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Additional Evaluation of Wildlife Habitat Conservation Measures

I. Introduction

This appendix provides a summary of additional analyses pertaining to the wildlife habitat conservation measures of FEIS alternatives, with emphasis on the old-growth habitat conservation strategy adopted for the Revised Forest Plan (FEIS Alternative 11). Included are an explanation and overview of a second set of panel assessment meetings held in March and April 1997, a comparison of the results of these panels with the analysis contained in Chapter 3 of the FEIS, and discussions of how this and other information was used in strengthening the Forest Plan (Sections II and III of this appendix). Section IV is a detailed analysis of the old-growth forest habitat conservation strategy of the Forest Plan; how it was developed, its relationship to other proposed strategies, and its effectiveness in providing the amount and distribution of habitat sufficient to maintain viable and well distributed wildlife populations of old-growth associated species across the Tongass National Forest. Section IV also contains additional evaluations of the viability strategies for the Alexander Archipelago wolf and Queen Charlotte goshawk. Section V lists all references cited.

II. Panel Assessment Process and Analyses

A. Panel Process

In the Final Environmental Impact Statement (FEIS), Alternatives 10 (Forest Supervisors' preferred alternative in the Revised Supplement to the Draft Environmental Impact Statement) and 11 (FEIS Preferred Alternative), were not subjected to risk assessment panels as were the full array of draft alternatives (Alternatives 1, 2, 3, 4, 5, 6, 7, 8, and 9). In the description and analysis of panel results in the FEIS (Chapter 3, Biodiversity and Wildlife sections), there was a strong correlation between the acres of productive old-growth (POG) scheduled for harvest in an alternative and the mean outcome scores for that alternative. As the number of acres harvested increased among alternatives, the mean outcome scores also increased, resulting in greater risk that habitat may not be sufficient to maintain viable and well distributed populations.

Based upon this strong relationship that emerged, the likely effects of Alternatives 10 and 11 were inferred from the acres of old-growth forest scheduled for harvest in these two alternatives, the features of these alternatives as compared to the paneled alternatives, and the relative importance of these features as judged from panel discussions for individual species. Using this approach the likely effects of Alternatives 10 and 11 were discussed in the Biodiversity and Wildlife sections of the FEIS. Because this strong relationship facilitated development of an effects analysis and time and expense of reconvening all panels was a consideration, alternatives 10 and 11 were not originally subjected to panel risk assessment.

To examine if these inferences were appropriate and presented an accurate analysis of likely effects of implementing Alternatives 10 and 11, a second set of risk assessment panels was conducted in March and April 1997. This second set of six risk assessment panels included the northern (Queen Charlotte) goshawk, Alexander Archipelago wolf, brown bear, American marten, fisheries resources, and other terrestrial mammals. These panels followed the same process described in the FEIS (Chapter 3, Biodiversity, Fish and Wildlife sections) for panels conducted in late 1995 and early 1996.

The panels were conducted with a modification of the Delphi process that was used, tested, and judged effective in the President's Northwest Forest Plan. The panels were designed to evaluate various

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alternatives for the likelihood of maintaining sufficient, well distributed habitat to maintain viable populations of old-growth associated wildlife species over the 100-year planning horizon.

In addition to Alternatives 10 and 11, the following alternatives also were assessed to provide a context to help interpret panel results: 1, 2, 5, 9 (1979 Forest Plan), 9' (1979 Forest Plan with updated Geographic Information System timber suitability layers), and the historic forest condition (pre-1954) prior to large-scale commercial timber harvest. From a science process standpoint, this array of alternatives was deemed sufficient to aid with interpretation of results for Alternatives 10 and 11.

