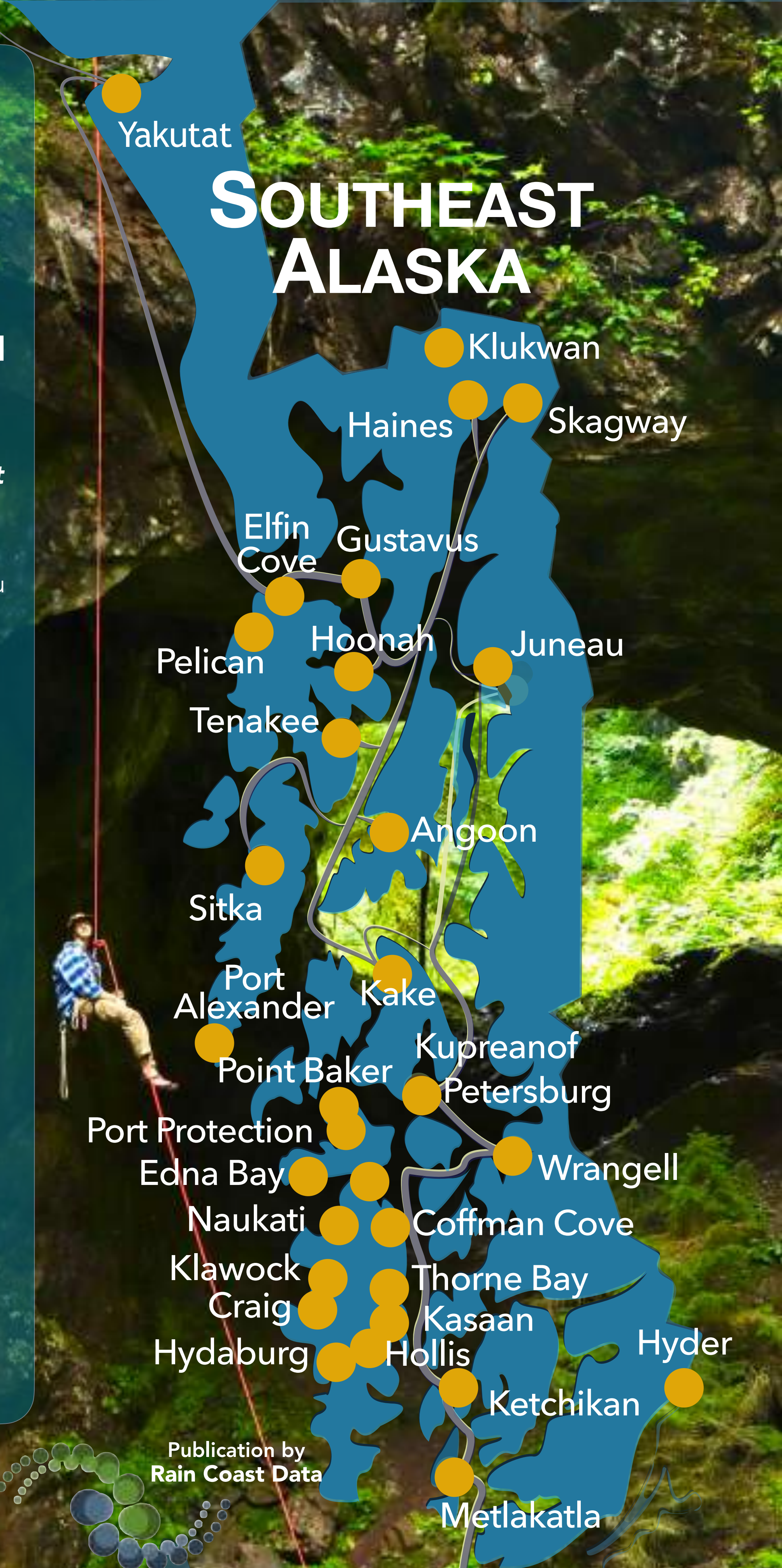

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SOUTHEAST ALASKA by the Numbers 2025

SOUTHEAST CONFERENCE

CHANGES 2023 TO 2024

THE **LABOR FORCE** INCREASED BY **701 JOBS** TO **45,722, +1.6%**

TOTAL WAGES INCREASED BY **$99 MILLION** TO $2.9 BILLION, **+3.6%**

TOURISM JOBS INCREASED BY **6%**, **WAGES** INCREASED BY **9%, +$29 MILLION**

VALUE OF SEAFOOD LANDED IN THE REGION DECREASED BY **19%, -$43 MILLION** CATCH WAS DOWN BY **86 MILLION POUNDS**

REGIONAL **POPULATION** DECREASED BY **576 PEOPLE** TO **70,613, -1%**

HOUSING AVAILABILITY 79% OF BUSINESS LEADERS SAY THAT LIMITED HOUSING CAUSES STAFF TO LEAVE OR DECLINE JOB OFFERS, LEADING TO LABOR SHORTAGES

SOUTHEAST ALASKA'S **ECONOMY**

2024 Last year was good for Southeast. In 2024, jobs were up by 1.6% and wages were up by 3.6% over 2023, as earnings grew by $99 million. All but three communities gained workers as 700 new annualized jobs were added across the region. Jobs were just 400 below the all-time record set in 2015, while overall wages were record-setting, even when adjusted for inflation.

In 2024, tourism continued to expand its lead as the largest sector in the region, as arriving cruise and air passenger numbers reached record levels. Tourism added nearly 500 year-round-equivalent jobs in 2024, while tourism workers earned $29 million more than the year before, a 9% increase.

Government jobs were up across the board. The State sector added workers for the first time in more than a dozen years. Altogether government wages grew by $33 million. The healthcare, retail, finance, and mining sectors all added workers to their payrolls. Jobs in business and professional services grew by 7%, the highest percentage increase of all the sectors. Nine communities saw double-digit percentage wage growth. Regional GDP was up by 6% to $6 billion.

Not all indicators were up. Social services were down, along with construction, trade, and timber. Population and school enrollment fell. Most notably, the seafood sector continues to decline, with regional ex-vessel values dropping to near historic lows, and the number of local commercial fishermen 21% below 2019 counts.

2025 The economy in the first half of 2025 has been relatively strong, but business leaders are approaching the future with reduced confidence, driven largely by federal actions. Recent policy changes have weakened the capacity to provide scientific and regulatory expertise to sectors like seafood and timber, created concerns about the impact of tariffs, and raised questions about future Medicaid coverage and social services funding. Together, these factors have created a climate of uncertainty that is slowing local hiring and business investment.

Tourism is having another strong year as a record 1.73 million cruise passengers are expected to visit. The outlook for mining in the region is very positive, buoyed by strong metals prices.

The seafood sector continues to be of concern, as early 2025 harvest levels are below the weak 2024 returns, although prices are finally on the rise.

The primary problem for the Southeast economy is one of demographics. Housing scarcity and costs are partially responsible for driving this dynamic, leaving young families and workers unable to move to the region, or stay longer term — despite near record job levels. The region has lost 2,200 kids and 5,500 residents of prime working age in the last decade alone. For Southeast to prosper in future years, the focus must be on attracting and retaining a vibrant future population now.

Photo by Huna Totem Corporation

A **SOUTHEAST CONFERENCE** PUBLICATION BY RAIN COAST DATA

The Whole **Southeast Alaska Economy** 2024

In 2024, Southeast Alaska gained more than 700 year-round equivalent jobs and $99 million in workforce earnings compared to 2023.

Annual Average Jobs

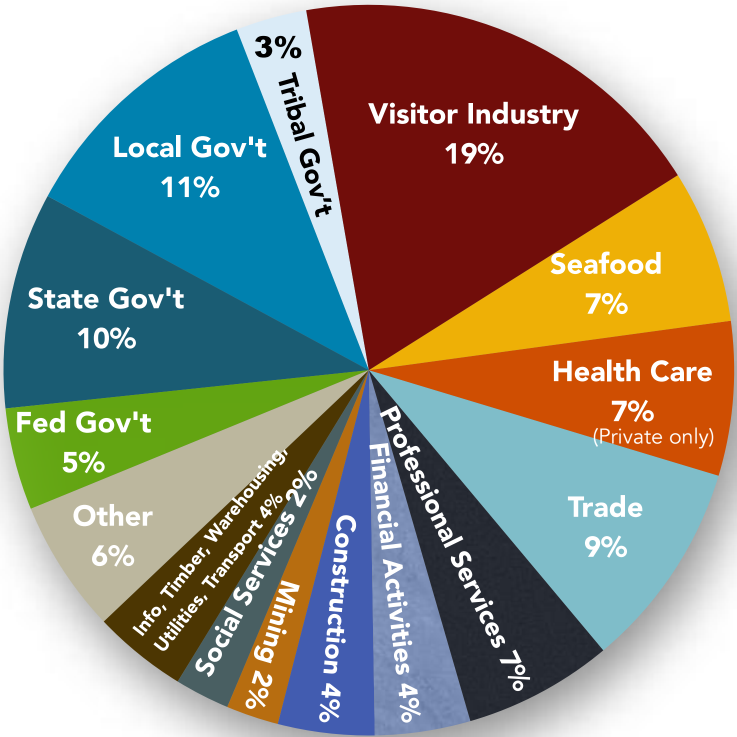
45,722 Jobs

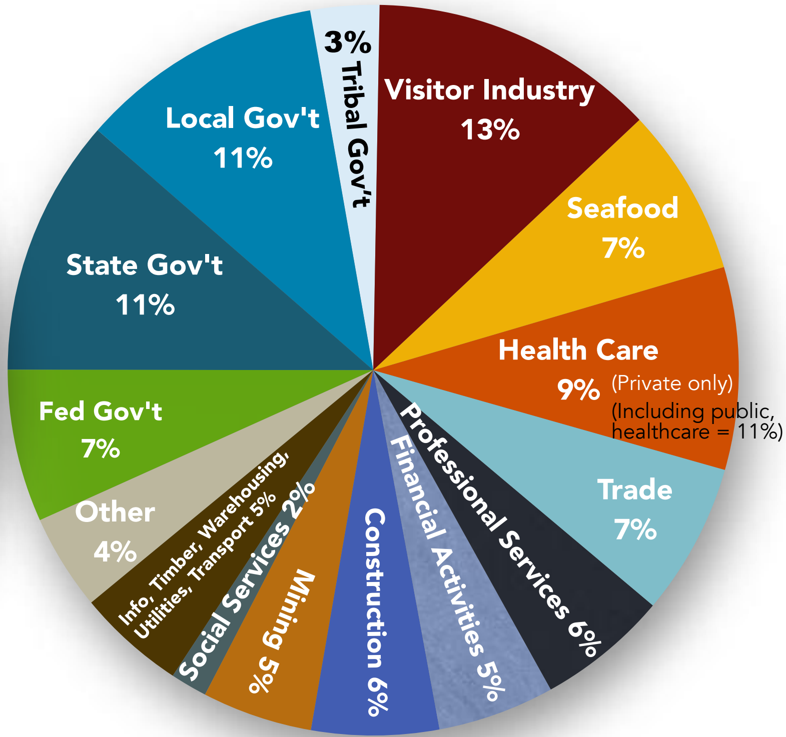
UP 701 JOBS IN 2024 +1.6%

Employment Earnings

$2.9 Billion Workforce Earnings

UP $99 MILLION +3.6%





2024 Southeast Alaska Employment Earnings

	EMPLOYMENT RELATED EARNINGS			EMPLOYMENT NUMBERS			
	Wages (2024)	Self-Employment Earnings (est.)	Total Earnings	Annual Average Employment (2024)	Self-Employed (est.)	Total Employment	Change 2023 to 2024
Government (includes Coast Guard)	$880,916,929	*$44,691,842	**$925,608,771**	12,385	*623	**13,008**	**230**
Visitor Industry	$335,323,105	$32,088,445	**$367,411,550**	7,691	898	**8,589**	**494**
Seafood Industry	$90,951,293	$124,668,261	**$215,619,554**	1,412	1,697	**3,109**	**-144**
Trade: Retail and Wholesale	$153,722,415	$41,004,659	**$194,727,074**	3,774	451	**4,225**	**-185**
Health Care Industry (private only)	$242,523,928	$16,536,731	**$259,060,659**	2,854	267	**3,121**	**43**
Construction Industry	$124,452,828	$38,460,536	**$162,913,364**	1,459	492	**1,951**	**-27**
Financial Activities	$65,347,176	$84,050,642	**$149,397,818**	1,057	875	**1,932**	**77**
Professional and Business Services	$108,373,587	$59,060,982	**$167,434,569**	1,690	1,332	**3,022**	**200**
Mining Industry	$141,040,697	$31,853	**$141,072,550**	1,055	7	**1,062**	**1**
Social Services	$43,192,351	$3,860,250	**$47,052,601**	993	118	**1,111**	**-63**
Information	$18,338,779	$1,572,225	**$19,911,004**	329	55	**384**	**4**
Timber Industry	$16,368,471	$1,556,660	**$17,925,131**	232	42	**274**	**-8**
Warehousing, Utilities & Non-Visitor Transportation	$78,617,273	$22,017,219	**$100,634,492**	1,014	230	**1,244**	**72**
Other	$83,125,421	$39,463,000	**$122,588,421**	1,741	949	**2,690**	**7**
Total	**$2,382,294,253**	**$509,063,305**	**$2,891,357,558**	**37,686**	**8,037**	**45,722**	**701**

Sources: Alaska Department of Labor Employment & Wage data; (latest available) US Census Nonemployer (self-employment) Statistics; Active Duty Military Population. ***Active duty Coast Guard personnel employment and wages, and not self-employment data.** **Notes: Seafood Industry** includes animal aquaculture, fishing & seafood product preparation, and Southeast Alaska resident commercial fishermen (nonresident fishermen & crew who did not report income are excluded). **Visitor Industry** includes leisure & hospitality, and visitor transportation (air, water, scenic). **Timber** includes forestry and logging support activities for forestry, and wood product manufacturing.

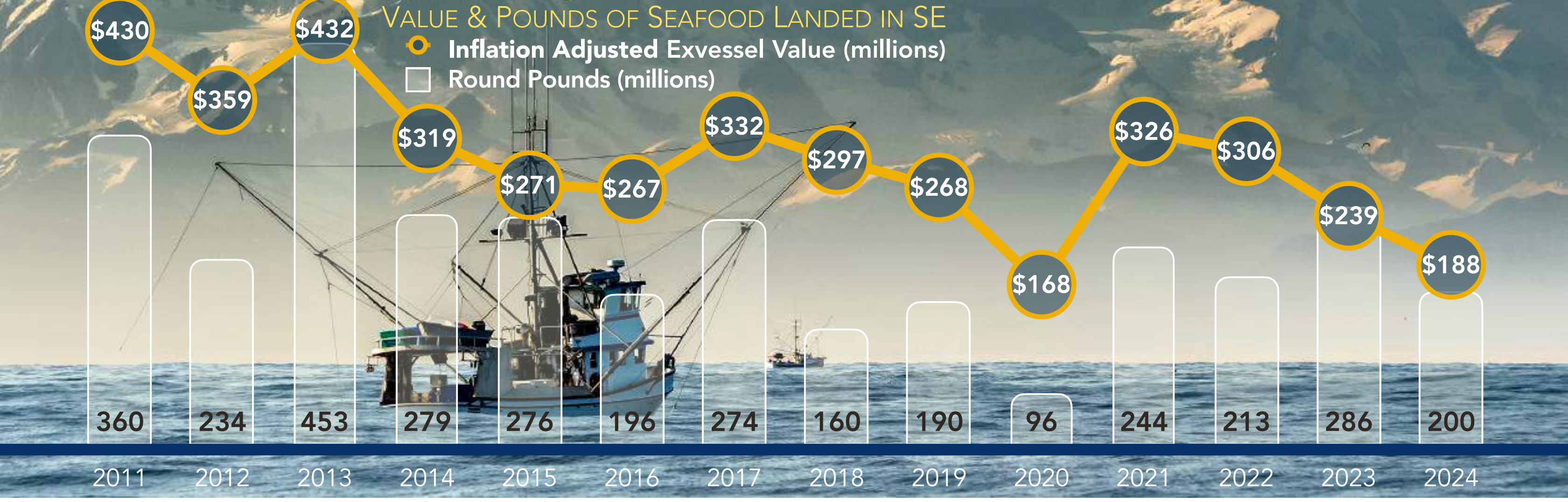
Change in the Last Year: 2023 to 2024

Table tracks key Southeast indicators over the past year, along with associated changes.

Demographics	2023	2024	% Change 2023-2024	Change 2023-2024
Total Population [1]	71,189	70,613	-1%	-576
Under Age 15 [2]	12,016	11,701	-3%	-315
Twenty-somethings [2]	7,725	7,459	-3%	-266
Ages 65 and older [2]	13,722	14,234	4%	512
UAS Enrollment (fall enrollment)	2,177	2,313	6%	136
K-12 School District Enrollment [3]	10,653	10,289	-3%	-364
General Economic Conditions	**2023**	**2024**	**% Change**	**Change**
Total Labor Force (jobs, includes self-employed & USCG) [1,5,6]	45,021	45,722	2%	701
Total Job Earnings [1, 5, 6]	$2.8 billion	$2.9 billion	4%	$99 million
Total Private Sector Payroll [1, 6]	$1.9 billion	$2 billion	3%	$66 million
Average Annual Wage [1]	$62,021	$63,238	2%	$1,217
Annual Unemployment Rate [1]	3.9%	4.1%	0.2%	0.2%
Top Economic Sectors	**2023**	**2024**	**% Change**	**Change**
Government	Public Sector: 32% of all employment earnings			
Total Government Employment [1, 5]	12,778	13,008	2%	230
Federal Employment [1, 5] (8% of all employment earnings)	2,044	2,068	1%	24
State Employment [1] (14% of all job earnings)	4,287	4,378	2%	91
City and Tribal Employment [1] (14% of all job earnings)	6,446	6,562	2%	116
Total Government Payroll (includes USCG) [1, 5]	$892.4 million	$925.6 million	4%	$33.2 million
State of Alaska Payroll [1]	$315 million	$329.3 million	5%	$14.3 million
Visitor Industry	Key Industry: 13% of all employment earnings			
Total Visitor Industry Employment [1, 6]	8,095	8,589	6%	494
Total Visitor Industry Wages/Earnings [1, 6]	$338.4 million	$367.4 million	9%	$29 million
Total Southeast Alaska Passenger Arrivals	**2,145,049**	**2,216,131**	3%	71,082
Cruise Passengers [10]	1,669,500	1,732,000	4%	62,500
Total Air Passenger Arrivals from Outside SE [11]	467,738	477,592	2%	9,854
Total AMHS Passengers from Outside SE [12]	7,311	6,539	-11%	-772
Commercial Fishing & Seafood Industry	Key Industry: 7% of all employment earnings			
Total Seafood Employment (includes fishermen) [1, 6]	3,253	3,109	-4%	-144 jobs
Total Seafood Employment Earnings [1, 6]	$248.3 million	$215.6 million	-13%	-$32.7 million
Commercial Fishing Boats Homeported in SE [15]	2,661	2,582	-3%	-79 boats
Value of Seafood Processed [7]	$508.5 million	$379.3 million	-25%	-$129.1 million
Pounds (whole seafood landed pounds by SE residents) [8]	286.4 million	200.3 million	-30%	-86.1 million
Estimated Gross Earnings (ex-vessel value of pounds landed) [8]	231.8 million	188.3 million	-19%	-$43.5 million
Health Care Industry (Public & Private Health)	Key Industry: 11% of all employment earnings			
Health Care Employment [1, 6]	3,883	3,889	0.2%	6 jobs
Health Care Wages [1, 6]	$310.1 million	$314.7 million	1%	$4.6 million
Maritime Economy (Includes employment from all industries)	Key Industry: 14% of all employment earnings			
Private Maritime plus USCG Employment [1,5,6]	5,967	6,028	1%	61 jobs
Private Maritime plus USCG Wages [1,5,6]	$436.5 million	$413.9 million	-5%	-$22.6 million
Other Selected Statistics	**2023**	**2024**	**% Change**	**Change**
Construction Employment [1, 6] (6% of all employment earnings)	1,978	1,951	-1%	-27
Mining Employment [1] (5% of all employment earnings)	1,061	1,062	0%	1
Price of Gold [7]	$1,954	$2,405	23%	$452
Total Southeast AMHS Ridership [12]	127,461	129,529	2%	2,068
Cost of Living: Consumer Price Index [1]	260.4	266.2	2.2%	$6
Housing Units Permitted/Completed [4,1]	258	232	-10%	-26
Avg. Daily Volume ANS Oil Production (mbbls/day) [14]	468,445	464,084	-1%	-4,361
Annual Avg. Domestic Crude WTI Oil Prices (in $/Barrel) [14]	$82.57	$80.19	-3%	-$2.39

Sources: [1]Alaska Department of Labor (ADOL); [2]ADOL Southeast Alaska Population by Age; [3]Alaska Department of Education and Early Development; [4]Based on the quarterly Alaska Housing Unit Survey, a survey of local governments and housing agencies; [5] US Coast Guard; [6] US Census Nonemployer (self-employment) Statistics and estimates based on business climate surveys; [7]Kitco Metals Inc.; [8]ADF&G Southeast Alaska Commercial Seafood Industry Harvest and Ex-Vessel Value Information; [10]Cruise Line Agencies of Alaska; [11]US Bureau of Transportation Statistics (RITA); [12]Alaska Marine Highway System data; [14]Alaska Department of Revenue Crude Oil and Natural Gas Prices; [15]Commercial Fisheries Entry Commission.

SEAFOOD INDUSTRY



Seafood Industry

3,109 Annualized Jobs 2024

$216 Million in Wages 2024

JOBS DOWN 4% -144
EARNINGS DOWN 13% -$33M

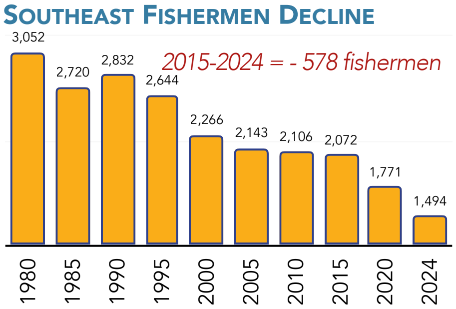
2024 While seafood was the top wage provider in the region as recently as 2022, the years since have been very difficult for the industry.

In 2024, regional fishermen caught 200 million pounds of seafood. Due to low prices, the catch had one of the lowest values on record with an ex-vessel value down by $117 million from 2022 values to $188 million. Only 2020 was lower in recent history.

In 2024, shorebased processors and direct marketers processed just 151 million pounds of seafood in the region, with a wholesale value of $379 million, a 50% decline in value as 106 million fewer pounds of seafood were processed compared to 2022.

In 2024, the five salmon species represented 69% of the regional seafood catch by pounds landed, and slightly less than half the overall value (45%). Halibut, black cod, crab, and the dive fisheries accounted for just 13% of pounds landed, but were 43% of the total harvest value.

Southeast Fishermen Decline



In the last decade, the number of resident Southeast fishermen who fished dropped by nearly 600 fishermen, a 28% decline. In 2024, the region had fewer than half the fishermen it had in 1980, fundamentally reshaping the regional economy.

The regional seafood industry generated 3,109 annualized regional jobs and $216 million in earnings in 2024, making up 7% of earnings and jobs in the region.

The 2024 Southeast Catch
Compared to the 2022 Catch in Millions

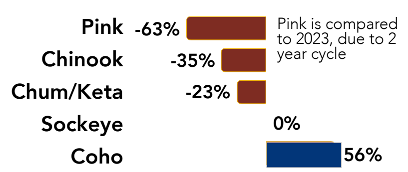
Species	2022 Pounds Landed	2024 Pounds Landed	2024 Catch Value	22-24 Change in Value
Pink Salmon	57.8	53.9	$17.1	-45%
Chum Salmon	50.6	72.2	$38.8	-35%
Herring	51.3	26.1	$4.1	-51%
Black Cod	16.9	15.4	$33.7	-38%
Halibut	8.6	7.5	$35.7	-32%
Coho Salmon	7.4	7.3	$10.1	-22%
Sockeye Salmon	6.7	3.7	$6.5	-53%
Crab	3.5	3.5	$14.1	-12%
Chinook	3.1	2.1	$11.4	-35%
Geoduck, Sea Cucumbers, Urchins	2.0	2.2	$12.3	38%
All Other	5.7	6.5	$4.4	23%
Pounds	**213.5 million**	**200.3 million**	**$188.3 million**	**-$117 million**

Seafood Industry Problem

Southeast Alaska's seafood values have been at historic lows. Since 2020, Southeast Alaska fishermen have faced low seafood earnings due to a perfect storm of global and US market pressures. The pandemic sharply reduced demand as restaurant closures—where most Americans consume seafood—erased a key market, while significant global salmon harvests created a glut that drove prices down. Excess inventory from these oversupplied seasons carried over, continuing to suppress prices.

2025 The 2025 harvest-to-date is down from 2024, which was already a low catch year. ASMI's August 2025 update is below:

SE Salmon Catch: 2024 vs. 2025
Year over year: week 32



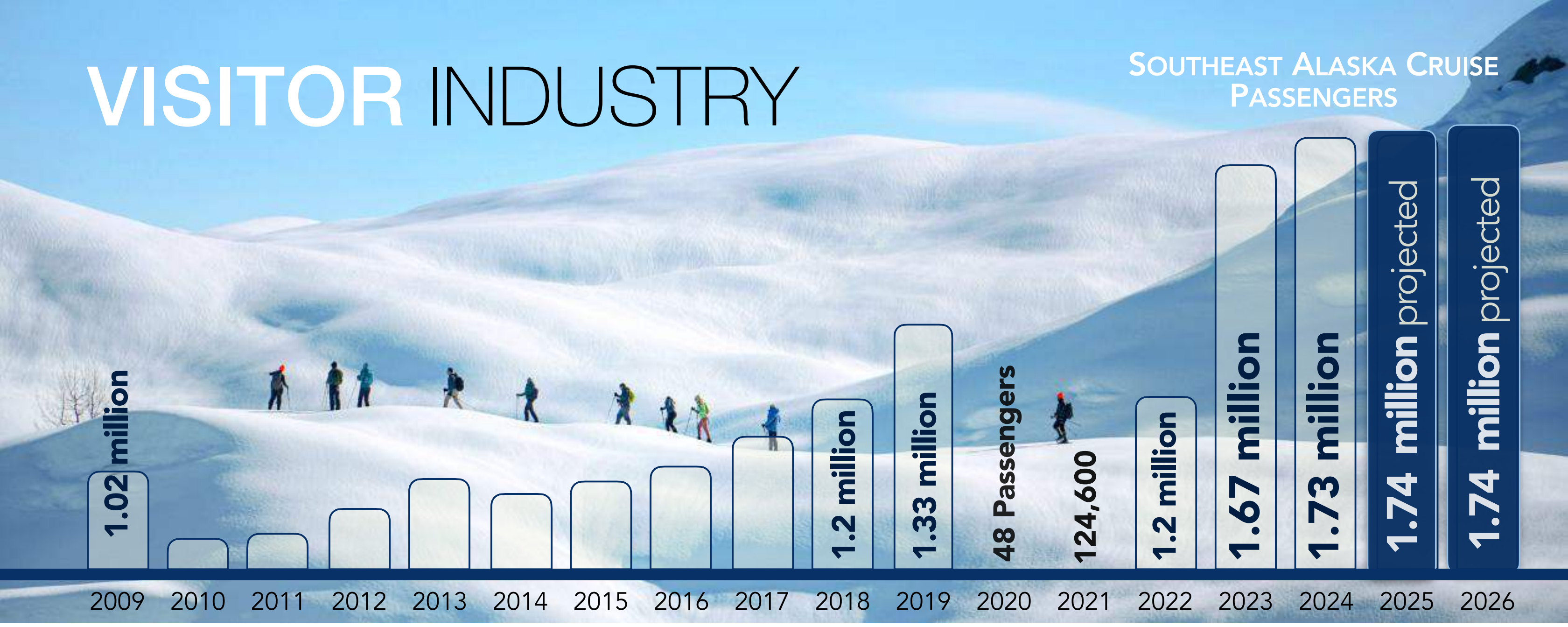
The silver lining is that as inventory declines, prices are rebounding. However, tariffs could significantly disrupt Southeast Alaska's export-dependent model, undermining its global competitiveness.

"The seafood industry continues to face headwinds. Uncertainty in the market with unknown impact of tariffs will have downward pressure on ex-vessel value. We continue to face increasing costs of doing business (insurance, fuel, parts, moorage, labor, etc). As harvesters, we have nowhere to pass those additional/increasing costs on to, all while we are getting paid less per pound than we were decades ago."

-Business Climate Survey Respondent 2025.

Sources: Combination of ADOL Employment and Wage data; US Census Nonemployer (self-employment) Statistics; ADF&G Seafood Production of Shorebased Plants in Southeast Alaska; ADF&G Southeast Alaska Commercial Seafood Industry Harvest and Ex-Vessel Value Information; Alaska Commercial Salmon Harvests and Ex-vessel Values, ADF&G. Weekly Alaska Salmon Harvest Updates are produced for ASMI by McKinley Research. **Seafood Industry** includes animal aquaculture, fishing, & seafood product preparation and Southeast Alaska resident commercial fishermen (nonresident fishermen & crew who did not report income are excluded). **Photo by Chris Miller: Cross Sound Trolling.**

VISITOR INDUSTRY



Visitor Industry

8,589 Annualized Jobs
$367 Million in Wages in 2024

JOBS UP 6% +494 IN 2024
EARNINGS UP BY 9% +$29M

2024 More than 2.2 million passengers arrived in Southeast Alaska by air, ferry, and cruise ship in 2024.

RECORD BREAKING VISITOR SEASON

The 2024 season's 1.73 million cruise ship passengers marked a new regional record. Cruise passenger numbers grew by 62,500 passengers, a 4% increase from 2023. Airline passengers increased by nearly 10,000 passengers, a 2% increase, setting a record for the third year in a row. Use of the ferry by tourists decreased again in 2024, with 11% fewer visitors arriving via ferry.

The visitor sector was the region's top economic sector, both in terms of jobs and wages, for the second year in a row. In 2024, visitor sector wages grew by $29 million, representing a 9% increase. Those working in the visitor industry earned $367 million in 2024, comprising 13% of all regional employment income. Jobs increased by 6% as nearly 500 new year-round-equivalent jobs were added, so that tourism jobs represented 19% of all annualized employment. Klawock became Southeast's newest cruise ship port.

2025 Tourism business leaders reported a strong 2025 economic climate with 68% calling the business climate good or very good for their business – down from 81% a year earlier. Nearly a third (31%) expected their business operations to be even stronger moving into 2025 and 2026.

OUTLOOK FOR 2025

The 2025 tourism season is shaping up to closely mirror 2024. Cruise ship volumes remain strong. By the end of summer 2025, ships are expected to carry a new record of 1,737,400 passengers–just above the 1,732,000 recorded in 2024 (note: these figures were revised upward to include non-revenue passengers).

Some operators have reported reduced independent and international travelers, primarily due to weakened Canadian and European markets. However, these segments represent a small share of total visitor volume. Tourists appear increasingly price-sensitive as consumer spending softens across the U.S. Additionally, inclement early-season weather reduced participation in high-end excursions, which contributed to lower visitor spending for some. However, others are reporting record spending.

"Our numbers are up from last year. Our businesses are heavily staffed and running very smoothly this season."
-Tourism business leader in August 2025

WORKFORCE AND HOUSING CHALLENGES

With a record number of visitor sector jobs in the region, attracting and housing a sufficient workforce remains a critical challenge. In the 2025 business climate survey, 80% of tourism employers said the lack of available and lower-cost housing directly deters potential hires and contributes to employee turnover. In a separate Visitor Industry Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, tourism leaders identified limited housing as the sector's top weakness, workforce housing development as the greatest opportunity, and housing shortages as the most significant threat (see page 14.)

JET PASSENGERS

In the first half of 2025 total air passenger arrivals for the region was 2% above 2024 levels, paving the way for a 4th year of record deplaning airline passengers.

2026 **SIMILAR-SIZED CRUISE SEASON EXPECTED IN 2026**

Looking ahead to 2026, regional cruise ship passenger volumes are expected to be comparable to the previous two years. Local governments such as the City and Borough of Juneau (CBJ) have collaborated with cruise lines on passenger management strategies aimed at constraining growth. In 2024, CBJ implemented a five-ship-per-day limit, eliminating hot berthing. Beginning in 2026, new daily passenger caps—16,000 on weekdays and 12,000 on weekends—will take effect. Additionally, the 2026 cruise season will be shorter, beginning in late April and ending in early October. Due to these changes, not all cruise ships will stop in Juneau in 2026, which has historically been the norm. Royal Caribbean will be moving several port calls to Ketchikan.

Sources: CLIA Alaska & Cruise Line Agencies of Alaska. Combination of ADOL Employment and Wage data and US Census Nonemployer (self-employment) Statistics; US Bureau of Transportation Statistics (RITA); Alaska Marine Highway System; Juneau International Airport Passenger Statistics; Juneau Docks & Harbors capacity figures. **Note:** In this analysis, the visitor industry includes leisure and hospitality businesses, along with air, water & scenic transportation companies. **Photo by UnCruise Adventures: Snowshoeing in Glacier Bay.**

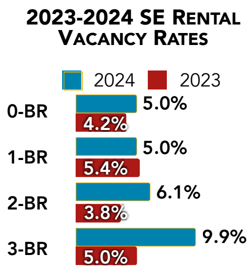
Housing Indicators

A lack of housing represents the region's greatest economic problem, maintaining an artificial lid on the economy by keeping potential workforce from moving to the region, and young people from staying in the region. Southeast has 30,500 occupied housing units.

New Housing: In the past 10 years, Southeast communities added more than 2,235 new housing units, an 8% increase, and increased total occupied housing units by the same amount.

Growth in Single-Person Households: Counteracting these gains is the rise of single-occupancy households — growing from 8,300 to 10,300 over the last decade — erasing most of the newly added housing inventory. This is primarily due to residents aged 65 and older, a segment that is more likely to live alone, generating 1,600 additional single-occupancy households in the past ten years (from 2,240 households to 3,900 senior living-alone households). The result: more homes are now needed to house fewer people.

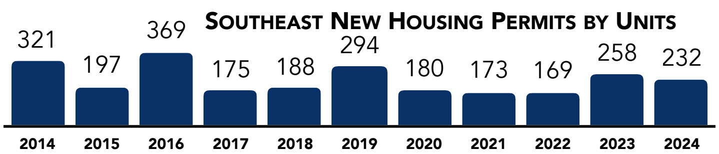
Rental Housing: The region has approximately 10,300 rental units. The overall rental vacancy rate was 6.1% in 2024, an improvement over 4.5% in 2023. A healthy vacancy rate is considered to be about 8%. Three-bedroom rental units now exceed that with a 9.9% vacancy rate — perhaps indicating fewer families are moving to or staying in the region. The median adjusted rent in Southeast Alaska was $1,441 in 2024, a 12% increase over 2022. Sitka saw the lowest increase at 4%, while Ketchikan rents increased by 18.5%.



Short-Term Rentals: Use of short-term rentals, like Airbnb and Vrbo, have risen by 1% from 979 active listings in the summer of 2024 to 991 active listings in July of 2025. Just 115 of these regional listings are available all or most of the year, making the overall impact on the housing market relatively low.

Housing Values: Over the last decade, the average value of a single-family home has increased at a rate slightly lower than inflation.

Housing availability has also been exacerbated by flooding and landslide events in recent years.



Construction Industry

1,951 Annualized Jobs in 2024

$163 Million in Wages

Jobs Down 1% -27

Earnings up by 4% +$6.5M

2024 Construction employment was down in 2024. Construction jobs decreased by 1% (27 jobs), while wages grew by 4%. Construction workers in the region earned $163 million, representing 6% of all regional workforce earnings in 2024. Early data shows construction jobs were flat in the first half of 2025.

2025 According to the 2025 business climate survey, optimism among construction and engineering business leaders fell by 14%. Respondents anticipate rising material costs, supply chain disruptions, and persistent labor shortages. Tariffs and inflation are expected to further elevate expenses for materials and freight, potentially affecting project feasibility. Reductions and delays in government infrastructure funding may result in project cancellations. Recruitment, particularly of skilled labor, is expected to remain challenging. The Statewide Transportation Improvement Program (STIP)—Alaska's four-year plan for federally funded transportation projects—has faced approval delays and funding shortfalls, likely slowing or postponing construction in Southeast Alaska, reducing near-term work for contractors, and constraining the longer-term pipeline of projects. While steady residential construction is expected in some communities, the overall sector will likely face constraints from economic uncertainty, regulatory obstacles, and high operational costs.

"I am very concerned about tariffs raising the cost of construction materials. Construction is already extremely expensive in our area and a lack of contractor confidence in pricing stability is going to raise bid pricing. Uncertainty is bad for business."

-Business Climate Survey Respondent 2025.

Sources: ADOL Quarterly Alaska Housing Unit Survey, a survey of local governments and housing agencies; US Census; Zillow; Air DNA. Combination of Alaska Department of Labor Employment and Wage data and US Census Nonemployer (self-employment) Statistics; State of Alaska.

Photography credit: City and Borough of Wrangell.

Kensington Mine

PeaceHealth

Mining Industry

1,062 Annualized Jobs in 2024

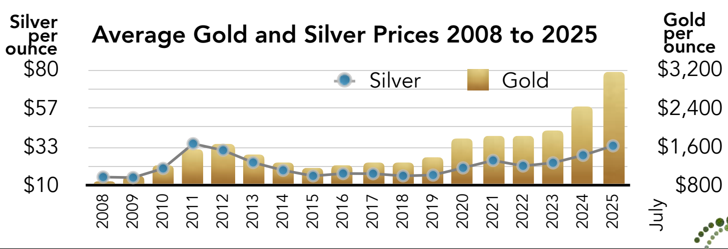
Up 1 Job in 2024, Wages up by 5%, +$7M

2024 Total mining jobs in Southeast remained steady in 2024, while wages were up by 5%. The average annual mining wage was $132,837 in 2024 — more than twice the overall regional wage of $63,238. There are three operating mines in the region.

- **Hecla Greens Creek** is one of the largest silver mines in the world and has been in production since 1989. In August 2025, Hecla Greens Creek employed 530 full-time permanent workers (+10 from 2024) and continues to ramp up production and employment. Greens Creek is the largest private sector employer in Juneau as well as the highest taxpayer. In 2024, Greens Creek produced 8.5 million ounces of silver, a 13% decline from 2023. Greens Creek has several large capital projects planned in the coming years, bringing above-average investment to regional contractors and businesses that support the mine.
- **Coeur Alaska's Kensington** gold mine began operations in 2010. Kensington produced 95,671 ounces of gold in 2024, a 13% increase from 2023. In 2025, Kensington employed 395 full-time permanent staff (+26 from 2024).
- **Dawson** is a smaller gold and silver project on Prince of Wales. Dawson Mine reported 48 full-time workers in 2024.

Additional mining exploration projects are active in the region, including the Palmer Project in Haines, Herbert Gold in Juneau, and both Bokan Mountain and Niblack on Prince of Wales.

The outlook for mining in the region is very positive, driven by high metals prices. Gold and silver surged in 2025, rising 29% and 35% respectively since the start of the year. Gold reached a new peak of over $3,400 per ounce in 2025.



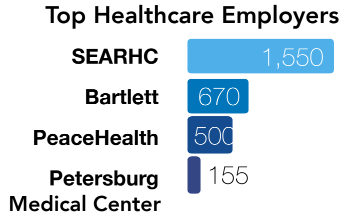
Health Care Industry

3,889 Annualized Jobs in 2024

$315 Million in Wages

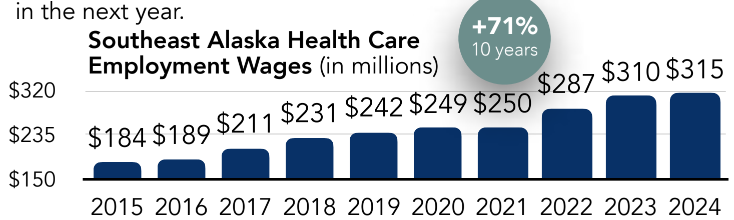
Jobs up 6, Wages up by $4.6 million

2024 Southeast Alaska's nearly 3,900 public and private healthcare workers made up 8.5% of the regional workforce in 2024, earning 11% of all wages, or $315 million. Despite growing demand driven by an aging population and rising visitor numbers, the region added just six healthcare jobs in 2024. Providers have repeatedly raised wages to compete for staff, contributing to a $131 million (71%) increase in total healthcare wages over the last decade.



Four institutions employ three-quarters of the region's healthcare workers. The SouthEast Alaska Regional Health Consortium (SEARHC), the largest provider, employed 1,550 staff across 16 communities in 2024. Bartlett Regional Hospital in Juneau employed 672; PeaceHealth, serving Ketchikan and Prince of Wales, employed about 500; followed by Petersburg Medical Center with 155 workers.

Southeast Alaska's healthcare system faces uncertainty as federal reductions to Medicaid coverage threaten to reduce hospital revenues, putting some residents at risk of diminished access to local care. The Rural Health Transformation Fund may offset these losses, but the overall impact remains unclear, as Medicaid coverage losses are expected to begin affecting 2,700 residents in the region in 2027. But no major changes are coming to healthcare in the next year.



Sources: Combination of Alaska Department of Labor Employment and Wage data and US Census Nonemployer (self-employment) Statistics; State of Alaska; Kitco Metals Inc; Coeur Mining Inc. Annual Report; Hecla Mining Company Annual Report.

GOVERNMENT

Government

13,008 Annualized Jobs in 2024

Jobs Up 230 in 2024
Wages up by 4%, $33 million

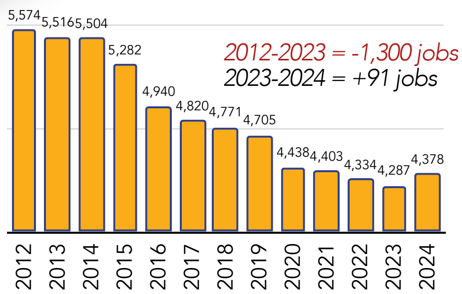
2024 Government workers accounted for 28% of Southeast Alaska's jobs (13,008) in 2024 and 32% of total regional earnings ($926 million). Public sector wages rose by $33 million in 2024, a 4% increase, while total government employment grew 2%.

State Government Jobs up for first time in 13 years

From 2012 to 2023, state government employment fell 23%, a reduction of nearly 1,300 positions—two-thirds of them in Juneau. In 2024, for the first time in more than a dozen year, state jobs increased by 91 across Southeast, and early 2025 data indicate this growth is continuing.

Southeast State Jobs

State jobs in the region are up for the first time since 2012



Federal Government

Federal employment in Southeast Alaska rose 1% in 2024 to 2,089 jobs, with total wages of $195 million. Early 2025 data indicate a decline as layoffs and incentivized retirements take full effect, reducing the region's federal workforce. These reductions are expected to impact communities reliant on federal jobs and services, including sectors like seafood that depend on federal research and regulatory support.

Businesses across the region report widespread uncertainty and concern over federal policy changes—tariffs, regulatory shifts, staffing cuts, and funding reductions. Businesses worry about potential rising costs, reduced consumer spending, and delays in federally funded projects. According to the business climate survey, nearly half (47%) of Southeast Alaska businesses expect negative impacts from federal changes, including 23% anticipating very negative outcomes (see page 12).