Panel evaluators were instructed to evaluate the effect that implementation of TLMP alternatives 1, 2, 5, 9, 9', 10, or 11 for 100 years would have on the abundance and distribution of habitats suitable to support well distributed and persistent populations of species assessed. One hundred likelihood outcome points were distributed among five possible outcomes (see Biodiversity and Wildlife sections in FEIS). In addition, panel evaluators were asked to appraise features used to construct alternatives (e.g. reserves, beach buffers) as to their contribution to maintaining habitat for species assessed. These qualitative appraisals of specific features and the panel discussions were used by the authors of the written summaries prepared for each panel, to interpret the quantitative evaluation of alternatives as indicated by the assignment of likelihood points by outcome and to identify important ecological considerations. (Summary reports for each panel are included in the planning record.)

In the presentation of panel assignment of likelihood outcome points in each table below, the 'after' likelihood outcome ratings are used to compare among alternatives since these second ratings benefit from professional interaction and a likely greater understanding of differences among features in alternatives. The 'before' ratings occurred following presentations on alternatives and local information on each species, but before the merits of individual alternatives were discussed among panel evaluators. The average rating for all panelists also is used, rather than focusing on differences among individual evaluators.

B. Concepts of Viable and Well Distributed Populations

In the discussion and analysis of the first set of panel results in the FEIS, Outcomes I and II were often combined as an expression of likelihood of sustaining habitat sufficient to support viable and well distributed populations. Conversely, Outcomes III, IV, and V were often combined in effects analysis as representing increased risks of not maintaining the habitat necessary to sustain viable and well distributed populations. By virtue of its description, Outcome III was difficult to interpret due to the statement that "significant gaps" would be created and the "significance of gaps must be judged relative to the species distributional range, and life history." There was considerable variability in the interpretation of this concept by individual panelists. The original panelists convened in late 1995 and early 1996 were not specifically queried about the relationship between outcomes and the maintenance of viable well-distributed populations. These conclusions were generally inferred, based largely upon whatever discussion occurred during panel deliberations. In general, the interdisciplinary planning team (IDT) inferred that Outcome III represented a condition where gaps were significant enough to substantially preclude interaction among populations of the species. In this condition, a species would not be well distributed, and continued existence of the species across the planning area would be at risk.

Because of the difficulty the IDT encountered in interpreting the first set of panel results relative to the maintenance of well distributed and viable populations, the second set of panelists were provided an opportunity to directly and explicitly discuss these issues. The same five outcomes were used in the second panels conducted in 1997. However, focused discussion provided additional information relative to Outcome III and the panelists' interpretation of gaps in distribution, well distributed populations, and viability.

Outcome III, defined as providing habitat to maintain breeding populations but with significant gaps in historic distribution, was interpreted as an array of conditions. For some of the panels, one end of this array was any condition where gaps in habitat existed as small as the territory of a single animal or single pair of animals of the species being assessed. At the other end, this array could include conditions with broad gaps in habitat distribution and significant limitations on population interactions. The panelists considered some part of this array of conditions as meeting their concept of viable and well distributed. They indicated that

the concepts of well distributed and viable, as they used them for the purposes of assessing risk, were not necessarily synonymous. Their views on well distributed habitat dealt primarily with the likelihood that modified habitat would, because of gaps, no longer be able to support a continuous territory-to-territory distribution of resident individuals or groups. That is, some previously occupied territories might become permanently vacant within a 100-year timeframe.

The panelists interpreted viability as a condition in which populations could continue to interact and interbreed within their historic distribution across the Tongass National Forest. They felt that a distribution that included some gaps could still be considered viable as long as there was still interaction among the population segments on the forest and those population segments were distributed across the species range. For example, the marten panel understood that their concept of a habitat gap being as wide as a previously occupied home range likely had little if any effect on species interaction or interbreeding. Thus, in the panelists' interpretation, the criterion of well distributed was more restrictive than the criterion of viable.