US Coast Guard

The federal job count includes 623 active-duty U.S. Coast Guard personnel, down 45 from the prior year. The recently commissioned USCGC Storis, the first new polar icebreaker in over 25 years, will be homeported in Juneau after port upgrades are completed. Full deployment with a 190-member crew is expected over the next several years, bringing a meaningful boost to the local and regional economy.

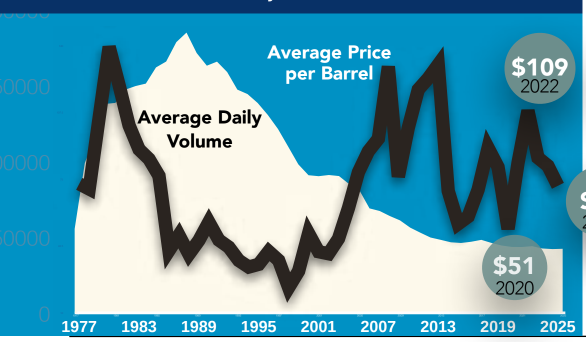
Local Government

Local governments added 36 jobs in 2024, reaching 5,126, a 1% increase, though early 2025 data show a slight decline. Nearly 2,000 local government employees (40%) work in K-12 education, and 15% are in public healthcare roles. Municipal staff also include firefighters, paramedics, police officers, water and wastewater operators, public works crews, airport and utility workers, and harbor staff.

Tribal Government Grows

Tribal government employment rose 6% in 2024 to 1,436 annualized jobs, with wages up 11% to $88 million. Over the past three years, tribal government jobs increased 29% and wages grew 50%. Tribal governments now account for 11% of all government jobs in the region and 3% of all Southeast Alaska employment and wages.

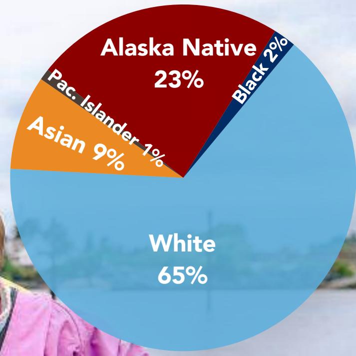
Avg. Daily Volume of the Trans Alaska Pipeline System and Inflation Adjusted Price Per Barrel, 1978-2025

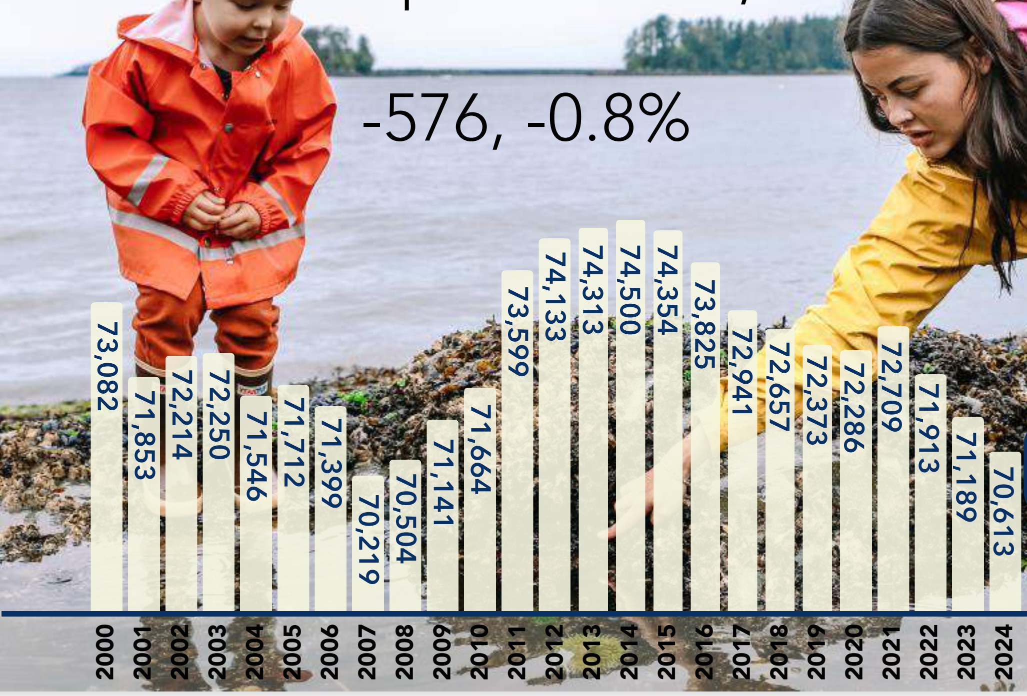


Sources: ADOL Employment and Wage data; Alaska Department of Revenue Crude Oil Prices. Alaska Office of Management Budget. Photo credit Governor Attends Sitka Graduation Ceremony by Austin McDaniel

DEMOGRAPHICS

Population 70,613





2024 The region's population declined again in 2024, falling by less than one percent to 70,613 residents — a loss of nearly 600 people, although 12 communities saw population gains.

School Enrollment

K–12 enrollment was down 3%, as student counts fell by 385 in 2024, for a 10-year loss of 1,200 students. Losses over the past decade were led by Juneau — down 16%, or 740 students — and Sitka, down 22%, a loss of 300 students. Six of the region's smallest school districts gained students over the decade: Craig, Hydaburg, Kake, Klawock, Skagway, and Yakutat.

Declining Youth and Workforce Aged Population

In the past ten years, the number of kids in the region decline by 2,200, while the 60+ population grew from 17% to 27% of total residents. The working-age population (ages 19–59) shrank by more than 5,500 residents, while total jobs decreased by just 400 — resulting in a growing gap between workforce supply and demand. If trends continue, the Alaska Department of Labor projects Southeast will lose another 5,000 children and 5,300 working-age residents by 2050.

Great Summer Job Market

In 2025, Juneau was named the 15th best city in the US for summer jobs (out of 182), highlighting the number high-quality seasonal work opportunities for young people in the region.

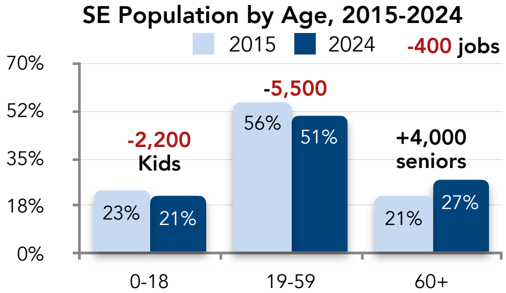
Workforce Residency

In 2023, 30% of workers were not eligible for a PFD, and thus considered nonresident. Non-Alaskans earned 20% of all regional wages. The highest share of nonresidents work in seafood processing (71%), while the sector with the highest resident share is utilities (91%).

Out Migration

In 2024, 660 more people moved away from Southeast Alaska than those who moved here, include about 250 from Juneau,150 from Sitka, and 100 from Ketchikan. Studies show that the primary reasons are housing scarcity and high housing costs.

SE Population by Age, 2015-2024



Population Change 2023 to 2024

Community	2023	2024	Change
Juneau Borough	31,616	31,436	-0.6%
Ketchikan Borough	13,505	13,420	-0.6%
Sitka Borough	8,203	8,063	-1.7%
Petersburg Borough	3,371	3,379	0.2%
Haines Borough	2,539	2,537	-0.1%
Wrangell Borough	2,044	2,030	-0.7%
Metlakatla	1,450	1,389	-4.2%
Skagway Borough	1,127	1,123	-0.4%
Craig	1,021	972	-4.8%
Hoonah	888	835	-6.0%
Klawock	695	734	5.6%
Gustavus	657	659	0.3%
Yakutat Borough	680	637	-6.3%
Kake	533	522	-2.1%
Thorne Bay	479	497	3.8%
Hydaburg	338	354	4.7%
Angoon	344	350	1.7%
Coffman Cove	193	209	8.3%
Hollis	145	155	6.9%
Naukati Bay	131	125	-4.6%
Tenakee Springs	124	123	-0.8%
Whale Pass	91	96	5.5%
Pelican	90	89	-1.1%
Klukwan	87	84	-3.4%
Port Alexander	51	63	24%
Kasaan	50	45	-10%
Edna Bay	49	44	-10%
Hyder	47	42	-11%
Elfin Cove	38	41	7.9%
Port Protection	36	31	-14%
Game Creek	18	16	-11%
Point Baker	10	11	10%
Remainder	539	502	-6.9%
Total	**71,189**	**70,613**	**-0.8%**

Sources: Alaska Department of Labor (ADOL); ADOL Southeast Alaska Population by Age, Sex and Borough/Census Area; Alaska Population Projections; US Census. WalletHub. Nonresidents Working in Alaska (ADOL).

Jobs by Community

Looking at all communities across Southeast in 2024, job counts were up in nearly every community compared to 2023.

The largest 2023 to 2024 job gains percentage-wise included **Skagway** (+12%), **Hoonah** (+7%), and **Sitka** (+5%). Three communities experienced job losses in 2024 compared to 2023: **Yakutat, Angoon**, and **Hyder.**

Wages were up in most communities, and six saw half saw double digit wage increase percentages. The largest increases in total wages were seen in **Klukwan** (+24%), **Haines** (+15%), **Hoonah** (+13%), **Skagway** (+12%), and **Kake** (+12%).

Regional job rates are above 2019 levels with some notable exceptions, including Ketchikan, Petersburg, Wrangell, and Prince of Wales.

Approximately half of all regional jobs (48%) and wages (52%) are in **Juneau**.

Note: *This analysis* ***excludes self-employment data****, which is not made available below the borough/census area level. Still, monitoring change in labor figures is an important way to track overall workforce changes in a community.*

Annual Employment Change by Community 2023 to 2024

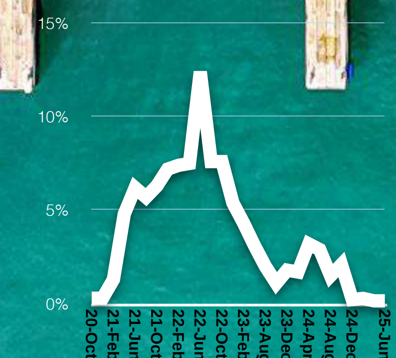
Community	2023 Annual Average Employment	**2024 Annual Average Employment**	2023 Wages in millions	**2024 Wages in millions**	**Employment Change 2023-2024**	**Wage Change 2023-2024**
Juneau	17,722	**18,036**	$1,171	**$1,232**	**2%**	**5%**
Ketchikan	7,281	**7,350**	$432.6	**$456.8**	**1%**	**6%**
Sitka	4,341	**4,550**	$265.1	**$277.5**	**5%**	**5%**
Prince of Wales	1,436	**1,441**	$73.0	**$77.1**	**0%**	**6%**
Petersburg	1,253	**1,265**	$67.4	**$68.4**	**1%**	**2%**
Haines	1,017	**1,046**	$46.9	**$53.8**	**3%**	**15%**
Wrangell	749	**778**	$41.3	**$44.3**	**4%**	**7%**
Skagway	1,017	**1,138**	$54.9	**$61.3**	**12%**	**12%**
Metlakatla	493	**508**	$27.9	**$28.8**	**3%**	**3%**
Hoonah SSA	520	**557**	$26.5	**$29.9**	**7%**	**13%**
Yakutat	340	**333**	$21.9	**$20.6**	**-2%**	**-6%**
Gustavus SSA	279	**282**	$14.7	**$16.2**	**1%**	**10%**
Kake	166	**170**	$6.1	**$6.8**	**2%**	**12%**
Angoon SSA	134	**132**	$4.7	**$4.8**	**-2%**	**2%**
Hyder	42	**40**	$2.6	**$2.5**	**-5%**	**-3%**
Klukwan	54	**55**	$1.3	**$1.6**	**2%**	**24%**

Source: Alaska Department of Labor and Workforce Development, Research and Analysis Section.
Notes: A sub-subarea (SSA) is the smallest unit for which the Quarterly Census of Employment and Wages is analyzed. The Hoonah SSA includes Pelican and Elfin Cove. The Angoon SSA includes Tenakee Springs. Prince of Wales includes the Hollis, Thorne Bay and Hydaburg SSAs.

Southeast Alaska GDP 2023 = $5.9 billion Change 2022 to 2023 = 6%

Source: BEA

Alaska Inflation 2020 to 2025: % change by year



Source: BLS

Alaska Marine Highway Southeast Ridership

2% increase in AMHS service 2023-2024

Source: AMHS

Photography credit: City and Borough of Wrangell

SOUTHEAST ALASKA REGIONAL OVERVIEW

VIRTUALLY ALL OF THE REGIONAL LAND BASE IS FEDERAL. THE FEDERALLY-MANAGED TONGASS NATIONAL FOREST MAKES UP NEARLY 4/5TH OF ALL SOUTHEAST ALASKA LANDS.

Southeast Alaska Land Ownership
Circle size = Number of Acres

78% TONGASS

94% FEDERAL LANDS

16% OTHER FEDERAL HOLDINGS MAKE UP NEARLY ALL THE REST (MOSTLY GLACIER BAY)

3.4% ALASKA NATIVE ORGANIZATIONS ARE THE REGION'S NEXT LARGEST LANDOWNER

2.5% STATE OF ALASKA LANDS INCLUDE THOSE MANAGED AS PART OF THE MENTAL HEALTH TRUST

0.25% MUNICIPAL LAND HOLDINGS

0.05% PRIVATE LANDOWNERS

Sources: State of Alaska; US Forest Service; Sealaska. *Economies in transition: An assessment of trends relevant to management of the Tongass National Forest, USDA 1998. Image Credits: Mike Dangeli and George Nickerson*

THE REGION

The Southeast Alaska panhandle extends 500 miles along the coast from Metlakatla to Yakutat, encompassing approximately 33,500 square miles of land and water. The saltwater shoreline of Southeast Alaska totals approximately 18,500 miles. More than 1,000 islands make up 40 percent of the total land area. The region is home to 34 communities. The three largest communities – Juneau, Ketchikan, and Sitka – together are home to 75 percent of the regional population.

CULTURE

The dominant culture in the region is Indigenous. Alaska Natives, predominantly the Tlingit, Haida, and Tsimshian, make up 23% of the region's population. Alaska Natives have resided in the region for at least 11,000 years. The region's mild climate, abundant food sources, and raw materials supported the development of highly organized, culturally advanced societies, with extensive trade networks and a rich artistic legacy. Alaska Native Culture and Heritage was ranked as the region's number one economic strength by more than 400 business leaders in 2024 (see page 14).

ECONOMIC TRENDS

Beginning in the 1880s and accelerating after statehood in 1959, Southeast Alaska experienced a century of economic growth. From statehood into the 1990s, the region's population and employment more than doubled, with growth concentrated in mining, government, tourism, and especially timber and fishing. But in the early 1990's, pulp mills and sawmills closed, laying off 3,200 workers. The population declined through 2007. In 2008 the region experienced an economic recovery, reaching record highs in jobs, wages, and population by 2015. In 2020 the economy was devastated when the pandemic wiped out 6,000 jobs, all but 350 of which were recovered by 2025.

The Southeast economy of 2025 is an economy in transition. In the past decade and a half, the region lost 1,200 State jobs (-21%) and 600 local commercial fishermen (-29%), while doubling mining employment (+530 jobs) and adding 2,700 annualized tourism jobs (+46%). Total jobs and wages are up, but population is down. Housing has become the region's most significant economic constraint, driving away workers and young families even as workforce needs continue to grow.

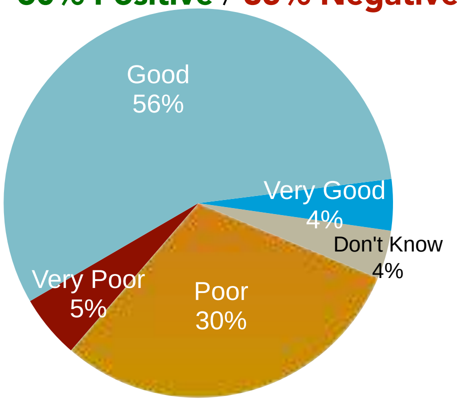
LAND OWNERSHIP

A major constraint for economic development in Southeast Alaska is the scarcity of privately owned or accessible land (see infographic on the left.) Federal lands dominate the region, accounting for 94% of the land base, most of it is within the Tongass National Forest (78% or 16.7 million acres). The rest is largely in Glacier Bay National Park. Alaska Native organizations — including village, urban, and regional corporations, as well as the Annette Island Reservation — own 3.4% of the land base (728,100 acres). The State of Alaska manages 2.5% (511,500 acres). Local governments own 53,000 acres, or just 0.25% of the regional land base. Privately owned non-Native land makes up only 0.05% of the total regional land base.

SOUTHEAST **ECONOMIC OUTLOOK** SURVEY

"How do you view the overall **business climate** right now?"

60% Positive / 35% Negative



Declining Business Climate

2025 In April 2025, 422 Southeast Alaska business owners and top managers responded to Southeast Conference's Business Climate Survey.

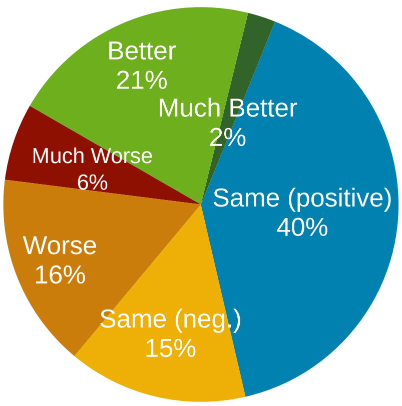
Three-fifths (60%) have a positive view of the Southeast business climate — a 13% drop from two years ago, and a 7% decline from 2024.

Leaders of **Alaska Native and mining organizations** were the most positive about the business climate. Business leaders in **Sitka**, **Yakutat**, **Prince of Wales**, and **Skagway** reported the most positive business perspectives.

The **timber** and **energy** sectors were most likely to rate the 2025 economy as poor or very poor, along with business leaders in **Gustavus** and **Wrangell**.

"What is the **economic outlook** for your business or industry over the next year (compared to the previous year)?"

63% Positive / 37% Negative



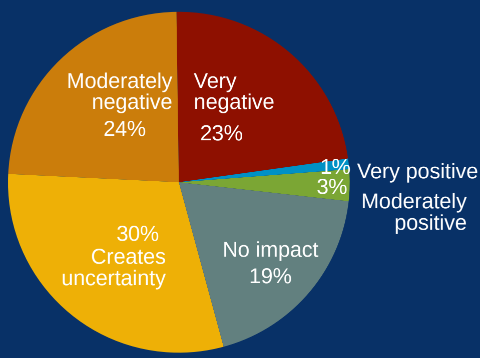
The Outlook is Declining

Business leader optimism about the future is falling. Nearly a quarter (23%) of respondents expect their prospects to be better or much better over the next year, with an overall positivity rating of 63% — a 16% drop from two years earlier.

Outlooks were the most positive in the **financial activities** and **real estate** sectors. Among communities, **Sitka**, **Ketchikan**, and **Skagway** had the most optimistic forecasts, while business leaders in **Gustavus** and **Haines** were the most pessimistic.

Expected **Federal Impacts** on Businesses

When asked about expected business impacts from federal changes (e.g., tariffs, executive orders, regulatory or staffing shifts), nearly half (47%) of Southeast Alaska businesses said they expect negative impacts on their sectors, including 23% who anticipate very negative effects. Just 4% expect positive impacts.



Retention & Turnover: "How do these factors impact worker attraction & retention?"

Lack of Housing Continues to Create Workforce Shortages for Regional Businesses

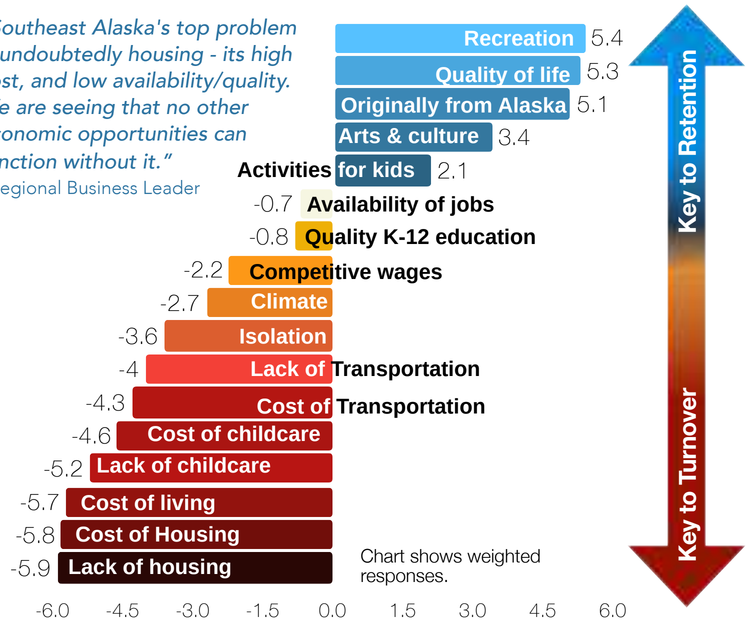
Southeast Alaska business leaders were asked to assess the impact of various factors on workforce attraction, retention, and turnover.

Most (79%) said that **housing availability** and **housing costs** cause staff to leave or decline job offers — including 53% who called it a significant factor contributing to staff shortages. Nearly as many (73%) said **childcare availability** is limiting their ability to hire or retain workers, including 32% who identified it as a significant barrier.

On the positive side, regional employers say that workers are attracted to Southeast jobs — or are more likely to stay — due to the region's **recreation opportunities**, **high quality of life**, and because they are originally from here. Eighty-two percent of business leaders said that access to high-quality recreation leads to workers moving to or remaining in the region, including 46% who called it a significant factor.

"Southeast Alaska's top problem is undoubtedly housing - its high cost, and low availability/quality. We are seeing that no other economic opportunities can function without it."

- Regional Business Leader



A Message from **Southeast Conference**

Executive Director **Robert Venables**

Rooted in Resilience is this year's annual meeting theme. Definitions of resilience range from the ability to adapt, recover from setbacks, maintain well-being, and above all, remain calm. For our region and State, it has been all of the above. We have seen unprecedented investment in recent years and now our economy seems surrounded by uncertainty and change. While much has been accomplished in the past year, there is more work to be done.

What will guide our work over the next five years is the newly released **2030 Comprehensive Economic Development Strategy** (CEDS). It is a strategy-driven blueprint developed over the past year by over 400 people representing small businesses, Alaska Native organizations, municipalities, Tribes and NGOs (see page 15 for a summary).

It is gratifying to see how effective the CEDS has been over the last five years. I invite you to check out the amazing work of the Alaska Mariculture Cluster and progress made to accelerate mariculture to an industry status. Also, the opportunity to utilize renewable energy resources for beneficial electrification and the installation of over 6,000 heat pumps between Ketchikan and Kodiak is a game-changer for households and communities.

Our population may shift and shrink, but what hasn't changed is our collective resolve to work together on the needs and opportunities before us. From modernizing our ferry system and fisheries to natural resource development and housing and childcare, our community and business leaders are committed to developing solutions that will enhance the economic sustainability of our region and position Southeast Alaska as an economic leader in the global economy.

Southeast Conference will continue to work hard to create place-based economies with community scale solutions that will lower the cost of living to consumers while raising the quality of life. That is our mission: supporting activities that promote strong, vibrant economies, sustainable communities and a healthy environment in Southeast Alaska!

Incoming President **Katie Koester**

Katie Koester is the City Manager for the City & Borough of Juneau

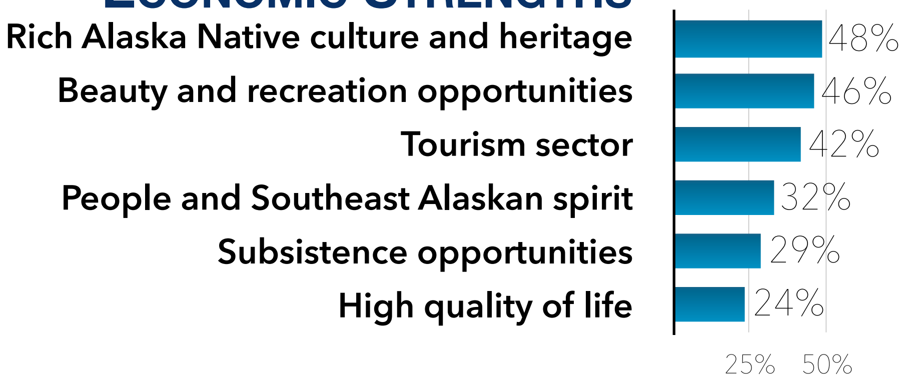
I was called to Southeast Alaska. Years of serving as a seasonal legislative staffer opened my eyes to the secret sauce of epic landscapes, respect for the Tlingit, Haida and Tsimshian people, and harmonious blend of different economic sectors. I moved my family to Juneau permanently in 2020 when I became the Engineering and Public Works Director for the City and Borough of Juneau. Fall of 2023 I was appointed City Manager.

For me Juneau is the big City - sophisticated with history and a sense of place. I grew up in Homer, a small coastal Alaskan town that thrives on commercial fishing and tourism. My dad ran an outboard mechanic shop out of our back yard and my mom worked part time at the school district exclusively for health insurance. I know the struggle of a small business to be your own boss, bookkeeper, and marketer - you never get a day off. Dad spent his days making "harbor calls" to trouble shoot a charter captain's engine problems or traveling by float plane to fix an outboard on a seiner's skiff because they couldn't be slowed down in the middle of a set. I was drawn to public service because I saw how important infrastructure is to keeping businesses running - harbors to launch from, docks to receive goods, roads to deliver those goods and airports to take off from. Government provides basic infrastructure and essential systems for business to prosper. Our communities thrive when government and industry work together.

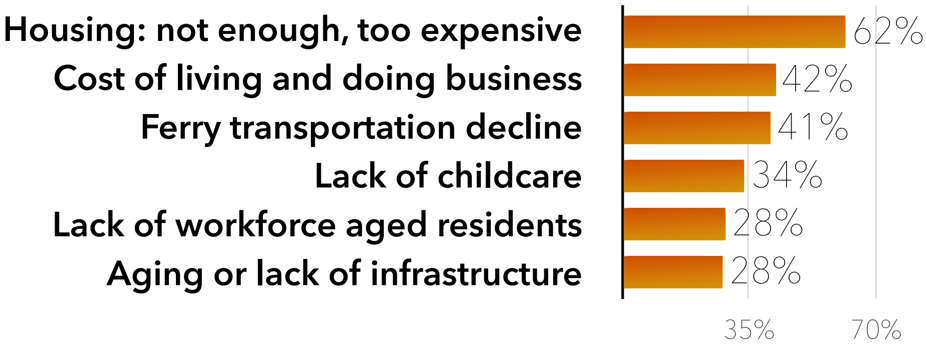
That is what is so beautiful about Southeast Conference! It brings us together in innovative ways to improve our communities. At our annual meetings, fly ins, and committees we build relationships that are leveraged to create new opportunities for our people. As an organization - Southeast Conference is doing amazing things in mariculture, transportation and small business support. It is a tremendous honor to serve this organization and be a small part of the success that is all of us coming together to work towards the common goal of a healthy, vibrant and sustainable Southeast Alaska.

The mission of Southeast Conference is to **undertake and support activities that promote strong economies, sustainable communities, and a healthy environment in Southeast Alaska**. As the state- and federally-designated regional economic development organization, Southeast Conference serves as the collective voice for advancing the region's economy. Southeast Conference has 200 member organizations representing 1,200 people from 32 regional communities. Southeast Conference started 67 years ago with a group of people supporting the establishment of a regional transportation system, leading to the formation of the Alaska Marine Highway System. Its members stayed together through more than a half-century of change to focus on concerns unique to the region.

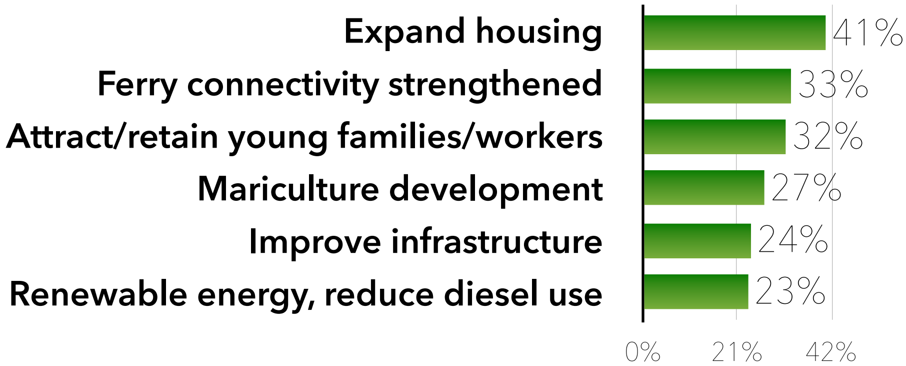
Economic Strengths



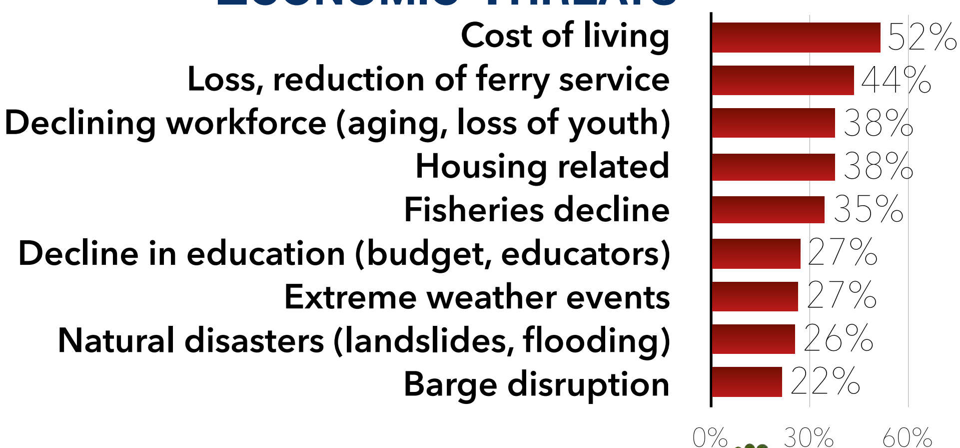
Economic Weaknesses



Economic Opportunities



Economic Threats



2030 Economic Plan Development

Every five years Southeast Conference develops a five-year economic plan, which includes engaging more than 400 regional leaders in a strengths, weaknesses, opportunities, and threats (SWOT) analysis for Southeast. The overall regional SWOT is on the left, and the sector specific SWOTs are below.

Seafood

- *Top Strength*: **High quality product**
- *Top Weakness*: **High costs**
- *Top Opportunity:* **Increase value-added processing**
- *Top Threat:* **Low seafood prices**

Visitor Industry

- *Top Strength:* **Natural beauty of region**
- *Top Weakness*: **Limited seasonal housing**
- *Top Opportunity:* **Workforce housing development**
- *Top Threat:* **Housing shortages**

Transportation

- *Top Strength:* **Connecting communities**
- *Top Weakness*: **Lack of qualified workforce**
- *Top Opportunity:* **Improve ferry service**
- *Top Threat:* **Demise of AMHS**

Energy

- *Top Strength:* **Abundant hydropower**
- *Top Weakness*: **High costs of infrastructure**
- *Top Opportunity*: **Heat pump installation**
- *Top Threat:* **Inadequate workforce**

Mining

- *Top Strength*: **Provides high paying jobs**
- *Top Weakness*: **Extreme opposition by environmental groups**
- *Top Opportunity:* **Explore and develop new mineral deposits and expand existing mines**
- *Top Threat:* **Anti-mine advocacy**

SOUTHEAST **2030 STRATEGIC PLAN** SUMMARY

In 2025, Southeast Conference released the Southeast Alaska 2030 Economic Plan, a five-year strategic plan for the region - also known as a Comprehensive Economic Development Strategy. The membership worked together to develop an overall vision statement, 45 objectives, and 7 priority objectives, along with regional and industry specific SWOT analyses. More than 400 people representing small businesses, tribes, Native organizations, municipalities, and nonprofits were involved in various elements of the planning process. The Plan's prioritized objectives are listed below.

Economic Development

1. ★ **Housing objective:** Support the sustainable development of housing *#1 Plan priority*
2. ★ **Childcare objective:** Increase childcare capacity in Southeast Alaska
3. **Infrastructure maintenance**
4. **Education objective:** Partner with University of Alaska Southeast and K-12 school districts to build career pathways
5. **Workforce attraction and retention objective**
6. **Coast Guard Objective:** Support Coast Guard vessel homeporting opportunities
7. **Natural disaster planning objective:** Support disaster preparation and relief efforts
8. **Solid waste objective:** Support regional solid waste management solutions
9. **Healthcare workforce objective**
10. **Telecommunications objective:** Improve communications access in Southeast Alaska
11. **Manufacturing objective:** Promote regionally-manufactured local products
12. **Food security objective:** Increase supply and distribution of local foods

Transportation

1. ★ **Support the stability, sustainability and longevity of the Alaska Marine Highway System**
2. Develop a long-term, strategic, multi-modal, regional transportation plan
3. Improve and expand opportunities to move freight to and from markets
4. Ports and harbors infrastructure improvements
5. Transportation workforce development
6. Ensure the stability and safety of passenger transportation services
7. Improve marine and road connection to Lower 48
8. Disaster resilient transportation infrastructure

★ = Priority Objectives

Seafood

1. ★ **Further develop markets for Alaska seafood**
2. ★ **Seafood modernization initiative**
3. Work to further promote a year-round seafood economy in the region
4. Full resource utilization and ocean product development
5. Mariculture development
6. Bring back seafood jobs to Southeast's smallest communities
7. Support access to capital for harvesters and processors
8. Maintain a stable regulatory regime

Natural Resources

1. Prepare for potential Chinook salmon listings
2. Work with USFS to direct federal contracts toward locally-owned businesses
3. Support an innovative, integrated timber industry
4. Attract capital investments, maintain global competitiveness
5. Provide an economically viable supply of timber from the Tongass to regional operators
6. Increase access to minerals and energy sources for mining on state and federal lands
7. Advocate for the regulators
8. Revise the Tongass National Forest Land Management Plan

Visitor Industry

1. ★ **Support local tourism ownership and entrepreneurship**
2. Workforce housing for visitors sector
3. Cultural tourism development
4. Collective regional strategy for accommodating tourism industry growth in Southeast

Energy Sector

1. ★ **Reduce energy costs and increase deployment of renewables**
2. Support consumer education on heat pumps
3. Policy and regulatory development to meet community energy needs and priorities
4. Continue to support PCE for rural communities
5. Biomass in energy

SOUTHEAST ALASKA

SOUTHEAST CONFERENCE

Southeast Conference Board

Zak Kirkpatrick – President
Ketchikan Assistant City Manager, Assistant KPU General Manager

Katie Koester – 1st Vice President
City Manager, City & Borough of Juneau

Gracia O'Connell– 2nd Vice President
Tongass Federal Credit Union Director, Ketchikan

Alec Mesdag – Treasurer
President and CEO, Alaska Electric Light and Power Company

Chelsea Goucher – Secretary
Ketchikan Agricultural Producers

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Climate change implications in the northern coastal temperate rainforest of North America

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Abstract We synthesized an expert review of climate change implications for hydroecological and terrestrial ecological systems in the northern coastal temperate rainforest of North America. Our synthesis is based on an analysis of projected temperature, precipitation, and snowfall stratified by eight biogeoclimatic provinces and three vegetation zones. Five IPCC CMIP5 global climate models (GCMs) and two representative concentration pathways (RCPs) are the basis for projections of mean annual temperature increasing from a current average (1961–

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1990) of 3.2 °C to 4.9–6.9 °C (5 GCM range; RCP4.5 scenario) or 6.4–8.7 °C (RCP8.5), mean annual precipitation increasing from 3130 mm to 3210–3400 mm (3–9 % increase) or 3320–3690 mm (6–18 % increase), and total precipitation as snow decreasing from 1200 mm to 940–720 mm (22–40 % decrease) or 720–500 mm (40–58 % decrease) by the 2080s (2071–2100; 30-year normal period). These projected changes are anticipated to result in a cascade of ecosystem-level effects including: increased frequency of flooding and rain-on-snow events; an elevated snowline and reduced snowpack; changes in the timing and magnitude of stream flow, freshwater thermal regimes, and riverine nutrient exports; shrinking alpine habitats; altitudinal and latitudinal expansion of lowland and subalpine forest types; shifts in suitable habitat boundaries for vegetation and wildlife communities; adverse effects on species with rare ecological niches or limited dispersibility; and shifts in anadromous salmon distribution and productivity. Our collaborative synthesis of potential impacts highlights the coupling of social and ecological systems that characterize the region as well as a number of major information gaps to help guide assessments of future conditions and adaptive capacity.

1 Introduction

The northern coastal temperate rainforest of southeastern Alaska and British Columbia is the largest contiguous coastal temperate rainforest in the world, and yet there is limited synthesized information on transboundary climate change implications (Fig. 1). Steep, sloping watersheds where average winter temperatures are within a few degrees of freezing (Simpson et al. 2005), drain the Coast Range into estuaries of the eastern Pacific Ocean. This sharp environmental gradient results in a high degree of climatic sensitivity and changes in ecological communities over relatively short distances, our understanding of which would benefit from increased interdisciplinary collaboration. This paper represents the synthesis efforts of 15 regional resource experts to identify important social and ecological implications in the context of a long-term climate modeling exercise.

The governing watershed dynamics in this ecoregion can be grouped into three general categories: glacial melt, snowmelt, or rainfall systems (Edwards et al. 2013; Fig. 2). In lowland forest streams, the annual pattern of watershed discharge tracks the annual pattern of precipitation. These watersheds are predominantly found on island provinces (sections 2, 4, 5, and 6 in Fig. 1). Snowmelt watersheds are characterized by a spring snowmelt peak, a summer discharge minimum and an autumnal flow peak. These watersheds can be found on central

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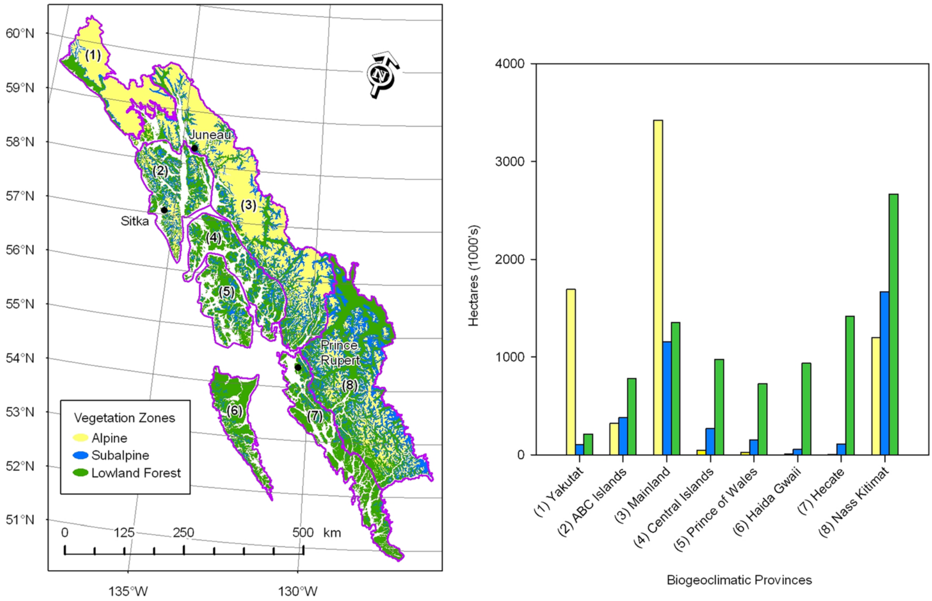

Fig. 1 A map of the study area with the eight biogeoclimatic provinces, three vegetation zones, and current habitat totals (ha) for the coastal temperature rainforest of southeast Alaska, USA, and northern coastal British Columbia, Canada

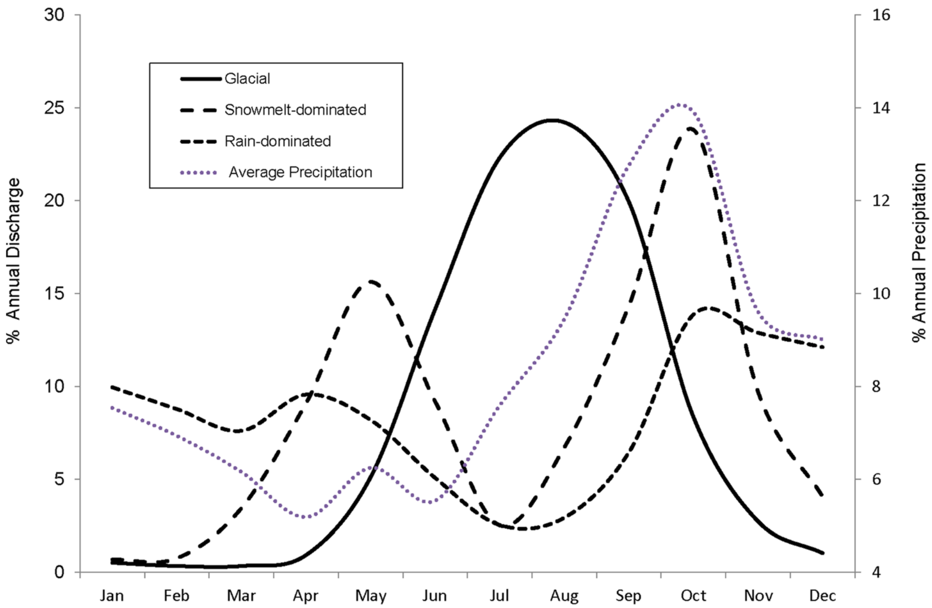

Fig. 2 Characteristic hydrographs for the three watershed types (glacial, snowmelt-dominated, and rain-dominated) in the coastal temperate rainforest of southeast Alaska and northern coastal British Columbia. Hydrographs are long term averages (30–60 years) from three individual representative streams in southeast Alaska, and are compared with long-term average precipitation in Juneau, Alaska, USA

parts of mountainous islands and in mainland provinces (1, 3, 7, and 8). Finally, high-elevation glacial watersheds export little water during winter and early spring, and have their main peak discharge during late spring to early fall. Glacial watersheds are found almost exclusively in mainland provinces (1, 3, and 8). Within this framework, a primary control on the timing and magnitude of stream flow is the proportion of the watershed that lies above the rain-snow transition zone, making the hydrology of this region particularly sensitive to changes in snowline elevation. For instance, water temperatures in rainfall dominated watersheds are 5–12 °C warmer during summer than snowmelt and glacial watersheds (Fellman et al. 2014).

Although species diversity is low relative to other rainforests globally, ecosystem productivity is extraordinarily high (Alaback 1996). For example, the total carbon stock in the forest and soils of the Tongass National Forest in southeast Alaska is 8 % of that in the conterminous United States (Leighty et al. 2006). Southeast Alaska (Halupka et al. 2003) and northern British Columbia (Temple 2005) contain a combined estimate of 7700 anadromous salmon streams with six Pacific salmonids (*Oncorhynchus* spp.). In southeast Alaska, salmon support an annual commercial and sport fisheries harvest of 30–70 million fish per year with a value estimated at $600 million to $1 billion (Waters 2010). Species distributions are consistent with island biogeography theory with a wide range of genetically isolated species or sub-species (Cook and MacDonald 2013). Rural human communities (approximately 50 % of the region's population) are isolated by waterways and steep terrain, and rely on ferry, barge, and plane services for transportation. These communities rely on ecosystem services related to fish, wildlife, forests, water and scenery (Beier et al. 2008b; Crone and Mehrkens 2013; Patterson and Coelho 2009).

We synthesized an expert review of climate change implications for this region based on an analysis of projected temperature, precipitation, and snowfall. Each author was provided with a series of maps for each climate variable including the raw data from which to draw inferences. Implications for two general biophysical systems were considered—hydroecological (freshwater hydrology and fishes) and terrestrial ecological (vegetation and wildlife), and concluded with their associated ecosystem services. Five IPCC CMIP5 global climate models (GCMs) that performed well for the North Pacific were analyzed (Walsh et al. 2008; Radic and Clarke 2011): CCSM4, GFDL-CM3, GISS-E2-H, IPSL-CM5B-LR, and MRI-CGCM3. These were run for two representative concentration pathways (RCPs): RCP4.5 assumes medium-low global anthropogenic emissions and RCP8.5 assumes high emissions. The spatial climate modeling software ClimateWNA 4.85 (Wang et al. 2012b) and GIS were used to conduct the analysis at a 1-km resolution for the 2080s (2071–2100; 30-year normal period). Precipitation values were rounded to the nearest 10 mm. This climate tool is based on the PRISM climate model (Daly et al. 2002) and provides a historical mean (1961–1990) to which predicted changes can be compared. Biogeoclimatic zones with similar energy flow, vegetation and soils developed by the BC Forest Service (Meidinger and Pojar 1991) and the US Forest Service (USFS 2008) were used to stratify our analysis by eight geographic provinces and three vegetation zones: alpine (Coastal Alpine), subalpine (Mountain Hemlock), and lowland forest (Northern Coastal Hemlock/Pacific Silver Fir).

2 Climate model results

Our analyses projected an overall regional increase in mean annual temperature (MAT) and mean annual precipitation (MAP), and a decrease in annual precipitation as snow (PAS) (Figs. 3 and 4). Based on projections for five IPCC CMIP5 global climate models (GCMs) and two representative concentration pathways (RCPs), predicted mean annual temperature will increase from a current average (1961–1990) of 3.2 °C to 4.9–6.9 °C (5 GCM range; RCP4.5 scenario) or 6.4–8.7 °C (RCP8.5), mean annual precipitation is predicted to increase from 3130 mm to 3210–3400 mm (3–9 % increase; RCP4.5) or 3320–3690 mm (6–18 % increase; RCP8.5), and total precipitation as snow is anticipated to decrease from 1200 mm to 940–720 mm (22–40 % decrease; RCP4.5) or 720–500 mm (40–58 % decrease; RCP8.5) by the 2080s (2071–2100; 30-year normal period).

Projected changes in climate variables generally followed a high to low pattern along two gradients, from north to south and from mainland to the outer coast; with northern mainland areas showing the greatest change in temperature and precipitation and southern island provinces exhibiting the least (Figs. 3 and 4). For example, averages changes for MAT by the 2080s across vegetation zones showed a north-south and mainland to outer coast trend. Yakutat showed the largest average increase of 2.9 °C (0.9 °C SD over 5 GCMs) in RCP4.5 and Mainland increased 4.7 °C (1.0 °C SD) in RCP8.5; Haida Gwaii exhibited the smallest increase with 2.2 °C (0.7 °C SD) to 3.6 (0.8 °C SD) in projected change. The pattern of change for MAP primarily followed a mainland mountain to low-elevation outer coast trend. Yakutat received the largest average increase in MAP with 290 mm in RCP4.5 (160 mm SD) and 490 mm (220 mm SD) in RCP8.5; Nass Kitimat changed the least with increases of 130 mm in RCP4.5 (100 mm SD) to 270 mm in RCP8.5 (190 mm SD). Changes in PAS showed a

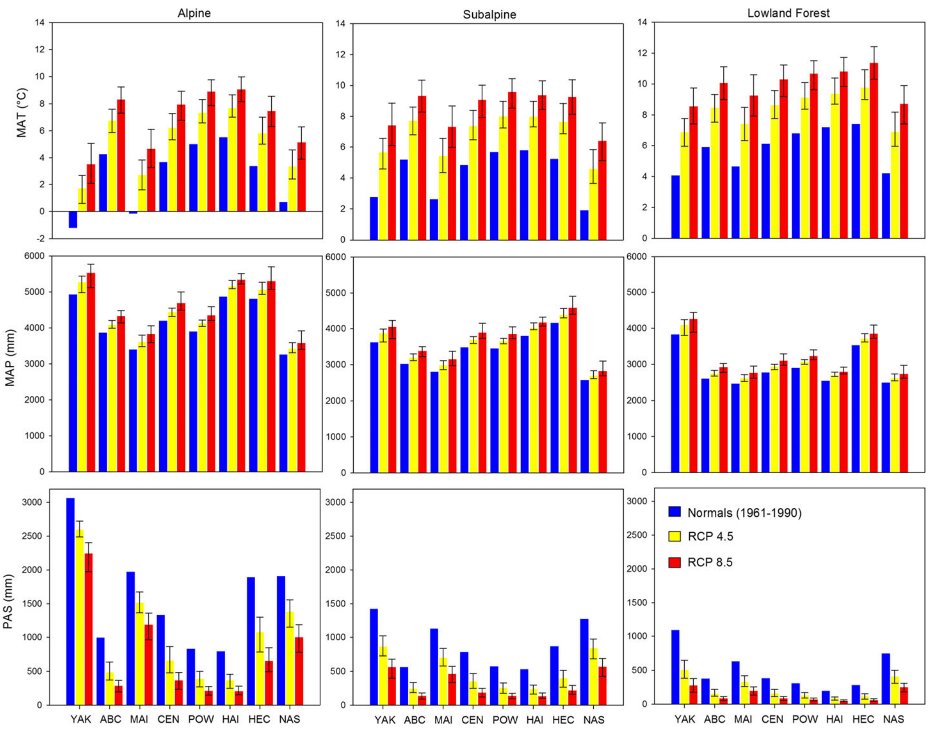

Fig. 3 Histograms of mean annual temperature (MAT), mean annual precipitation (MAP), and precipitation as snow as water equivalent (PAS). These were stratified by eight biogeoclimatic provinces and three vegetation zones: alpine, subalpine and lowland forest. The historical normals (1961–1990) are presented next to a five global climate model ensemble average with range bars (CCSM4, GFDL-CM3, GISS-E2-H, IPSL-CM5B-LR, and MRI-CGCM3) from the IPCC CMIP5 scenarios RCP4.5 and RCP8.5 for the 2080s (2071–2100; 30-year normal period)

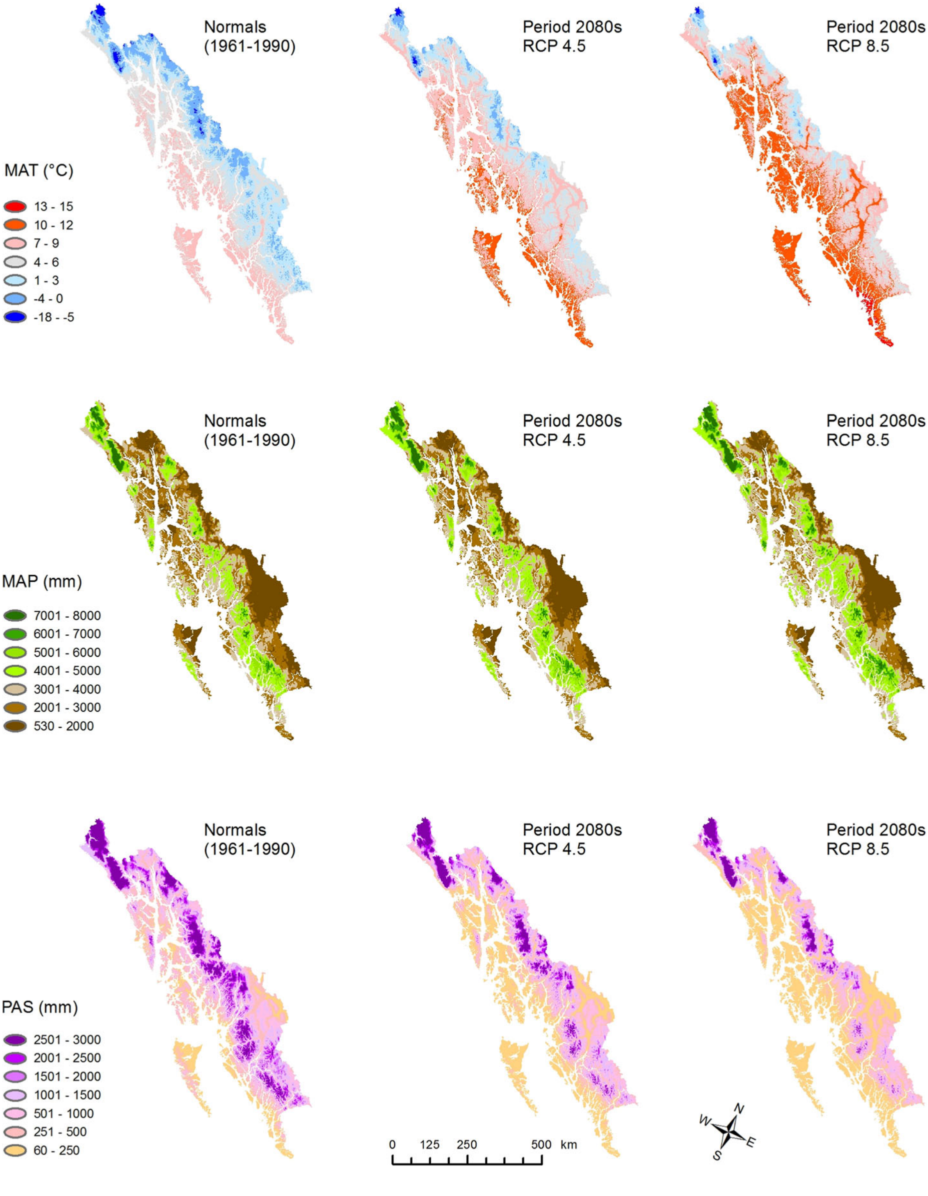

Fig. 4 A map series of potential climate change showing the current mean annual temp (MAT), mean annual precipitation (MAP), and precipitation as snow as water equivalent (PAS) compared to corresponding projections for the 2080s (2071–2100; 30-year normal period) using a five global climate model ensemble average (CCSM4, GFDL-CM3, GISS-E2-H, IPSL-CM5B-LR, and MRI-CGCM3) from the IPCC CMIP5 scenarios RCP 4.5 and RCP 8.5

mainland to outer coast trend, with Yakutat showing the largest decrease of 540 mm (120 mm SD) in RCP4.5 and 830 mm (130 mm SD) in RCP8.5; Haida Gwaii showed the smallest decline of 280 mm (60 mm SD) in RCP4.5 and 380 mm (30 mm SD) in RCP8.5.

Projected increases in MAT showed a uniform pattern of change on average across vegetation zones with 2.5 °C (0.8 SD; RCP4.5) and 4.2 °C (1.0 SD; RCP8.5). Alpine showed the largest increases in MAP and largest decreases in PAS. Projections for MAP in alpine showed an increase of 240 mm (120 mm SD) in RCP4.5 and 460 mm (200 mm SD) in RCP8.5. Alpine PAS decreased by 540 mm (140 mm SD) in RCP4.5 and 830 mm (120 mm SD) in RCP8.5.

3 Implications for freshwater hydrology and fishes

Currently, the average freshwater discharge in our study area is approximately 780 km^3/year, or roughly twice the magnitude of the annual discharge of the Mississippi River Basin (Morrison et al. 2011; Neal et al. 2010). Projected declines in PAS are anticipated to moderate the storage of water as snow, thereby changing the magnitude and timing of seasonal snowmelt runoff (Shanley and Albert 2014). As the rain-snow transition zone increases in elevation in response to increased MAT, less PAS will be stored in seasonal snowfields or ice (Fig. 4). Therefore, runoff patterns are expected to transition toward lower elevation watershed types, shifting from glacial to snow melt and from snow melt to rainfall-dominated (Fig. 2). In southeast Alaska, snow melt-dominated watersheds have already shifted towards higher winter stream flows and lower summer time stream flows during the warm phase of the Pacific Decadal Oscillation (PDO; Neal et al. 2002), and based on modeling results, we anticipate this trend will be more prevalent in the future.

Whereas the greatest projected decreases in PAS are for alpine habitats in the mainland provinces (1, 3, 7 and 8), southern island provinces (5 and 6) may show the first signs of transitioning from snow to rain-dominated systems because their mean winter temperature is closer to the freezing threshold. Mainland provinces (1, 3, 7 and 8), however, may be more prone to rain-on-snow and flooding events with the increasing spring and summer temperatures melting subalpine and alpine snowpacks (Fig. 4).

Glacial watersheds currently contribute approximately 30 % of total freshwater discharge in southeast Alaska (Neal et al. 2010), and 95 % of glaciers in this region are losing volume, some at among the highest rates on earth (Berthier et al. 2010; Larsen et al. 2007; Pike et al. 2008). As increased MAT causes glacier mass balance to become more negative, stream flow in glacier-dominated watersheds will initially increase and then eventually decrease as glaciers retreat to occupy only a small fraction (<10 %) of the watershed (Casassa et al. 2009; Moore et al. 2009). This pattern initially may be most pronounced in the southern portions of mainland provinces (3 and 8) with smaller glaciers. In watersheds with a high percentage of ice cover (1 and 3), the initial runoff increase could be substantial (>50 %; Adalgeirsdottir et al. 2006) and will likely exceed climate-driven runoff changes expected from other components of the water budget (Jansson et al. 2003). However, in the long term, loss of ice is anticipated to contribute to lower water yields. Increases in climate-driven discharge are already evident in the few glacial watersheds with temporally extensive stream flow records (Neal et al. 2002).

Runoff from glaciers also has pronounced impacts on water temperature and clarity (Fellman et al. 2014; Hood and Berner 2009; Moore et al. 2009) and riverine concentrations of bioavailable organic matter (Bhatia et al. 2010; Hood et al. 2009), phosphorus (Hodson et al. 2004; Hood and Scott 2008), and micronutrient iron (Schroth et al. 2011). The unique suite of solutes associated with glacial runoff can influence biogeochemistry and productivity in downstream freshwater and near-shore marine ecosystems (e.g., Fellman et al. 2010). Stream flow and stream temperature affect production and timing of benthic fauna that forms much of the food base for freshwater fishes in lowland forest streams (Wipfli 1997; Wipfli and Baxter 2010). Changes in flow, temperature, and nutrient dynamics in freshwater ecosystems influence fish abundance across life-history stages (Bryant 2009). For example, high-flows during the winter incubation period increase salmonid embryo mortality, causing steep declines in adult returns (e.g., pink salmon [*O. gorbuscha*] and coho salmon [*O. kisutch*] in Glacier Bay; Milner et al. 2013).

Salmonids are a cold-water species with high critical thermal maxima (e.g., ~29 °C in juvenile coho salmon; Konecki et al. 1995), although most salmonid functions (incubation, feeding, growth) are compromised when temperatures exceed ~12–15 °C (Richter and Kolmes 2005). Dramatic declines in gamete viability have been observed in pink salmon in southeast Alaska when stream temperatures exceed 15 °C during the spawning run (A. Gharrett, pers. communication, 2013). As ectotherms, fish are strongly governed by temperature. Demographic studies have shown that salmonid run timing has shifted and is more temporally compressed (Kovach et al. 2012, 2013, 2015). For example, coho salmon currently return to Auke Creek in southeast Alaska to spawn 17 days earlier than they did in the 1970s (Kovach et al. 2013). However, increased summer temperatures in Auke Lake increase the biomass of juvenile coho and sockeye salmon (*O. nerka*) smolts the following fall (Kovach et al. 2014), implying that moderately higher temperatures will positively affect some salmon life history stages while negatively impacting others. The diversity of salmon species and life histories will likely be an important source of resilience to climate change throughout the northern coastal temperature rainforest in the future (Kovach et al. 2015).

Winter high flows may be particularly important to monitor for scour of salmon eggs from the gravel (Montgomery et al. 1999; Shanley and Albert 2014). The nests of larger females should be more resistant to scour; however increasing temperatures during the marine phase can lead to smaller adult size in salmonids (Jonsson et al. 2012), thus compounding the effects of warming. According to the climate projections, scour may initially be most pronounced in northern mainland provinces (1 and 3) with increased MAT and MAP. Acute temperature-driven physiological and from snow melt to rainfall-dominated likely to occur during summer months in provinces with a higher likelihood of low flows and diminished snowpack (5, 6 and 7), although increased MAP could mediate lower flows in some watersheds. Temperature-related phenological shifts are expected throughout a fish's life cycle, but phenological changes are likely to be most pronounced during spawning migrations (mid-summer to fall). Marine-derived nutrients and energy are anticipated to be less available to those species whose own phenologies do not track shifts in these migrations. However, because marine subsidies propagate through freshwater and riparian ecosystems (Wipfli and Baxter 2010), effects might occur in other seasons as well.

Warmer temperatures are expected to slowly influence the lowland forest landscape towards a greater proportion of deciduous trees, especially *Alnus* spp. (Implications for terrestrial ecosystems—vegetation and wildlife section, this paper), leading to allochthonous litter inputs that are more concentrated in autumn and higher food quality for riparian and aquatic food webs (Wipfli 1997; Wipfli and Baxter 2010). *Alnus*, an N fixer, rapidly colonizes deglaciating watersheds and will therefore potentially increase nitrate abundance in adjacent streams through increases in soil nitrogen pools (Hood and Scott 2008).

Among glacial watersheds in mainland provinces (1, 3, and 8), near-term increases in summer glacial runoff is anticipated to buffer increases in water temperatures, potentially reducing the likelihood that marginal glacial streams become optimal for spawning and development, but in the long term, diminishing glacial influence may also lead to warmer, more thermally optimal streams supporting increased production of food for stream-rearing salmonids as well as conditions for salmon development and spawning (Fellman et al. 2014; Milner et al. 2009). For example, the warm phase of the PDO has also been correlated with high commercial harvest of salmon in Alaska (Mote et al. 2003). The effect of climate change on local marine subsidies will depend on the amount of suitable spawning habitat, species' phenologies, and fluctuations in anadromous fish populations.

Sea-level is projected to rise under current climate change scenarios, due to thermal expansion of seawater, melting of land ice, and changes in liquid storage on land (Church et al. 2013). IPCC projections for 2081–2100 range from 0.4 to 0.63 m above 1986–2005 levels (ibid), and vary considerably geographically due to variable changes in ocean temperature and salinity related to changes in ocean circulation. In northern southeast Alaska (1, 2, and northern 3), however, sea level is decreasing by as much as ~3 cm/year as a result of isostatic rebound from glacier mass loss (Larsen et al. 2005). Sea-level changes have important implications for coastal tidal wetlands and salmonid rearing habitats (e.g., Bryant 2009). Some models predict that 20–60 % of the world's tidal wetlands will be lost this century due to sea level rise (e.g., Craft et al. 2009).

4 Implications for terrestrial ecosystems—vegetation and wildlife

A key feature of current vegetation patterns is the disturbance ecology of frequent wind, snow and ice storms from fall through early spring (Alaback et al. 2013). These winter storms not only constrain growing seasons for vegetation, but also have important effects on associated soil ecosystems (D'Amore and Hennon 2006), nutrient cycling (D'Amore et al. 2010) and forest regeneration rates (Alaback 1982). For example, Alaska yellow-cedar (*Callitropsis nootkatensis*) decline appears to be closely related to changes in transient snow—reduced snowpacks affect soil insulation, causing fine root damage and mortality in areas with poor drainage (Hennon et al. 2012).

Given projected increases in MAT, we expect distribution shifts in individual species and ecological communities (Hamann and Wang 2006; Wolken et al. 2011). Some wide spread genetically diverse species, such as western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), are expected to colonize new habitats rapidly (Farr and Harris 1979; Gavin and Hu 2006). Other species, such as the cedars and many understory plants are expected to change more slowly, due to both regeneration requirements and low genetic diversity (Gilliam 2007; Bunnell and Kremsater 2012) that may lead to new plant communities (Oakes et al. 2014).

Projected increases in MAP suggest that lowland coastal forests will remain characteristically wet places (Fig. 3). Hydrologic changes (previous section, this paper) in the occurrence and intensity of flooding events could lead to changes in the nature and extent of riparian forest disturbance dynamics (Naiman et al. 1998). Assuming that seasonality of precipitation does not change significantly, fire will remain unimportant as a disturbance agent, but higher MAT is anticipated to increase the incidence and severity of insects and disease in lowland forests (Haughian et al. 2012; Hennon et al. 2012). Exceptions to this general rule are anticipated where periodic droughts and fires do occasionally occur i.e., in the southern provinces (6, 7 and 8) (Haughian et al. 2012). This impact is projected to increase in severity, as MAT is also projected to increase (Figs. 3 and 4). Decomposition rates are also anticipated to increase, and some wetlands (bogs, fens etc.) may become productive forests, as has occurred in the past (e.g., Neiland 1971).

Subalpine and alpine habitats are anticipated to undergo more rapid changes than lowland forests. For example, Wang et al. (2012a) suggest that British Columbia's coastal alpine habitat will shift upward in elevation more than 200 m by the 2080s. Alpine habitat MATs are projected to exceed current subalpine habitat MAT by the 2080s (temperatures that trees currently grow) in all the island provinces (2, 4, 5, and 6) in RCP4.5, and most of the mainland provinces (3, 7, and 8) with the exception of Yakutat in RCP8.5. At the same time, accumulated PAS in alpine habitats will on average decline by 15–54 % across provinces for RCP4.5 and 27–74 % in RCP8.5. The combination of warmer alpine MAT and lower snowpacks are anticipated to raise the elevation of treeline (Wang et al. 2012a), moving treeline to mountaintops, and resulting in a regional loss of high elevation tundra ecosystems. Subalpine vegetation can occur at relatively low elevations due to the persistence of snow in the late spring and early summer, and the high frequencies of snow avalanches (due to steep topography and wet heavy snow). With projected reductions in snowpack, however, the lower boundary of the subalpine habitats is anticipated to increase in elevation.

Climate, vegetation, and weather interact to affect wildlife in the region through food availability and habitat quality, which affect species fitness and demography. Populations of animals and resource selection in northern climates are often determined by the weather severity (Brinkman et al. 2011; Person and Russell 2010). For example, the availability of salmon greatly influences habitat quality for brown bear (*Ursus arctos*) (Hilderbrand et al. 1999). When salmon populations move or decline as a result of weather and climate-driven changes in hydrology, brown bear populations will also move or decline. Persistent deep alpine and subalpine snow forces mountain goats (*Oreamnos americanus*) and Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) to move to lowland forest habitat (Schoen and Kirchhoff 1990; White et al. 2011); condensing winter range and reducing habitat carrying capacity. Deep snow also increases energetic costs by hindering locomotion and restricting movement among forage patches (Parker et al. 1984). Cold, rainy weather in the spring potentially increases thermoregulatory demands and parental investment in wildlife species.

Future climate predictions, however, may cumulatively reduce the severity of ecological and niche limitations on wildlife. Projected increases in MAT may expand lowland forest habitat available to ungulates during the winter and reduce energetic costs (Parker et al. 1984). Future projections of PAS suggest that deep snow may no longer be a limiting factor for deer in the southern and island provinces (5, 6 and 7). Where PAS is still anticipated in the future (1, 2, 3 and 4), snow accumulation and persistence may decline and alleviate winter stress for wildlife. Further, a longer growing season may increase food availability for wildlife in the spring when energy demand of winter-stressed individuals is high. Any negative effects of potentially increasing rain-on-snow and other icing events may be short lived because winter temperatures in the region typically fluctuate close to freezing.

Wildlife habitats associated with coastal and estuarine wetlands are anticipated to undergo changes due to sea-level rise and an increase in the frequency and severity of storm surges (Michener et al. 1997). The direct ecological effects of sea-level rise include coastal inundation, flood damage, increased erosion, and saline water intrusion (Nicholls and Cazenave 2010); with associated changes in wetland community structure (Craft et al. 2009). Wildlife species dependent on these habitats, such as brown bears (Schoen et al. 1994), Vancouver Canada geese (*Branta canadensis fulva*; Fox 2008), and shorebirds (Iverson et al. 1996) are anticipated to see declines in essential seasonal habitats in southern provinces not experiencing isostatic rebound (6, 7, 8 and southern 3, 4, and 5; Larsen et al. 2005).

Endemic species may be particularly vulnerable to the effects of climate change due to habitat change coupled with limited migration potential in the naturally fragmented and glacier-bounded island archipelago. As MAP and MAT increase in the island provinces (2, 4, 5, 6 and portions of 7), which tend to be the hotspots of endemism in this area, critical aspects of ecological niches are anticipated to also change, and these conditions may trigger extirpations (Cook and MacDonald 2013).

Temperature-related shifts of wildlife ranges northward (Root et al. 2003) may increase interspecific competition, especially for endemic species. However, the isolated geography may slow immigration to the region compared to other parts of North America. Little is known how interactions in wildlife communities may change as the climate becomes more tolerable for southern species currently at the northern extent of their range.

5 Implications for ecosystem service benefits

Increased MAT and MAP coupled with decreased PAS are anticipated to primarily affect ecosystem services that regulate water quality, water quantity, greenhouse gas fluxes and nutrient fluxes (or subsidies). Changing hydrologic regimes could alter the distribution and productivity of fisheries, dependability on hydropower, and desirable tourism activities (e.g., wildlife viewing)—three key pillars of local and regional economies in southeast Alaska and northern coastal British Columbia (Crone and Mehrkens 2013).

The legacy of industrial-scale forest management in southeast Alaska and northern coastal British Columbia has continued influence on both the supply and demand of forest products in the region. Harvesting of wood fiber and fuel is seen as less sensitive to projected climatic changes than the existing constraints on logging in the region (Albert and Schoen 2013; Beier 2011). However, the climate-driven decline of Alaska yellow-cedar across the region has resulted in localized but geographically widespread areas (2, 4, and 5) of high-value salvage logs that may be processed locally into high value wood products (Beier et al. 2008a). Accelerated forest growth rates, if driven by MAT warming, may in turn increase the quantity but decrease the tight grain quality (especially for spruce and cedar) of forest products from second-growth forests, relative to those harvested from primary forests during the 20th century. Greater attention to greenhouse emissions and renewable energy alternatives may promote more widespread use of pre-commercial second-growth forests for biomass energy.

Climate change impacts on ecosystem services related to fish and wildlife populations will undoubtedly influence their many beneficiaries in the region, which include subsistence, commercial and recreational users (Beier et al. 2008b). Wild food sources remain vital to cultural activities for residents, especially in remote First Nation and Alaskan Native communities. Commercial fisheries remain essential in many communities in addition to a rapidly growing guide and outfitter sector (Colt et al. 2007). For fisheries, climate changes that disrupt the regular timing and distribution of salmon runs (Kovach et al. 2013) may reduce fishing success. Conflicts among fisheries may emerge if potentially negative impacts reduce the allowable catch. Related changes that disrupt estuarine systems and near-shore food webs (Schoch et al. 2013) could also impact the availability of shellfish that support locally important subsistence and personal use fisheries. On land, Sitka black-tailed deer are the most harvested game species in southeast Alaska (Brinkman et al. 2011) and because their population movements are sensitive to changing snow patterns, hunters may experience increased difficulty locating deer on traditional hunting grounds or in accessible areas (Brinkman et al. 2009). Overall, if traditional hunting and fishing grounds become less productive or predictable due to climate change, it remains to be seen whether residents, business owners and visitors will continue to either seek or ‘capture’ these ecosystem service benefits.

6 Synthesis and conclusion

Our collaborative synthesis of potential climate change impacts across biophysical systems highlights the coupling of social and ecological dynamics that characterize the northern coastal temperate rainforest of North America. The sharp environmental gradient from icefields to coastal estuaries creates a unique climate sensitivity to warmer and seasonally wetter climate projections with elevated snowlines. Globally, projected increases in days above freezing are only comparable to the southern Andes in South America as well as central and northern parts of Europe and Asia (Meehl et al. 2004; Sillmann et al. 2013). The southern Andes and northern Europe contain temperate rainforest ecosystems (Dellasala et al. 2011) that may provide opportunities for shared learning internationally. Finer scale monitoring and systematic placement of additional long-term hydro-meteorological stations will improve capacity to evaluate

Table 1 Information needs cited by disciplinary experts involved in this review paper for increasing understanding of climate change implications for the northern coastal temperate rainforest region of North America

Information need	Justification
Longitudinal datasets on hydro-meteorological parameters from ridge tops to mean high tide	Hydro-ecological changes are expected to be driven largely by an increase in the elevation of the rain-snow transition line
Magnitude and composition of glacial runoff	Glacial composition is understood to be a key source of variability in watershed responses to climate shifts
Quantification of processes that influence anadromous fish ecology and life history success	Statistical models derived from current environmental conditions alone will be insufficient to predict responses to climate (Evans 2012).
Salmonid distribution and productivity across a range of watershed conditions	Hydrological conditions in de-glaciating watersheds could become optimal for salmon spawning and development
Efficacy of forest restoration from historical logging on improving flood plain connectivity	Improved resilience to hydrological variability and buffering against higher frequency flooding events
Characterization of the steepness of environmental gradients from oceans to interior coasts and landscapes	Large climatic changes can manifest at smaller scales, especially with respect to abrupt environmental shifts and locally important environmental factors mediated by the ocean and physiography like fog, winds, and storms
Migration and adaptation patterns of individual species to rapid environmental change	Current understanding of adaptation is not useful under extremely rapid rates of change forecasted and based on ex situ commercially important and cultivated species
Fine-scale vulnerability of habitats and wildlife populations to climate-driven changes	Data used to parameterize risk-assessment tools and spatiotemporal resolution of modeled outputs is insufficient for management level decisions
Characterization of climate variability, seasonal patterns and frequency of severe events	Episodic climatic variability, weather extremes, and seasonal climatic stressors, in contrast to long-term trends in climatic means, more heavily influences ecological responses and productivity
Consequences of fire and disease on succession trajectories of contemporary forest ecotypes	Potential increases in the frequency and scale of fire prevalence in southern portions of the region and climate-mediated disease outbreaks across the region
Magnitude of changes in the abundance, phenology and distribution of provisioning species with economic importance	Mitigation of actual or perceived shifts in ecosystem service availability is important for the adaptive capacity of human communities
Magnitude and relevance of interactions and feedbacks among hydrological features	Proximity results in coupling of cryospheric, freshwater, wetlands and near-shore estuarine systems
Linkages and material flow among terrestrial, freshwater, and marine ecosystems	Ecosystems and the fish and wildlife they support often rely heavily on exchanges of nutrients, prey, and detritus among them, and changing climate holds large and unpredictable consequences for consumers

assumptions and uncertainty associated with global climate models that do not account for the significance of local variability (e.g., Wright and Stevens 2012). Greater research integration (e.g., interagency collaborations) will provide better insights into the complexity and coupling within and between ecosystems and climate for policy and planning direction. Most information needs cited as a part of this review process (Table 1) relate to improved modeling of changes in hydrology, and the social and ecological consequences of those changes. Immediate recognition and prioritization of our findings is critical because of the rapid rate of change anticipated, and the relatively high dependence on the cultural and provisional ecosystem services in the northern coastal temperate rainforest of southeast Alaska and British Columbia.

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Using LiDAR and Random Forest to improve deer habitat models in a managed forest landscape

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ABSTRACT

Conservation strategies are hindered by a lack of accurate maps of important habitat for many wildlife species, but especially for species inhabiting managed forest landscapes. Prioritizing restoration efforts on Alaska's Tongass National Forest from past extensive clearcut logging is extremely challenging given the difficulty in accurately mapping its remote, rugged temperate rainforest landscapes. We tested the application of airborne light detection and ranging (LiDAR) technology to build a winter habitat model for Sitka black-tailed deer (*Odocoileus hemionus sitkensis)*, the primary herbivore in the coastal temperate rainforest. We analyzed the importance of geomorphometric and forest structure characteristics as predictors of deer winter habitat selection using Random Forest applied to a 3-year GPS relocation dataset collected from 40 adult female deer. The LiDAR-based habitat model had a predictive performance of 94% (Out-of-bag error = 6%), a 10% lower model error compared to air-photo interpreted polygons and modeled plot data. Random Forest also outperformed analogous resource selection function models based on a comprehensive *k*-fold cross-validation. Deer habitat selection patterns in the LiDAR-based model were nonlinear across geomorphometric and forest structure predictive variables, and generally supported existing studies of deer habitat selection. Besides improving deer conservation and management on the Tongass National Forest, our approach could greatly enhance the accuracy and resolution of habitat maps used for conservation and restoration planning across large managed forest landscapes.

1. Introduction

Effective conservation strategies require an accurate understanding of the distribution and quality of species' habitats (Groves et al. 2002), which remains challenging for many parts of the world due to limited resources and difficulty in mapping complex habitat structures (Hansen et al. 2013; Kerr and Ostrovsky 2003). Forested habitats are often impacted by land use decisions that are complicated by poor-quality maps (Lindenmayer and Franklin 2002, Palm et al. 2020), yet they are key for the maintenance of global species diversity (Venter et al. 2016, Hebblewhite 2017). Threats to many forest-dependent species stemming from landscape change are increasing and urgently require spatially-explicit, cost-effective conservation strategies (Mappin et al. 2019, Tempa et al. 2019). Thus, the application of new technologies to better map forest habitats is critical for effective conservation of forest ecosystems that provide habitat for economically important or vulnerable species.

Recent explosions in the availability of remotely-sensed vegetation data have the potential to increase the efficacy of targeted conservation efforts in forested landscapes (Buchanan et al. 2018). Furthermore, light detection and ranging (LiDAR) data provide 3-dimensional mapping of forest structure and geomorphometric characteristics (Evans et al. 2009, Greaves et al. 2019) that are much higher resolution compared to land cover spectral imaging such as Landsat (U.S. Geological Survey 2016). To date, LiDAR data has primarily been acquired for North America and Europe, and for a few specific conservation applications in Africa and

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South America (Vierling et al. 2008, Davies and Asner 2014, Simonson et al. 2014). LiDAR is being adopted as a primary mapping tool for forest structure in western North America (Kane et al. 2010, Strunk and Gould 2015, Guo et al. 2017) and will likely expand to other regions around the globe as acquisition costs decrease and the technology improves. For instance, recent satellite efforts (e.g., NASA's GEDI and ICESTAT 2 programs) aim to provide nearly worldwide coverage that could provide vast opportunities for conservation practitioners working in difficult-to-map forests.

The Tongass National Forest (TNF) in southeast Alaska, USA, is the largest (6.8 million ha) and most intact coastal temperate rainforest on Earth (DellaSalla 2011) and a globally relevant carbon sink (McNicol et al. 2019, Harris et al. 2021). Commercial-scale, even aged harvest of old-growth forest has occurred on the TNF for decades; however, the U. S. Forest Service (USFS) is transitioning to a focus on second growth timber management and forest restoration (USDA 2021). Over the last century, 67% of the most ecologically valuable, low-elevation productive forest lands have been harvested (Albert and Schoen 2013). Within the harvested land base, approx. 42% has received a post-harvest silvicultural treatment to reintroduce structural complexity (Alaback et al. 2013, Hanley et al. 2013). Without continued research and targeted restoration efforts (Person and Brinkman 2013), the untreated stands will take at least an estimated 150 years to provide the ecological benefit and resilience of mature forests (Alaback 1982) and may not attain growth patterns conducive to large tree branch characteristics (Tappeiner et al. 1997, Poage and Tappeiner 2002).

Partly in response to threats of continued old-growth logging on the TNF, conservation groups have petitioned the U.S. Fish and Wildlife Service (USFWS) multiple times to review the Alexander Archipelago wolf (*Canis lupus ligoni*), a keystone species, for threatened and endangered species listing (USFWS 2016), citing the need for improved management of wolf harvest and habitat concerns for their primary prey, Sitka black-tailed deer (*Odocoileus hemionus sitkensis*; Roffler et al. 2018, 2021). Besides their importance as prey for wolves, Sitka black-tailed deer are one of the most sought-after ungulate species for subsistence and recreational hunting in southeast Alaska (Hanley 1993, Titus et al. 2009, Crone and Mehrkens 2013). While subsistence hunters initially benefited from increased access to and visibility of deer from the large-scale clearcutting of old-growth forest and accompanying road expansions, desirable hunting conditions and habitat quality has rapidly declined since the mid-1990s as these harvested, second-growth forests regenerated into thick stands that decreased the visibility of deer for subsistence hunters (Brinkman et al. 2009) and reduced deer population productivity (Brinkman et al. 2011). Thus, targeted restoration of these managed forests to conserve deer populations is a primary motivation to develop accurate deer habitat maps for the region.

Like many commercial timber producing regions in the world (e.g., coastal British Columbia, Canada), TNF vegetation maps used for deer habitat modeling and forest restoration are currently derived from air-photo interpreted polygons and modeled plot data that was originally developed to map merchantable timber volume, not wildlife values (Caouette et al. 2000, Caouette and DeGayner 2005), and few major advances to this approach have occurred for the past two decades beyond pilot studies. However, in the past 10 years, almost 1 million hectares of LiDAR remote-sensing data were collected across southeast Alaska, 76% of which were on national forest lands, and the majority of which occurred on Prince of Wales (POW) Island (Fig. 1). This rapidly advancing technology provides an important opportunity to develop new data-driven habitat models by combining LiDAR-derived habitat variables with Global Positioning System (GPS) animal relocation data to guide conservation and restoration planning (Vierling et al. 2008, Merrick et al. 2013, Davies and Asner 2014, Simonson et al. 2014). Furthermore, recent studies suggest combining machine learning algorithms with GPS data (Shoemaker et al. 2018, Heffelfinger et al. 2020) and LiDAR forest structure metrics (Ciuti et al. 2017) could improve habitat maps beyond traditional resource selection function (RSF) modeling techniques (e.g., mixed-effects logistic regression; Gillies et al. 2006) to infer complex, nonlinear effects of LiDAR predictor variables on the relative strength of habitat selection (e.g., Shoemaker et al. 2018).

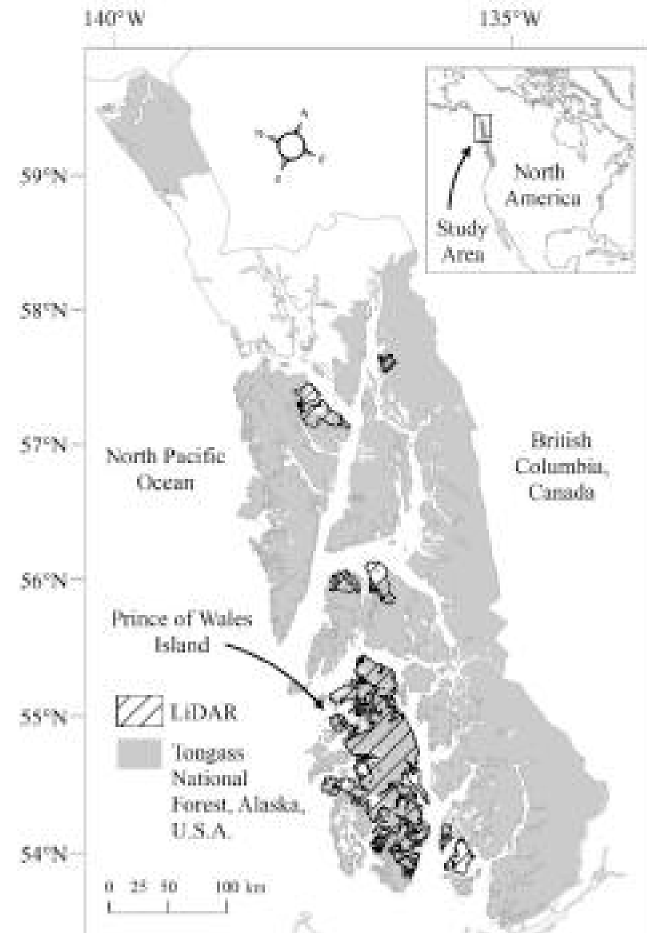

Fig. 1. The extent of watershed-scale LiDAR remote sensing data in southeast Alaska, USA, collected 2012–2018. The LiDAR extent used in this study for Prince of Wales Island was collected in summer 2017.

Here, we capitalized on high-resolution GPS relocation data for Sitka black-tailed deer recently collected on POW Island (Gilbert et al. 2017) and combined these data with LiDAR-derived geomorphometric and forest structure characteristics to test the ability of machine learning methods to predict deer habitat selection and map important deer winter habitat for forest conservation and restoration efforts. Our primary goals were to (1) develop an improved model of habitat suitability for deer in winter (the most limiting season for deer populations; Gilbert et al. 2020); (2) compare the predictive performance of the LiDAR-based model to existing habitat quality metrics derived from air-photo interpreted polygons and modeled plot data, and to (3) compare our machine learning approach that pools individual relocation data to a RSF analysis that accounts for individual variation using random effects.

2. Methods

2.1. Study area

Our study was conducted on Prince of Wales Island (POW) in southeast Alaska, USA (Fig. 1; 55.7473°N, −132.8630°W). Coniferous forests dominate the landscape with an extensive matrix of naturally regenerating clearcuts and old-growth stands. Old-growth stands (>180–200 yrs) are characterized by a complex, multilayer canopy driven by gap-dynamics with large-scale disturbances in areas prone to windstorms, landslides, and flooding (Alaback et al. 2013). The primary tree species are Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Alaska (yellow) cedar (*Callitropsis nootkatensis*). The maritime climate ranges from a historical mean temperature of 12 °C in August to 1 °C in January with approx. 250 cm of precipitation annually. The mountainous terrain of relatively steep coastal watersheds have a tree line of approx. 600 m and reach a maximum elevation of approx. 1,200 m. POW is the largest island (669,400 ha) in southeast Alaska with the highest concentration of biological values (Cook et al. 2006) and longest history of commercial timber harvest (early 1900′s–present; Albert and Schoen 2013). Approximately 40% of the land base is zoned for commercial timber development with 106,000 ha harvested to date, a large proportion of which are now entering older successional stages in which deer forage in the understory dies off due to lack of sunlight penetration through even-aged forest canopy (Alaback 1982). Sitka black-tailed deer are the primary herbivore in the coastal temperate rainforest and play a major social and ecological role as a subsistence hunting species (Brinkman et al. 2009) and prey for the apex predators, the Alexander Archipelago wolf (Roffler et al. 2021) and black bears (*Ursus americanus*) (Gilbert et al. 2020).

2.2. LiDAR processing

Airborne LiDAR data was collected in summer 2017 with U.S. Geological Survey QL1 specifications (ANPS $\leq$ 0.35 m, ANPD $\geq$ 8 pls/m^2, RMSEz $\leq$ 10 cm, NVA 95% CI $\leq$ 19.6 cm, and VVA 95th percentile $\leq$ 29.4 cm). The raw point cloud data was further processed into forest structure metrics using FUSION software version 3.80 (McGaughey 2018; Fig. 2). Forest structure metrics were computed using returns above 2 m and a cover threshold of 2 m, meaning no data points were used below 2 m where ground shrubs might affect the overstory metrics. Canopy statistics were analyzed using 1-m resolution canopy height models, and then summarized to a 30-meter resolution using a moving window analysis to capture the scale of canopy ecological processes (e.g., snow interception and light penetration; McGarigal et al. 2016). Lastly, strata cover metrics were taken from their specified strata (e.g., 0–1 m from the ground). These were combined with geomorphometric variables at multiple spatial scales that are known to predict deer habitat selection when snow is present (Schoen and Kirchhoff 1985, Kirchhoff and Schoen 1987, Farmer et al. 2006, Gilbert et al. 2017, McCoy and Gregovich 2021): elevation, slope, and southing. This resulted in 21 potential predictor variables that captured a broad-spectrum of relevant forest height structure, canopy complexity, and topography (Table 1).