The panelists were not providing a legal interpretation of the requirement in the NFMA regulations to provide for viable populations. In the discussion of population viability in the NFMA regulations, the concept of "well-distributed" is tied to the ability to continue interactions among individuals of a species, not necessarily to the maintenance of a territory-to-territory distribution of the species. The interpretation of well distributed is expressed most clearly in the stipulation that maintenance of a viable population requires providing habitat to support "at least a minimum number of reproductive individuals and that habitat must be well distributed so that those individuals can interact with others in the planning area" (36 CFR 219.19). This has been interpreted to mean that the condition of viable and well distributed allows for gaps within a species distribution as long as the population segments of the species continue to interact and are distributed throughout the planning area. Thus, the concept of well distributed used by the panelists was more stringent than the concept as applied in the NFMA regulations.

It is difficult to determine how many likelihood points were assigned to the outcome of a viable population since the panelists considered that only some part of the array of conditions under Outcome III met their definition of viable. Thus, the likelihood of maintaining habitat sufficient to support well distributed and viable populations is appropriately presented as being within the span of scores that bracket Outcome III. Consequently, in some of the tables in the following discussions, ratings are expressed as being greater than the sum of likelihood scores for Outcomes I and II, but less than the sum of likelihood scores for Outcomes I, II and III. Expression of data as a range also illustrates the uncertainty in the process and the variability in the professional judgments regarding the concepts of viable and well distributed populations. Use of a range also avoids presenting a single absolute value that might suggest a level of precision that does not exist in this assessment process.

Finally, in some of the following tables, 1995 and 1996 panel outcome scores are expressed in the same manner of bracketing scores as for the 1997 scores discussed above. Expression of the first panel information in this manner is for comparative purposes only. These combinations do not infer any conclusions on behalf of the 1995/1996 panels because they did not specifically discuss viable and well distributed populations relative to the specific outcomes.

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III. Discussion of Panel Results and Other Information on Species Habitat Outcomes

A. Relationship of 1997 Panel Results to Analyses in FEIS Chapter 3

1. Assessment of Fish Species

Results of the panel assessments conducted in 1997 generally confirmed the outcomes for fish species described in FEIS Chapter 3. For fish species, the range of variation for alternatives assessed in both 1995 and 1997 was 1 to 16 points, and the ranking of these alternatives remained identical. Of those alternatives reviewed in both 1995 and 1997, Alternatives 1, 5, 2, and 9' were ranked in order from least to highest risk to fish habitat in both of the assessments. The ranking of all alternatives in Chapter 3 (FEIS 3-63), based on the 1995 panels and an approximation for Alternatives 10 and 11, is also consistent with the results of the 1997 panels. In both cases, Alternative 11 with riparian option 2a is ranked between Alternatives 1 and 5 and Alternative 10 is placed between 5 and 2. The full rank order of the alternatives, from least to greatest risk, is 1, 11, 5, 4, 3, 10, 6, 2, 9, 9', and 7.

2. Assessment of Terrestrial Vertebrate Species

The 1997 panel assessment of terrestrial vertebrates also generally confirmed the outcomes described in Chapter 3. However, comparison between Chapter 3 and the 1997 panels is more complex for terrestrial vertebrates than for fish, and some differences were noted. Results for each species or group are discussed below.

a. Northern Goshawk

Variation in ratings for alternatives assessed in both 1995 and 1997 ranged up to 18 points based on the sum of likelihood points assigned to Outcomes I, II and III (Table 1). Of those alternatives reviewed in both 1995 and 1997, Alternatives 1, 5, 2, and 9' were ranked in order (based on average weighted outcomes-see Chapter 3) from least to highest risk to goshawk habitat in both of the assessments. The 1997 panels also confirm the judgment in Chapter 3, based on a detailed analysis of VCU's, that Alternatives 5 and 11 have the highest likelihood of sustaining goshawk habitat across the forest of all alternatives that propose to continue timber harvest. However, the analysis in Chapter 3 resulted in a conclusion that Alternative 11 had a slightly higher likelihood of maintaining goshawk habitat than Alternative 5. The panel evaluators convened in 1997 rated Alternative 5 somewhat higher than Alternative 11. Additional measures applied to Alternative 11 subsequent to the evaluations would make overall outcomes for the two alternatives even more similar. Those additional measures are described in a following section (subpart B.). Further discussion of the effects of the Forest Plan on goshawks is presented in Section IV of this appendix.