2.3. Used-available design

We used a 2nd-order scale of selection in a used-available design to quantify the relative importance of covariates and model deer habitat selection across winter range (Johnson 1980, Manly et al. 2002, McGarigal et al. 2016, Avgar et al. 2017). We started with a GPS relocation dataset from 62 adult female deer captured and monitored from 2010 to 2012, with a location every 2 h for one year for each animal (n = 385,033). Deer captures were on central POW in 6 adjacent watersheds: 3 watersheds had extensive timber harvest and 3 watersheds were primarily intact old-growth forest (mean watershed area = 167 km^2). These watersheds were selected to characterize a range of habitats with road access. Because winter habitat is the limiting factor in deer survival in southeast Alaska (Kirchhoff and Schoen 1987, Schoen and Kirchhoff 1990, Doerr et al. 2005, White et al. 2009, Brinkman et al. 2011), we used locations that occurred between 1 January to 1 April of each year to build a winter habitat model. To reduce spatial autocorrelation and decrease location errors respectively, we rarefied GPS data to a 6-hr fix rate using the package 'amt' (Signer et al. 2019) in Program R (R Core Team, 2020) and screened locations by removing 3-dimensional fixes with positional dilution of precision (PDOP) $>$ 15 and 2-dimensional fixes with PDOP $>$ 5 (Lewis et al. 2007). Lastly, we removed individuals that had$<$70% coverage over the winter period, resulting in 40 individual deer for our 'used' data. We had high rates of GPS fix success (97.9%) despite the dense forests in southeast Alaska. Additional details of the capture and GPS-collaring can be found in Gilbert et al. (2017).

We delineated availability on deer winter range by constructing a population-level, 95% kernel density contour (409 km^2) based on our rarefied deer locations using the reference value as the smoothing parameter in R package 'adehabitatHR' (Calenge 2006). To address active timber harvest during the study period, we masked the available deer winter range to TNF lands that were not harvested since 2010 (i.e., areas where clearcuts had occurred since the animal relocation data were collected were not included in the analysis). We further masked elevations above 460 m (observed max. elevation used by deer was 454 m) since these areas were unlikely to be used by deer in winter due to the relatively small body size of deer (mean adult female weight = 36 kg) and deep snowpack above these elevations (Shanley et al. 2015, McCoy and Gregovich 2021).

We sampled random available locations separately for individuals within our masked winter home range area using R package 'sp' (Pebesma and Bivand 2005, Bivand et al. 2013). We found no effect of this strategy on our results compared to using the same available set for all individuals (C. S. Shanley, unpublished data), and this strategy allowed us to maintain a uniform used-to-available point ratio across individuals. We randomly sampled available points at a starting ratio of 1-to-1 used-to-available locations (DeCesare et al. 2012), but also tested

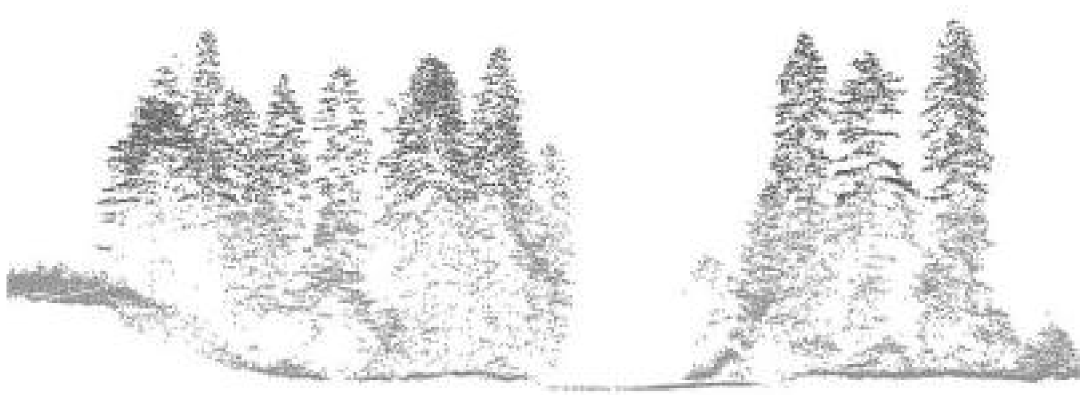

Fig. 2. LiDAR point cloud illustrating the 8-point per square meter resolution of the data in a riparian forest stand in southeast Alaska, USA, collected in summer 2017.

Table 1
Model variables from LiDAR, FUSION software version 3.80 (McGaughey, 2018), and current U.S. Forest Service deer habitat modeling vegetation frameworks (Habitat Suitability Index and FRESH) categorized by ecological function on the Tongass National Forest in southeast Alaska, USA.

Variable	Primary ecological function	Description
LiDAR		
all_cover_above2	canopy complexity	% canopy cover computed using all returns > 2 m
1st_cover_above2	canopy complexity	% canopy cover computed using first returns > 2 m
canopy_average_height	canopy complexity	average canopy height from 1 m canopy height model
canopy_rumple	canopy complexity	ratio of the canopy surface area to the area of the cell
canopy_stddev_height	canopy complexity	canopy height standard deviation
strata_0p5to1m_cover	understory complexity	% understory cover from 0 to 1 m height strata
elev_p50_2plus	forest height structure	return height 50th percentile > 2 m
elev_p60_2plus	forest height structure	return height 60th percentile > 2 m
elev_p70_2plus	forest height structure	return height 70th percentile > 2 m
elev_p75_2plus	forest height structure	return height 75th percentile > 2 m
elev_p80_2plus	forest height structure	return height 80th percentile > 2 m
elev_p90_2plus	forest height structure	return height 90th percentile > 2 m
elev_p95_2plus	forest height structure	return height 95th percentile > 2 *m*
elev	snow accumulation	ground elevation from 30 m DEM
slope	solar exposure / predation risk	degrees slope from 30 m DEM
slope100	solar exposure / predation risk	degrees slope 100 m moving window average
slope500	solar exposure / predation risk	degrees slope 500 m moving window average
southing	solar radiation	degrees from North (1-180°; South = 180°) from 30 m DEM
south100	solar radiation	degrees from North (1-180°; South = 180°) from 100 m moving window average
south500	solar radiation	degrees from North (1-180°; South = 180°) from 500 m moving window average
opendist	predation risk	distance to opening with < 25% cover from all returns > 2 *m*
USFS Habitat Suitability Index		
SD67, SD5N, and SD5S	forest productivity	high volume old-growth
SD5H, SD4S, and SD4N	forest productivity	medium volume old-growth
SD4H	forest productivity	low volume old-growth
unproductive and non-forest	forest productivity	non-productive lands
logged 25–200 years old	management history	stem excluded second growth
logged < 25 years old	management history	stem initiation second growth
elevation class	snow accumulation	low < 244 m, medium = 244–457 m, high > 457 m (60 m DEM)
aspect class	solar exposure	east = 46-135°, south = 136-225°, west = 226-315°, north = 316-45° (60 m DEM)
snow class	snow accumulation	USFS Snow Map, 1997 TLMP
USFS FRESH nutrition model		
winter shrub forage biomass	forage	total shrub biomass forage plants available (kg/km^2) in winter (Hanley et al. 2012) calculated by Gilbert et al. (2017)

ratios of 1 used location to 5, 10, 15, and 20 available locations. We conducted this sensitivity analysis to select a used-to-available point ratio that ensured stable model predictions and coefficient estimates by adequately sampling available points on the population home range.

2.4. Random forest habitat modeling

We built a deer habitat model using Random Forest (Evans et al. 2011) in Program R. Random Forest can analyze large non-parametric datasets with high multicollinearity and nonlinear relationships. It is also useful for identifying important habitat variables (e.g., Evans and Cushman 2009, Murphy et al. 2010, Shoemaker et al. 2018, Heffelfinger et al. 2020). The method helps guard against overfitting by randomly selecting training data to create decision trees that vote for an optimal final model over many iterations.

For our Random Forest approach, we conducted model selection using R package ‘rfUtilities’ (Evans et al. 2011, Evans and Murphy 2018) to select the most parsimonious model with the smallest Out-of-Bag (OOB) error, smallest maximum within-class error, and fewest parameters. Each model was run with 1,000 decision trees. First, a Pearson’s correlation analysis was conducted to identify redundant LiDAR variables ($|r| \geq 0.7$). Next, the model selection algorithm was iteratively run until the final model included the highest-ranking variables with the lowest correlations. For model comparison and evaluation, we calculated the prediction error of random data (Out-of-Bag [OOB] error; R package ‘randomForest’; Liaw and Wiener 2002) with a permutation test cross-validation (kappa statistic, $n = 1000$ permutations; R package ‘rfUtilities’) and tested the aggregate measure of performance (area under the receiver operating characteristic curve [ROC AUC]; R package ‘verification’; NCAR Research Applications Laboratory 2015), quality of predictions (log loss; R package ‘rfUtilities’), and significance (*P*-values; R package ‘rfUtilities’). For each variable in the final model, the relative selection strength (RSS; Avgar et al. 2017) was predicted over the range of observed values (i.e., used locations) by holding all other predictors at their means and rescaling the final prediction between 0 and 1 (i.e., dividing by the maximum value).

2.5. LiDAR vs. HSI and FRESH

We compared the LiDAR-based habitat model to two primary habitat models used by the U.S. Forest Service (USFS) using the same used-available location dataset and internal validation tests. For the first comparison, spatial data used in the Tongass Interagency Deer Winter Habitat Suitability Index (HSI) model was tested (see Table 1). For the second comparison, the USFS Forage Resource Evaluation System for Habitat (FRESH; Hanley et al. 2012) winter shrub biomass estimate calculated by Gilbert et al. (2017) was tested along with the HSI landscape variables (elevation, aspect, and snow) (Table 1). The HSI and FRESH air-photo interpreted stand polygons (approx. 6.6 ha mean size) and size-density forest classes (Caouette and DeGayner 2005) were converted into 30-m rasters for comparative analysis. The OOB error, kappa statistic, ROC AUC, log loss, and *P*-values were calculated for each model. For visual comparison, the LiDAR-based habitat model, HSI, and FRESH were mapped in their native format using a standardized score.

2.6. Resource selection function modeling

We developed resource selection functions (RSFs; Manly et al. 2002) for comparison to our Random Forest approach because few studies have implemented machine learning methods to model habitat selection from GPS animal relocation data (Shoemaker et al. 2018, Heffelfinger et al. 2020). However, because our primary goal was to model deer winter range with updated LiDAR-derived variables (Table 1), we restricted comparisons with HSI and FRESH metrics to the Random Forest model. We used generalized linear mixed-effects models (GLMMs) and included random intercepts and slopes for individual deer (Gillies et al. 2006). Including both random intercepts and slopes allowed us to estimate the variance in RSS across individuals for each predictor (Gillies et al. 2006). Further, including random intercepts accounted for the slightly unbalanced sample across individual deer and the inherent pseudoreplication of covariate values measured within individuals (Muff et al. 2019).

Following Manly et al. (2002), we used an exponential function of our continuous covariates to predict a vector of weights ($\widehat{w}$) for our study area locations (s; i.e., raster cells) following:

$$\widehat{w}(s) = \exp\left(\widehat{\beta}_0 + \widehat{\beta}_1 x_1 + \widehat{\beta}_2 x_2 + \cdots + \widehat{\beta}_n x_n\right) \quad (1)$$

where x_n are vectors of n predictor covariates and $\widehat{\beta}_n$ are the associated coefficient estimates from a logistic regression model fit. The estimated intercept ($\widehat{\beta}_0$) is commonly dropped from RSF models because the model predictions are assumed only proportional to the probability of use (i.e., a relative selection strength [RSS]), and thus, the predicted surface across the study area is unaffected by the intercept; however, we retain the intercept given our inclusion of random individual intercepts and slopes (Gillies et al. 2006).

We used a GLMM with logit link function, $g(x)$, to model our binary response data (y_{ij}: used = 1, available = 0) as a linear function of our continuous predictor covariates following:

$$g(y_{ij}) = (\beta_0 + \gamma_{0j}) + (\beta_n + \gamma_{nj})x_{nj} \quad (2)$$

where the i^{th} observation is clustered within the j^{th} individual deer in a two-level random-effects structure (Skrondal and Rabe-Hesketh 2004, Gillies et al. 2006). Here, β_0 is the grand mean intercept; β_n represents the fixed, population-level coefficients for the n^{th} predictor covariate (x_{nj}) for individual j; and γ_{0j} and γ_{nj} are the random intercept and slopes, respectively, for the j^{th} individual and n^{th} coefficient. We assumed that the random intercepts and slopes for individual j arose from uncorrelated Gaussian distributions (Hosmer and Lemeshow 2000). We specified no correlation between the random intercepts and slopes since the intercept had no biological interpretation in our model (Gillies et al. 2006). We examine this assumption of normally distributed random effects using exploratory data analysis (Gillies et al. 2006).

We used the R package 'glmmTMB' (Brooks et al. 2017) to estimate parameters for GLMMs which implements maximum likelihood estimation. We scaled our continuous predictors by 1 standard deviation and centered them at zero to compare RSS effect sizes, but we unstandardized coefficients to make spatial predictions of RSS across our study area from covariate raster data. Finally, we followed recommendations for these models by assigning a set of model weights of 1 for used and 1000 for available observations and fixing the variance of the random intercepts (σ_0^2) to 10^6 (Fieberg et al. 2021; Muff et al. 2019); however, we found that using model weights and fixing the variance of the random intercepts had negligible effects on the results as expected under a binomial likelihood (see Muff et al. 2019).

2.7. Random forest vs. RSFs

We considered the Random Forest model selection routine superior given the issues in using information theoretic approaches (e.g., Akaike Information Criteria [AIC]; Anderson and Burnham 2002) to discriminate among competing models in RSFs (i.e., the potential to select uninformative parameters given the augmented dataset; Boyce et al. 2002; Gillies et al. 2006) and the difficulty in handling large sets of potentially correlated LiDAR predictor variables within parametric regression frameworks. Thus, we used the top model formula from the Random Forest model selection routine for comparison with our RSF approach but used AIC as a post hoc test of parameter importance if there was disagreement between the Random Forest and RSF models.

We used two metrics to compare our Random Forest and RSF approaches: 1) a k-fold cross-validation routine to compare the ability of each model to predict a partition of training data from a test partition of the data (Boyce et al. 2002); and 2) correlation within and among the predicted RSS surface outputs of each modeling approach (see Supplemental Materials S1). For our k-fold cross-validation routine, we blocked by individual deer and fit models to 80% of the animals ('training set') and then extracted the predicted RSS for the used data from the other 20% of individuals ('test or validation set'). We also used random number generating seeds in Program R to ensure that the training and validation sets were identical within each fold and trial across prediction methods, and we ensured that all animals were included in at least one validation set out of the 5 folds that we used (Roberts et al. 2017). We performed 10 trials of 5-fold cross-validation and calculated the mean Spearman's correlation coefficient ($\overline{\rho}$) across trials for each method (Johnson et al. 2006). The method with the highest $\overline{\rho}$ between the area-adjusted frequencies of binned ($n = 10$) RSS scores of the observations (i.e., validation set of used locations) and the binned RSF scores from the model fit on the training data indicated a better ability to predict deer winter habitat selection for our sample population (Boyce et al. 2002). For both modeling approaches, we estimated k-fold cross-validation statistics at two spatial scales–the 95% kernel density estimate of population home range and the study area level.

3. Results

3.1. Sampling summary

A total of 13,489 locations for 40 individual deer ($\overline{x} = 337.2$ locations/deer, SD = 24.8, range = 261–359) were available for analysis during 2010–2012 on TNF lands that had not been logged since 2010. We found that a 1:5 used-to-available points ratio provided the best trade-off between computational efficiency and maintaining high correlation (i.e., Pearson's $r > 0.80$) with model predictions that were based on higher used-to-available point ratios (Pearson's $r_{RandomForest}$ = 0.83–0.90; Fig. S1; Pearson's r_{RSF} = 0.98–0.99; Fig. S2). Thus, our final analysis dataset included 67,455 randomly selected available locations.

3.2. Random forest habitat modeling

The scaled variable importance scores for the LiDAR-based winter habitat model showed geomorphometric variables were 20–40% more important than the forest structure predictors (Fig. 3). Elevation was the most important geomorphometric variable followed by southing (500 m moving window) and slope (100 m moving window) (Fig. 3). The most important forest structure variable was tree height (90th Percentile) followed by % understory cover (0–1 m), distance to opening, and lastly, % forest cover (all returns) (Fig. 3).

The marginal effects from our Random Forest model showed a threshold pattern for elevation, with deer predicted to primarily select elevations below 250 m (Fig. 4A, Fig. 5); there was a slight increase in RSS at higher elevations, owing to a small number of deer that remained at relatively high elevation during the winter. Deer mainly selected flatter terrain with low to moderate slopes < 10° (100 m moving window average), although some preference for steeper slopes resulted from a few higher-elevation deer (Fig. 4C); this was expected since elevation

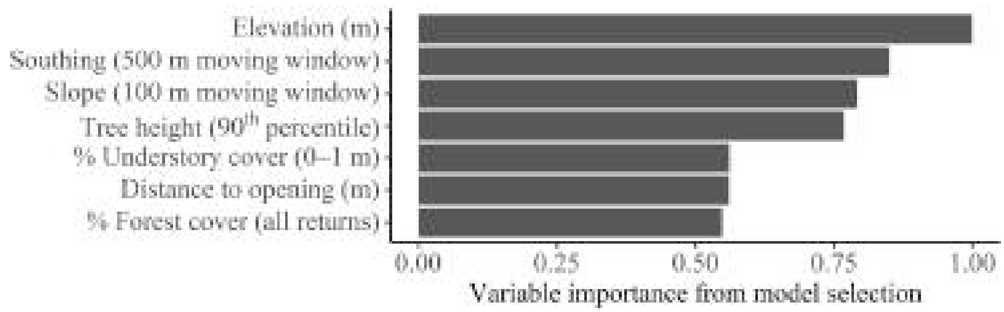

Fig. 3. Scaled variable importance plot from a Random Forest model selection process to achieve the smallest out-of-bag error, smallest maximum within class error, and fewest parameters for a Sitka black-tailed deer winter habitat model using structural and geomorphometric characteristics from LiDAR on Prince of Wales Island in southeast Alaska, USA, during 2010–2012. Higher values indicate increased variable importance.

and slope had a moderate, positive correlation (Pearson's $r = 0.63$). Deer selected northernly aspects (500 m moving window average; Fig. 4B) as well as more southernly aspects (i.e., >90° from north; Fig. 4B, Fig. 5). Tree height (90th percentile in meters) had the most important effect on the RSS of the forest structural predictors (Fig. 3), with deer showing the strongest RSS for trees < 5 m in height and a marginal increase in RSS as tree height increased > 25 m (Fig. 4D); however, selection decreased with increasing tree height (90th percentile) between 5 and 25 m. We found that deer selection for understory cover generally increased as % understory cover (0–1 m) increased, but the strongest selection occurred for understory cover < 10% (Fig. 4E). Although less important to the overall model predictions, % forest cover (all returns) followed a similar pattern to tree height (90th percentile) since the two variables had moderate, positive correlation ($r = 0.67$), with deer selection for % forest cover decreasing as the variable increased but having the strongest selection for > 90% forest cover (Fig. 4G). Lastly, distance to opening had similar importance as understory and overstory metrics, with deer largely selecting for edge habitats < 150 m and to a lesser degree about 500–700 m from an edge, which were likely areas of larger tree height since distance to opening and tree height (90th percentile) had a moderate, positive correlation (Pearson's $r = 0.53$).

3.3. LiDAR vs. HSI and FRESH

The model comparison showed the LiDAR-based habitat model performed better than the USFS HSI and FRESH data inputs by all metrics evaluated (Table 2). All models were considered statistically significant (Table 2; $P < 0.001$). The OOB error, a measure of classification accuracy, was lowest for the LiDAR-based habitat model (OOB = 5.8%, $k = 0.77$), followed by FRESH (OOB = 16.2%, $k = 0.12$), and HSI (OOB = 15.7%, $k = 0.06$; Table 2). The ROC AUC scores showed a similar pattern with the LiDAR-based habitat model being highest (AUC = 0.99), followed by FRESH (AUC = 0.64), and HSI (AUC = 0.57). Similarly, the LiDAR-based habitat model had the lowest log loss at 0.06, followed by FRESH (log loss = 3.68), and HSI (log loss = 4.65).

The mapped model comparison shows clear differences (Fig. 6). First, the resolution of each model is most apparent with the LiDAR-based habitat model mapped at a 30-m resolution versus FRESH and HSI which are based on stand-level air-photo interpreted polygons (average stand size = 6.6 ha). Second, the LiDAR-based habitat model predicted a higher habitat score for many low-elevation old-growth stands, and selected areas that received forest restoration treatments post-harvest. Finally, FRESH and HSI predicted a higher habitat score for higher elevation unharvested stands than the LiDAR-based habitat model (Fig. 6).

3.4. Random forest vs. RSF

We found moderate, positive correlation between our binned spatial predictions of RSS from Random Forest and RSF models (Spearman's $\rho = 0.49$–0.61) (Supplemental Materials S1, Table S1). Random Forest models performed consistently better compared to RSF models in our *k*-fold cross-validation routine of 10 trials of 5 data folds over two spatial scales except for one data fold (95% home range: $\bar{\rho}_{RandomForest} = 0.93$, $\bar{\rho}_{RSF} = 0.77$; study area: $\bar{\rho}_{RandomForest} = 0.94$, $\bar{\rho}_{RSF} = 0.88$; Fig. S3, Fig. S4); and RSF models tended to have more low-value correlation coefficients compared to Random Forest models. The lower correlation coefficients (i.e., $\rho = 0.10$–0.50) resulted mainly from stratifying individual deer that used lower and higher elevations in the training and test datasets, respectively.

We found the effects of southing (standardized $\beta = -0.15$, $P = 0.59$) and slope (standardized $\beta = -0.44$, $P = 0.12$) were inconsequential in our RSF models based on *P*-values (Table 3); however, we found contrasting evidence from comparing models without one or both variables using AIC, where the closest model was 5,462.4 AIC units away from our top selected model based on Random Forest. Regardless, both models agreed that elevation was the most important covariate influencing deer winter habitat selection at the 2nd-order of selection (Table 3, Fig. 3). While deer tended to select against higher elevations in general (Table 3, Fig. 4A), we found from our mixed-effects RSF models that 8 deer exhibited extremely negative selection as elevations increased relative to other animals that had weaker negative selection or slightly positive (Fig. S5). Accordingly, The RSS coefficients were most variable across individuals for elevation ($\sigma^2 = 19.5$), followed by slope ($\sigma^2 = 3.2$), southing ($\sigma^2 = 3.1$) and distance to opening ($\sigma^2 = 2.1$), with the random variation in the relative selection of elevations being about 6 orders of magnitude larger than the absolute value of the fixed, population-level coefficient for elevation (standardized $\beta = -3.24$). We found that the random individual coefficients for elevation deviated from normality and were left-skewed with some individuals being outliers in their selection for elevation (Fig. S5); thus, the strong negative selection for higher elevations exhibited by some deer may cause the effect to be overestimated in our RSF models (median $\beta_{elev} = -1.08$ vs. mean $\beta_{elev} = -3.24$).

Overall, the directional pattern of selection across predictors was similar between Random Forest and RSF models (Fig. 4). However, we found that the models disagreed about the effect of % forest cover (all returns); Random Forest predicted deer selection for forest cover to generally decrease as the percentage of forest cover increased (except > 90%), while the RSF model predicted the inverse (Fig. 4G). As expected, the marginal effect predictions from Random Forest models were more complex and nonlinear, while RSF models were only capable of predicting the RSS as a monotonic, curve-linear function of the predictor variables given that we used no quadratic or interaction terms. When predictions extended outside the range of the observed locations (i.e., used data; see Fig. 4C–4G), Random Forest models predicted a constant average RSS (flat line), whereas extrapolated RSF model predictions continued to change with increasing levels of the covariate.

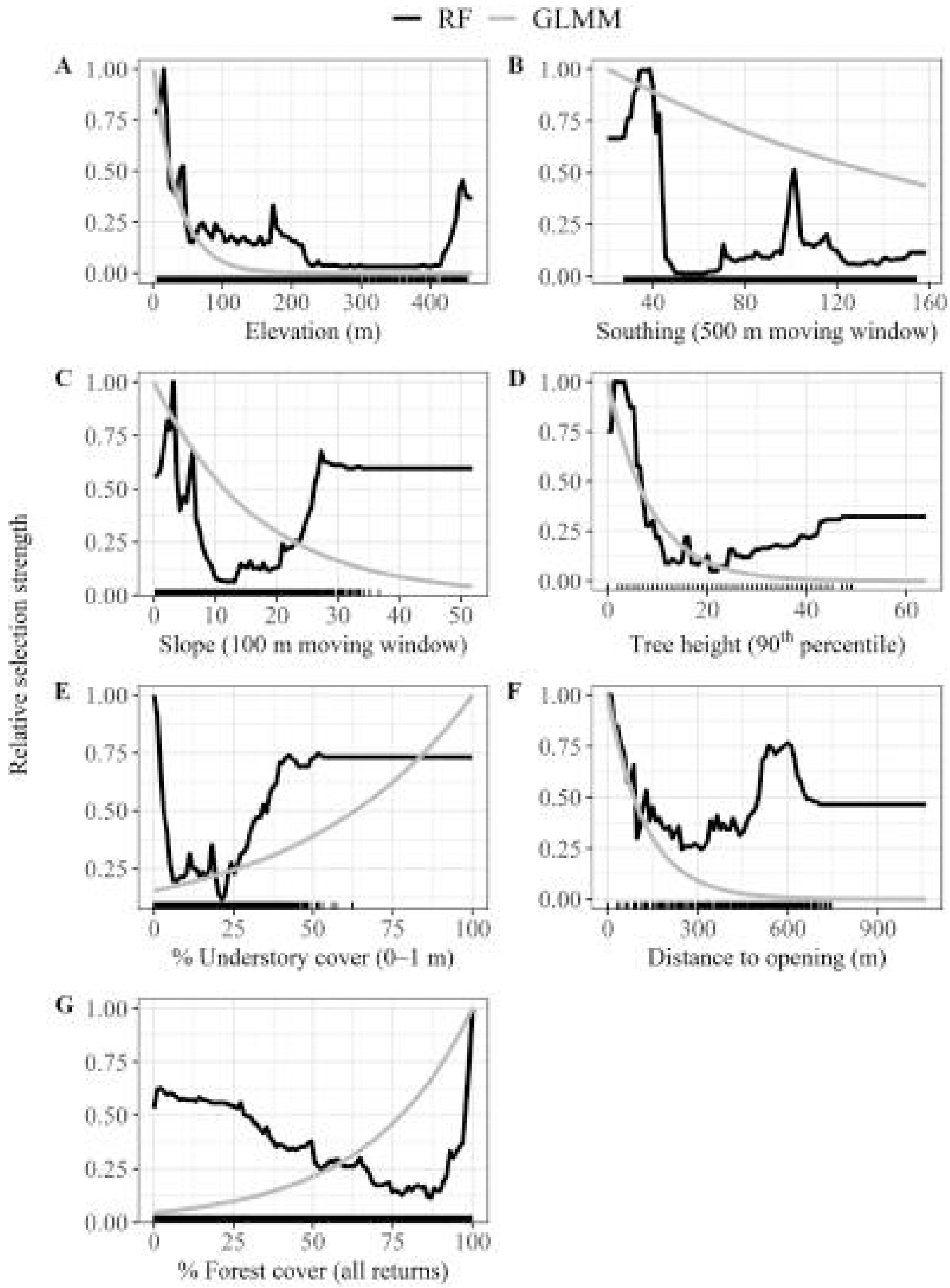

Fig. 4. Predicted marginal effects of relative strength of selection from Random Forest (RF) and resource selection function (RSF) models for Sitka black-tailed deer on Prince of Wales Island in southeast Alaska, USA, during 2010–2012. Marginal effects are given for each predictor variable in order of importance: elevation (A) southing (B), slope (C), tree height (D), % understory cover (E), distance to opening (F), and % forest cover (G). Note that for both methods, we predicted the marginal effect of each predictor over the range of observed values ($n = 100$ per variable) while holding all other predictors at their means and rescaled the predictions between 0 and 1 for comparison. We show the data 'rug' for each predictor that only includes the covariate values for used locations.

4. Discussion

We developed the first winter habitat model for Sitka black-tailed deer on the Tongass National Forest (TNF) based on LiDAR covariates using a Random Forest approach. This approach yielded more accurate, fine-scale spatial predictions of relative selection strength (RSS) and more detailed patterns in deer-habitat relationships relative to other methods analyzed. Given the implications for deer conservation and ongoing forest management decisions based on outdated maps, our comparison between LiDAR and traditional USFS predictors (i.e., HSI and FRESH; Table 1) highlights the need to update methodologies for deer and other important wildlife. The results of this study clearly show that current USFS deer habitat models, while cutting-edge when they were developed, do not capture important ecological variability within

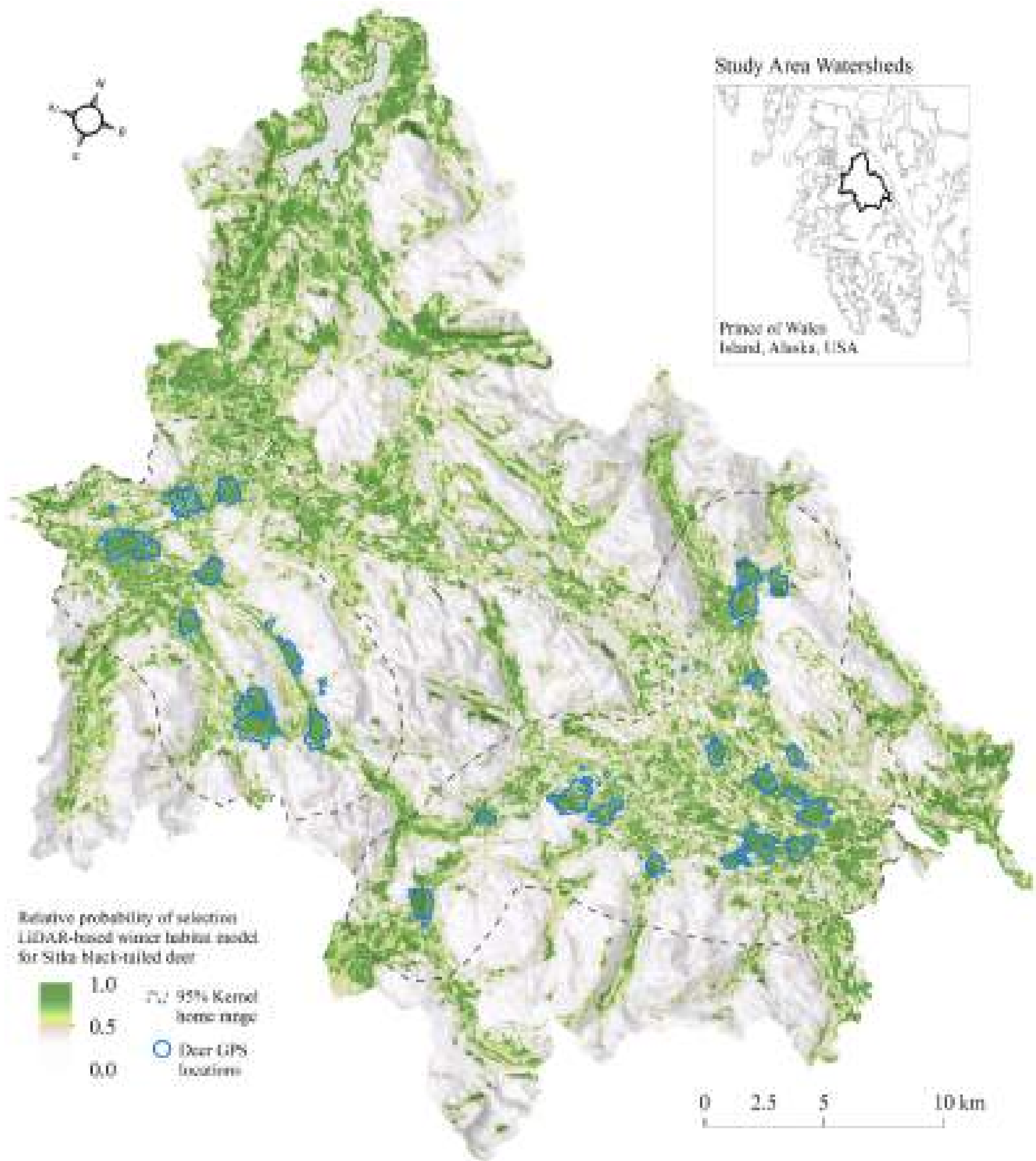

Fig. 5. A LiDAR-based winter habitat model for Sitka black-tailed deer using a Random Forest machine learning algorithm on Prince of Wales Island in southeast Alaska, USA, during 2010–2012. All deer GPS locations are buffered by 100 m for visual purposes.

Table 2
Random Forest model results for a LiDAR-based habitat model and two current U.S. Forest Service (USFS) vegetation model frameworks used to map Sitka black-tailed deer winter habitat on the Tongass National Forest, Alaska, USA, during 2010–2012. We report the kappa statistic (k), area under the receiver operating characteristic curve (AUC), quality of predictions (log loss), and significance (P-values).

Model	Model error	k	AUC	LogLoss	P
LiDAR-based habitat model	5.8%	0.77	0.99	0.06	<0.001
Nutrition-based forage model (FRESH)	16.2%	0.12	0.64	3.68	<0.001
Tree size-density habitat suitability index (HSI)	15.7%	0.06	0.57	4.65	<0.001

regenerating and old-growth forest stands (Fig. 6). We found strong support for using more advanced methods as our continuous LiDAR covariates had a predictive performance of 94% (i.e., 6% error) using Random Forest, a 10% lower model error compared to modeling HSI and FRESH in the same framework (Table 2). Also, given that Random Forest is an emerging approach in the field of habitat selection analysis, we included a comparison with contemporary resource selection function (RSF) models that account for individual variation in resource selection through both random intercepts and coefficients. Random Forest models outperformed RSF models in nearly all comparisons (Fig. S3, Fig. S4), supporting their use in predictive habitat modeling of GPS animal relocation data.

The superior performance of the 30-m LiDAR-based habitat model was able to capture deer selection in much finer detail than stand-level mapping from air-photo interpreted polygons (6.6 ha) common to commercial timber producing regions globally. As a result, our suite of LiDAR-based geomorphometric and forest structure characteristics proved highly predictive of deer winter habitat selection relative to a similar GPS-collar study by McCoy and Gregovich (2021) using air-photo interpreted polygons on Chichagof Island in southeast Alaska. Like previous studies (Schoen and Kirchhoff 1990, Doerr et al. 2005, Person et al. 2009), we found that geomorphometric variables were 20–40% more important than forest structure predictors in the LiDAR-

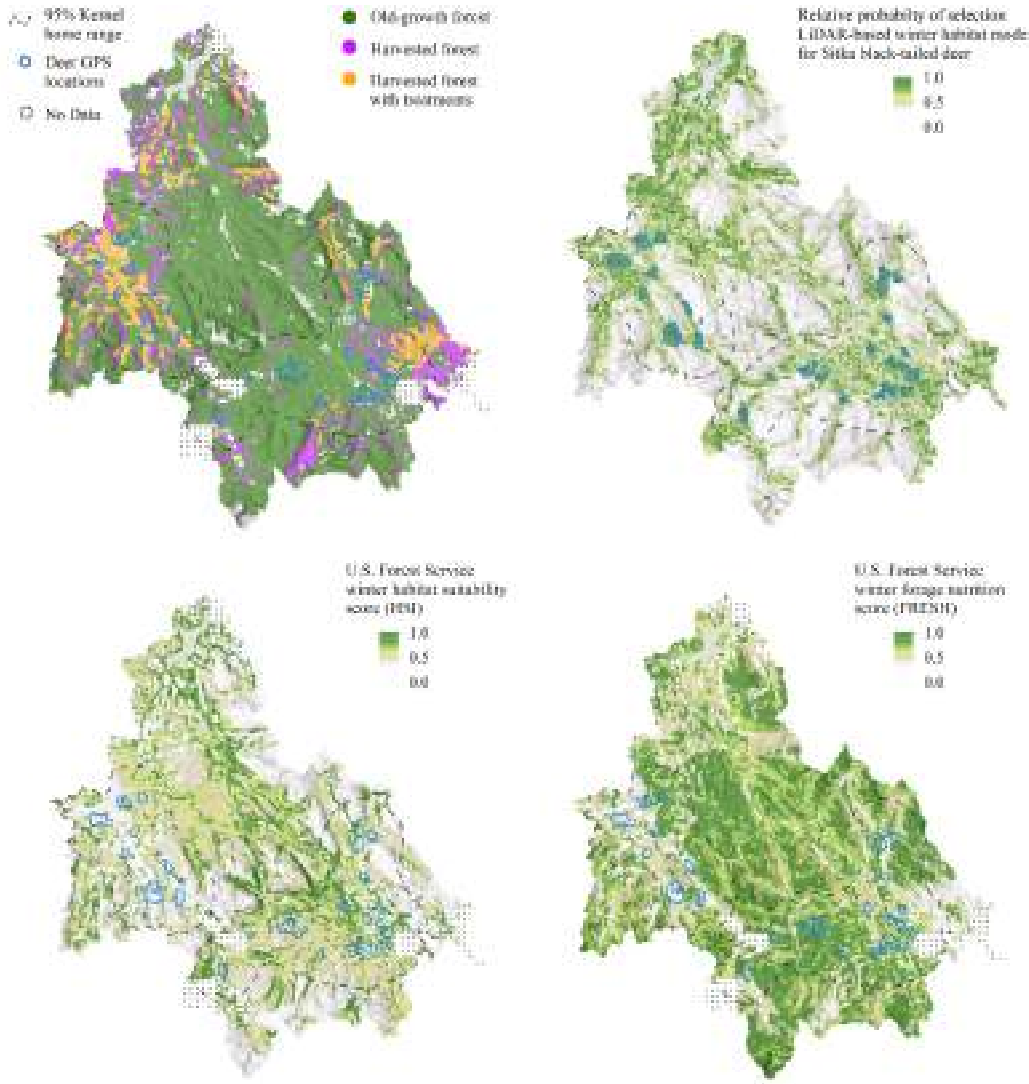

Fig. 6. The results of a LiDAR-based habitat model for the study area watersheds mapped in comparison to two existing U.S. Forest Service habitat models that are used to identify Sitka black-tailed deer winter habitat on the Tongass National Forest in southeast Alaska, USA, during 2010–2012. All deer GPS locations are buffered by 100 m for visual purposes.

Table 3
Population-level, fixed-effects coefficient estimates of relative selection strength on the natural logarithmic scale (β) with standard errors (SE) and lower (LCI) and upper (UCI) 95% confidence intervals from generalized linear mixed-effects model of Sitka black-tailed deer on Prince of Wales Island in southeast Alaska, USA, during 2010–2012 for 7 continuous LiDAR-derived predictor variables. Note that variables were scaled by 1 standard deviation and centered at their means prior to analysis for relative coefficient comparisons.

Parameter	β	SE	LCI	UCI	*P*
Elevation	−3.24	0.70	−4.64	−1.84	<0.001
Southing (500 m moving window)	−0.15	0.28	−0.70	0.40	0.59
Slope (100 m moving window)	−0.44	0.28	−1.00	0.12	0.12
Tree height (90th percentile)	−0.94	0.16	−1.26	−0.62	<0.001
% Understory cover (0–1 m)	0.17	0.07	0.04	0.30	0.01
Distance to opening (m)	−1.06	0.23	−1.51	−0.61	<0.001
% Forest cover (all returns)	0.78	0.11	0.56	1.01	<0.001

based winter habitat model (Fig. 3). At the 2nd-order of selection (i.e., population home range), elevation, aspect, and slope are the best proxies for modeling the effects of landscape-scale snow accumulation (Hanley et al. 2012, Shanley et al. 2015) and resulting decreases in forage availability and increases in locomotive costs for deer (White et al. 2009). Snowfall depth and the interaction with the forest canopy (i.e., snow interception) is highlighted in multiple studies as a main driver of winter habitat selection and population productivity of Sitka black-tailed deer (Schoen and Kirchhoff 1990, Person et al. 2009, Gilbert et al. 2020).

As deep snowfall accumulates and temperature declines in higher elevation mountainous areas during winter, deer primarily select for lower elevations (<250 m; Fig. 4, Fig. 5) where the precipitation mainly falls as rain down to sea-level throughout the winter (Shanley et al. 2015). McCoy and Gregovich (2021) also found that deer strongly selected against higher elevation in winter. At lower elevation on Prince of Wales Island, terrain is flat or moderately sloped and we found that most deer in our study selected for flatter terrain. These low-elevation, flatter areas may increase the predation risk for deer from wolves that frequent flat valley bottoms (Farmer et al. 2006, Roffler et al. 2018). However, the fact that many deer in our sample had winter home ranges close to roads may suggest selection for road-side forage or possibly mitigated predation risk if human activity resulted in lower predation for deer at fine spatial scales (Hebblewhite and Merrill 2009). Person et al. (2009) also noted that deer were attracted to roads, and Doerr et al. (2005) suggested that deer occupied lower elevations because they had the highest densities of roads. A post hoc analysis showed that one individual deer drove selection in the Random Forest RSS plot for steeper slopes (Fig. 4C, Fig. S6). This post hoc analysis suggests the marginal effects plots of RSS that hold all other variables at their means can show useful patterns for interpretation and comparisons but have inference limitations when applied to Random Forest given the complex interactions among variables that are being modeled (Fig. 5). Additionally, the rescaling of RSS plots between 0 and 1 can exaggerate the variation in predictions within and between covariates (Fig. 4, Fig. S6). This underscores the importance of relying on the mapped outputs for final interpretation.

We detected selection for northerly aspects (i.e., 30–34° from north; Fig. 4B) as well as southerly aspects (i.e., >90° from north; Fig. 4B, Fig. S6). Selection for northerly aspects in the Random Forest RSS plot appeared to be driven by a small number of individual deer while the predominate selection was for more southerly aspects (Fig. 5, Fig. S6). While some studies found only weak effects of aspect (Schoen and Kirchhoff 1990, McCoy and Gregovich 2021), others noted the potential for warm maritime winds originating from a southerly direction causing snow to melt faster and found support for selection of south-facing aspects (Doerr et al. 2005). Person et al. (2009) found that deer selection for old-growth forest depended on aspect, with increasing selection for coarse-canopy old-growth forest at aspects between 124 and 214° (i.e., an interaction). Our detection of selection for more southerly aspects (Fig. 4B, Fig. 5) was relatively consistent across individual deer (Fig. S6) and intuitive since these aspects would likely receive more solar radiation in winter relative to north-facing aspects. Regardless, the effect of aspect on deer habitat selection may decline in general at these northern latitudes where day lengths are shorter and the sun is lower in the sky compared to more southern latitudes (Schoen and Kirchhoff 1990), and we suspect that the large proportion of deer collared on the southern end of Mitkof Island (~50% of individuals) in Doerr et al. (2005) may have led to an overestimate of the importance of south-facing aspects for deer in southeast Alaska.

Despite the strong influence of geomorphometric variables in predicting 2nd-order resource selection for deer on Prince of Wales Island, we found support for forest structure metrics and especially for tree height. Interestingly, selection was highest in forest stands < 5 m in height (Fig. 4D), which was most strongly driven by deer that occupied second-growth and unproductive forest types (Fig. S7). During snow free periods, young second-growth stands, clearcuts, and the edge of muskeg meadows can provide winter forage for deer from abundant shrubs (Gilbert et al. 2017). Selection also increased for tree heights > 25 m in primarily old-growth stands (Fig. 4, Fig. S6). Our finding that deer selected strongly for edges (i.e., < 150 m from an opening) agrees with earlier studies that also detected strong edge effects (Chang and Verbyla 1995; Doerr et al. 2005). These shorter distances to openings are selected since light penetrates to the forest floor along edges and increases forage productivity while still providing deer with cover. Also, deer can move more easily along edges relative to the interior of clearcuts, which may present significant barriers to movement especially in deep snow conditions (Gilbert et al. 2017). However, our Random Forest RSS plots also detected weaker selection for distances ~ 500–700 m from an opening, which appeared to be driven by a small number of deer that selected for interior habitats within primarily second-growth forests (Fig. S6, Fig. S7). Similarly, we found a bimodal pattern to both % understory cover and % forest cover, that also appeared to result from individual variation in habitat selection. Deer that occupied more natural old-growth forests tended to select for higher % understory cover and lower % forest cover (Fig. S7). However, most deer selected for lower % understory cover (Fig. S6), but patterns were less apparent for % forest cover with some deer in second-growth and unproductive forest selecting for higher % forest cover (Fig. S7). The selection for higher % of forest cover is intuitive since this denser canopy provides greater interception of snow in winter (Hanley et al. 2012), but the selection for lower % understory cover may simply result from the denser canopy letting less light to the forest floor, and thus, having less understory shrubs relative to young or thinned second-growth forest (Hanley et al. 2012). Alternatively, the airborne LiDAR laser pulses may not have been able to reach the forest floor to measure understory cover consistently with taller or more dense canopy types. We recommend testing terrestrial-based LiDAR in future studies for measuring understory, and potentially calibrating cover type biases in airborne LiDAR. Overall, it appears that the Random Forest models captured individual variation in deer habitat selection but allowed the predictions to be driven by the dominant trends in selection across individuals (Fig. 4).

Our results show nonlinear patterns of selection that were missed by traditional resource selection function (RSF) modeling techniques. While RSF models included both random intercepts and slopes to account for individual variation in selection (Fig. S5; Gillies et al. 2006), the model predictions are based on population-level, fixed-effect coefficients in practice. Shoemaker et al. (2018) also demonstrated the benefit of machine learning prediction methods by comparing Random Forest model outputs with traditional linear modeling techniques (e.g., mixed-effects logistic regression) for habitat selection of mule deer (*Odocoileus hemionus*). In their study, however, they did not include random coefficients, which yielded estimates of individual variation in resource selection. Overall, conducting a joint modeling exercise using both Random Forest and traditional (i.e., constrained) RSF models allowed us to make deeper insights into our data and feel more confident about using the relatively new application of machine learning to model winter habitat selection for deer. Thus, we believe the field of resource selection modeling will likely move in this joint modeling direction, combining traditional mixed-effects modeling techniques to understand individual variation and machine learning algorithms (e.g., Heffelfinger et al. 2020) to make high-resolution landscape predictions from continuous covariates such as LiDAR and other remotely-sensed metrics.

Importantly, we could have included more rigorous model selection including testing for interactions and quadratic effects for covariates in our RSF model comparison, but our goal was to compare the two modeling frameworks using the exact same model formulation. However, despite not including interaction or quadratic terms in our constrained models, the RSF models had only a 6% and 16% lower cross-validation score than the Random Forest models at the study area and population home range area prediction scales, respectively. The results of this study may also be biased towards lower elevation deer because alpine captures were not attempted for this study as in McCoy and Gregovich (2021), with our sample (6–454 m) more closely reflecting elevational ranges used by lower elevation (i.e., resident) deer in their study (3–431 m) compared to high elevation (i.e., migratory) deer (8–667 m). While alpine captures are more challenging and expensive, it would be informative for future studies to examine differences in habitat selection for this population segment. Finally, because winter habitat selection and population productivity of Sitka black-tailed deer is driven by winter severity, particularly depth of snowfall (Gilbert et al. 2020), it is important to note that these specific modeling results are most relevant to winter 2010–2012 snowfall averages that would be considered mild (0.33 m) to moderate (1.28 m) total snowfall (Gilbert et al. 2017, 2020); therefore, significantly different snowfall levels due to climate change (Shanley et al. 2015) may produce different results. Thus, the deer habitat model developed in this study should be updated in the future with new GPS data since winter snowfall could significantly deviate from historical averages and collecting more GPS data in this area would allow for external validation of our model predictions.

The results of this study represent a significant step forward in the accuracy, resolution, and ability to implement effective conservation and restoration strategies in a large managed forest landscape. LiDAR remote sensing acquisition should be continued to cover the complete TNF through interagency and partner cost-sharing collaboration and repeated at appropriate intervals to record landscape change. To date, there are approx. 103,000 ha of regenerating clearcuts on the TNF that represent some of the historically most productive habitats for wildlife. At the current cost of approx. $1,200/ha USD to conduct forest-restoration treatments (USFS forest stewardship contract average, 2015–2019), it would cost approx. $124 million USD to treat all these stands—clearly, a prioritization process will be necessary. More broadly, our approach could be applied to any forest landscape where similar high-resolution data is collected, particularly those that are remote and difficult to evaluate using traditional methods. Furthermore, a similar approach could be used by pairing LiDAR with different types of models that use animal detection data (e.g., occupancy models and camera trap data), potentially yielding insights in landscapes where GPS-collaring animals is not feasible. As the big data revolution continues to unfold within the conservation community, such approaches hold great potential to increase the efficiency and accuracy of habitat evaluations, improving conservation planning outcomes in forested landscapes and beyond.

CRediT authorship contribution statement

Colin S. Shanley: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Daniel R. Eacker:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - review & editing, Visualization. **Conor P. Reynolds:** Conceptualization, Resources, Writing - review & editing. **Bonnie M.B. Bennetsen:** Writing - review & editing. **Sophie L. Gilbert:** Telemetry Data Collection, Conceptualization, Resources, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2021.119580.

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The influence of human disturbance on Pacific salmon (*Oncorhynchus* spp.) in the diet of American black bears (*Ursus americanus*) in two areas of coastal British Columbia, Canada

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Abstract

Recent studies have highlighted the importance of salmon (genus *Oncorhynchus* Suckley, 1861) in the diet of bears, and of bears as consumers and key agents supporting the transport of salmon-derived nutrients to riparian ecosystems. Salmon abundance and human disturbance are known influences on bear ecology and behaviour, though few studies have quantified shifts in bear diet due to these effects. We used stable isotope analysis to investigate how salmon escapement and human presence influenced the proportion of salmon in the diet of American black bears (*Ursus americanus* Pallas, 1780) in two locations in coastal British Columbia, Canada. We found that salmon constituted a small proportion of black bear diet across sexes and ecosystems, while bears appeared to gain a similar amount of energy and lean mass from terrestrial sources. Salmon consumption was not related to the total annual abundance of salmon in a watershed but was significantly lower in large streams with regular human presence, suggesting that human disturbance can cause a dietary shift in bears that could have important consequences to their fitness. We also observed that the isotopic signatures of key bear foods did not vary between foliage and fruit, simplifying data collection for future isotopic studies on bear diet.

Key words: behavioural response, dietary shift, ecosystem management, foraging, marine-derived nutrients, *Oncorhynchus* spp., Pacific salmon, stable isotope analysis, *Ursus americanus*, American black bear

Résumé

Des études récentes ont souligné l'importance des saumons (genre *Oncorhynchus* Suckley, 1861) dans le régime alimentaire des ours et celle des ours comme consommateurs et agents de soutien clés du transport de nutriments dérivés des saumons vers les écosystèmes riverains. S'il est établi que l'abondance des saumons et les perturbations d'origine humaine influencent l'écologie et le comportement des ours, peu d'études ont quantifié les changements du régime alimentaire d'ours découlant de ces effets. Nous utilisons l'analyse d'isotopes stables pour examiner l'influence de l'échappement de saumons et de la présence humaine sur la proportion de saumons dans le régime alimentaire d'ours noirs (*Ursus americanus* Pallas, 1780) en deux endroits le long de la côte de la Colombie-Britannique (Canada). Nous constatons que les saumons représentent une petite proportion du régime alimentaire des ours noirs des deux sexes et dans différents écosystèmes, les ours semblant obtenir des quantités similaires d'énergie et de masse maigre de sources terrestres. La consommation de saumons n'est pas reliée à l'abondance annuelle totale de saumons dans un bassin versant, mais est significativement plus faible dans les grands cours d'eau caractérisés par une présence humaine régulière, ce qui indiquerait que les perturbations d'origine humaine peuvent causer un changement du régime alimentaire des ours qui peut avoir d'importantes conséquences sur leur aptitude. Nous observons également que les feuilles et les fruits d'aliments clés des ours ont des signatures isotopiques semblables, ce qui simplifie la collecte de données pour des études isotopiques futures sur le régime alimentaire des ours. [Traduit par la Rédaction]

Mots-clés : réaction comportementale, changement du régime alimentaire, gestion des écosystèmes, quête de nourriture, nutriments d'origine marine, *Oncorhynchus* spp., saumon du Pacifique, analyse d'isotopes stables, *Ursus americanus*, ours noir

Introduction

The prominence of ecosystem management has led some authors (Hilderbrand et al. 2004; Piccolo et al. 2009; Lincoln et al. 2020) to call for the management of Pacific salmon (genus *Oncorhynchus* Suckley, 1861) to consider not only escapement goals for fisheries harvest, but also for the needs of wildlife. Salmon are an important source of nutrients and energy for riparian ecosystems and terrestrial wildlife (Quinn et al. 2018; Reimchen 2018). The transfer of marine-derived nutrients from salmon between these ecosystems has influences on biodiversity (Hocking and Reynolds 2011) and ecosystem productivity and integrity (Ben-David et al. 1998; Helfield and Naiman 2006). Transfer of salmon nutrients to terrestrial ecosystems is accomplished by multiple predators and scavengers, including at least 23 species of mammals and birds (Cederholm et al. 1999).

Of the vertebrate species of salmon predators and scavengers, American black bears (*Ursus americanus* Pallas, 1780) are one of the most influential and the best candidate for an "umbrella species" (Roberge and Angelstam 2004) around which to focus development of riparian ecosystem-integrity indicators (Shardlow and Hyatt 2013). Many recent studies have highlighted the importance of brown bears (*Ursus arctos* Linnaeus, 1758) as key agents in the transport of salmon biomass and nutrients between aquatic and riparian ecosystems (e.g., Naiman and Latterell 2005; Quinn et al. 2009; Darimont et al. 2010). Other studies have highlighted the importance of ecological factors such as stream morphology on salmon consumption by brown bears (Quinn et al. 2017). While black bears are abundant, distributed widely, and exhibit strong temporal and spatial associations with spawning salmon (Shardlow and Hyatt 2013; Levi et al. 2020), quantitative assessments of the use of salmon by black bears are less common than for brown bears. Quantitative research into the drivers of salmon consumption by black bears is required in order to provide reliable support for managing the abundance of both salmon and bears for the maintenance of ecosystem integrity (Piccolo et al. 2009; Lincoln et al. 2020).

Along with influencing terrestrial ecosystem processes, the consumption of salmon is also an important influence on bear ecology and demographics as salmon provide a major source of protein and fat in the fall as bears prepare for winter denning. Brown bears that consume more salmon are usually larger, more fecund, and have higher population densities than those that do not (Hilderbrand et al. 1999), while black bear reproduction is dependent on body condition on which salmon consumption is a key influence (Belant et al. 2006). When present, salmon are usually the most important dietary source of protein for brown bears and body condition correlates with salmon assimilation (Hilderbrand et al. 1999; Shirane et al. 2021). Female bears must consume adequate amounts of protein and fat in the fall to support their cubs through the winter and can abandon their pregnancy if they fail to do so (Lopez-Alfaro et al. 2013). Black bears eat much less salmon than brown bears on the coastal British Columbia mainland (Adams et al. 2017), but the importance of salmon has not been measured where black bears occur outside the range of brown bears.

Black bear behaviour and ecology are influenced by anthropogenic patterns on the landscape (Switalski and Nelson 2011; Stillfried et al. 2015). Increasing human presence can cause bears to alter their use of habitat both spatially and temporally (Lustig et al. 2021; Watabe and Saito 2021). Human activity in areas surrounding salmon-bearing streams could cause changes in bear behaviour such as avoidance of high human-use areas. If areas of high human use overlap with areas of salmon availability, avoidance could result in reduced salmon consumption. Reductions in the amount of salmon in the black bear diet may force black bears to rely more on plant foods which do not provide the same levels of protein or fat, resulting in reductions in body condition and reproduction (Belant et al. 2006; McLellan 2011).

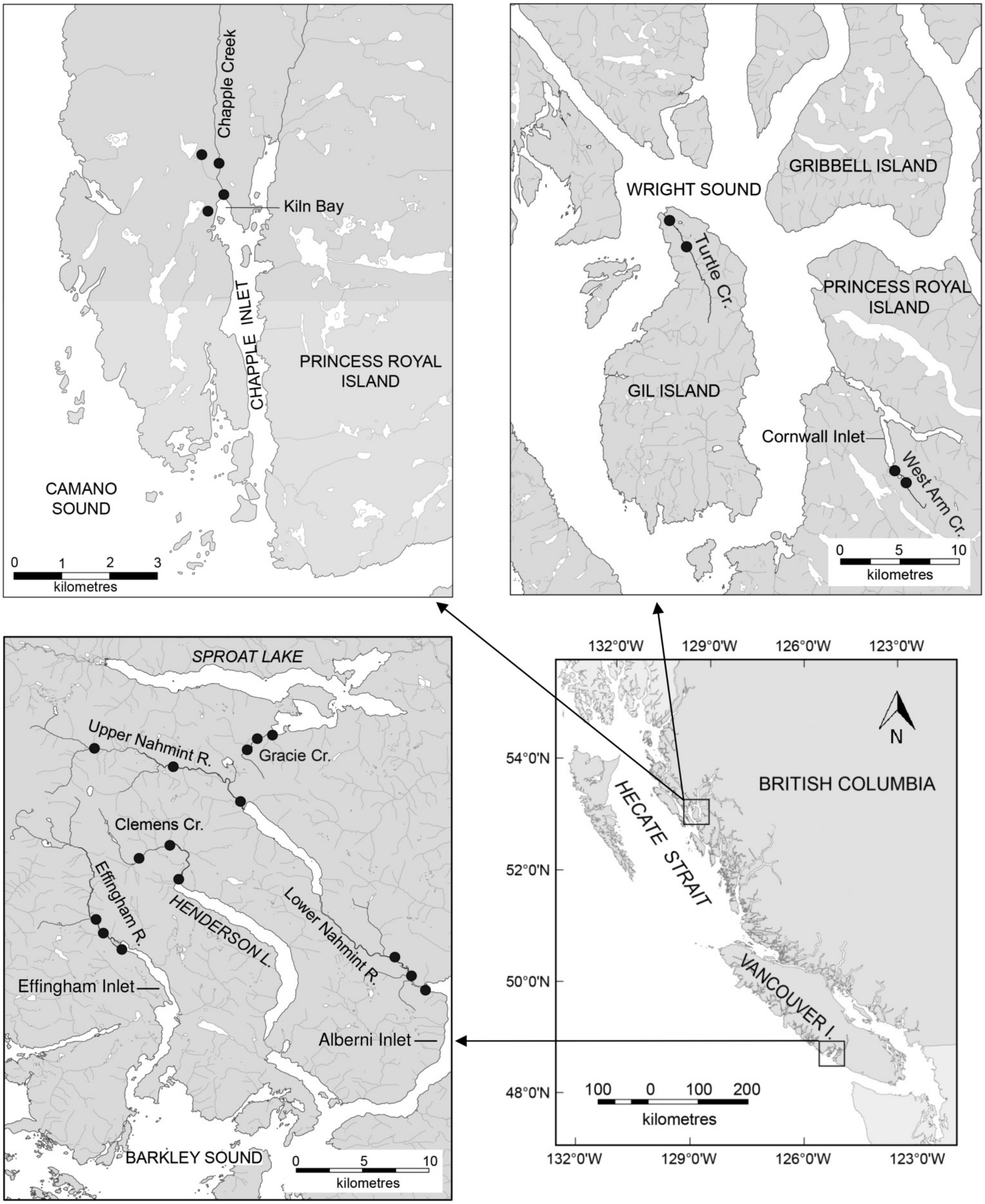
In this study we describe the influence of bear sex, salmon abundance, stream morphological characteristics, salmon species diversity, and human disturbance on the use of salmon by black bears using stable isotope analysis. We measured stable isotope signatures from known foods collected during this study, along with values taken from literature, to create isotopic baselines to calculate diet.

Materials and methods

Location of the study

This study took place in the riparian zones of four adjacent watersheds on Vancouver Island, two watersheds on Princess Royal Island, and one on Gil Island in coastal British Columbia, Canada (Fig. 1). Princess Royal Island is isolated from mainland British Columbia by the Inside Passage which is about 1 km across. Gil Island is isolated from other neighbouring islands by 2.5–5 km of ocean; both islands are likely largely isolated populations (Service et al. 2021). Vancouver Island is large and has >300 000 human inhabitants, as well as active industrial forestry in our study area. Princess Royal and Gil islands are smaller (2500 and 230 km^2) and uninhabited with no recent forestry activity. Despite the size differences of the islands, each watershed we sampled was similar in size, habitat, and stream morphology. There were no established brown bear populations on any of these islands at the time of our study. Sampling sites (Fig. 1) were located in the Upper Nahmint River and Clemens Creek on Vancouver Island in 2008. In 2009 and 2010 the Lower Nahmint River, Effingham River, and Gracie Creek were added. Princess Royal and Gil islands (Fig. 1) were sampled in 2010 and 2011. Surveys of spawning salmon numbers were conducted on all streams. Measurements of stream flows, drainage

Fig. 1. A map of western British Columbia, Canada, showing our study areas and sampling locations. Neither locations supported brown bear (*Ursus arctos*) populations. Princess Royal Island is not inhabited by people, while Vancouver Island features a large human population. The basemap is provided by the government of British Columbia Freshwater Atlas, projected with NAD 1983 BC Environment Albers coordinate system.



area, and salmon escapement were also conducted on all streams.

Watershed characteristics

Vancouver Island

Gracie Creek is small and flows through dense forest (30-year-old second growth) before flowing into Sproat Lake. Small populations of sockeye (*Oncorhynchus nerka* (Walbaum in Artedi, 1792)) and coho (*Oncorhynchus kisutch* (Walbaum, 1792)) salmon (annual mean escapement <1000 combined) spawn primarily in the creek's lower 2.5 km. A logging road, which parallels and crosses the creek, supports regular recreational and logging traffic from the city of Port Alberni, which is 15 km away. Logging activity was ongoing in adjacent areas, but not in the Gracie Creek watershed during our study.

The Effingham River is located in a watershed of regenerating stands (40+ years old) and old growth forest (200+ years). Although there had been no timber harvest in the watershed in recent years, there was logging activity in adjacent watersheds during our study. Salmon, mostly chum (*Oncorhynchus keta* (Walbaum in Artedi, 1792)) with small numbers of sockeye and coho, spawn in the lower 2 km of the river. There were no roads, hiking trails, or evidence of recent human activity in this watershed.

The Upper Nahmint River drains into Nahmint Lake. The area was primarily covered by regenerating stands <20 years old; active logging was in progress during this study along the road that parallels the river. No salmon spawn was found in the upper Nahmint which is hydraulically impassable for fish other than for a few steelhead salmon (*Oncorhynchus mykiss* (Walbaum, 1792) that manage to surmount Nahmint Falls.

The Lower Nahmint River extends from the outlet of Nahmint Lake to Alberni Inlet and Barkley Sound. Like the Upper Nahmint, the lower portion of the watershed had been extensively logged and was dominated by early seral vegetation with some regenerating stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg) and Pacific silver fir (*Abies amabilis* Douglas ex J. Forbes). The area immediately adjacent to the river was old growth forest. Salmon spawners, mostly chum, but with some chinook (*Oncorhynchus tshawytscha* (Walbaum in Artedi, 1792)) and coho, were distributed relatively equally from the river mouth to the upper limit of migration at Nahmint Falls located 6 km upstream of Alberni Inlet (Fig. 1). Much of the Lower Nahmint was not easily accessible by road or trail.

Clemens Creek flows into Henderson Lake which drains into Alberni Inlet and Barkley Sound. Sockeye and coho spawn in the lower 7 km of the creek, are the predominant salmon species with chinook and chum also present in small numbers. Clemens Creek was the most extensively logged of all areas studied and was dominated by early seral forest. Some logged areas extended to the creek edge. Non-industry-related road access was restricted in 2008 but opened for the first time in 2009. A lodge at the mouth of the creek was also opened for the first time in 2009, during the second year of our study.

Princess Royal Island

Chapple Creek enters Kiln Bay at the head of Chapple Inlet on the west side of Princess Royal Island. The east side was undisturbed, while the west side of the creek and the peninsula extending southward were logged and were in early seral growth. The deactivated logging road was overgrown and there was little or no human activity in this watershed. An area of regenerating forest parallels some of the creek. Pink salmon (*Oncorhynchus gorbuscha* (Walbaum, 1792)) were the predominant spawners along with small numbers of chum.

West Arm Creek enters Cornwall Inlet also on the west side of Princess Royal Island. Some of the watershed was logged until the mid-1990s. A disused road paralleled the creek's north side. Pink, chum, and coho spawned in this creek. Department of Fisheries and Oceans stream survey crews, who were separate from our study, were active throughout the spawning period.

Turtle Creek, on Gil Island, flows north into Wright Sound. The island was in a natural state with no road or trail access. The shallow creek has many small pools covered by large organic debris and supported a pink salmon run.

Plant sample collection

Plant samples for isotopic analysis were collected along the bear trails that paralleled the study streams and from the sides of old access roads in the regenerating forest areas. Most of the plant samples were dried for storage in the field because freezing was not practical. In the laboratory the berries were ground with mortar and pestle for analysis. During this process some seeds were included in the sample used for isotope determination. Plants consumed by black bears were not always in fruit when we were in the field. When no berries were available, leaves were collected as the sample material. We evaluated differences in isotopic signatures between berries with and without seeds and between berries and foliage, using Wilcoxon matched-pairs test.

Other foods

Sources of marine-derived nutrients were assumed to be salmon but may also have included foods consumed during intertidal foraging by bears, which has been observed by ourselves and others. We collected shore crabs (species of the genus *Hemigrapsus* Dana, 1851), isopods (*Idotea wasnesenskii* Brandt, 1851), and pricklebacks (*Phytichthys chirus* (Jordan and Gilbert, 1880)) from overturned rocks. In addition, black bears overturned many rocks along trails and old roadways and while foraging for ants. Ants (species of the genus *Monomorium* Mayr, 1855) found under these rocks were collected for isotope analysis.

Hair capture methods

Hair collectors consisted of single strands of barbed wire strung about 50 cm above the ground to form enclosures approximately 5 m × 5 m around the location of a scent lure. Hair snag sites were set adjacent to rivers and streams to form a linear transect along the riparian zone. Snag sites were generally placed 1–3 km apart along each stream (Fig. 1). All snag sites were located within 5–30 m of the stream bank and at

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least 250 m from any road except for five sites on Princess Royal Island which were placed in cut-blocks 0.5–3 km from the nearest stream.

Hair samples were collected approximately every 3 weeks during the summer and approximately every 10 days in the fall as samples were deposited more often in the fall and we wanted to avoid the mixing of samples so we could genotype individual bears. The hair, often wet from rainfall, was dried over a warming pad for several hours before being placed in a coin envelope and stored at room temperature.

Hair and plant isotope signatures

The longest hairs from each hair sample were selected for isotope analysis; all hairs used in isotope analysis were ≥7.5 cm. Selecting the longest hairs maximizes the temporal period for which stable isotope analysis would estimate diet. Vancouver Island hair samples were collected in the spring (May to June) and hair samples from Princess Royal Island were collected in the summer (July and August). Based on documented hair growth rates from brown bears, we assumed that most of these hairs were grown the previous summer, and thus represented the diet for the entire period of hair growth (approximately June to October) the previous year (Mowat et al. 2017; Jimbo et al. 2020). No similar studies have been done on black bears or any other bear species, but we expect hair growth patterns will be similar among temperate-dwelling bears. We examined the relationship between carbon and nitrogen isotopic signatures and the date of sampling to test our assumption.

Carbon and nitrogen isotopic signatures were analyzed by Aquatech Enviroscience Laboratories Inc. in Victoria, British Columbia, Canada using standard methods and instrumentations. Samples of bear hair were cleaned of surface oils using repeated rinses of a 2:1 chloroform:methanol solution and then dried in an oven at 60 °C overnight. Hair in the amount from 0.2 to 0.4 mg was cut and placed into tin cups. The amount of sample or standard analyzed in the procedure was based on the criteria that the range of N must be within 0.02–0.2 mg.

In the laboratory, samples of berries and plant material were either freeze-dried or oven-dried at 60 °C, if fresh. All plant samples were ground by mortar and pestle to achieve sample homogeneity and an amount between 5 and 10 mg, depending on the nitrogen content, was transferred into a tin capsule.

Nitrogen and carbon isotope compositions were determined for hair and plant samples using thermal combustion elemental analyzer Costech ECS 4010 from Costech Analytical Instruments Inc. (Valencia, California, USA) coupled via the flow reducing interface ConFlow III with continuous flow isotope ratio mass spectrometer (EA-IRMS) Thermo Finnigan Delta^{PLUS} Advantage from Thermo Finnigan Inc. (Bremen, Germany). Each batch of samples included quality assurance and quality control samples: three types of secondary reference material in duplicates were analyzed before and after each batch of samples, a sample duplicate, and a procedural blank. The N and C contents of these samples were determined based on the EA-IRMS analysis of acetanilide used as a calibration standard. Nitrogen and carbon isotope data are reported in conventional δδ notation in units of per mil (‰) with reference to atmospheric nitrogen (Air) and Vienna Pee Dee Belemnite (VPDB) carbonate standard, respectively, according to the following equation, for nitrogen, for example:

$$\delta^{15}\mathrm{N}_{\mathrm{sample}}\ (‰) = \frac{(R_{\mathrm{sample}} - R_{\mathrm{standard}})}{R_{\mathrm{standard}}} \times 1000$$

where $R = {}^{15}\mathrm{N}/{}^{14}\mathrm{N}$ and the standard is atmospheric nitrogen with a $^{15}\mathrm{N}/^{14}\mathrm{N}$ ratio of 0.00368 and a $\delta^{15}\mathrm{N}$ value of 0‰.

The instrument was calibrated with the following international reference standards: IAEA-N1 (ammonium sulphate reference material certified by the International Atomic Energy Agency) with a $\delta^{15}\mathrm{N}$ value of 0.43‰ and IAEA-N2 with a $\delta^{15}\mathrm{N}$ value of 20.32‰ (used for N isotopic quantification); Sucrose ANU with a $\delta^{13}\mathrm{C}$ value of −10.43‰ and NBS-22 OIL with a $\delta^{13}\mathrm{C}$ value of −29.74‰ (used for C isotopic quantification). Long-term performance of the mass spectrometer was monitored by analysis of secondary reference materials in every batch: acetanilide with C and N contents of 71.09% and 10.36%, respectively, dorm with $\delta^{13}\mathrm{C}$ and $\delta^{15}\mathrm{N}$ values of −17.17‰ and 14.33‰, respectively, and caffeine with $\delta^{13}\mathrm{C}$ and $\delta^{15}\mathrm{N}$ values of −42.02‰ and −0.95‰, respectively. The long-term standard deviation of the values obtained from measurements of the secondary reference materials were 0.33‰ and 0.25‰ for $\delta^{13}\mathrm{C}$ and $\delta^{15}\mathrm{N}$, respectively.

Genetic analysis

DNA analysis of hair samples was conducted by Wildlife Genetics International (Nelson, British Columbia, Canada) using established primers and PCR conditions (Paetkau et al. 1998). The first samples were analyzed at 21 microsatellite markers, however, as samples accumulated during the study, 4 original markers with low variability were dropped in favour of new more variable markers and the final selection of markers used for identifying individual black bears was G10B, G10U, MU23, MU26, GIA, and G10P, with the mean heterozygosity for these six markers being 0.72. Only two pairs of identified individuals shared genotypes at five of the six markers, so there is a low probability that we sampled more than one individual with any given six-locus genotype (Paetkau 2003). Error checking was conducted using the procedures outlined by Paetkau (2003). These procedures were validated by Kendall et al. (2009) through a variety of methods, including blind testing, and have been shown for all practical purposes to eliminate the identification of false individuals through genotyping error. At least one sample per identified individual was also analyzed at the amelogenin gender marker (Ennis and Gallagher 1994) to determine sex.

Salmon abundance estimates

Seasonal changes in abundance of maturing adult salmon on or near their spawning areas were obtained through foot, snorkel, and float-survey methods (Cousens et al. 1982). Between five and seven surveys were conducted on each stream (Supplementary Table S1) during the period of active salmon migration and spawning. Survey crews' presence was brief (a few hours per week) and occurred at consistent levels across the study area. Numeric estimates of live and dead salmon were recorded on each survey date for all the major salmon species entering a given system. Lower Nahmint River chum salmon abundance estimates were based on visual counts during downstream floats. Some escapement estimates were gained from the Department of Fisheries Oceans Canada (DFO) nuSEDS V2.0 database (Supplementary Table S1). At Clemens Creek, snorkel surveys conducted by DFO staff were supplemented with streamside foot surveys to count sockeye and coho spawners. Foot surveys were used on all Princess Royal streams. Area-under-the-curve estimates (English et al. 1992) using species-specific stream life estimates from Perrin and Irvine (1990) were calculated for estimates of total escapement.

Diet estimation and analysis

We derived isotopic endpoints for each dietary source using several methods (Supplementary Table S2). An endpoint for ants was calculated using sampled ants from Princess Royal Island. An endpoint for coastal black-tailed deer (*Odocoileus hemionus* (Rafinesque, 1817)) was taken from Darimont et al. (2009). Due to the similarity of these two endpoints (Supplementary Table S2), they were averaged to create a single source for terrestrial meat. We averaged salmon isotopic signatures from all species of salmon measured in several studies (Bilby et al. 1996; Hilderbrand et al. 1996; Ben-David et al. 1997; Jacoby et al. 1999; Chaloner et al. 2002; Satterfield and Finney 2002; Ben-David et al. 2004; Tom Johnston, personal communication) to determine an endpoint for salmon in the diet. Two plant endpoints were used in different models. First, we used an evenly weighted average of sampled plants from the two islands respectively. Skunk cabbage (*Lysichiton americanus* Hultén and H. St. John) and horsetail (species of the genus *Equisetum* L.) were removed from this average due to their high nitrogen isotopic signatures. To account for unknown variation in the consumption of different vegetation, we also used a generalized plant endpoint calculated by Mowat and Heard (2006). This was calculated based on the isotopic signatures of grizzly bears presumed to eat only plants.

Isotopic signatures in consumers are usually higher than those in dietary sources due to preferential assimilation of heavy isotopes, a process known as discrimination (Robbins et al. 2005). To account for this change, we assigned discrimination rates for each diet source for both carbon and nitrogen. Due to uncertainty surrounding the relationship between carbon isotopic signatures and carbon discrimination, we used a fixed rate of carbon discrimination for all diet sources of 3.7% ± 0.2% from Fortin et al. (2007) and Van Daele et al. (2013). The relationship between nitrogen discrimination and different food sources is better understood (Van Daele et al. 2013). Thus, we used different rates for each diet source based on the relationship between discrimination and the food isotopic signature using the following equation:

$$\Delta\delta^{15}\mathrm{N} = \left(0.88 \times \delta^{15}\mathrm{N} + 5.28\right) - \delta^{15}\mathrm{N}$$

from Felicetti et al. (2003). This relationship was first presented by Hilderbrand et al. (1996) based on feeding trials of captive brown bears.

Phillips and Koch (2002) recommend considering the concentration of each measured element in dietary sources, particularly for omnivores, due to plants being nitrogen-poor relative to dietary meat. To account for variation in concentration of C and N, we used concentration values for carbon and nitrogen available in the literature (Philips and Koch 2002). We also ran models without concentration dependence to compare the effects these parameters had on the model outcome.

To investigate the effect of human disturbance on bear diet, we subjectively classified each hair sample site based on how likely a foraging bear would come into contact with humans (Supplementary Table S3). Human disturbance was classified into five categories based on the regularity of human activity in the area. After initial analyses, we collapsed these categories into a binomial variable of disturbed and undisturbed areas. Undisturbed areas were those with little human access and no consistent human use. Disturbed categories varied from occasional human use and no active roads to areas with frequent traffic and bear hunting. Our disturbance variable considered only human presence near the stream and not historical habitat disturbance or stand structure. Thus, areas such as cutblocks on Princess Royal Island were classified as undisturbed due to the remote nature of the island and deactivation of logging roads; human use in the area was extremely low and black bear hunting was prohibited.

Service et al. (2019) found that salmon species diversity was an important influence on salmon consumption by black bears. We investigated the effects of salmon species diversity by including a categorical variable for the number of species in regressions. We created two different measures of salmon species diversity: first we used the total number of salmon species present in the watershed, and second, we used the number of species that constituted substantial runs and were most readily available to bears (Supplementary Table S1) which we called "dominant species."

Levi et al. (2015) found that brown bears utilize a variety of different stream habitats for salmon foraging, while Quinn et al. (2017) found that increasing stream depth and width resulted in lower salmon consumption by brown bears. Thus, we assessed how high and low flow rates, as well as stream width, affected salmon consumption by black bears.

We estimated dietary proportions using the Bayesian model framework MixSIAR (Stock et al. 2018). Isotopic values for all bears are available in Supplementary Table S4. Using this framework allowed us to include distributions of diet source endpoints and discrimination rates and produce probability distributions for estimated diet proportions. It also allowed us to include up to two fixed and (or) random effects in each model but not the full set of covariates of interest. We ran models for each island separately. In all models we used individual as a random effect to account for random variation among individuals, some of whom were sampled multiple times, and sex as a fixed effect to account for known variation in diet between sexes. Seven individuals were sampled twice, two individuals were sampled three times, and

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one was sampled four times within a given year of sampling. One individual was sampled once in multiple years, while no individuals were sampled across multiple watersheds. Models were run for 100 000 or 300 000 iterations and evaluated for convergence based on the Gelman–Rubin statistic (Brooks and Gelman 1998). All statistical analyses were completed using R (R Core Team 2020).

We compared the proportion of salmon in the diet between the sexes, the two study areas, and in the salmon- or non-salmon-bearing watersheds using Welch's two-sample *t* tests. We used the mean estimate for each diet class as calculated from the probability distributions of each individual. To investigate ecological effects on salmon consumption, we fit multiple linear regressions using the proportion of salmon in the diet as the independent variable to (*i*) stream and watershed measures (average wetted width, and low and high creek flow rates); (*ii*) salmon escapement estimates in each stream; (*iii*)categorical or binomial variables for human disturbance at hair-capture sites; and (*iv*) salmon species diversity per stream. We did not include both salmon escapement and salmon presence/absence, or salmon species diversity and presence/absence in the same models because their measures were not independent. We did not include samples from the logged area on Princess Royal Island in our multivariate analyses because they could not be assigned to a specific watershed with confidence. We assessed model fit by investigating parameter influence on salmon consumption via analysis of variance (ANOVA) tests and using Akaike's information criterion (AIC).

Results

The most abundant salmon species were sockeye, pink, and chum, with some streams having small populations of chinook and coho (Supplementary Table S1). Spawning populations ranged from 800 in West Arm Creek to 13 800 in Clemens Creek.

Plants and other food items

Stable isotope signatures of plant foods varied considerably (Fig. 2, Supplementary Table S5). There was no significant difference in the isotopic signatures of berry samples with or without seeds, nor was there any difference in the signatures of the foliage and fruit of individual plants (Table 1). Therefore, we used leaves to index fruit isotope values when berries were not available.

There was no significant difference (Welch's two-sample *t* test, $P > 0.05$) in δ^{13}C or δ^{15}N between Princess Royal Island and Vancouver Island for all six plant species in common (Supplementary Table S5). Plants in habitats with salmon versus those without salmon spawners had higher isotope ratios, particularly N (Table 2). On Vancouver Island, the Upper Nahmint River does not support a salmon run and had lower values of δ^{15}N than adjacent watersheds that supported spawning populations, though the difference was not significant ($P = 0.14$). On Princess Royal Island, plants foods collected from the regenerating logged forests of adjacent slopes had higher δ^{13}C ($P = 0.02$) and lower δ^{15}N ($P = 0.02$) values than plant foods collected in the riparian zone of salmon streams (Table 2). We combined plant isotope signatures for both salmon- and non-salmon-bearing watersheds for diet analysis because the variation among plants was greater than among streams.

Isotopic signatures for intertidal foods (shore crabs, isopods, pricklebacks) were −17.4‰ ± 0.8‰ for δ^{13}C and 11.0‰ ± 1.9‰ for δ^{15}N (Fig. 2) and were similar to our Pacific salmon signature and we thus averaged these for diet modelling (Fig. 3, Supplementary Table S2). Ant and deer signatures were similar and averaged as well (Fig. 3).

Black bear diet

Diet source endpoints and trophic correction factors used in our estimation of diet are given in Supplementary Table S2 and shown in Fig. 3. Models using the plant source endpoints collected in the field did not converge and produced unrealistic results. Thus, to estimate bear diet we used the generalized plant endpoint from Mowat and Heard (2006). Models considering concentration effects produced nearly entirely vegetarian estimates for all bears in this study. Given the many field observations of bears consuming salmon and ants (Shardlow and Hyatt 2013), we only present results from models that did not consider concentration effects in our subsequent analyses.

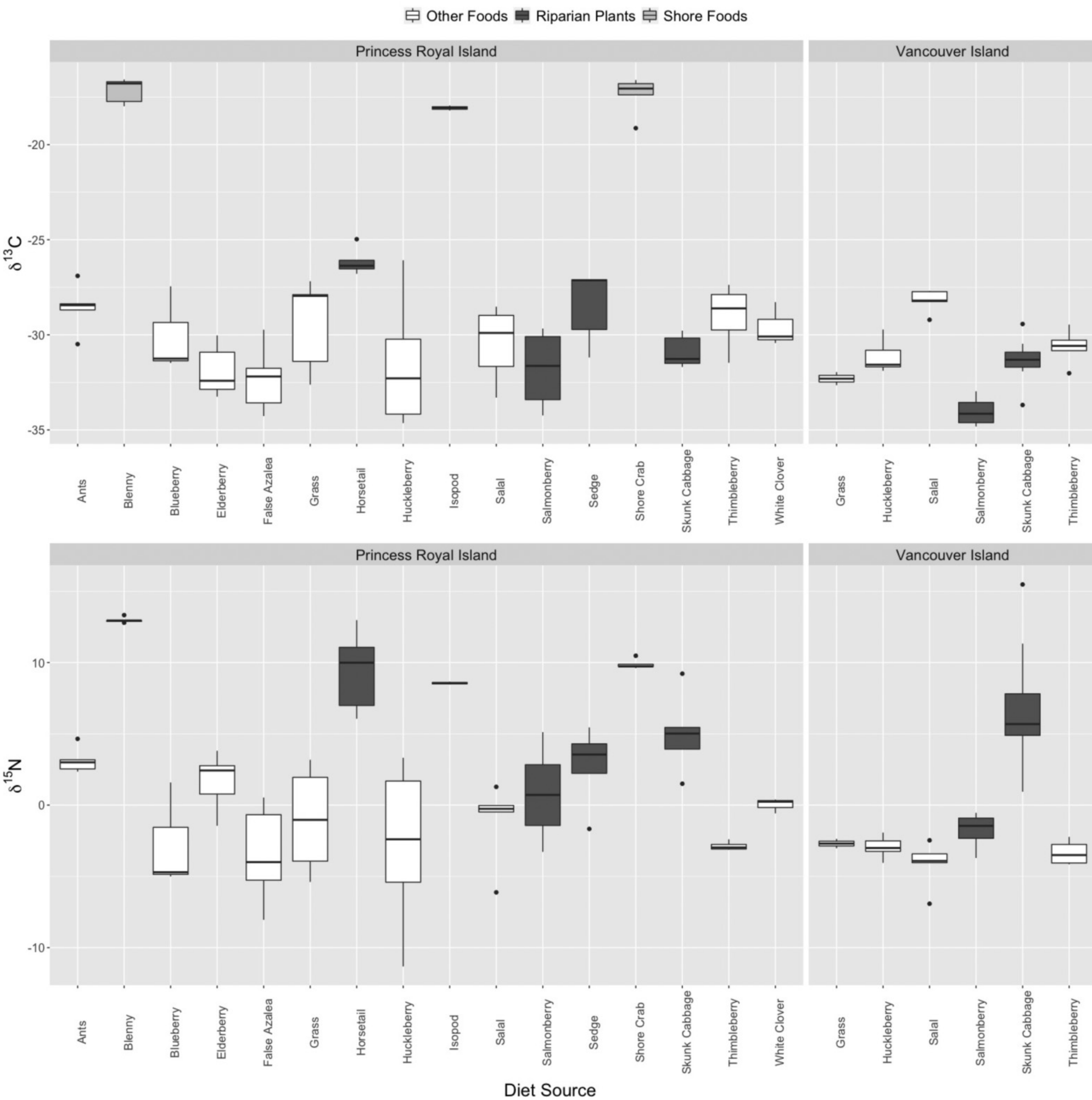
The black bears we sampled were largely vegetarian and assimilated more terrestrial-derived meat than ocean-derived foods (Fig. 4). Bears on Princess Royal Island consumed more salmon than bears on Vancouver Island (Supplementary Table S6, 10.0% versus 3.0%; $P = 0.003$). Male bears on Vancouver Island consumed more salmon than females (4.2% versus 1.0%, $P = 0.0006$). Male bears also ate more salmon on Princess Royal Island, though not significantly (13.5% versus 8.0%, $P = 0.26$) (Fig. 4). On Vancouver Island, bears sampled in salmon-bearing watersheds consumed similar amounts of salmon than bears sampled in the Upper Nahmint, where salmon were absent (3.3% versus 2.8%, $P > 0.63$).

Our data did not support the hypothesis that greater salmon abundance or species diversity facilitated greater salmon consumption. Salmon escapement was not related to the proportion of salmon in the diet of bears captured in that watershed ($P = 0.33$, $R^2 = 0.03$; Fig. 5, Table 3). The total number of salmon species did not influence salmon consumption ($P = 0.63$, $R^2 = 0.008$; Fig. 5, Table 3), nor did the number of dominant salmon species ($P = 0.87$, $R^2 = 0.001$; Fig. 5, Table 3). Additionally, there was not a strong relationship between the presence or absence of salmon in the watershed and salmon consumption by bears ($P = 0.20$, $R^2 = 0.06$).

Several watershed characteristics were related to salmon consumption in univariate regressions (Table 3). Average creek wetted width ($P = 0.02$, $R^2 = 0.18$) and low flow rates ($P = 0.002$, $R^2 = 0.28$) were significant predictors of salmon consumption, while high flow rates ($P = 0.34$, $R^2 = 0.03$) were not.