Table 1.
Northern Goshawk Panel Results¹.

Outcomes	Alternatives							Historic
	1	2	5	9	9'	10	11	
A. 1997 Panels								
I	63	1	35	0	0	8	23	89
II	38	19	50	10	8	40	48	11
III	0	61	15	61	61	48	28	0
IV	0	16	0	26	29	5	3	0
V	0	5	0	3	3	0	0	0
POG Harvest	0	853,270	462,880	1,042,428	1,402,800	670,270	475,000	-414,000
B. 1995 Panels								
I	66	0	23		0			
II	31	24	51		23			
III	3	40	25		43			
IV	0	33	1		33			
V	0	4	0		3			
POG Harvest	0	1,106670	572,300		1,402,800			
C. Range Between Outcomes I + II and I + II + III								
Panel Year								
1997	100	>20, <61	>85, <100	>10, <61	>8, <61	>48, <96	>71, <97	100
1995	>97, 100	>24, <64	>74, <99		>23, <66			

¹ Mean likelihood outcome scores for the northern goshawk by evaluators on the Northern Goshawk Assessment Panel in 1997 are shown in A. Scores from the 1995 panel also are shown in B. for alternatives common to both rating periods for comparison purposes. Alternatives 1 and 9' are identical in features and acres of POG harvested. Alternatives 2 and 5 are identical in features but with fewer acres of POG harvested. A range for all alternatives is shown in C. for the likelihood of maintaining habitat to support viable and well distributed goshawk populations. Only 'after' scores are shown. The -414,000 value for POG harvest under Historic represents the acreage harvested since 1954.

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b. American Marten

Of those alternatives reviewed in both 1995 and 1997, Alternatives 1, 5, 2, and 9' were ranked in order from least to highest risk to marten habitat in both assessments (Table 2). The 1997 panel results also are consistent with conclusions drawn concerning the relative ranking of all alternatives based on other evidence in Chapter 3 and other information in the planning record. This includes the conclusion that outcomes of Alternative 11 would be similar to those of Alternative 3.

Table 2.
American Marten Panel Results¹.

Outcomes	Alternatives							Historic
	1	2	5	9	9'	10	11	
A. 1997 Panels								
I	84	0	1	0	0	0	0	90
II	9	19	65	13	11	30	36	9
III	8	64	29	53	50	59	55	1
IV	0	18	5	35	39	11	9	0
V	0	0	0	0	0	0	0	0
POG Harvest	0	853,270	462,880	1,042,428	1,402,800	670,270	475,000	-414,000
B. 1995 Panels								
I	54	3	18		3			
II	25	5	53		6			
III	21	56	24		46			
IV	0	21	6		24			
V	0	15	0		21			
POG Harvest	0	1,106,670	572,300		1,402,800			
C. Range Between Outcomes I + II and I + II + III								
Panel Year								
1997	>93, <100	>19, <83	>66, <95	>13, <66	>11, <61	>30, <89	>36, <91	>99, 100
1995	>79, <100	>8, <64	>71, <95		>9, <55			

¹ Mean likelihood outcome scores for the marten by evaluators on the Marten Assessment Panel in 1997 are shown in A. Scores from the 1995 panel also are shown in B. for alternatives common to both rating periods. Alternatives 1 and 9' are identical in features and acres of POG harvested. Alternatives 2 and 5 are identical in features but with fewer acres of POG harvested. A range for all alternatives is shown in C. for the likelihood of maintaining habitat to support viable and well distributed marten populations. Only 'after' scores are shown. The -414,000 value for POG harvest under Historic represents the acreage harvested since 1954.