Disturbance varied across watersheds (Supplementary Table S7), and salmon consumption roughly declined with human disturbance ($R^2 = 0.29$; Fig. 5, Table 3). Due to our small sample size, particularly for category 1 disturbance (Fig. 5), and the lack of difference among categories, we

Fig. 2. Isotopic signatures for carbon and nitrogen of all diet items measured in the field as a part of this study. Data in dark grey depict riparian plants, while white shows the other sampled plant species. Data in light grey are the foods collected along the littoral zone of the ocean. Riparian and non-riparian plants were included as a single dietary item in diet modelling. Horsetail (*Equisetum* spp.) and skunk cabbage (*Lysichiton americanus*) had much higher carbon and nitrogen signatures than other plant foods and were excluded from dietary modelling signatures.



amalgamated disturbance into two different binary variables. First, we amalgamated category 1 with categories 2 to 4 to create a binary variable of areas with and without disturbance, which we referred to as “binary disturbance.” Second, we amalgamated category 1 with category 0 to create a binary variable of areas with high (categories 2 to 4) and low (categories 0 to 1) disturbance, which we referred to as “disturbance influence.” The relationship between disturbance and salmon consumption was stronger when disturbance was categorized as “high” versus “low” ($P = 0.01$, $R^2 = 0.19$; Table 3, Supplementary Fig. S1), than when categorized as areas with or without disturbance ($P = 0.34$, $R^2 = 0.03$).

Multivariate regressions showed human disturbance was the most consistent influence on salmon consumption (Table 4), accounting for 18.9% of variation across all models (including in the global model). Salmon consumption

Table 1. Comparison of stable isotope values (mean ± SD) across parts of key plant foods for American black bears (*Ursus americanus*) on Vancouver Island, specifically: (A) berries with and without seeds and (B) berries versus leaves.

		With seeds		Without seed	
Group	*n*	δ13C (‰)	δ15N (‰)	δ13C (‰)	δ15N (‰)
A	10	−29.4 ± 1.3	−3.4 ± 3.2	−29.6 ± 1.2	−3.6 ± 3.6
		Berries		Leaves	
		δ13C (‰)	δ15N (‰)	δ13C (‰)	δ15N (‰)
B	16	−30.8 ± 2.4	−1.9 ± 3.1	−31.6 ± 1.6	−2.6 ± 1.8

Note: Group A consists of huckleberry (n = 5) and salal (n = 5) and group B consists of huckleberry (n = 7), thimbleberry (n = 4), elderberry (n = 2), salmonberry (n = 2), and blueberry (n = 1).

Table 2. Comparison of plant stable isotope values (mean ± SD) for Vancouver Island and Princess Royal Island for watersheds with and without Pacific salmon (*Oncorhynchus* spp.).

	Vancouver Island			Princess Royal Island		
Salmon presence	*n*	δ13C (‰)	δ15N (‰)	*n*	δ13C (‰)	δ15N (‰)
Without salmon[a]	10	−31.1 ± 2.5	−3.8 ± 1.6	27	−30.2 ± 2.2	−2.2 ± 4.5
With salmon	8	−30.7 ± 1.8	−2.8 ± 1.0	26	−31.7 ± 2.2	0.4 ± 2.2

Note: Plant species compared for Vancouver Island were thimbleberry, salal, huckleberry, and salmonberry. Plant species compared for Princess Royal Island were thimbleberry, salal, huckleberry, salmomberry, elderberry, sedge, blueberry, and false azalea.
[a]There were no salmon on Vancouver Island's Upper Nahmint River or on Princess Royal Island's regenerating forest area.

declined with greater human disturbance and this variable was included in all the best-fitting six models. A measure of watershed characteristics was also included in all the top six models and these variables consistently suggested black bears ate more salmon in smaller streams. High creek flow was the strongest predictor of salmon consumption among the watershed characteristics, followed by low creek flow then wetted width. High creek flows were negatively related to salmon consumption and accounted for over 20% of model variation in several models, while low creek flow was positively related and accounted for 13.1% in the best model. Wetted width was a weaker predictor, accounting for 6.9% of variation in several models. Variables related to salmon were overall weaker predictors of salmon consumption than disturbance and watershed characteristics. Salmon escapement explained marginally more variation than salmon presence, although both variables were largely not influential. Escapement was positively related to salmon in diet in one of the six top models.

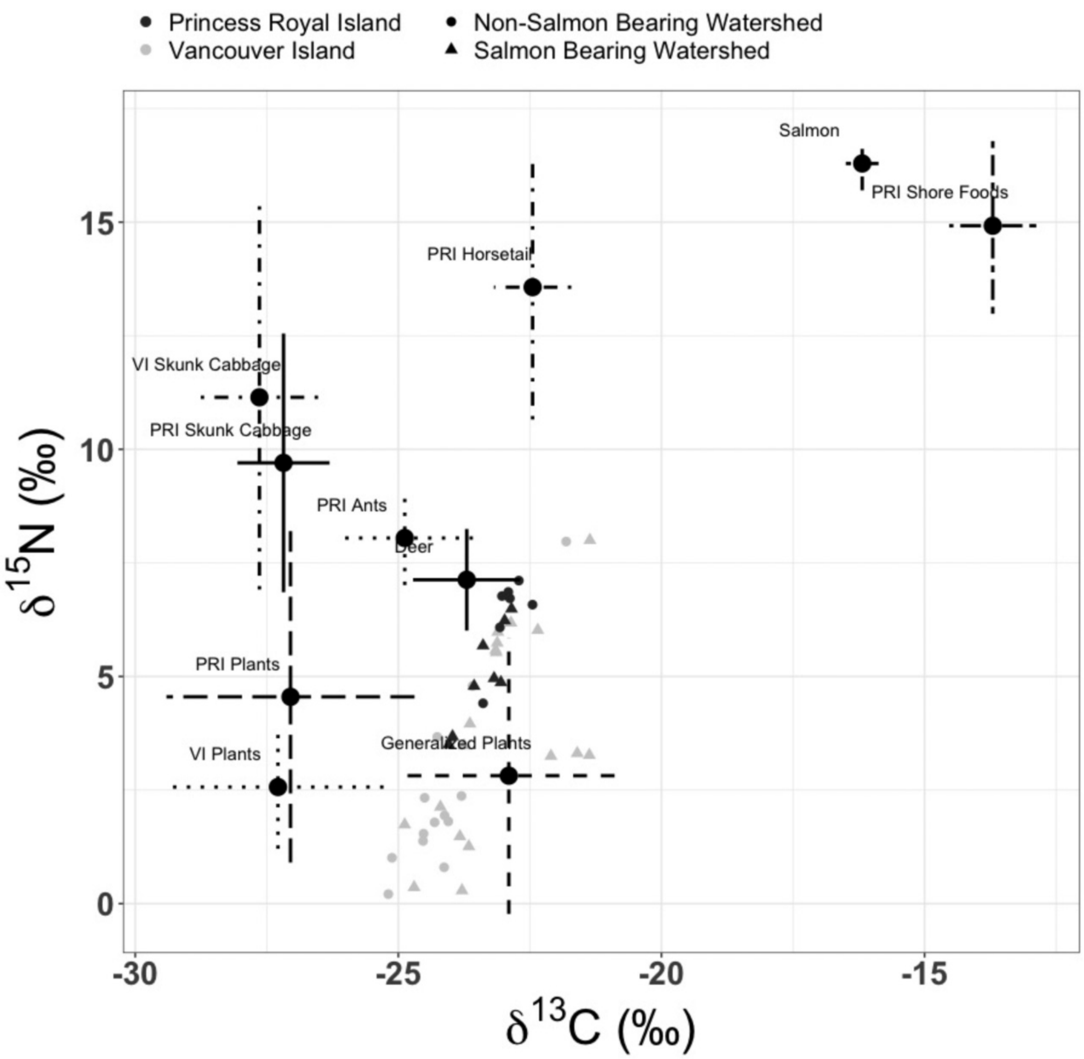
Discussion

Human disturbance

Black bears are known to alter their behaviour and habitat selection based on human presence (Matthews et al. 2006; Stillfried et al. 2015). Of the variables we analyzed, human disturbance was the strongest influence on salmon consumption by bears, suggesting that human disturbance reduced salmon consumption by black bears on Vancouver Island; further study that includes objective measurement of disturbance would better elucidate the nature of this relationship. Salmon are a key food for bears in many environments (Belant et al. 2006), and our data suggest that small amounts of human presence could have influential ecological effects on bear foraging success and nutrition. Black bears perceive humans as a risk (Blackwell et al. 2016), often retreat from humans at first sight (Reimchen 1998), and adjust their movements over extended time periods to avoid areas they perceive as risky (Stillfried et al. 2015). Research on brown bears in Scandinavia found that bears exhibit stress responses in the presence of humans (Støen et al. 2015), and strong negative responses to approaching humans, including leaving habitat areas and altering their movement for several days following the disturbance (Ordiz et al. 2019). Shardlow and Hyatt (2013) reported that black bear photo capture rates declined significantly in Clemens Creek after public road access was permitted; this response did not occur in the four other streams where access did not change.

Our results suggest that human presence is potentially a more important factor influencing bear diet than habitat disturbance through forestry. Salmon consumption was consistently high on Princess Royal Island, which featured extensive nearby logging activity but little to no regular human presence. While several studies found that black bears avoid roads (Carter et al. 2010; Simek et al. 2015), Switalski and Nelson (2011) found that black bears were regularly detected on logging roads during daylight hours if roads were closed to human access. Human population density is known to affect black bear habitat selection (Lustig et al. 2021), but how humans access bear habitat is variable across the landscape. Forestry activity can provide some benefits to bears, such as an increase in the availability of key plant foods (Davis et al. 2006), though these benefits could

Fig. 3. An isospace plot for American black bears (*Ursus americanus*) from two study areas in coastal British Columbia, Canada. In dietary mixing models, the generalized plant signature (from Mowat and Heard 2006), Pacific salmon (*Oncorhynchus* spp.) signature (based on several studies), and an average of deer signature (from Darimont et al. 2009) and the ant signature measured in the field were used. Diet estimates using the plant signatures measured in the field produced unrealistic results and were thus not included in subsequent analyses. Some bears in this figure were excluded from subsequent statistical analyses as they were not assigned to a specific watershed.



be overshadowed by increases in human activity following development.

Our results describing the importance of salmon in the black bear diet were similar to those of Adams et al. (2017), but lower than that of other studies (Belant et al. 2006; Service et al. 2019). This could be due to ecological and anthropological differences in study systems: Belant et al. (2006) studied bears in a network of remote national parks, while Service et al. (2019) focused on a remote area of the Great Bear Rainforest. Adams et al. (2017) assessed diet across a large, diverse area of British Columbia, including a wide range of habitats and human densities. In our study, particularly on Vancouver Island, industrial activity, human population densities, and human activity in bear habitat were much higher than wilderness areas and appeared to result in lower salmon diet fractions.

Quantifying how human activity affects bear ecology will help better understand human–bear coexistence and provide a baseline for human access management to protect habitat. Lamb et al. (2017) showed that human development can result in increased food availability for grizzly bears and, when combined with human activity in the area following development, can result in an ecological trap. Black bear preference for areas of regenerating forest has been well documented (Costello and Sage 1994; Davis et al. 2006), as has the negative effects of human activity on black bear ecology (Switalski and Nelson 2011; Smith et al. 2012), suggesting the potential for a similar trap for black bears. Many studies have used road density as a proxy for human activity, though the presence of roads may not correlate well with human disturbance if human use is more important than the simple presence of a road (Switalski and Nelson 2011). On Vancouver Island,

Fig. 4. Boxplots showing the distribution of American black bears (*Ursus americanus*) dietary source proportions from coastal British Columbia, Canada, sampled in 2008 through 2010, separated by sex, location, and whether the watershed in which bears were sampled supported salmon populations. Pacific salmon (*Oncorhynchus* spp.) consumption was significantly higher on Princess Royal Island than on Vancouver Island, and males consumed significantly more salmon than females only on Vancouver Island. Salmon consumption was not significantly higher in watersheds with salmon runs than in non-salmon-bearing watersheds.

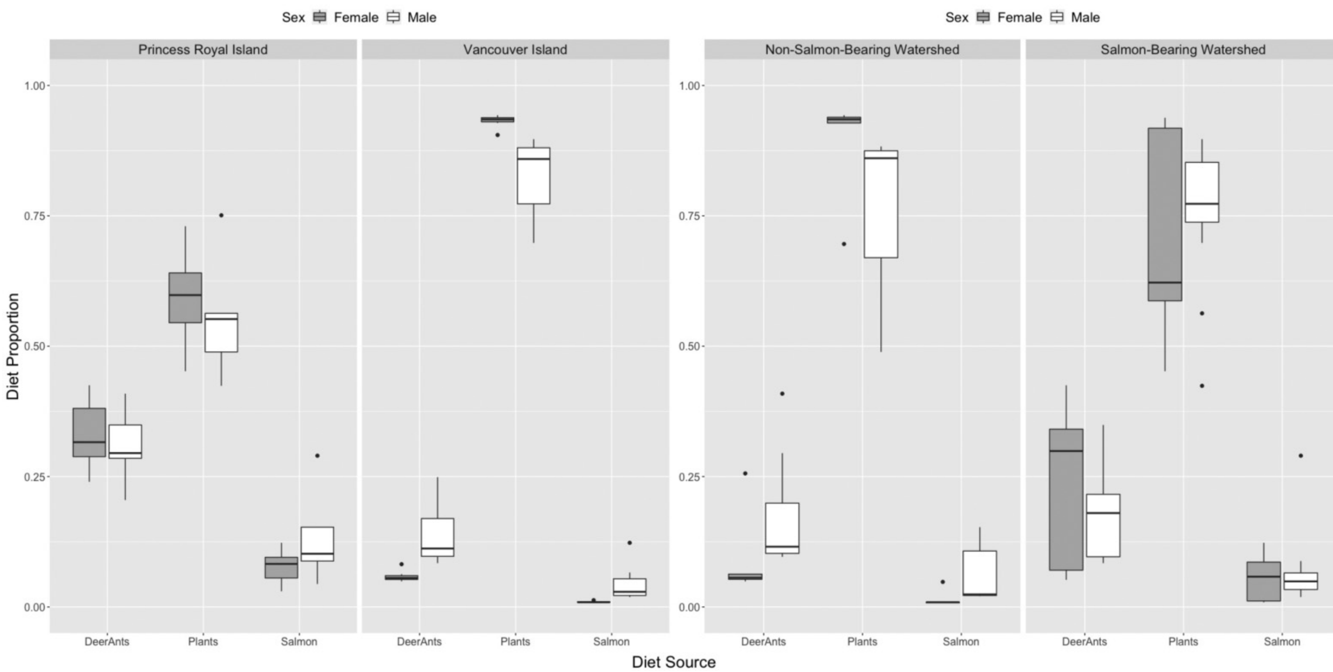
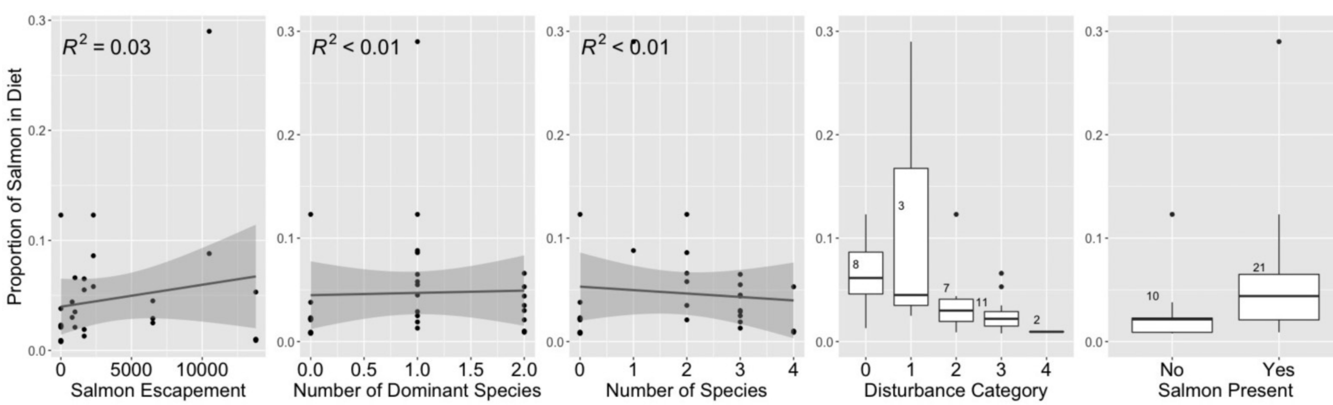


Fig. 5. The relationship between the amount of Pacific salmon (*Oncorhynchus* spp.) in the diet of American black bears (*Ursus americanus*) from the two areas of coastal British Columbia, Canada, and five variables that were hypothesized to influence salmon consumption. Individually, salmon escapement, salmon presence, or salmon species number did not significantly correlate with salmon consumption. Due to small sample size, particularly for category 1 ($n = 3$), human disturbance was combined in subsequent analyses into two different binomial variables.



the Effingham River drainage, undisturbed at the time of our data collection, has since seen extensive forestry activity and a subsequent increase in human use; future research should seek to understand causal relationships for dietary shifts following anthropogenic landscape change.

Reductions in salmon consumption, particularly for female bears, could have important ramifications for bear populations. In our study, female bears consumed less salmon than males, consistent with other research (Adams et al. 2017), and had a smaller range of salmon proportions in the diet, particularly on Vancouver Island, where disturbance was higher. Salmon consumption is a major source of both protein and fat (Hilderbrand et al. 1999), particularly as bears seek to meet nutrition needs in the fall before they begin denning (Lopez-Alfaro et al. 2013). Though our estimates for salmon in the diet were low, concentration of key salmon macronutrients,

Table 3. Summary of bivariate linear regression models, with the response variable for all models being the proportion (0 to 1) of Pacific salmon (*Oncorhynchus* spp.) in American black bear (*Ursus americanus*) diet.

Model	Variable	Variable type	Coefficient	P	R^2
Average creek wetted width	Wetted width (m)	Continuous	−0.002	0.02	0.18
Low creek flow	Flow (m^3/s)	Continuous	0.012	0.00	0.28
High creek flow	Flow (m^3/s)	Continuous	0.001	0.34	0.03
Salmon escapement	Escapement	Continuous	2.00×10^{-6}	0.34	0.03
Salmon presence	Salmon present	Binary categorical	0.028	0.20	0.06
Salmon species	Salmon species	Continuous	−0.003	0.63	0.01
Dominant salmon species	Dominant salmon species	Continuous	0.002	0.87	0.00
Disturbance	Disturbance level 1	Categorical	0.057	0.11	0.29
	Disturbance level 2		−0.023	0.38	
	Disturbance level 3		−0.037	0.12	
	Disturbance level 4		−0.054	0.19	
Disturbance presence	Disturbed	Binary categorical	−0.022	0.34	0.03
Disturbance influence	Low disturbance	Binary categorical	0.049	0.01	0.19

and their strong seasonal effects, indicate their importance in bears' diets (Coogan et al. 2018). Zeller et al. (2019) found black bears are more sensitive to human presence in the spring and fall, possibly due to the lack of abundant plant foods in comparison to the summer. The potential of losing salmon in their diet through the fall due to human disturbance could result in negative demographic effects if female bears are not able to meet dietary requirements for supporting their young through the winter.

Watershed and stream characteristics

Though we did not measure specific stream morphologies such as pool and riffle distributions, our watershed metrics suggest that stream characteristics affect black bear predation on salmon. Multivariate regressions controlled for the influence of all factors simultaneously and showed that creek flow rates were more important than creek width, which had been shown to significantly influence salmon consumption on brown bears (Quinn et al. 2017). Streams in our study areas are often subject to rapid changes in flow following precipitation events, likely driving the relative importance of stream flow over stream width. Interestingly, low creek flow was positively related to salmon consumption while high creek flow was negatively related. In our study area, scavenging of salmon carcasses represents a major contribution to salmon consumption by black bears (Shardlow 2013); thus, we hypothesize that the negative influence of high creek flow is due to freshet events flushing creeks of salmon carcasses. Future black bear research would benefit from further investigation into the effects of creek flow variability, particularly given compounding effects on salmon populations in light of the effects of climate change on stream hydrology (Hernández-Henríquez et al. 2017).

The importance of stream morphology in our study on black bear salmon consumption is consistent with past findings on brown bears (Quinn et al. 2001; Quinn et al. 2017) indicating that in the absence of competition from brown bears, black bears exhibit similar functional responses to brown bears and are able to select for more optimal foraging habitat across watersheds. Levi et al. (2015) found that brown bears forage for salmon in a range of different stream morphologies, while both Quinn et al. (2001) and Quinn et al. (2017) found that stream morphology, particularly stream width, affects the rate at which bears consume salmon. Future investigations into coastal black bear ecology should consider the flexibility of black bear niche in the presence or absence of competition.

Salmon escapement

Salmon abundance and the presence of salmon in a watershed were weakly related to salmon consumption by bears suggesting that bears moved between watersheds, though we note that we did not observe bears moving between watersheds with our limited sampling. Future studies should explicitly consider the scale of bear movements when examining how salmon abundance influences bear diet. Though black bears have small home ranges in coastal areas (Kolenosky and Strathearn 1987), the density of watersheds on the Pacific coast could provide them with diversity in foraging habitat for salmon and other foods. Brown bear home range size increases with landscape homogeneity (Mangipane et al. 2018) and black bears may exhibit a similar response. Given our findings on human presence and bear diet, and the relationship between the nutritional biology of bears, diet, and home range size (Mangipane et al. 2018), changes to home range size through anthropogenic disturbance could have important effects on bears' nutritional biology.

Additionally, our estimates for terrestrial meat in the diet were consistently higher than those for salmon, indicating that bears may be able to offset protein losses from salmon with terrestrial meat consumption. The variation in salmon abundance in the streams we sampled was small, limiting the detection power of this variable in our analyses. The variation in stream morphology and its consequential effect on salmon capture success may be functionally more important than the number of salmon in the stream, which is supported by our data.

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Table 4. Summary of linear mixed-effect models, with the response variable for all models being the proportion (0 to 1) of Pacific salmon (*Oncorhynchus* spp.) in American black bear (*Ursus americanus*) diet.

Model	Variable	Variable type	Coefficient	*P*	R^2	% Variation explained	AIC	ΔAIC
Disturbance influence, low creek flow, high creek flow	Low disturbance	Binary categorical	0.049	0.011	0.54	18.91	−106.44	0.00
	Low flow (m^3/s)	Continuous	1.09×10^{-2}	0.004		13.08		
	High flow (m^3/s)	Continuous	−0.003	0.001		21.52		
Disturbance influence, escapement, salmon species, wetted width, low creek flow, high creek flow—global model	Low disturbance	Binary categorical	0.010	0.804	0.58	18.91	−103.72	2.72
	Escapement	Continuous	-1.03×10^{-7}	0.971		1.82		
	Salmon species	Continuous	−0.017	0.150		14.23		
	Low flow (m^3/s)	Continuous	0.013	0.019		8.44		
	High flow (m^3/s)	Continuous	0.000	0.967		12.03		
	Wetted width (m)	Continuous	−0.002	0.221		2.76		
Disturbance influence, escapement, high creek flow	Low disturbance	Binary categorical	0.075	0.000	0.45	18.91	−101.04	5.40
	Escapement	Continuous	3.49×10^{-6}	0.052		1.82		
	High flow (m^3/s)	Continuous	−0.004	0.002		23.95		
Disturbance influence, wetted width, low creek flow	Low disturbance	Binary categorical	0.010	0.643	0.40	18.91	−98.76	7.68
	Wetted width (m)	Continuous	-1.44×10^{-3}	0.061		6.88		
	Low flow (m^3/s)	Continuous	0.010	0.016		14.65		
Disturbance influence and high creek flow	Low disturbance	Binary categorical	0.073	0.001	0.36	18.91	−98.62	7.82
	High flow (m^3/s)	Continuous	−0.003	0.010		17.29		
Disturbance influence, wetted width, high creek flow	Low disturbance	Binary categorical	0.066	0.010	0.37	18.91	−96.89	9.55
	Wetted width (m)	Continuous	-4.20×10^{-4}	0.629		6.88		
	High flow (m^3/s)	Continuous	−0.003	0.040		10.96		
Disturbance influence and low creek flow	Low disturbance	Binary categorical	0.027	0.197	0.32	18.91	−96.64	9.80
	Low flow (m^3/s)	Continuous	0.009	0.028		13.08		
Disturbance influence, escapement, low creek flow	Low disturbance	Binary categorical	0.025	0.244	0.32	18.91	−94.86	11.58
	Escapement	Continuous	-9.12×10^{-7}	0.669		1.82		
	Low flow (m^3/s)	Continuous	0.011	0.039		11.73		
Disturbance influence and wetted width	Low disturbance	Binary categorical	0.035	0.093	0.26	18.91	−93.94	12.50
	Wetted width (m)	Continuous	−0.001	0.118		6.88		
Disturbance influence and salmon species	Low disturbance	Binary categorical	0.056	0.008	0.23	18.91	−92.97	13.47
	Salmon species	Continuous	−0.008	0.208		4.54		
Disturbance influence, escapement, wetted width	Low disturbance	Binary categorical	0.036	0.096	0.26	18.91	−92.02	14.42
	Escapement	Continuous	5.24×10^{-7}	0.796		1.82		
	Wetted width (m)	Continuous	−0.001	0.178		5.25		
Disturbance influence and escapement	Low disturbance	Binary categorical	0.048	0.019	0.21	18.91	−91.89	14.55
	Escapement	Continuous	0.000	0.430		1.79		
Disturbance influence and dominant salmon species	Low disturbance	Binary categorical	0.049	0.017	0.19	18.91	−91.20	15.24
	Dominant salmon species	Continuous	0.001	0.914		0.00		
Disturbance influence and salmon presence	Low disturbance	Binary categorical	0.048	0.041	0.19	18.91	−91.20	15.24
	Salmon present	Binary categorical	0.002	0.918		0.03		

Note: AIC is Akaike's information criterion.

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Plant isotopic signatures

The influence of salmon on riparian nutrient inputs in coastal forests, and the importance of bears in this nutrient flow, is well documented (Darimont et al. 2010; Hocking and Reynolds 2011; Quinn et al. 2018). Though we did not specifically investigate the effects of salmon-derived nutrients on plants, we did find some enrichment in riparian plants and in plants in salmon-bearing watersheds. The effects of salmon on riparian plant isotope signatures could affect the source signatures used in stable isotope mixing models and should be considered when using stable isotopes to estimate the diet of salmon-eating bears.

We did not find a difference in isotopic signatures between the leaves and berries of the same plants, nor between fruits with and without seeds. These results help provide some consistency in the use of isotopes for estimating bear diet. Seasonal fruits are a key diet item for some bear populations (McLellan 2011) and need to be included when creating plant source signatures. Many bear foods are only available through part of the year and understanding the range of variation in the isotopic signatures of those foods will help bear researchers better quantify diet.

Stable isotope mixing models and sources of uncertainty

Methodological differences highlight important considerations for the use of stable isotope methods for diet research. Though dietary source signatures were similar between the studies, our study did not include a diet baseline for intertidal foods due to our measured signature's similarity to our salmon signature, while Service et al. (2019) did not include a dietary baseline for terrestrial meat based on low meat diet proportions found by Adams et al. (2017). Our terrestrial meat estimates of over 15% were similar to results from scatological analysis by Fortin et al. (2007) in south-central Alaska, which are known to underestimate meat in the diet (Robbins et al. 2004). Missing or including erroneous sources is a major source of error for stable isotope research (Parnell et al. 2013). The relatively low proportion of salmon in the diet of black bears in our study is partly due to our consideration of terrestrial meat sources. Our terrestrial meat endpoint was a composite of deer and ants; ants are key diet items for black bears, with consumption peaking during summer (Noyce et al. 1997; Fujiwara et al. 2013). Two plants in our study systems that black bears are known to eat, horsetail and skunk cabbage, had much higher N than other sampled plants. If consumption of these plants was higher than where the generalized plant signature was derived, then the estimate of both terrestrial- and ocean-sourced meats would be lower.

Intertidal foraging by black bears has been reported throughout North America with the majority of reports coming from British Columbia and Alaska (Carlton and Hodder 2003). Black bears on Vancouver Island have been observed flipping rocks in search of prey (Ramsay 1985) and we frequently sighted black bears traversing the foreshore on Princess Royal Island. Despite this, our ability to measure intertidal foraging using stable isotope analyses was limited because the isotopic signatures from salmon and intertidal fauna were nearly identical. As such, any intertidal foraging would have reduced our estimates of the proportion of salmon in the diet of bears. Future research on the importance of intertidal foods would require the addition of other diet markers that discriminate these two food classes.

Our estimates of salmon in the diet were influenced by variability in the plant baseline used in the models. Source signatures that we measured from plants collected in the field resulted in unrealistic results in diet estimation. Despite the wide range of key plant foods we investigated, the ineffectiveness of these measurements in our mixing model highlights the complexity of using SIA on bear species given their highly variable diet, particularly the large range of plants they consume. Like other studies (e.g., Adams et al. 2017; Mowat et al. 2017) we used the dietary baseline from Mowat and Heard (2006), to account for this variation. This baseline was calculated based on the isotopic signatures of entirely herbivorous grizzly bears in British Columbia's Monashee and Selkirk mountains, and general plant isotope signatures may differ in other ecosystems. In particular, the plant baseline did not account for our findings that plant isotope values varied between salmon-bearing and non-salmon-bearing watersheds, findings that are in keeping with those previously reported (Ben-David et al. 1998; Hocking and Reynolds 2011). Combining diet analysis with behavioural observations of species consumption could suggest weighting of various plant foods for isotopic plant baselines, though correctly weighting each local baseline based on the proportion of each plant in the diet will always be problematic due to the spatial ranges of different food sources.

Researchers using stable isotope analysis on bear hair should consider the length and seasonality of hair in their analyses. Guard hair collected in summer could potentially provide biased diet estimates that do not include fall diet because they were grown that year. Samples collected in the late fall or early spring of the following year describe diet for the longest possible period of time (Mowat et al. 2017). Samples collected during the season when salmon are abundant may show much higher salmon signatures than those collected in late fall or spring because isotope ratios increase considerably during the often-short salmon season before declining through the late fall (Mowat et al. 2017; Service et al. 2021). Though our samples from Princess Royal Island were collected later in the year than those on Vancouver Island, we found no relationship between the date of sampling and isotopic signatures (Supplementary Fig. S2) suggesting the bulk of our samples were grown the previous year and hence represented a full season's diet. Jimbo et al. (2020) present a simple macroscopic way to classify the year a hair was grown which should reduce this bias in the future.

Like other studies, we found models that did not use concentration effects were a better fit to our system than those that did (e.g., Deacy et al. 2018; Service et al. 2019). The inclusion of concentration effects resulted in estimates of almost entirely herbivorous bears, results that did not align with several field observations of bears consuming meat, and with previous research (e.g., Fortin et al. 2007). Elemental concentrations do not account for the disparity in digestibility of plants and meat (Robbins et al. 2002), and commonly cited diet source concentrations from the literature (e.g., Phillips and Koch 2002) are usually based on ecosystems and taxa that are dissimilar to a studies' focal systems. Future consideration of concentration effects would benefit from measurements on known diet sources that are specific to the ecosystems in question.

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Spatially explicit analysis of contributions of a regional conservation strategy toward sustaining northern goshawk habitat

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Original Article

Spatially Explicit Analysis of Contributions of a Regional Conservation Strategy Toward Sustaining Northern Goshawk Habitat

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ABSTRACT Setting aside habitat is a common strategy to maintain viable wildlife populations, but underlying assumptions or effectiveness are rarely evaluated. The Tongass National Forest prioritized habitat management for sensitive species in Southeast Alaska's rainforest, and standards and guidelines were established for northern goshawks (*Accipiter gentilis*). I used guidelines from other portions of its range and data from Southeast Alaska, USA, to evaluate the conservation strategy. I used published data and nests from this study to define choice habitats; published juvenile movements and female use areas were used to estimate an "average" post-fledging area and female breeding range, respectively. I used nest-tree locations ($n = 136$) to delineate corresponding virtual post-fledging areas and female home ranges, within which I calculated acreage of 4 cover-type and 4 land-use categories. About 30% of nests had >51% of post-fledging areas in choice habitat; 60% of nests had >51% in unsecure (unprotected from development) land-use designations, whereas 16% had >51% in a protected old-growth designation. The female range was similar to post-fledging areas, but the proportions predominantly (>75%) available for development (land use that modifies landscapes) or with 26–50% of total area in choice habitat were larger than post-fledging areas, and half as many nests had >51% of area in choice habitat. Among cover types, choice habitat averaged 39.4% of the post-fledging area. These findings increase uncertainty about conservation measures contributing sufficient habitat to sustain well-distributed, viable populations of northern goshawks throughout Southeast Alaska and demonstrate the need and feasibility of evaluating assumptions of conservation plans.

KEY WORDS *Accipiter gentilis*, conservation strategy, land-use planning, northern goshawk, population viability, southeastern Alaska, temperate rainforest.

Maintaining biological diversity, especially viability of endemic organisms, continues to rank high among land-management issues on public (Possingham et al. 1993, Szaro and Johnston 1996, Iverson and René 1997, Smith and Zollner 2005) and private lands (Lindenmayer and Possingham 1996) because wildlife species are valued by many segments of society (Naess 1986, Catton and Mighetto 1998) and because persistence of indigenous wildlife populations at "ecologically effective" densities (*sensu* Soulé et al. 2003, p. 1,239) is a crucial component of healthy ecosystems (Pimm 1991, Petchey 2000, Pyare and Berger 2003, Soulé et al. 2003). Loss or fragmentation of habitats due to human activity are directly associated with the rapid decay of ecological and evolutionary diversity worldwide (Pereira et al. 2004, Reed 2004). Undoubtedly, global demands for natural resources will continue to increase and land managers will experience greater and more complex challenges to safeguarding ecosystem functions (Costanza et al. 1997, Newton and Freyfogle 2005).

In Southeast Alaska, USA, the Tongass National Forest responded to challenges of sustaining viable and widely distributed wildlife populations across the planning area by developing a comprehensive, regional conservation plan. The 1997 Tongass Land and Resource Management Plan established a system of small, medium, and large reserves to provide large areas of protected, intact old-growth forest and site-specific standards and guidelines to manage locally important habitat for sensitive species (U.S. Forest Service 1997). A fundamental assumption was that lands managed for timber production would contribute little toward maintaining well-distributed and viable populations (U.S. Forest Service 1997: appendix N); rather, reserves and other protected lands would provide sufficient habitat to sustain indigenous wildlife (Iverson and René 1997).

Setting aside essential habitat is a common strategy to maintain indigenous wildlife in modified landscapes, but the underlying assumptions or the effectiveness of such strategies are rarely evaluated (Smith et al. 2011). Although land-use or conservation plans typically stipulate long-term effectiveness monitoring of framework elements and specific measures (U.S. Forest Service 1997: chapter 6), the costs required to do so often are prohibitive, and thus monitoring plans rarely are fully implemented (Patla 2005, Smith et al. 2011). More importantly, irreparable negative impacts can occur before long-term monitoring uncovers flaws in the underlying conceptual framework, or

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in deficiencies in the implementation of specific management guidelines or conservation measures (Smith et al. 2011). However, Smith and Person (2007) demonstrated the feasibility and value of evaluating elements and assumptions of the underlying theoretical framework of a regional conservation plan.

The northern goshawk (*Accipiter gentilis*) in Southeast Alaska received special consideration as a "sensitive species" in the revised forest plan (U.S. Forest Service 1997, pp. 4–89), in part because of concerns over the viability of endemic Queen Charlotte goshawk (*A. g. laingi*) populations (Iverson et al. 1996, Iverson and René 1997, U.S. Fish and Wildlife Service 2007). Standards and guidelines for forest management actions were established using important ecological aspects of this species' biology (Iverson et al. 1996). The 1997 standard and guidelines specific to goshawk reproduction stipulated that managers should "preserve nesting habitat around all confirmed and probable nest sites" (U.S. Forest Service 1997, pp. 4–89) and included several criteria for identifying nest sites and guidance related to achieving this objective.

Much of the science used to develop the Tongass standards and guidelines and policy for managing habitat for northern goshawks was based on studies conducted elsewhere because local information was largely unavailable (Iverson et al. 1996). Since 1997, however, considerable effort has yielded valuable empirical data about the life history, ecology, and habitat needs of northern goshawks in Southeast Alaska, especially during the breeding season (Flatten et al. 2001, Lewis et al. 2006). In addition, there have been numerous studies and reviews completed throughout its range (Penteriani 2002, Andersen et al. 2005, Greenwald et al. 2005, Boal et al. 2006). Moreover, reviews and studies in British Columbia, Canada, have substantially increased our knowledge about goshawks in temperate rainforests (Cooper and Stevens 2000; McClaren et al. 2002, 2003, 2005; Mahon and Doyle 2005, Doyle 2006).

In western North America, the breeding home ranges of northern goshawks often are represented as a hierarchical sequence of 3 areas (Andersen et al. 2005), all of which need to be considered simultaneously in land-use planning or mitigation (Reynolds et al. 2006, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008): 1) nest area, 2) post-fledging (family) area, and 3) foraging area. Nest areas provide alternate nest trees, roost trees, prey-plucking posts, and serve as centers of essential breeding behaviors or life-history events (Reynolds et al. 1992, 2006). Post-fledging areas surround active nest trees and represent the core-use area of an adult female and of young goshawks after fledging but before becoming independent of adults and dispersing (Kennedy et al. 1994). McClaren et al. (2005) suggested the biological role of post-fledging areas and nest areas are similar and therefore it is useful to consider them as one functional component. Regardless, the habitat composition (i.e., overstory) of post-fledging areas should be similar to nest areas (Reynolds et al. 2008). Foraging areas comprise the majority of northern goshawk breeding home ranges and are especially important for adults providing food to young and for juveniles prior to natal dispersal. Adults may have foraging areas that are a considerable distance from nests and may change their foraging areas seasonally or from 1 year to the next (Titus et al. 1994). Foraging areas generally are large ($\geq$2,000 ha) but vary among localities and according to individual experience, hunting efficiency, food requirements (brood size), and availability of food within home ranges (Kennedy et al. 1994). Also, the combined home range of male and female pairs can be substantially larger than that of individual birds (Boal et al. 2003). The most imminent threats to breeding populations are loss or fragmentation of nesting and foraging habitat, especially reductions in prey diversity and availability (Reynolds et al. 1992, 2006, 2008; Finn et al. 2002, McGrath et al. 2003, Salafsky et al. 2007, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008).

Despite a substantial increase in knowledge since the revision of the 1997 Tongass Land and Resource Management Plan, the implications of those new insights to goshawk conservation and land-use policies in Southeast Alaska have not been rigorously examined. In particular, it is unclear whether a system of old-growth reserves designed explicitly for other wildlife species and protection of goshawk nest trees in landscapes intensively managed for timber (clearcut logging) would provide sufficient habitat to sustain breeding populations of the northern goshawk across the planning area (Finn et al. 2002). The purpose of this study is to evaluate the underlying framework and assumptions of the Tongass conservation strategy to sustain well-distributed, breeding populations of a species whose home range encompasses entire watersheds and whose life history in Southeast Alaska appears to require vast amounts of old-forest habitat (Iverson et al. 1996). To accomplish this, I undertook a spatially explicit analysis that quantified contributions of the 1997 Tongass conservation strategy toward sustaining suitable habitat in 2 essential components of northern goshawk breeding pairs' home ranges: post-fledging area and breeding home range of females. Specific objectives were to 1) use the findings of habitat-use analyses from Southeast Alaska (Iverson et al. 1996) in conjunction with the observed habitat composition of nest sites to identify choice habitat for nest areas; 2) use juvenile post-fledging movements to estimate the radii of circular, virtual post-fledging areas and broader landscapes represented by the median 90% minimum convex polygons breeding home range ("use areas," Iverson et al. 1996) of females; 3) quantify contributions (total acreage) of the Tongass conservation elements to conserving secure (protected from development) habitat in projected goshawk post-fledging area and female breeding home ranges; 4) compare the cover-type composition of virtual post-fledging areas with the observed composition of nest sites in Southeast Alaska and to published recommendations for post-fledging area composition (Reynolds et al. 1992, 2006, 2008); and 5) classify projected northern goshawk post-fledging and breeding home ranges according to the extent (percentage categories) that the habitat composition approached recommended guidelines or the observed percentages of habitat types among nest sites in Southeast Alaska.

STUDY AREA

The Tongass National Forest encompassed about 95% of southeastern Alaska; this included the Alexander Archipelago with thousands of islands, and a narrow mainland region that extended from Dixon Entrance (54°30′N latitude) to the Malaspina Glacier (59°45′N latitude; U.S. Forest Service 1997). The Tongass was unique among national forests in several ways (Everest et al. 1997), including a dynamic geological history, naturally fragmented and isolated landscapes, and extraordinary environmental complexity (MacDonald and Cook 1996).

Southeastern Alaska had glaciated mountain ranges and fjords, and a cool, wet (200- to 600-cm precipitation) maritime climate with mean monthly temperatures ranging from 13° C in July to 1° C in January (Searby 1968). About 4 million ha (60%) was forestland (U.S. Forest Service 1997), of which 2.2 million ha was productive forests (Julin and Caouette 1997). Coniferous rainforest dominated the landscape from shoreline to about 600 m elevation, with approximately 90% of productive forests in Sitka spruce (*Picea sitchensis*)—western hemlock (*Tsuga heterophylla*) forests, which typically are the old-growth forests of upland sites; remaining areas were alpine, muskeg, or riparian (Hutchinson and LaBau 1974). Unmanaged forests typically had a multi-layered overstory of uneven-aged trees, dominant trees that generally were >300 years old, and extensive, structurally diverse understories (Ver Hoef et al. 1988). These forests varied in structure from "scrub" or low-volume communities of short (<10 m), small (<0.5-m diam) trees with open canopies and dense, shrubby understories on poorly drained sites (peatland), to highly productive sites that supported high-volume stands with a closed canopy; tall (>60 m), large (>3-m diam) trees; and a predominantly herbaceous understory (Harris and Farr 1974, Alaback 1982). The *Tsuga–Picea* forest type constitutes most of the closed-canopy forests in the region (Alaback 1982). It was spatially heterogeneous at a fine scale—<1 ha (Schoen et al. 1984)—and typically occurred on low elevation, well-drained sites, frequently as a mosaic with muskegs (Neiland 1971). The primary disturbance was wind, with infrequent (100–200 yr) catastrophic windstorms blowing down tens to hundreds of hectares of old-growth rainforest, which produced relatively homogeneous, naturally regenerated second growth with dense canopies (i.e., wind-originated stands; Nowacki and Kramer 1998). More frequent, but less severe, windstorms blow down one or a few trees, which produces gap-phase old-growth stands with more fine-scale heterogeneity and much larger and older trees (Alaback 1982).