c. Alexander Archipelago Wolf

Overall, the results of the 1995 and 1997 evaluations were consistent. Of those alternatives reviewed in both 1995 and 1997, Alternatives 1, 5, 2, and 9' were ranked in order from least to highest risk to wolf habitat in both assessments (Table 3). In the 1997 evaluation, Alternatives 11, 10, and 5 were all given relatively high ratings, and these were similar to ratings given to Alternative 3 in 1995. These results are consistent with the discussion of alternatives in Chapter 3, except that the analysis in Chapter 3 clearly distinguishes Alternative 11 as the most favorable for wolves among the alternatives that propose to continue timber harvest, primarily due to the more extensive reserve system in Alternative 11. Further discussion of the effects of the proposed plan on wolves is presented in Section IV of this appendix.

Table 3.
Alexander Archipelago Wolf Panel Results¹.

Outcomes	Alternatives							Historic
	1	2	5	9	9'	10	11	
A. 1997 Panels								
I	88	20	55	18	18	54	58	89
II	6	43	29	30	30	26	25	8
III	3	34	13	44	44	16	14	1
IV	3	3	3	6	6	3	3	1
V	1	1	1	3	3	1	1	1
POG Harvest	0	853,270	462,880	1,042,428	1,402,800	670,270	475,000	-414,000
B. 1995 Panels								
I	80	35	48		3			
II	14	25	34		31			
III	3	30	16		48			
IV	2	9	1		18			
V	1	1	1		1			
POG Harvest	0	1,106,670	572,300		1,402,800			
C. Range Between Outcomes I + II and I + II + III								
Panel Year								
1997	>94, <97	>63, <97	>84, <97	>48, <92	>48, <92	>80, <96	>83, <97	>97, <98
1995	>94, <97	>60, <90	>82, <98		>34, <82			

¹ Mean likelihood outcome scores for the wolf by evaluators on the Wolf Assessment Panel in 1997 are shown in A. Scores from the 1995 panel also are shown in B. for alternatives common to both rating periods. Alternatives 1 and 9' are identical in features and acres of POG harvested. Alternatives 2 and 5 are identical in features but with fewer acres of POG harvested. A range for all alternatives is shown in C. for the likelihood of maintaining habitat to support viable and well distributed wolf populations. Only 'after' scores are shown. The -414,000 value for POG harvest under Historic represents the acreage harvested since 1954.

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d. Brown Bear

Overall, the results of the 1995 and 1997 evaluations were consistent. Of those alternatives reviewed in both 1995 and 1997, Alternatives 1, 5, 2, and 9' were ranked in order from least to highest risk to brown bear habitat in both assessments (Table 4). However, the panel results suggest that Alternatives 5 and 11 would produce similar outcomes for brown bears, while analysis based on the components of the alternatives (Chapter 3) indicates that Alternative 11 is more effective than Alternative 5 in reducing risk to bears. Alternative 11 has a much greater reserve system than Alternative 5, including additional large reserves on Northeast Chichagof island in a landscape that was identified as high risk by the 1995 panels. In addition, Alternative 11 provides more substantial riparian protection than Alternative 5, and this feature was identified as important for bears.

Table 4.
Brown Bear Panel Results ¹.

Outcomes	Alternatives							Historic
	1	2	5	9	9'	10	11	
A. 1997 Panels								
I	16	0	0	0	0	0	0	81
II	78	49	65	16	16	56	68	19
III	6	41	33	63	59	33	25	0
IV	0	10	3	21	25	11	8	0
V	0	0	0	0	0	0	0	0
POG Harvest	0	853,270	462,880	1,042,428	1,402,800	670,270	475,000	-414,000
B. 1995 Panels								
I	40	4	8		0			
II	53	35	59		14			
III	8	38	34		45			
IV	0	24	0		41			
V	0	0	0		0			
POG Harvest	0	1,106670	572,300		1,402,800			
C. Range Between Outcomes I + II and I + II + III								
Panel Year								
1997	>94, <100	>49, <90	>65, <98	>16, <74	>16, <75	>56, <89	>68, <93	100
1995	>93, <100	>39, <77	>67, <100		>14, <59			