METHODS

Discerning Post-Fledging Area Habitat

I used the 2003 geographic information system (GIS) database of northern goshawk nest-tree locations obtained during 1989–2003 from annual surveys of nests conducted by the Tongass National Forest, Alaska Department of Fish and Game, and U.S. Fish and Wildlife Service (Flatten et al. 2001). Some nests were found by tracking radiocollared goshawks, coincidentally while conducting other fieldwork (e.g., timber sale surveys), or from reports by individuals recreating on the National Forest (Iverson et al. 1996). I updated the 2003 database with new nest trees obtained from surveys conducted through July 2005 by the Tongass National Forest and cooperators. Because many goshawk nests were located during timber-sale surveys or layout (Iverson et al. 1996), the relative amount of high- and medium-volume old growth distributed among land-use designations might have been biased toward the Development category (lands available for timber production and other uses that modify landscapes) as compared with a random sample collected across the region (Daw et al. 1998). However, Schempf et al. (1996) used standardized protocols to survey 724 points within 62 plots across 67 km^2 of roadless areas in Southeast Alaska. They recorded responses from only a single adult goshawk and concluded that the much lower (order of magnitude) detection rate (compared with similar surveys in other portions of this species' range) suggested a low density and widely dispersed goshawk population across the sampling area.

The desired condition of a post-fledging area is habitat composition similar to the nest area (Reynolds et al. 1992, McClaren et al. 2005). Therefore, I identified habitat for post-fledging areas by averaging the composition of cover types (e.g., old-growth forest, muskeg, managed forest) within nest areas of previously occupied nest sites in the region. Post-fledging area habitat was delineated according to the findings of an analysis of habitat selection during the breeding season that compared the proportion of radiotelemetry locations in each habitat type with the proportion that each corresponding habitat type comprised in "use areas" represented by 100% minimum convex polygons (Iverson et al. 1996). During the breeding season, goshawks selected high-volume (forest-wide mean $\pm$ 95% CI = 201.5 $\pm$ 4.7 m^3/ha) and medium-volume (146.2 $\pm$ 4.5 m^3/ha) strata old-growth forests (Julin and Caouette 1997). Mature sawtimber (75- to 150-yr second growth), low-volume (91.5 $\pm$ 4.5 m^3/ha), and scrub forests (<76 m^3/ha) received much less use, which did not differ from that expected according to availability; clearcut (approx. 0–40 yr) and non-forest cover types were avoided. Because nest areas typically are 10- to 12-ha areas immediately surrounding the nest site (Reynolds 1983; Reynolds et al. 1992, 1994), I used a 10.5-ha nest area to accomplish English GIS queries.

To discern available vegetation community types comprising goshawk habitat, I overlaid the location of each nest tree on a 2003 Tongass National Forest data layer of forest stand volume and totaled the area within each polygon that represented a unique volume strata of old-growth forest (low, medium, high). I summed total area of each stratum to determine relative composition of a nest area, centered on the nest tree, and to determine the frequency distribution of nest areas by low-, medium-, or high-volume old-growth forest. Because the vast majority of second-growth was <50 years old (Barbour et al. 2005), mature sawtimber represented a very small (approx. 1%) component of the forested landscape. Scrub forests are peatlands with little or no forest canopy (Harris and Farr 1974). None of the 136 nests were in sawtimber or scrub forests. Therefore, I assumed that medium- or high-volume old-growth forests provided the resources needed by northern goshawks during the breeding season based on the previous findings of habitat selection (Iverson et al. 1996) and because nest trees were invariably in medium- or high-volume old-growth stands.

Composition of Virtual Areas

To determine contributions of the Tongass conservation strategy toward meeting breeding-season habitat objectives, I estimated the size of a post-fledging area in Southeast Alaska according to concepts in Kennedy et al. (1994), the behavior of post-fledged juveniles (Kenward et al. 1993), and published data on juvenile movements during the post-fledging period (Iverson et al. 1996). I used 1,600 m to estimate the average limit of all movements of post-fledged juveniles because this was assumed to be the distance that defined when juveniles were undertaking post-fledging movements (Kenward et al. 1993) and because 23 of 28 juvenile goshawks monitored with radiotelemetry in Southeast Alaska moved $\geq$1,600 m (Iverson et al. 1996). I then used this estimate of distance moved during the post-fledging period as the radius of circular areas centered on a nest to represent an "average post-fledging area." I used the median home range (90% mononuclear probability polygon; Iverson et al. 1996) of adult females during the breeding season (21 km^2) to delineate broader landscapes that comprised essential foraging habitat (Reynolds et al. 1992, 2006, 2008). Because goshawk males typically do most of the hunting during the nesting period (Kenward 1982), this approach assumes that the male's breeding-season range, which averaged about 50% larger than females, did not differ substantially in habitat composition. I overlaid each nest's virtual post-fledging area and breeding home range on GIS layers of cover types and land-use designations based on stand volume and management history. The area within each polygon that represented a unique land-use description was summed to determine relative composition of 4 land-use categories: Development—lands available for timber production and other uses that modify landscapes; Non-National Forest lands; Natural Setting—lands that maintain a natural setting, such as wild and scenic rivers and remote recreational areas; and Old Growth—protected old-growth forests. The same procedure was used to determine composition of 4 cover types: Habitat—high or medium-volume old-growth forests; Low—low-volume old-growth forests; Clearcut—all lands harvested between 1954 and 2005; Non-forest—all lands that do not support productive forests (Julin and Caouette 1997). The extent to which the female home range and post-fledging area differed in composition served as a metric of landscape heterogeneity that also provided insights about the sensitivity of this analysis to sampling error and the likelihood that habitat composition of male breeding ranges differed from females. Results are presented as separate summaries of average land-use designation or cover-type composition for post-fledging areas and seasonal home ranges.

RESULTS

Nest Area and Habitat

I determined habitat used by goshawks for the post-fledging area analysis using the habitat composition of 136 nest areas across the Tongass National Forest: overall, 100% of the nest trees were in productive (low-, medium-, or high-volume) old-growth forests, which comprised 66.1% (SD = 0.05) of goshawk nest areas. The remainder of nest areas was in scrub forests (fens), non-forested areas (muskegs), or regeneration stands following clearcut logging. A total of 58 nest areas primarily (>50%) consisted of high-volume old growth; 57 and 15 nest areas primarily consisted of medium- and low-volume old growth, respectively. Six nest areas did not contain any old-growth forest; according to notes in the database file, those nest trees were located in portions of the forest that were clearcut-logged after a breeding pair had selected a nest tree. If nest trees on clearcut sites or near a natural feature creating an abrupt forest edge (e.g., shoreline) were excluded ($n = 11$), mean proportion of productive old-growth forest in nest areas was 0.712 (SD = 0.041). The mean proportions of volume strata in the remaining nest areas ($n = 125$) were 0.097 (SD = 0.025), 0.283 (SD = 0.039), and 0.289 (SD = 0.039) for low-, medium-, and high-volume forests, respectively. Based on the habitat at 125 nest sites and within corresponding nest areas and on the findings of a previous habitat selection study (Iverson et al. 1996), I refer to medium- or high-volume old growth in virtual areas below as "choice habitat."

Land-Use Designation and Habitat Composition of Virtual Areas

The composition of land-use designations of an average post-fledging area contained a relatively large proportion of Development (land uses that modify landscapes) lands, with >30% of all nest areas having >91% of the post-fledging area as lands available for timber production (Fig. 1a; Appendix A). Cover-type composition of post-fledging areas contained a relatively large proportion of non-forest cover types (Fig. 1b). About 30% of the nests had >51% (i.e., 51–75%, 76–90%, or >90%) of the corresponding post-fledging area in medium- or high-volume old growth (choice habitat); 51% of nests had 26–50% of the post-fledging area in choice habitat. Most (60%) of this choice habitat was in the Development land-use designation or Non-National Forest designation (Fig. 1a); 16% of the nests had >51% of the post-fledging area in the Old-Growth land-use designation, with the remainder in Natural Setting. Across all nest areas, the Old-Growth land-use designation averaged 14.8% (100 ha; SE = 4.6) of the total post-fledging area acreage. Development, Non-National Forest, and Natural Setting averaged 41.1% (278 ha; SE = 7.6), 13.5% (91 ha; SE = 4.6), and 27.2% (184 ha; SE = 6.9), respectively. Among cover types, choice habitat averaged 39.4%

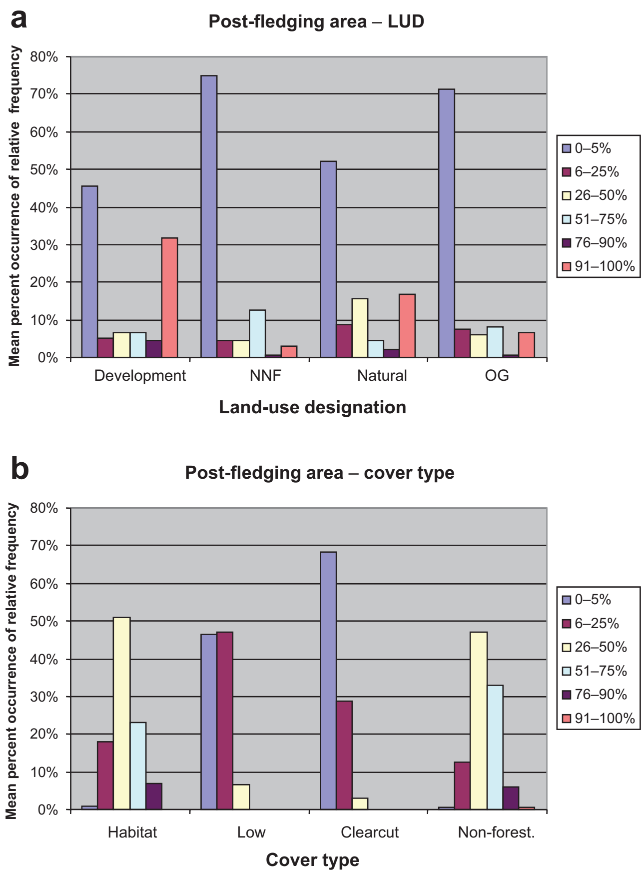

Figure 1. Mean percent occurrence of relative frequency (%) categories of land-use designations (a) and cover types (b) in 136 virtual northern goshawk (*Accipiter gentilis*) post-fledging areas (800 ha) in Southeast Alaska, USA. Total area was calculated from an estimate of the average post-fledgling movements (1,600 m), which served as radius of a circular area. Development = lands available for timber production and other uses that modify landscapes; NNF = non–national forestlands; Natural = lands that maintain a natural setting, such as wild and scenic rivers and remote recreational areas; and OG = protected old-growth forests. Cover types: Habitat = high- or medium-volume old-growth forests; Low = low-volume old-growth forests; clearcut = all lands harvested between 1954 and 2005; Non-forest = all lands that do not support productive forests (Julin and Caouette 1997).

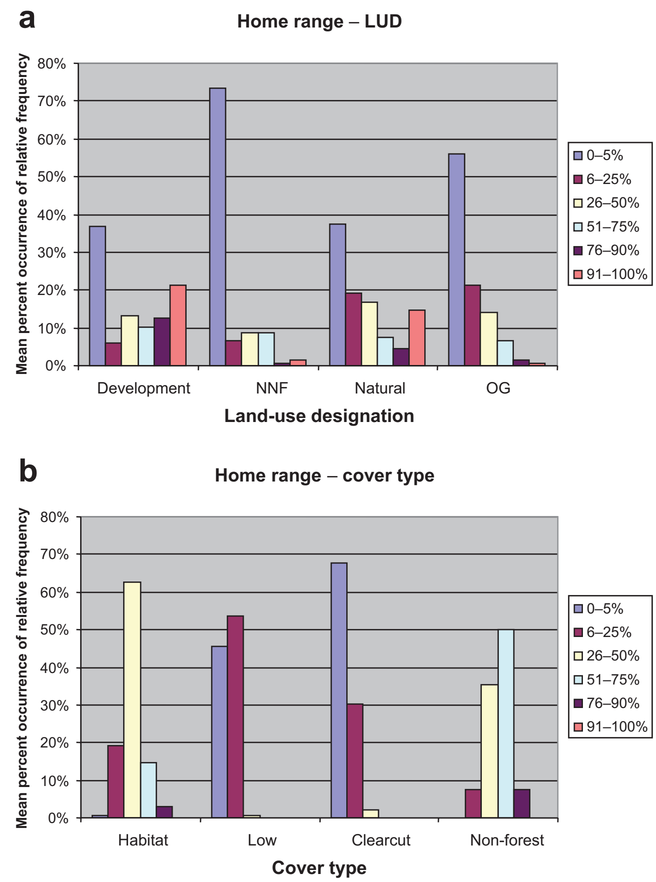

Figure 2. Mean percent occurrence of relative frequency (%) categories of land-use designations (a) and cover types (b) in virtual female breeding home ranges (2,100 ha) encircling 136 northern goshawk (*Accipiter gentilis*) nest sites in Southeast Alaska, USA. Total area was calculated from an estimate of goshawk movements (2,600 m), which served as radius of a circular area. Land-use designations: Development = lands available for timber production and other uses that modify landscapes; NNF = Non-National Forest Lands; Natural = lands that maintain a natural setting, such as wild and scenic rivers and remote recreational areas; and OG = protected old-growth forests. Cover types: Habitat = high- or medium-volume old-growth forests; Low = low-volume old-growth forests; clearcut = all lands harvested between 1954 and 2005; Non-forest = all lands that do not support forests (Julin and Caouette 1997).

(266 ha; SE = 9.3) of the post-fledging area; low volume forest, clearcut, and non-forest lands averaged 8.3% (56 ha; SE = 2.6), 3.9% (27 ha; SE = 1.5), and 45.0% (304 ha; SE = 10.3), respectively.

Similar results were obtained from an analysis of the female breeding home range, but with 3 notable differences. The percentage of this broader landscape that consisted predominantly (>75%) of lands available for development was greater than in post-fledging areas (Fig. 2a; Appendix A). The percentage of the total area with 26–50% of the total area in choice habitat also increased in comparison with the post-fledging area, whereas about half as many nests had ≥51% of this broader landscape in choice habitat as compared with the post-fledging area (Fig. 2b).

DISCUSSION

The 1997 Tongass Land and Resource Management Plan included multiple conservation measures to maintain habitat, with a goal of sustaining viable and widely distributed populations of indigenous wildlife throughout the planning area. Although some elements of the 1997 Tongass Land and Resource Management Plan have undergone revision, the wildlife conservation strategy remains largely unchanged (Smith et al. 2011). Individual species, such as the northern goshawk, received specific conservation measures to reduce viability risks (Iverson et al. 1996). According to the conservation assessment, implementation of the 1997 Tongass Land and Resource Management Plan for 100 years would result in "a moderately high likelihood of providing the amount and distribution of habitats to sustain long-term well distributed viable populations of goshawks throughout the Tongass" (U.S. Forest Service 1997: appendix N38). This long-term projection, an inherent assumption of the conservation strategy, was based on analyses at multiple spatial scales (U.S. Forest Service 1997). This study used contributions of various elements of the conservation strategy to biological components of the breeding range centered on specific nest sites. This approach allowed an examination of the underlying assumption that the 1997 Tongass Land and Resource Management Plan provides habitat needed to sustain breeding populations of goshawks across the planning area. Productive old-growth forests unavailable for timber harvest were used frequently by northern goshawks and "thus the contribution of these habitats must be included in an assessment of overall risk to sustainability of goshawk habitat" (U.S. Forest Service 1997: appendix N38).

Standards and guidelines prescribed for protection of goshawk nest areas (40 ha) in Southeast Alaska are unlikely to meet breeding-season habitat objectives established for goshawk populations elsewhere (Reynolds et al. 1992, McClaren et al. 2005). The expectation that, in landscapes managed intensively for timber products, habitat contributed by other elements of the Tongass conservation strategy (e.g., old-growth reserves) will mitigate this deficiency was not supported by my analysis. An ideal northern goshawk home range consists entirely of older forests with small, dispersed openings (Reynolds et al. 2006, 2008). Guidelines for the composition of post-fledging areas stipulate that "the majority (60%)" of a post-fledging area should be in forest of older age classes (Reynolds et al. 1992, p. 23), which continues to be corroborated by further study in other portions of this species' range (Daw and DeStefano 2001), including temperate rainforests (McClaren et al. 2005). In my study, nest areas averaged 71% productive old growth; 58% of the nest area consisted of medium- or high-volume old growth. Before logging, landscapes across Southeast Alaska likely were similar in composition to current nest areas (U.S. Forest Service 1997). At the time of my study, only about one-third of 136 virtual post-fledging areas contained >51% choice habitat. More importantly, the average composition of "unsecure" (i.e., Development or Non-National Forest land-use designations) habitat was 55%, and 60% of all post-fledging areas consisted of >51% unsecure habitat. Regardless of whether I compare these results with guidelines from the southwestern United States or the habitat at nest sites and in nest areas of Southeast Alaska (i.e., desired future condition of goshawk post-fledging areas; Reynolds et al. 2008), the observed composition of post-fledging areas was less than the minimum recommended or desired amount of habitat.

This conclusion differs from a general forest-wide habitat availability assessment (i.e., not linked to specific goshawk nest sites) based on analyses at multiple spatial scales (U.S. Forest Service 1997: appendix N43). I believe the disparity can be explained by differences in scale and biological relevance (i.e., linked to specific life-history needs; Reynolds et al. 2006) of analyses between this study and previous analyses (Iverson et al. 1996, U.S. Forest Service 1997: appendix N38). Some of the analyses cited in the summary appraisal were at a regional scale (forest-wide) and spatially neutral. For example, the conclusion that 95% of the northern goshawk range in the region has a high likelihood of sustaining habitat because 93% of the forests would have <47% of productive old-growth harvested over the planning horizon provides little spatially explicit information about breeding-season habitat, especially for populations occurring on islands. Also, results of stand-level analyses cited in the summary largely focused on aspects of forest management that were not immediately relevant to the life-history needs of breeding pairs. Conclusions that only a small percentage of nest areas examined had experienced any logging or that only a small proportion of nest areas were harvested says little about breeding-season habitat or resources available to breeding pairs, especially across the broader landscape. Intermediate-scale analyses and protective measures, such as limiting total harvest to $\leq$33% of a watershed during the planning horizon (effectively a 300-yr rotation), are spatially explicit and potentially have biological relevance (i.e., approximate size of goshawk home ranges). However, management guidelines not explicitly coupled to northern goshawk breeding ranges or life history are at risk of not meeting habitat needs of individual breeding pairs (Reynolds et al. 2006, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008).

At the time of the summary assessment (U.S. Forest Service 1997), about 5% (35/678) of the watersheds exceeded the stipulated threshold of total harvest, with 33–47% of the total available productive old-growth forests already harvested; 26 of those (74%) were concentrated in one Biogeographic Province (North Prince of Wales Island). The assessment acknowledged the higher risks of exceeding watershed thresholds of total harvest, especially across North Prince of Wales Island, but assumed that large reserves in those landscapes would mitigate the habitat loss from excessive timber harvest. The findings of this study suggest that contributions of old-growth reserves and other conservation elements (e.g., riparian or shoreline buffers) might not mitigate the cumulative habitat loss in intensively managed landscapes. This conclusion is supported by evidence on nearby islands that extensive loss and fragmentation of habitat from clearcut logging contributed to population declines of Queen Charlotte goshawks (Doyle 2006).

The threshold composition of suitable habitat to ensure successful breeding by goshawks in Southeast Alaska is unknown. To gain this knowledge requires extensive monitoring and research that chronicles reproductive histories of individual breeding pairs and links fitness to nesting habitat condition (Patla 2005, Reynolds et al. 2005, Salafsky et al. 2007). Still, the findings of this study increase uncertainty that northern goshawk breeding-season habitat objectives are being met in managed landscapes of Southeast Alaska. Two lines of reasoning support this conclusion.

First, spatially explicit analyses of contributions to northern goshawk breeding-season habitat revealed that conservation measures of the Tongass Land and Resource Management Plan contribute about half the secure habitat recommended for post-fledging areas of breeding pairs in the southern portion of this species range (Reynolds et al. 1992) and was less than half the relative amount of habitat documented in nest areas in Southeast Alaska. A similar conclusion was obtained for the broader landscape (21 km^2) that surrounded each nest. This is because much of the habitat across the landscape has been clearcut-logged and half the remaining choice habitat is in the Development land-use designation available for timber harvest. The potential for second-growth stands to become useable habitat (mature sawtimber) over the Tongass planning horizon is limited because unmanaged second growth typically requires ≥300 years following disturbance to develop old-forest features (Nowacki and Kramer 1998). Active management can hasten the development of old-forest condition, but pre- and commercial thinning has occurred in only about 30% of 267,000 ha that have been harvested across the region (Barbour et al. 2005).

Secondly, guidelines developed for northern goshawk populations in the southwestern United States may underestimate habitat needed by breeding pairs in Southeast Alaska. A critical consideration in conserving habitat to support breeding populations is sufficient habitat to sustain prey resources (Reynolds et al. 2006; Salafsky et al. 2005, 2007). Despite possible differences in life history or ecology across the range of northern goshawks, the nesting and foraging habitat of successful breeding pairs must support adequate prey populations. In Southeast Alaska, the predominant (frequency and biomass) prey items during the breeding season (Lewis et al. 2006) are bird and mammal species that are most abundant, or occur exclusively, in productive old-growth forests (Iverson et al. 1996, Russell 1999; Smith et al. 2001, 2004, 2005). Consider further that the mammal fauna of Southeast Alaska is depauperate (MacDonald and Cook 1996); few mammal species exclusively occur in low-volume or managed forests of Southeast Alaska (Smith et al. 2001, Smith and Nichols 2004); and the structure of dense second-growth stands effectively renders prey unavailable to foraging goshawks (Beier and Drennan 1997). Avian communities in managed forests include few, if any, additional prey for northern goshawks (Smith et al. 2001). Thus, breeding pairs in managed landscapes of Southeast Alaska likely rely almost entirely on productive old-growth forests as foraging and nesting habitat. That breeding pairs in managed landscapes of Southeast Alaska depend on productive old-growth forests to meet life-history needs was reflected in the findings of compositional analyses and radiotelemetry studies, both of which determined that northern goshawks strongly selected medium- and high-volume old-growth forests and avoided recently managed or non-forested habitats (Iverson et al. 1996).

PLANNING AND MANAGEMENT IMPLICATIONS

Management guidelines for northern goshawks in the southwestern United States recommend active management of the entire planning area to regenerate forests as well as provide nesting and foraging habitat. Despite insufficient local information to prescribe the design of a reserve-based approach to sustain northern goshawks, a hierarchical system of habitat reserves became the cornerstone of the TLMP wildlife conservation strategy to sustain viable and well-distributed populations across Southeast Alaska. This was to a large part a result of having to consider the risk to viability of multiple species for which there was more theoretical or empirical evidence that habitat reserves would sustain viable populations. Because additional conservation measures were incorporated at multiple spatial scales in the 1997 TLMP to provide sufficient nesting and foraging habitat for northern goshawks, the conservation strategy for northern goshawks in southeastern Alaska became a composite of conservation measures superimposed on a conceptual framework developed for other vertebrate species of concern.

More importantly, the 1997 TLMP did not incorporate the concepts of nest area, post-fledging area, and foraging area habitat management that underpin the current paradigm of conservation planning to sustain viable populations of northern goshawks across a significant portion of its range. However, applying these concepts to temperate rainforests and to a planning area that differs markedly in natural history, forest type, landscape structure, and management history requires a thorough understanding of differences and similarities in goshawk behavior and ecology among regions. Still, managing for uncertainty and avoiding the risk of trending the population downward can be improved by using biological concepts applied elsewhere to sustain northern goshawk habitat and populations throughout southeastern Alaska. The nuances of local ecological variability and subsequent refinement of management guidelines can be uncovered with additional field study. Meanwhile, biologists and land managers may want to consider ecological consequences to northern goshawk populations (and associated ecological communities) of potential habitat deficiencies in managed landscapes across the region. Planners and managers may want to revisit assumptions that current standards and guidelines and other conservation measures provide sufficient breeding season habitat to sustain viable and widely distributed goshawk populations. In the interim, project planning and land use management can be used to increase the longer-term security of preferred habitat (e.g., deferred harvest) or improve (e.g., thinning) marginal or unsuitable habitat in managed landscapes, especially across the North Prince of Wales Island Biogeographic Province.

Conservation plans rely on setting aside essential habitat to assure viability of indigenous wildlife communities in intensively developed landscapes. More often than not, little local information exists upon which to develop a sound conceptual framework or identify effective conservation measures. Thus, land-use planning frequently relies on biological data from other regions or incorporates multiple assumptions, many of which lack an underlying empirical or theoretical foundation. Determining the effectiveness of a conservation strategy is a daunting task, requiring long-term habitat and wildlife population monitoring. However, shorter term evaluations are possible and desirable to scrutinize underlying assumptions, identify deficiencies, refine elements and procedures, and prevent irreparable negative effects, should a conservation plan depend on long-term monitoring.

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Appendix A. Percentage of relative frequency (%) classes of 4 land-use designations (LUD) and 4 cover types in 2 types of ecological areas encircling 136 northern goshawk (*Accipiter gentilis*) nest sites in Southeast Alaska, USA. The radius of the post-fledging area (PFA) is based on the average movement (1,600 m) and the radius of the broader landscape is based on the average use area (90% mononuclear probability polygon) of radiocollared adult female goshawks during the breeding season (Iverson et al. 1996).

Ecological areas	LUD composition (%)				Cover-type composition (%)			
Percentage categories	Development	NNF	Natural	OG	Habitat[a]	Low-volume old growth	Clearcut	Nonproductive forest
PFA								
0–5	46	75	52	71	1	46	68	1
6–25	5	4	9	7	18	47	29	13
26–50	7	4	15	6	51	7	3	47
51–75	7	13	4	8	23	0	0	33
76–90	4	1	2	1	7	0	0	6
>90	32	3	17	7	0	0	0	1
Total	100	100	100	100	100	100	100	100
Home range								
0–5	37	74	38	56	1	46	68	0
6–25	6	7	19	21	19	54	30	7
26–50	13	9	17	14	63	1	2	35
51–75	10	9	7	7	15	0	0	50
76–90	13	1	4	1	3	0	0	7
>90	21	1	15	1	0	0	0	0
Total	100	100	100	100	100	100	100	100

[a] Medium- or high-volume strata old-growth rainforest (Iverson et al. 1996).

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REVIEW

Wildlife studies on the Tongass National Forest challenge essential assumptions of its wildlife conservation strategy

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Abstract

The Tongass National Forest in southeast Alaska, USA, includes the Alexander Archipelago and narrow North American mainland, comprising one of the largest remaining, largely pristine, coastal temperate rainforest in the world. Management of the Tongass has become increasingly challenging because of expectations of a conservation framework designed to maintain viable populations of native wildlife species while decades of extensive clearcut logging of old-growth forests has continued. We used the findings of multiple published studies conducted on the Tongass from 1998 to 2017 to examine 4 assumptions of its wildlife conservation strategy (WCS): forest planning assessments of wildlife viability were realistic, forest management and conservation policies are implemented at appropriate ecological scales, old-growth reserves are effective habitat conservation areas and ensure functional connectivity, and forest-wide standards and guidelines ensure sufficient habitat for sensitive species in managed landscapes. Several ecological field studies, population and spatial analyses and modeling, and statistical analyses revealed that wildlife viability assessments to evaluate forest plan alternatives underestimated the risk of extinction by only examining individual vulnerable species rather than considering joint probabilities across multiple species; the ecological scale of management and conservation policies do not adequately consider area-sensitive vulnerabilities of island communities as evidenced by the increasing risk of extirpation of island endemics whose populations have become isolated and reduced; old-growth reserves are unlikely to maintain viable populations of endemic small mammals in isolation or as functionally connected metapopulations; and a spatially explicit analysis of individual home ranges demonstrated that forest-wide standards and guidelines provide about half the breeding habitat needed by a federally listed endemic raptor, the Queen Charlotte goshawk (*Accipiter gentilis laingi*), of which only half of that is secure. Thus, assertions that the WCS is properly functioning as designed are dubious because a comprehensive monitoring plan has not been implemented and vital underlying assumptions are not supported by available science. We recommend 3 forest management and conservation policy adjustments: limit size and location old-growth forest harvests, restore forests through intermediate stand management of second growth, and conduct a formal review of WCS elements and assumptions.

KEYWORDS

biodiversity, clearcut logging, ecological scale, island endemics, old-growth forests, reserve network, temperate rainforest, wildlife viability

The Tongass National Forest (Figure 1) is one of the largest, relatively pristine, temperate rainforests in the world (DellaSala et al. 2011, 2022) with 6.7 million ha distributed across ≥20,000 islands and a narrow mainland in southeast Alaska, USA (Everest et al. 1997). It extends from the southern tip of Prince of Wales Island 800 km north to the Hubbard Glacier.

Southeast Alaska is globally recognized for its expansive tracts of intact rainforest that contribute to climate stabilization (DellaSala et al. 2022). Wind disturbance plays a fundamental role in shaping forest dynamics, at large and small scales, and over a continuum dependent on landscape features including exposure, landscape position, and topography. These forests support complete wildlife communities, most notably all-inclusive trophic assemblages that include primary producers to top carnivores (Vynne et al. 2021). The Alexander Archipelago has a terrestrial mammalian fauna with a nested structure that resulted primarily from differential colonization following glacial retreat (Conroy et al. 1999, Sawyer et al. 2019). Regardless of the primary mechanism, habitat loss and fragmentation are expected to reduce diversity of mammalian taxa in southeast Alaska through increasing extinction probabilities (Burkey 1995, Frankham 1998, Crooks et al. 2017, Püttker et al. 2020, Vynne et al. 2021). Furthermore, vital interspecific interactions across ecological communities are altered if a predator, prey, or symbiote is extirpated (Smith 2012*a*, Brodie et al. 2018, Kelt et al. 2019).

In 1997, Tongass planners were commissioned to manage wildlife habitats to maintain viable, widely distributed populations of existing native and desired non-native vertebrate species as directed by the 1982 viability rule of the 1976 National Forest Management Act (NFMA; U.S. Forest Service [USFS] 1982). Procedures

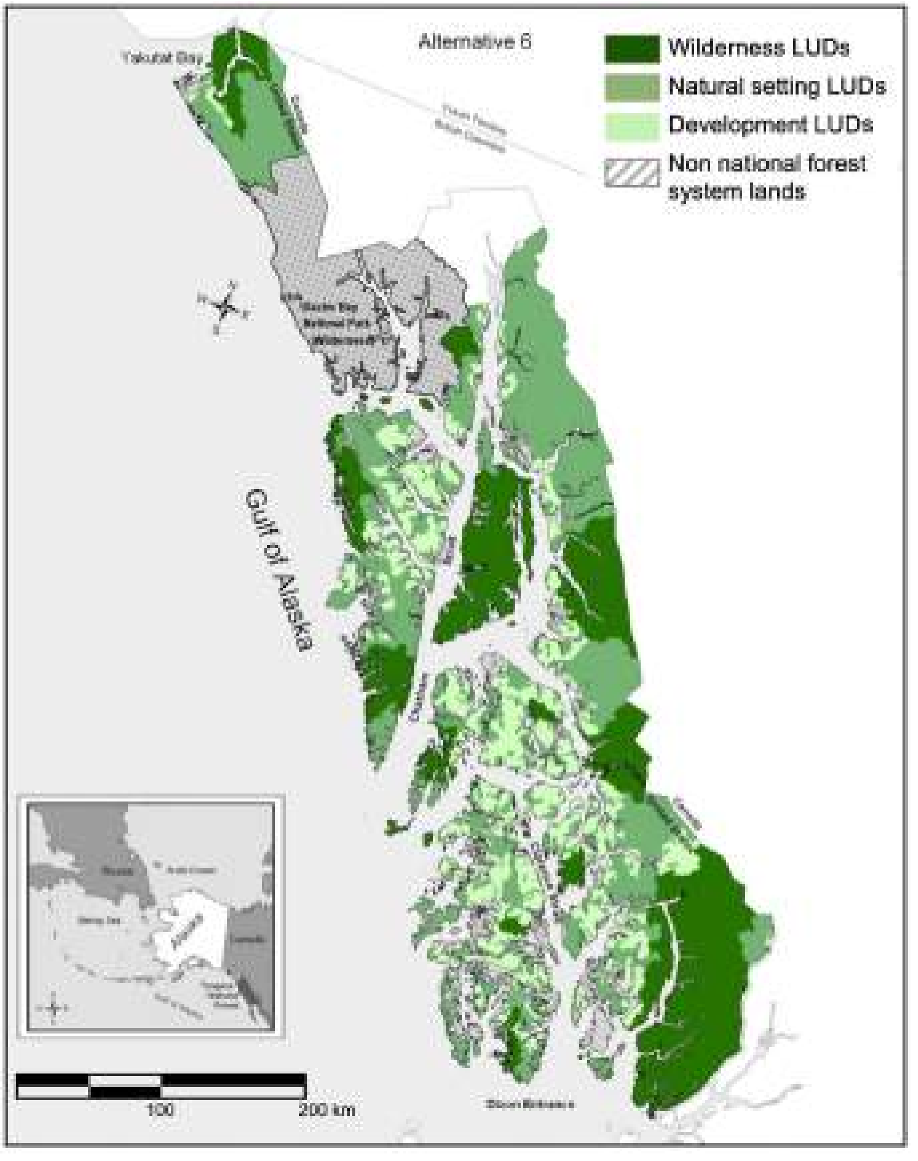

FIGURE 1 The Tongass National Forest in southeast Alaska, USA, extends from the southern tip of Prince of Wales Island 800 km north to the Hubbard Glacier and includes the Alexander Archipelago and a narrow strip of North American mainland encompassing 6.7 million ha. Single ranger districts exceed the size of many national forests in the continental United States. The Wildlife Conservation Strategy old-growth reserve network is depicted as wilderness and natural setting land use designations (LUDs) within Alternative 6 of the 2008 Forest Plan Amendment (USFS 2008). Wilderness LUDs include wilderness areas and National Monuments. Natural setting LUDs includes lands that maintain old-growth forest: congressionally designated unroaded areas; old-growth forest LUDs; remote and semi-remote recreation; municipal watersheds; special interest areas; wild, scenic, and recreational rivers; and research natural areas. Development LUDs include timber production, modified landscapes, scenic viewsheds, and experimental forests; <25% of these lands are suitable for timber harvest. Non national forest system lands represent state, Native, and private lands (USFS 2008).

for implementing NFMA viability provisions are expected to occur through the following processes: 1) describing the ecological context, 2) identifying species of viability concern, 3) collecting information on species of viability concern, 4) identifying species groups, 5) describing conservation approaches, 6) developing land and resource management plan (LRMP) alternatives, 7) evaluating the effects of LRMP alternatives on viability, and 8) conducting monitoring activities.

Historical timber management of the Tongass limited old-growth rainforest available to planners in framing a conservation strategy. A large majority of timber harvests occurred before the 1997 forest plan revision (USFS 2008), with cumulative disturbance and ecological consequences from 5 decades of high grading (i.e., exclusive harvest of the most valuable forests) across the region, including large-tree stands and expansive landscapes with contiguous productive old-growth (timber volume >46.6 m^3/ha) forests (Albert and Schoen 2012). While approximately 79% of the Tongass remains largely undisturbed and undeveloped (stream and shoreline buffers, reserves, wilderness areas), the majority of the unmanaged portion is highly fragmented, composed of ≥20,000 small (<400 ha), uninhabited islands with little opportunity for timber harvest (USFS 1997). The managed portion (~21%) has been subjected to intensive broad-scale disturbance from extensive clearcut logging that produced sharply contrasting land cover types within single landscapes (Figure 2). The highest rates of change occurred among biogeographic provinces and landform associations that originally contained the largest concentrations of highest volume, productive old growth (POG). Although only 12% of POG forests have been logged, large-tree stands were reduced by ≥28%, karst forests by 37%, and landscapes with the highest volume of contiguous old growth by 66.5% (Albert and Schoen 2012).

The USFS responded to this management challenge with a comprehensive, science-based revision of the forest plan (Swanston et al. 1996). The 1997 Tongass Land and Resource Management Plan (TLMP; USFS 1997) combined familiar, previously used elements and processes gleaned from the scientific literature with regional ecological information from journal publications, workshops, expert panels, and agency reports to design a unique, strategic conservation framework (Swanston et al. 1996, Everest et al. 1997, Smith and Person 2007, Smith et al. 2011, Smith 2013). Emulating natural disturbances offered an approach to designing management plans that maintain prevailing ecological conditions (Nowacki and Kramer 1998). Tongass planners chose a management plan alternative that departed substantially from the natural disturbance regime in which ≥95% of canopy openings produced by windstorms average <0.03 ha (Nowacki and Kramer 1998). The 1997 TLMP continued to emphasize

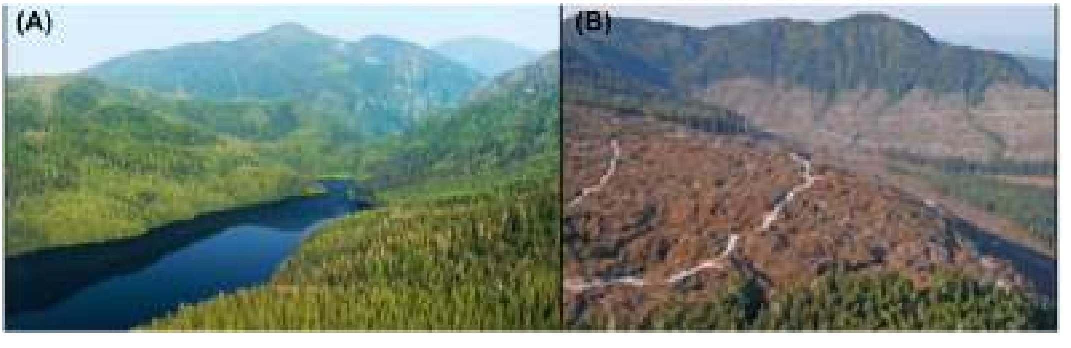

FIGURE 2 Timber management of the Tongass National Forest in southeast Alaska, USA, was dichotomous, producing sharply contrasting unmanaged and managed landscapes of A) intact old-growth temperate rainforests (photo by Alan Wu/Flickr Creative Commons) and B) extensive clearcuts (photo by John Schoen). A small proportion (12%) of the entire Tongass National Forest was logged; still, 67% of the highest volume forests were harvested (Albert and Schoen 2012). Some smaller islands experienced broad-scale disturbance across a significant proportion of the entire distribution of resident endemic mammals (Smith et al. 2011, Smith and Fox 2017).

clearcut logging, adding broad-scale disturbance to expansive landscapes of young, unmanaged, even-aged second growth (USFS 1997).

Despite its size and southeast Alaska's highly fragmented island biogeography, an important and far-reaching central hallmark of the 1997 TLMP is that the Tongass National Forest is largely managed as a single contiguous forest ecosystem. This has been evident from expectations that the Tongass would continue to persist as interconnected late-successional ecosystems across southeast Alaska (Shaw 1999), assessments and summary data would be presented as forest-wide statistics (USFS 1997, 2008, 2016), and management would disregard the variety and significance of unique biota and ecological communities (Smith 2012*a*), including the consequences of disproportionate loss and fragmentation of available habitat from cumulative effects of logging to island endemics (Smith and Person 2007, Smith et al. 2011, Albert and Schoen 2012, Smith 2013, Smith and Fox 2017).

Although amendments to TLMP have occurred since 1997 (USFS 2008, 2016), today the Tongass Wildlife Conservation Strategy (WCS) remains largely intact (USFS 2016). Unfortunately, a continuous decline in funding since 1997 has limited resources and capability to implement a proposed comprehensive long-term monitoring plan for sensitive or other vulnerable species (Smith et al. 2011, Smith 2013, Smith and Fox 2017). Consequently, there is little documentation regarding the implementation of management or conservation actions or corresponding responses and outcomes for intended forest resources.

Until recently, the most apparent alterations or amendments to the WCS have been the removal, movement, or change in composition of designated old-growth reserves (Smith et al. 2011). Small old-growth reserves have remained spatially inexplicit (USFS 2008), obscuring assessments of landscape structure and functional connectivity. In the 2016 forest plan amendment, an immeasurable number of small (many isolated) conservation areas totaling 1.3 million ha of old-growth forest were established across the Tongass, and 8,350 ha of old-growth forest was preserved among 73 watersheds to protect anadromous streams (USFS 2016: appendix D). It remains unclear if the watershed allocation was in addition to the old-growth reserve network expectation that ≥16% of the area be retained as old-growth forest (USFS 1997: appendix K). Regardless, without additional research, including spatially explicit analyses of watersheds and surrounding landscapes, contributions to functional connectivity or essential habitat of sensitive or old-growth obligate wildlife remain uncertain.

The Tongass WCS embodies a complex land and resource management framework intended to maintain biological diversity that comprises numerous elements, some of which are integrated within a hierarchical structure that is susceptible to systemic failure because each component is essential for overall functioning (Smith et al. 2011, Smith 2013). Although some elements have been successfully implemented for select species under specific circumstances elsewhere (USFS and Bureau of Land Management 1994), the Tongass WCS was implemented as an experiment with several essential underlying assumptions (Smith and Person 2007, Smith et al. 2011, Smith 2013). Yet statements asserting or accepting the 1997 Tongass WCS as a scientifically sound foundation from which to base management decisions continued to occur in forest and project planning documents (USFS 2008: D26, USFS 2016: K1–3), meetings, internal communications (W. P. Smith, USFS, personal communications), received emails, internal and cooperator meetings, oral comments during public workshops and meetings, and external communications (e.g., newspaper articles). Such assertions lack sufficient monitoring data or supporting evidence from scientific studies, potentially enabling further threats to essential old-growth ecosystems and native wildlife.

Our objective was to illustrate apparent disparities between designed expectations and documented outcomes of implementing the WCS through an investigation of published wildlife research conducted on the Tongass, including studies explicitly designed to examine inherent assumptions. Specific objectives were to use published results to examine 4 assumptions of the Tongass WCS: forest planning assessments of wildlife viability were realistic, forest management and conservation policies are implemented at appropriate ecological scales, old-growth reserves are effective habitat conservation areas and ensure functional connectivity, and standards and guidelines ensure sufficient habitat for sensitive species in managed landscapes.

STUDY AREA

Southeast Alaska is composed of mainland extending south along the western coast of Canada and >1,000 islands. The area includes fjords and glaciated mountain ranges and a cool, wet (200–600 cm annual precipitation) maritime climate, with mean monthly temperatures ranging from 13°C in July to 1°C in January (Smith and Nichols 2003, 2004). Elevation ranges from sea level to 1,643 m. The region is highly fragmented, with islands ranging in size from <1 ha to 6,670 km^2. The narrow mainland is largely isolated from other large, contiguous landmasses because of mountains, glaciers, and ice fields immediately to the east (Everest et al. 1997). Southeast Alaska is further stratified by 21 biogeographic provinces according to various configurations of physical, climatic, and biotic features. About 4 million ha (60%) is rainforest, of which 2.2 million ha is productive forests (USFS 1997). Coniferous rainforest dominates the landscape from shoreline to about 600-m elevation. The forest canopy is dominated by western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) in uplands but includes shore pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*), western redcedar (*Thuja plicata*), and Alaska-cedar (*Chamaecyparis nootkatensis*) in wetlands (Nowacki and Kramer 1998); remaining areas are riparian, alpine, muskeg, or sparsely vegetated mountain peaks and other rock formations (Smith and Nichols 2003, 2004). About 90% of commercial forests are upland Sitka spruce–western hemlock forests (USFS 1997).

Large trees (>75-cm diameter), downed and decaying wood, snags, and heterogeneous substrates are key components of old-growth rainforest ecosystems (Alaback 1982, Nowacki and Kramer 1998). The understory is dominated by blueberry (*Vaccinium* spp.), especially in canopy gaps (Smith and Nichols 2003, 2004; Smith 2012*a*). Unmanaged forests have a multilayered overstory of uneven-aged trees, dominant trees that generally are ≥300 years old, and structurally diverse understories (Alaback 1982; Smith and Nichols 2003, 2004). These forests vary in structure from scrub, or low-volume, communities of short (<10 m), small (<0.5-m diameter) trees with open canopies and dense, shrubby understories on poorly drained sites (peatland) to high-volume stands with a closed canopy, tall (>60 m), large (>3-m diameter) trees, and a predominantly herbaceous understory on highly productive sites (Harris and Farr 1974, Alaback 1982). The western hemlock-Sitka spruce forest type constitutes most of the closed-canopy forests in the region (Alaback 1982). It is spatially heterogeneous at a fine scale (<1 ha) and typically occurs on low-elevation, well-drained sites, often as a mosaic with fens and muskegs (Smith and Nichols 2003, 2004).

Southeast Alaska has a unique mammalian fauna that is significantly correlated with island isolation and extinction events resulting from differential colonization and island area effects (Conroy et al. 1999). Consequently, southeast Alaska is a hot spot of endemism (Cook et al. 2001), with varying and unique mammal assemblages and ecological communities (Cook and MacDonald 2001; Cook et al. 2001, 2006; Smith 2012*a*). The life history of birds is also influenced by the fragmented nature of the region, most notably northern goshawks (*Accipiter gentilis*) and other species that require large breeding ranges (Smith 2013). Prominent indigenous vertebrates include the Queen Charlotte goshawk (*A. g. laingi*), marbled murrelet (*Brachyramphus marmoratus*), Alexander Archipelago wolf (*Canis lupus ligoni*), brown bear (*Ursus arctos*), American marten (*Martes americana*), Sitka black-tailed deer (*Odocoileus hemionus sitkensis*), and numerous endemic small mammals whose distributions are restricted (MacDonald and Cook 1996, Smith 2005, Cook et al. 2006), including the following island endemics: Prince of Wales Island flying squirrel (*Glaucomys sabrinus griseifrons*), Wrangell Island vole (*Myodes gapperi wrangeli*), and Suemez Island ermine (*Mustela erminea seclusa*).

METHODS

Because the purpose of this review was not a meta-analysis or systemic literature review, we first conducted literature searches focused on our published research papers and the citations within and summarized the findings of numerous studies conducted in Southeast Alaska during 1998–2017. We then used a Web of Science™ word search conducted 31 May 2021 using the keywords Tongass, management, wildlife, and conservation. This search produced 57 results. We expanded our search by reviewing the publications citing relevant sources from this search and by reviewing the sources cited within all of these. We extracted publications from the search output that focused on research or management of wildlife within the Tongass that related to ≥1 of the 4 objectives for this review. We excluded studies of wildlife species that were not identified as a focal or management species within TLMP (e.g., bears, bald eagle [*Haliaeetus leucocephalus*]).

Viability assessments (objective 1)

An initial, integral step in developing a forest plan that prioritizes maintaining biological diversity is establishing a procedure in which planners can objectively evaluate the effect of LMRP alternatives on the persistence of native wildlife (Shaw 1999). The USFS convened numerous risk assessment panels during the 1997 TLMP revision (USFS 1997). Each panel comprised subject matter experts with knowledge of the natural resource under consideration. Seven panels estimated the relative risk that implementation of a range of alternative approaches to management of the Tongass would impose upon continued persistence of select wildlife species across the landscape. Ostensibly, the chosen set of species represented a broad enough range of taxa and ecological lifestyles that the breadth of possible responses to each of the 10 forest plan alternatives under consideration was captured in responses of vulnerable species but with little or no correlation among species' responses to a particular alternative (Shaw 1999).

An eighth panel evaluated old-growth ecosystems, assigning likelihood scores to outcomes that characterized the persistence of interconnected and representative late-successional ecosystems across southeast Alaska according to 3 attributes: abundance and ecological diversity, which considered if "old growth would be equal to or greater than long-term (i.e., 100 years) average and is well distributed across environmental gradients, provinces, and community types;" processes and functions, which considered whether the full range of disturbance processes are represented, and if "stand structure-dynamics and landscape structure-dynamics-age attributes occur across all provinces;" and whether connectivity would be as "effective as it was prior to large-scale timber harvest" (Shaw 1999: 11–12). Assessments from each of the panels became an integral element of the effects analyses that ultimately determined the management policies and actions incorporated in the 1997 TLMP (USFS 1997).

Risk assessment panels evaluated the likelihood of persistence of the northern goshawk, Alexander Archipelago wolf, brown bear, marbled murrelet, American marten, Sitka black-tailed deer, and other terrestrial mammals (Shaw 1999). Other terrestrial mammals included a group of more widely distributed mammals and a group of endemic small mammals whose known distribution in southeast Alaska is restricted (MacDonald and Cook 1996, Smith 2005, Cook et al. 2006). To assess the influence of varying management applications and intensities on wildlife viability, panels examined the marginal risk (individual extinction probability) of vulnerable species under each alternative and focused attention on the taxon with the highest projected risk of extinction with implementation of the alternative. This most sensitive species and its probability of extinction was used to reflect the risk to wildlife population viability for all vertebrates across the planning area for the alternative under consideration (Shaw 1999). This approach has been challenged because of untenable assumptions regarding the interpretation and application of select, individual vulnerable species from viability assessments to conservation planning (Soulé 1987, Smith and Zollner 2005, Jenkins et al. 2021).

Number of species influences the probability of any extinction

Smith and Zollner (2005) detailed an approach to assessing wildlife viability that explicitly considers the risk of any extinction among vulnerable vertebrate species in the planning area, calculated as the "likelihood of at least one success" (Snedecor and Cochran 1980: 115). Thus, the assessed probability of extinction following implementation of an alternative is the joint probability of marginal probabilities, each of which represents the risk to viability of individual species (Smith and Zollner 2005). They created a scenario with multiple hypothetical species at risk using each's corresponding independent marginal probabilities (acknowledging distinctive rather than correlated responses) for each of several management alternatives, similar to procedures used in planning TLMP (Shaw 1999). Smith and Zollner (2005) used this scenario to illustrate how the probability of any extinctions and the probability of the single most likely extinction differ as a function of the number of species examined. Recall, one panel assessed viability risks of a group of 26 terrestrial mammals (Shaw 1999) that included 14 endemic small mammal taxa and 12 additional terrestrial mammal taxa (USFS 2008: appendix D68). Moreover, endemic mammals were the most vulnerable of all wildlife species to future landscape disturbances assessed by the panel (Swanston et al. 1996: 11).

When marginal probabilities are used to calculate the joint probability of any extinction under each management alternative, the risk to wildlife viability is consistently and markedly higher than that obtained from selecting the most vulnerable species at risk (Figure 3). This occurs because the risk of local extirpation increases with the number of extinction-prone species in a region (Smith and Zollner 2005). Furthermore, the 1982 NFMA planning rule to ensure wildlife viability explicitly charges managers with the responsibility of protecting all vertebrates in a planning area, not just selecting species that appear to be the most vulnerable (Shaw 1999, Smith and Zollner 2005). Forest plan alternatives that pose the highest risk to more vulnerable species might not necessarily represent the greatest threat to wildlife communities, in part because of the variety of unique assemblages and their interspecific relationships and dependencies (Conroy et al. 1999, Smith 2012*a*, Smith and Fox 2017, Kelt et al. 2019, Jenkins et al. 2021) but also because of the varying number of sensitive species that occur among southeast Alaska's unique fragmented communities (Conroy et al. 1999, Smith 2012*a*, Colella et al. 2021).

Tongass planners in 2008 did acknowledge the influence of the number of species at risk on the probability of any extinction and compared 1997 assessment panel results among management alternatives with corresponding joint probability estimates and among proposed forest plan alternatives (USFS 2008: D85–86).

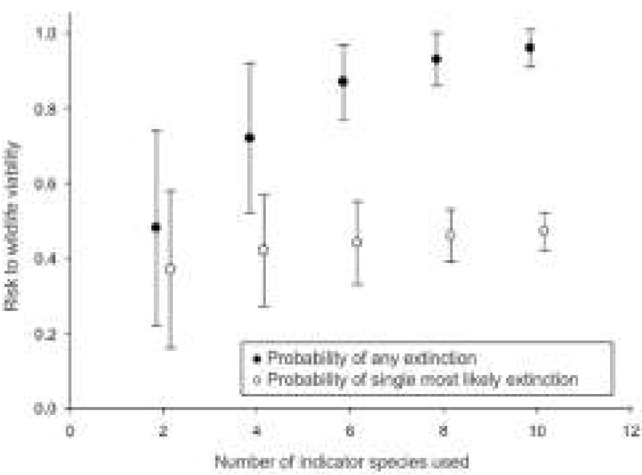

FIGURE 3 Disparity in risk to wildlife viability between estimating the probability of the most likely extinction (extinction of most sensitive species) and the probability of any extinction when assessing the relative risk that implementation of alternative approaches to management of national forest would impose upon continued persistence of indigenous wildlife across the landscape. Figure reprinted with permission from Smith and Zollner (2005).

Still, it remains unclear whether the joint probability calculations used the mean marginal probability of each wildlife assessment panel ($n = 7$) or included the marginal probabilities of each of the 14 individual endemic small-mammal taxa and 12 other terrestrial mammals. The latter seems unlikely because marginal probabilities were not assessed for each of the 26 terrestrial mammals (Shaw 1999). More importantly, the acknowledged higher extinction risks did not appear to raise concerns sufficient to generate discussion about acceptable threshold values of viability risks relative to policy or implementing future management actions or conservation measures (USFS 2008).

Implicit in the Tongass approach is an assumption that similar species are perfectly correlated in how each responds to a management alternative (Shaw 1999). Such an assumption is not ecologically tenable (Szaro 1986, Soulé 1987, Todd and Burgman 1998, Jenkins et al. 2021). Vertebrate faunas comprise diverse ecological assemblages of organisms that include herbivores, granivores, insectivores, carnivores, and omnivores, which often use the environment at different scales and in different ways (Wiens et al. 1993, Lancaster 1996, Kelt et al. 2019). Species in wildlife communities, even those with seemingly similar habitat affinities and life histories, do not respond to disturbance uniformly within habitat patches (Szaro 1986, Laurance 1991, Niemi et al. 1997) or across broader spatial scales (McGarigal and McComb 1995). Consider also the nature of forces that influence wildlife populations; anthropogenic disturbances are additive and extraneous to ecosystems (Püttker et al. 2020). Because wildlife communities evolved under unique environmental circumstances, local populations respond differently to anthropogenic disturbances compared with natural regimes (Wilson et al. 2005). Individual species likely respond differently to the same anthropogenic disturbance (Szaro 1986, Wiens et al. 1993, McGarigal and McComb 1995, Niemi et al. 1997). Within the same community, species of management concern can require strikingly different disturbance regimes and consequently respond divergently to the same management prescription (Smith 2013). Thus, it is unrealistic to expect that a select set of vulnerable species can represent the risk to viability of the entire vertebrate fauna across numerous unique, diverse communities with varying life histories and sensitivities to anthropogenic disturbance and spatial context (Wiens 1989, 1996).

Managing a large-scale island archipelago (objective 2)

Issues of ecological scale are a major concern in wildlife conservation, and many ecological patterns and processes are scale-dependent (Wiens 1989). Perceptions of how populations are spatially subdivided and impressions of extinction and dispersal dynamics depend on the scale at which the population is viewed (Wiens 1996). Conservation of biological diversity also requires maintaining evolutionary diversity (genetic and life-history attributes) of organisms indigenous to a region (Cook and MacDonald 2001, Colella et al. 2021), including the composition, structure, and functions of local ecological communities (Smith 2005, Watson et al. 2018, Grantham et al. 2020). Land management planning for the Tongass National Forest, however, has occurred at the scale of millions of hectares (USFS 1997, 2008, 2016), which is a much broader scale than the contiguous landscapes available to fragmented wildlife populations and ecological communities across an island archipelago and isolated mainland (MacDonald and Cook 1996, Conroy et al. 1999, Cook et al. 2001). Cook et al. (2001) listed 24 endemic mammals, several of which occur only on one or a few islands (MacDonald and Cook 1996, Smith 2005, Cook et al. 2006, Colella et al. 2021). The entire known distribution of the Suemez Island ermine, a small carnivore, is $<160\ km^2$ (MacDonald and Cook 1996). Moreover, several species encompass multiple, genetically distinct lineages (some representing incipient or new species) attributable to independent colonization histories from divergent source populations (Cook et al. 2006). The insular landscapes of the Alexander Archipelago have produced highly endemic populations that should be prudently managed as hotspots of biological and evolutionary diversity. Thus, islands available for timber harvest should each initially be considered an independent biological unit (Cook et al. 2006).

Consequences of management at inappropriate ecological scales among island communities

The Wrangell Island vole is a habitat specialist that achieves its highest densities in old-growth forests (Figure 4A) and is unable to sustain breeding populations in peatland scrub (mixed-conifer) forest (Figure 4B), clearcuts (Figure 4C), or second growth (Figure 4D,E; Smith and Nichols 2004, Smith et al. 2005*a*, Smith and Fox 2017). This red-backed vole is known only from Wrangell and Etolin islands (MacDonald and Cook 1996, Runck 2001). Wrangell Island is 544 km^2 (54,400 ha) and 85% of the island is in Tongass National Forest, of which 72% is available for timber harvest. Approximately 2,700 ha of old-growth forest has been clearcut logged, with a proposed timber project to harvest an additional 16,600 ha (USFS 2019). Moreover, there are no explicit conservation directions or actions to protect this vulnerable island endemic from local extirpations (USFS 1997: 4–87).

On Wrangell Island, voles are sympatric with the Keen's mouse (*Peromyscus keeni macrorhinus*), a habitat generalist that flourishes in old-growth, managed, and scrub forests (Smith and Fox 2017). Keen's mouse can be an intense competitor of voles, with interspecific competition between the 2 species explaining more variation in vole abundance (and vice versa) among habitats than the variance associated within habitats (Smith and Fox 2017). Thus, clearcut logging of old-growth forests on Wrangell Island favors populations of the Keen's mouse by creating habitats that breeding vole populations cannot exploit and further reducing vole abundance across managed landscapes because of increased interspecific competition from increasing mice populations (Smith and Fox 2017). Furthermore, opportunities for voles to reoccupy managed landscapes are limited because broad-scale disturbance can take ≥300 years for ecological succession to achieve old-growth forest conditions (Nowacki and Kramer 1998).

Thus, when forest management is applied indiscriminately across archipeleagos (*defacto* contiguous landscapes), it is implemented at inappropriate ecological scales and thus insensitive to the variation and uniqueness of species composition, phylogeography, life-history attributes, and interspecific relationships among island communities (Cook et al. 2006). The consequences of disproportional habitat loss and fragmentation typical of island endemics results in isolation, local extirpation, and overall reduction of endemic populations, increasing risk of extinction (Burkey 1995, Frankham 1998, Crooks et al. 2017, Püttker et al. 2020, Vynne et al. 2021).

Effectiveness of old-growth reserve system (objective 3)

The WCS has 2 components, each representing sharply contrasting management and landscape conditions. The first is a forest-wide, old-growth reserve network (Figure 1; USFS 1997) in which the reserves and other protected lands are expected to provide sufficient habitat to sustain viable, well-distributed populations of old-growth-obligate wildlife (Iverson and Renè 1997, Smith and Person 2007). This network was intended to serve as a coarse filter to maintain a functional and interconnected old-growth ecosystem (USFS 2008: D6). Coarse filters use the compositional integrity and functional proficiency of landscapes or ecosystems as surrogates to predict or ensure the wellbeing of particular taxa or ecological communities (Jenkins et al. 2021). A second function of the old-growth reserve system is to facilitate functional connectivity of protected lands, which also contributes old-growth structural elements in the development land-use designations of the Tongass planning area within which timber harvest and other anthropogenic disturbances occur over time.

The old-growth reserve network included all non-development lands and a system of large, medium, and small habitat conservation areas (reserves). Islands <400 ha were included and received protection from additional logging (USFS 1997, 2016). Each major watershed is required to have at least a small reserve encompassing ≥16% of its area. The preferred biological objective of a small reserve is to contain ≥50% POG; the minimum prescription is ≥25% POG. Medium reserves were delineated as contiguous landscapes of ≥4000 ha with ≥2000 ha of POG, of which ≥50% must be in the highest volume category. Large reserves must be ≥16,000 ha of contiguous landscape, with ≥50% POG and ≥25% in the highest volume category (USFS 1997: appendix K).

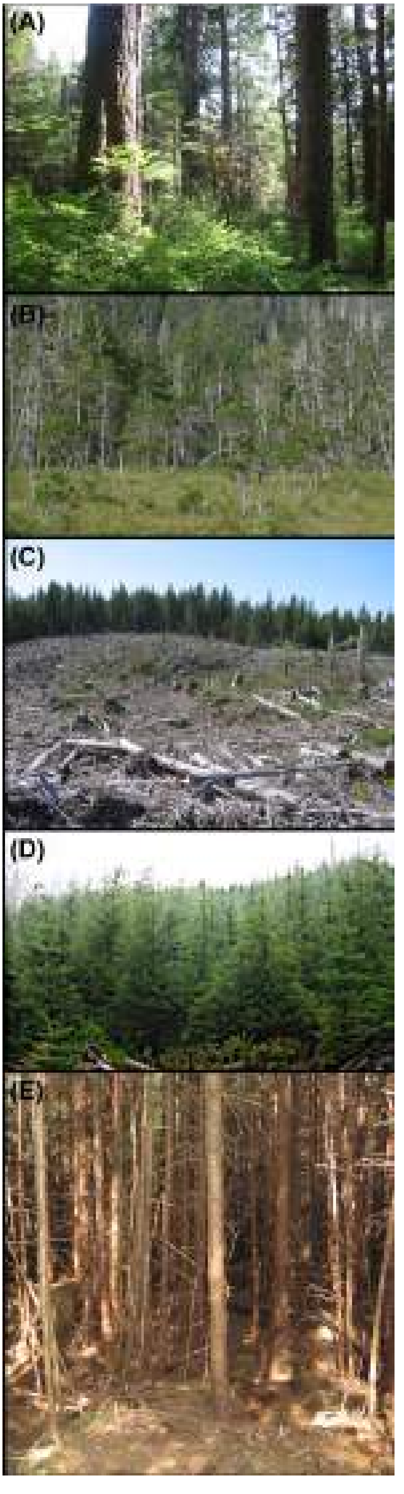

FIGURE 4 Common management stages and corresponding vegetation structure available to endemic small mammals in managed landscapes of the Tongass National Forest, southeast Alaska, USA: A) old-growth forest, B) peatland scrub forest, C) clearcut, D) young (<20 yr) second growth, and E) unthinned older (>40 yr) second growth.

The second WCS component includes active management of the matrix (commercial clearcut logging). Land managed for timber production was expected to contribute little toward maintaining biological diversity (USFS 1997: appendix N). Within the matrix, forest-wide standards and guidelines were implemented to uphold remaining components of the old-growth ecosystem. A standard is a course of action or level of achievement that must be accomplished to achieve forest goals and are mandatory. A guideline is also a course of action that must be followed, but guidelines relate to activities in which site-specific factors might require flexibility and require further analysis. Therefore, forest-wide standards and guidelines serve as fine filters to protect specific resources (e.g., old-growth forests) and functions (e.g., streamside buffers), facilitate connectivity across old-growth forests, and to ensure sufficient habitat for individual sensitive species (USFS 1997: chapter 4). Thus, for wildlife populations to persist in heterogeneous landscapes, either individual habitat patches must be large enough to provide for viable populations in isolation (Smith and Person 2007, Crooks et al. 2017) or the juxtaposition of suitable habitat within the matrix must allow for interpatch movements that facilitate meta-population dynamics (Smith 2012*b*, Fahrig et al. 2021).

Habitat conservation areas

The northern flying squirrel (*Glaucomys sabrinus*) was selected as the design (proxy) species for small old-growth reserves (≥650 ha) in the 1997 TLMP (USFS 1997) because of its assumed dependency on POG. Northern flying squirrels are k-selected, omnivorous, mature-forest obligates (Smith et al. 2004, 2005*b*; Smith 2007, 2012*b*; Holloway and Smith 2011) with specialized gliding locomotion (Scheibe et al. 2006). The underlying premise was that if the Tongass conservation strategy maintained viable and widely distributed populations of flying squirrels across the planning area, it would support other small mammals with similar life histories and habitat needs (Swanston et al. 1996, USFS 1997). Northern flying squirrels inhabit forests along southeast Alaska's mainland coast and occur on ≥15 islands of the Alexander Archipelagos (MacDonald and Cook 1996, Smith 2005, Schoen et al. 2006). The Prince of Wales Island flying squirrel (*G. s. griseifrons*) is an island endemic with reduced genetic variation (Bidlack and Cook 2001) that is considered a subspecies of ecological concern in the Tongass National Forest (Schoen et al. 2006) and is listed by the International Union for the Conservation of Nature as potentially endangered (Hafner et al. 1998).

Small old-growth reserves were expected to function as habitat conservation areas that provide sufficient habitat to facilitate occupancy by flying squirrels, and functionally connected populations interspersed throughout the matrix would behave as a metapopulation (Fahrig and Merriam 1985, Fahrig et al. 2021). Although there was no design requirement to ensure physical connectivity among old-growth reserves or with other non-development land-use designations, the assumption was that POG retained through other features of the conservation strategy (larger old-growth reserves, standards and guidelines) will establish landscape connectivity to facilitate dispersal across the matrix (USFS 2008: D8).

Persistence in habitat conservation areas

Smith and Person (2007) examined whether flying squirrels are likely to persist in isolation over a range of time periods in small habitat conservation areas with varying compositions of old-growth spruce-hemlock and mixed-conifer forests (Figure 4A) consistent with forest plan guidelines for both preferred and minimum habitat objectives (USFS 1997: appendix K). Given these guidelines, Smith and Person (2007) models revealed that the probability of persistence over a planning horizon of 100 years in small habitat conservation areas with the preferred prescription (50%) of spruce-hemlock composition was 0.73–0.77 and for the minimum prescription (25%), probabilities were 0.66–0.71. Furthermore, to sustain isolated populations over long periods (100 yr) with a high level (≥0.95) of confidence, flying squirrels require very large (244,600 ha) reserves of 100% optimum habitat. Medium (2000 ha POG) and large reserves (8000 ha POG) as currently specified (USFS 1997: appendix K) have a <0.90 probability of sustaining viable populations of flying squirrels over the 100-year planning horizon (Smith and Person 2007). These persistence estimates have been evaluated in the field. For example, on Kosciusko Island, flying squirrels were apparently extirpated from a 50-ha remnant patch of old-growth forest surrounded by <50-year-old second growth (E. A. Flaherty, Purdue University, unpublished data), and Shanley et al. (2013) observed that flying squirrels were not found in patches <29 ha and only selected the largest fragments locally and at the landscape scale with the minimum patch size for occupancy of 48 ha. Both suggest that likelihood of persistence is low in these small, isolated patches.

Functional connectivity and dispersal in managed landscapes

Given this uncertainty, Smith et al. (2011) evaluated the efficacy of small reserves as a functionally connected network that provided temporary suitable habitat for flying squirrels dispersing among large and medium reserves. They estimated the number of immigrants required to persist in small reserves for 25 and 100 years, landscape resistance to movement, and maximum effective dispersal distance via least-cost path analysis among small and larger reserves to ensure the required number of immigrants (Pyare and Smith 2005). Landscape resistance and risk of predation were higher in clearcuts (Figure 4C) than mature forests (Smith 2012*b*). Similarly, unthinned second growth (Figure 4E) obstructed visibility of suitable habitat (perceptual range) and impeded gliding (Flaherty et al. 2008, Smith 2012*b*). These dispersal barriers are a significant concern when an estimated 162 dispersers/year are needed to sustain populations for 100 years in small reserves comprising 25% primary habitat and ≥6 juvenile dispersers/year are needed to achieve a 0.95 probability that a breeding pair would reach a patch in which flying squirrels were recently extirpated (Smith et al. 2011).

Considerations of dispersal distance across managed matrix habitat is also important for maintaining persistence of flying squirrels. The maximum effective dispersal distance (Pyare and Smith 2005) for a 0.95 probability persistence over 100 years ranged from 844 m for small old-growth reserves with 25% primary habitat to 1,151 m for small old-growth reserves that comprise 100% primary habitat. Corresponding values for persistence in small old-growth reserves over 25 years were 1,172 m and 1,174 m (Smith et al. 2011). Remarkably, the maximum value of 1,174 m fell well within the distance that juveniles can move through intact landscapes (~7 km) over short time periods (Smith 2012*b*). Unfortunately, most of northern Prince of Wales Island has been clearcut logged (Figure 5), and ≥50% of small old-growth reserves prescribed in the 1997 TLMP for northern Prince of Wales (Figure 5) were isolated and not functionally connected to a source population (Smith et al. 2011).

These results underscore the vital role of immigration in rescuing sinks or facilitating metapopulation viability of northern flying squirrels among unsustainable fragmented populations, and the extent to which permeability of landscape elements can influence dispersal and functional connectivity of subpopulations in a managed matrix (With and Crist 1995, Richards et al. 2002, Pyare and Smith 2005, Smith et al. 2011, Trapp et al. 2019). The expectation that the Prince of Wales Island flying squirrel will function as a metapopulation with successful dispersal among old-growth fragments or reserves in managed landscapes is not supported by the findings of multiple studies examining this island endemic's habitat relations, population dynamics, and dispersal capability, including perceptual limitations, locomotion, energetics, and diet (Smith 2012*b*). Without large trees to facilitate gliding (Vernes 2001), flying squirrels must use quadrupedal (walking or running) locomotion, which is energetically more expensive than gliding (Scheibe et al. 2006, Flaherty et al. 2010*a*) and increases travel time (Byrnes and Spence 2011), leading to increased risk of predation (Smith 2012*b*). Additionally, flying squirrels cannot replenish energy stores by foraging as they disperse across clearcuts and second-growth stands because of the absence of preferred food resources (Flaherty et al. 2010*b*, Price et al. 2017). Finally, flying squirrels are unable to perceive old-growth forests across managed stands and are therefore unlikely to initiate movements across these more energetically expensive and risky land cover types (Flaherty et al. 2008).

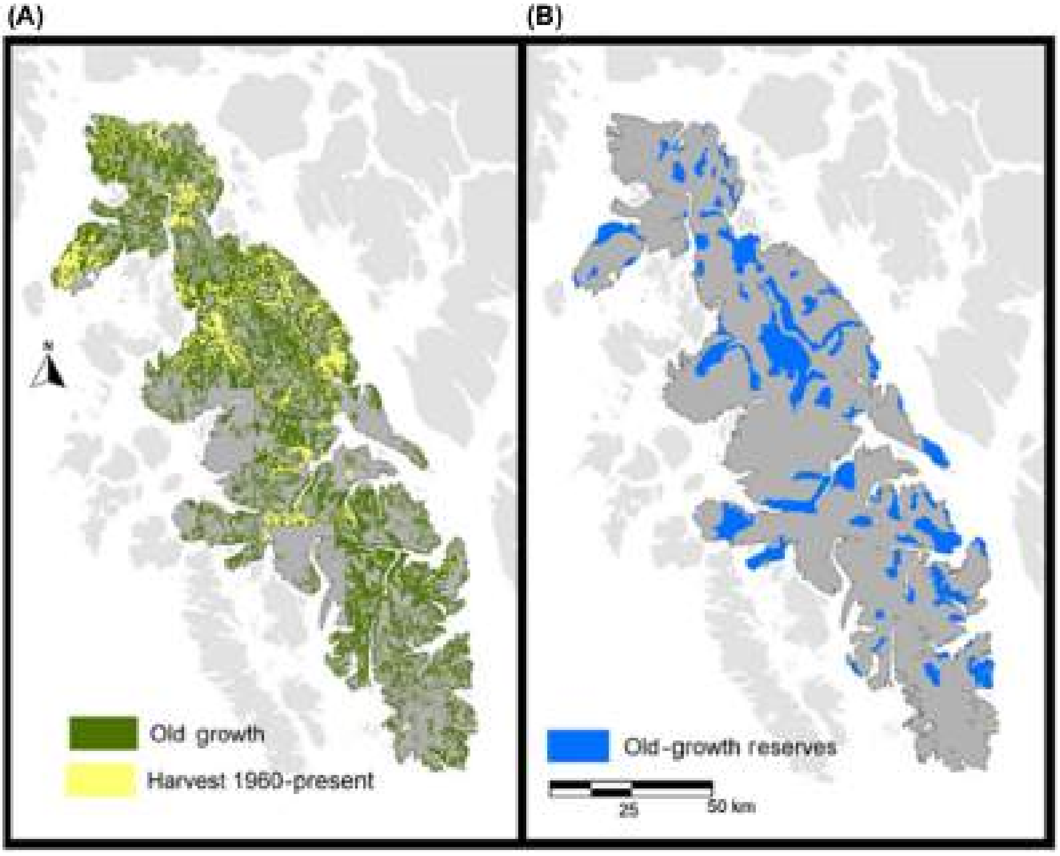

FIGURE 5 Prince of Wales Island, Alaska, USA, depicting the distribution of A) old-growth rainforest and areas logged since 1960 and B) old-growth reserves (USFS 1997).

Forest-wide standards and guidelines (objective 4)

The second component of the WCS uses forest-wide standards and guidelines, which are implemented for the protection or management of different forest resources (USFS 1997: chapter 4). Standards and guidelines apply to all or most areas of the Tongass, are organized by resource conservation status, and are used in conjunction with additional standards and guidelines included within each management prescription (USFS 1997: chapter 3). Standards and guidelines were established to manage locally important habitat for native wildlife (USFS 1997: chapter 4) and sensitive species (USFS 1997: 4–87), especially those that were not explicitly considered by viability assessment panels (Shaw 1999) or selected as ecological proxies in the design of the old-growth reserve network (Iverson and Renè 1997, USFS 1997, Smith 2013).

The northern goshawk was designated a sensitive species and underwent viability risk assessment (Shaw 1999). Goshawks received special consideration on the Tongass largely because of concerns over populations of the endemic Queen Charlotte goshawk (Iverson et al. 1996). Formally described as a metapopulation (Sonsthagen et al. 2012), the Queen Charlotte goshawk's distribution includes Prince of Wales and barrier islands and coastal British Columbia and nearby islands. The United States Fish and Wildlife Service listed all areas with known nests, except Prince of Wales Island, as threatened subpopulations in 2012 (U.S. Fish and Wildlife Service 2012), although all subpopulations are deemed essential for long-term viability (Sonsthagen et al. 2012) and ≥33% of POG on Prince of Wales Island has been converted to second growth (USFS 2008: appendix E; Albert and Schoen 2012). The most imminent threats to breeding populations are loss or fragmentation of nesting or foraging habitat from logging (Figure 2B) without ensuing intermediate stand management (Figure 4E), which eliminates nest trees and reduces prey diversity and availability (Reynolds et al. 1992, Finn et al. 2002, McGrath et al. 2003, Mahon and Doyle 2005, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008).

In western North America, breeding home ranges of northern goshawks are spatially configured as a hierarchical sequence of 3 areas (Andersen et al. 2005), all of which need to be considered simultaneously in land use planning (Reynolds et al. 2006, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008): nest area, post-fledging area, and foraging area. Nest areas provide alternate nest trees, roost trees, and prey plucking posts, and serve as centers of essential breeding behaviors or life-history events (Reynolds et al. 1992, 1994, 2006). Post-fledging areas surround active nest trees, average 800 ha in southeast Alaska (Iverson et al. 1996), and represent the core-use area of adult female and young goshawks after fledging but before becoming independent of adults and dispersing (Kenward 1982, Kenward et al. 1993, Kennedy et al. 1994). McClaren et al. (2005) suggested the biological role of post-fledging areas and nest areas are similar and to consider them as one functional component. Regardless, the habitat composition of post-fledging areas should be similar to nest areas (Reynolds et al. 2008). Foraging areas comprise the majority of northern goshawk breeding home ranges and are especially important for adults providing food to young and for juveniles prior to natal dispersal. Breeding home ranges in southeast Alaska average 21 km^2 (Iverson et al. 1996). The combined home range of breeding pairs can be much larger than that of individual birds (Boal et al. 2003).

The 1997 TLMP did not incorporate concepts of nest area, post-fledging area, and foraging area habitat management, which underpin conservation planning to sustain viable populations of northern goshawks across its distribution (Reynolds et al. 2006, Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008). Still, Tongass forest-wide policy is focused on protecting confirmed and probable goshawk nests (USFS 1997: chapter 4); standards and guidelines propose to accomplish this by maintaining an area of ≥40 ha of POG generally centered over the nest tree or probable nest site (Figure 6). Another stated objective is to manage foraging habitat to retain essential features of forest stand structure in areas of timber harvest (Figure 2B) because tree density of unmanaged second growth (Figure 4E) reduces prey abundance and diversity and prevents aerial pursuit of prey by goshawks (Reynolds 1983, Salafsky et al. 2007).

Despite a substantial increase in knowledge since the 1997 TLMP revision, the implications of those new insights to goshawk conservation and land-use policies in southeast Alaska had not been revised in forest plan amendments (Smith 2013). Without long-term monitoring, it has remained unclear whether a network of reserves designed explicitly for other wildlife species (USFS 1997) or protection of goshawk nest trees in landscapes intensively managed for timber, would provide sufficient habitat to sustain breeding populations of the northern goshawk across the planning area (Finn et al. 2002). What is clear from the literature is neither coarse-filter nor fine-filter components of the WCS appear relevant to northern goshawk life history or conservation planning; 40-ha nest buffers (Figure 6) and habitat conservation areas distributed across expansive landscapes of even-aged second growth have never been applied as mitigating measures elsewhere in its distribution (Smith 2013).

Smith (2013) conducted a spatially explicit analysis of contributions of the Tongass WCS to the breeding home ranges of northern goshawks across southeast Alaska. He used 136 confirmed nest-tree locations and empirically derived estimates (Iverson et al. 1996) to delineate corresponding virtual post-fledging areas and female breeding home ranges, within which they calculated the area of 4 cover types and 4 land-use categories. They derived preferred habitat from empirical studies in southeast Alaska (Iverson et al. 1996). About 30% of nests had >51% of post-fledging areas in preferred habitat but >91% of post-fledging area was in an unsecure (unprotected from development) land-use designation; 60% of post-fledging areas had >51% in an unsecure designation, whereas only 16% had >51% in the protected old-growth forest. Among cover types, preferred habitat comprised an average of 39.4% of the post-fledging area. Smith (2013) obtained similar results from an analysis of the female breeding home range but with notable differences. The percentage of the broader landscape that consisted predominantly (>75%) of lands available for development was greater than in post-fledging areas (Smith 2013). The percentage of the total

FIGURE 6 Northern goshawk nest sites (yellow spheres) during 1999 to 2001 in managed landscapes of the Tongass National Forest in southeast Alaska, USA (image courtesy of Google Earth), with an active nest (photo by Craig Flatten) in the canopy of old-growth rainforest. Red circles represent circular 40-ha old-growth buffers (360-m radius) prescribed for active goshawk nests by forest-wide standards and guidelines in the Tongass Land Management Plan (USFS 1997, 2008, 2016). Area with blue lines within the orange semi-circle depicts half the typical goshawk post-fledging area (PFA); the mean radius of goshawk PFAs is 1,600 m, whereas the radius of breeding female home ranges averages 2,600 m (Smith 2013). Light green areas along logging roads are recent clearcuts; light brown areas are muskegs.

home range with 26–50% of the total area in preferred habitat also increased compared with post-fledging areas, whereas about half as many home ranges had ≥51% of this broader landscape in preferred habitat as compared with the post-fledging area (Smith 2013). From these analyses, it is clear that the Tongass WCS is not contributing sufficient secure habitat to sustain breeding pairs of the northern goshawk across southeast Alaska.

RESULTS

Based on this review, we conclude that the Tongass Land Management Plan is not meeting expectations of ≥4 essential assumptions of the WCS. Additional empirical evidence from the literature supports a conclusion that the WCS has not met expectations of maintaining an interconnected old-growth forest ecosystem. Extensive high-grading and disproportional harvest of the most productive forest have substantially reduced old-growth forest abundance and diversity (Albert and Schoen 2012). Expansive even-aged clearcuts produced landscapes that support a fraction of the old-growth obligate species and provide little functional connectivity, isolating wildlife communities in many of the remnant old-growth patches (Smith et al. 2011).

The Tongass WCS was implemented as an experimental conservation plan composed of numerous elements, some of which are founded in sound ecological science and theory and were successfully implemented elsewhere with different wildlife species and circumstances. A systematic, comprehensive long-term monitoring scheme was proposed as a means to document implementation of management actions and conservation measures, and to record responses and outcomes of select forest resources (i.e., to evaluate if the WCS was functioning according to expectations). In the absence of monitoring data, we chose to use the results of wildlife studies on the Tongass that were designed to examine the robustness of vital underlying assumptions.

The enormity and complexity of the Tongass present unprecedented management and conservation challenges, most notably the highly fragmented and isolated nature of southeast Alaska. Empirical evidence from the literature provides examples of isolated ecological communities, varying in composition, ecological roles, and relationships among members, and the potentially irreversible consequences of cumulative broad-scale anthropogenic disturbances on old-growth obligate species, many of which are endemic. The Wrangell Island vole and Prince of Wales Island flying squirrel are examples of endemics for which a substantial part of their historical distribution has been clearcut logged, local populations have become extirpated or isolated, and total populations are reduced, all of which influence persistence. Given the proclivity for endemism, the discontinuity of landscapes further stratified among 21 biogeographic provinces, and the diversity of unique plant and animal assemblages with varied ecological functions and dependencies, it is unrealistic to expect that the Tongass can be managed as a single rainforest ecosystem or according to a conservation strategy that relies on isolated old-growth forest remnants scattered across vast landscapes of unmanaged, even-aged second growth (coarse filter) and uninformed, ineffective fine-filter mitigation measures.

The conceptual framework and procedures used by planners to assess the risk to viability of native wildlife underestimated the effects of implementing each of 10 forest plan alternatives across the planning area. Consequently, when forest management planning and implementation are considered in the context of widespread fragmentation, isolation and endemism, ecological scale, variation and complexity of ecological communities, and an incomplete monitoring plan with substantial gaps in data and analyses, serious questions arise about the effectiveness of the WCS in maintaining widely distributed, viable populations of native wildlife, especially old-growth obligate endemics.

A network of old-growth reserves functioning as habitat conservation areas across intensively managed landscapes can be effective in sustaining viable populations of sensitive, old-growth obligate species. Establishing small, medium, and large habitat conservation areas, each designed to sustain proxy species operating at appropriate ecological scales and collectively establishing functionally connected landscapes, is an empirically based coarse-filter approach. Nonetheless, demographic analysis revealed that the size of a habitat conservation area (with 100% POG) required to sustain viable northern flying squirrel populations in isolation over the planning horizon exceeds the size of medium and large old-growth reserves, the preferred prescriptions of which contain only 50% POG. Further analysis demonstrated that landscapes within the matrix were not functionally connected and incapable of facilitating demographic or genetic rescue among small-mammal endemics. Despite having comparably high densities, the viability risk of the Prince of Wales Island flying squirrel is higher today because subpopulations have become isolated, local extirpations have occurred, and the overall population is reduced. Furthermore, because the northern flying squirrel was selected as a proxy, the effects of cumulative habitat loss and functionally discontinuous landscapes have implications for other old-growth obligate small mammals, especially island endemics.

The WCS also includes forest-wide standards and guidelines as a fine-filter approach to retain, replace, or mitigate essential conditions, mostly in managed landscapes. Forest-wide standards and guidelines are essential for sensitive species such as the Queen Charlotte goshawk that require a diversity of land cover types, including mature or old-growth forest. Forest management guidelines throughout its distribution invariably prescribe rotational management of the entire planning area, which produces landscapes that are a mosaic of cover types varying in stand age, structure, and spatial extent, thereby supporting a wide range of potential avian and mammalian prey species. Landscapes across the Tongass are a sharply contrasting dichotomy of old growth and expanses of even-aged second growth, most of which were logged during a few decades with little (<20%) ensuing intermediate stand management. Unfortunately, neither the reserve network nor the prescribed standards and guidelines accomplish the objective of providing sufficient breeding habitat to sustain northern goshawks across the Tongass.

DISCUSSION

To address apparent deficiencies and meet expectations of the 1982 viability rule of the 1976 National Forest Management Act, we propose 3 revisions to forest management and conservation policies. First, further commercial harvests of old-growth forests should emulate the primary natural disturbance regime (wind) in size of canopy gaps, frequency of occurrence, and landscape conditions (e.g., forest stand composition and exposure, canopy structure) and circumstances (e.g., slope, aspect, wind severity and direction; Nowacki and Kramer 1998), which will prohibit commercial broad-scale clearcut logging. This policy will reduce further negative effects to old-growth obligate wildlife, especially island endemics (Cook et al. 2006, Smith and Person 2007, Smith et al. 2011, Smith and Fox 2017), and acknowledge the contribution of southeast Alaska's rainforest in mitigating climate change (DellaSala et al. 2022). Second, restoration of forests throughout the matrix through intermediate stand management of second growth should become a forest management priority, especially on Prince of Wales Island and other islands that support island endemics whose native distributions have been substantially reduced by clearcut logging. Priority should be given to landscapes in which old-growth forests are isolated and to second-growth forests along anadromous streams.

Intermediate stand management will reduce midstory density and expedite ecological succession toward achieving mature forest conditions (Nowacki and Kramer 1998) that will benefit the federally listed Queen Charlotte goshawk (Smith 2013) and increase functional connectivity of managed landscapes for endemic small mammals (Flaherty et al. 2008, 2010*a*, *b*; Smith et al. 2011; Howard 2022). Healthy anadromous streams support salmon populations that provide vital marine nutrients required for forest regeneration and development (Quinn et al. 2018, Schoen 2020). Restoration of riparian forests will directly contribute to the health and diversity of the old-growth forest ecosystem (Schoen 2020).

Thirdly, we recommend the Tongass National Forest undertake a formal review of WCS elements that appear incapable of achieving mandated or desirable expectations because of extensive historical timber harvests, misimplementation of proposed or established policies, or untenable assumptions. The review will require an updated assessment of forest resources to accurately inventory and map habitats (Shanley et al. 2021), and extensive research to document the diversity and life-history needs of southeast Alaska's unique ecological communities (Cook et al. 2006), with an initial focus on populations and habitat of the Queen Charlotte goshawk and island endemic mammals that have experienced substantial broad-scale disturbance (Smith et al. 2011, Smith 2013). Conservation measures need to consider the unique life-history attributes of sensitive species. Recognizing the hierarchical structure of goshawk breeding home ranges is fundamental to designing and implementing an effective conservation plan.

MANAGEMENT IMPLICATIONS

Future conservation and management policies and actions will require consideration of recent research findings (especially from the Tongass) and a comprehensive long-term monitoring plan to evaluate implementations and corresponding responses and outcomes. Clearly, an adaptive management approach that explicitly acknowledges and considers the uniqueness of southeast Alaska's varied landscapes and spatial context, geological history, fauna, and ecological communities will provide insights into the complexities and limitations of imposing established forest management policies and actions. A new paradigm that employs new knowledge with systematically scheduled assessments from monitoring programs will provide timely, meaningful evaluations of the consequences of management actions that can remedy existing deficiencies and improve WCS effectiveness.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

The work summarized in this manuscript did not analyze new data collected from studies of wildlife or humans.

DATA AVAILABILITY STATEMENT

Data sharing not applicable because we did not generate new data. All data referenced in this review are included in published articles cited in the manuscript.

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