¹ Mean likelihood outcome scores for the brown bear by evaluators on the Brown Bear Assessment Panel in 1997 are shown in A. Scores from the 1995 panel also are shown in B. for alternatives common to both rating periods. Alternatives 1 and 9' are identical in features and acres of POG harvested. Alternatives 2 and 5 are identical in features but with fewer acres of POG harvested. A range for all alternatives is shown in C. for the likelihood of maintaining habitat to support viable and well distributed brown bear populations. Only 'after' scores are shown. The -414,000 value for POG harvest under Historic represents the acreage harvested since 1954.

e. Other Terrestrial Mammals

There was general consistency in the 1995 and 1997 evaluations of other terrestrial mammals, although there was variation in the ratings assigned to alternatives by the two panels. Of those alternatives reviewed in both 1995 and 1997, Alternatives 1, 5, 2, and 9' were ranked in order from least to highest risk to habitat of the widely-distributed group in both assessments (Table 5). Differences between Alternatives 2 and 9' were slight in both assessments. Additionally, ratings of all these alternatives improved substantially from the 1995 to the 1997 assessment. The same pattern held true for the endemic mammal group (Table 6). Relative rankings of the four alternatives reviewed by both panels remained constant, but the ratings for each of the alternatives improved from the first to the second panel. These results also generally support the conclusion drawn in Chapter 3 that, of the alternatives that propose to continue harvesting timber, Alternative 11 poses the least risk to these species groups. However, the difference for these species between Alternative 11, as evaluated by the panelists, and Alternative 5 is small. Subsequent to the assessment by the panelists, additional measures were added to Alternative 11 to benefit these species groups.

Table 5.
Widely Distributed Mammals Group Panel Results ¹.

	Alternatives							
Outcomes	1	2	5	9	9'	10	11	Historic
A. 1997 Panels								
I	24	0	3	0	0	3	10	75
II	45	3	36	0	0	23	28	17
III	28	15	53	9	4	53	44	7
IV	4	68	6	68	70	19	16	1
V	0	15	3	24	26	4	3	0
POG Harvest	0	853,270	462,880	1,042,428	1,402,800	670,270	475,000	-414,000
B. 1995 Panels								
I	13	0	5		0			
II	20	5	18		3			
III	18	11	16		9			
IV	43	30	51		29			
V	8	54	10		60			
POG Harvest	0	1,106,670	572,300		1,402,800			
C. Range Between Outcomes I + II and I + II + III								
Panel Year								
1997	>69, <96	>3, <18	>39, <92	>0, <9	>0, <4	>26, <79	>38, <82	>92, <99
1995	>33, <51	>5, <16	>23, <39		>3, <12			

¹ Mean likelihood outcome scores for the widely distributed mammals by evaluators on the Other Terrestrial Mammals Assessment Panel in 1997 are shown in A. Scores from the 1995 panel also are shown in B. for alternatives common to both rating periods. Alternatives 1 and 9' are identical in features and acres of POG (POG) harvested. Alternatives 2 and 5 are identical in features but with fewer acres of POG harvested. A range for all alternatives is shown in C. for the likelihood of maintaining habitat to support viable and well distributed populations of widely distributed mammals. Only 'after' scores are shown. The -414,000 value for POG harvest under Historic represents the acreage harvested since 1954.

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Table 6.
Endemic Mammals Group Panel Results ¹.

Outcomes	Alternatives							Historic
	1	2	5	9	9'	10	11	
A. 1997 Panels								
I	6	0	1	0	0	1	3	59
II	34	0	9	0	0	13	16	26
III	31	8	45	8	4	34	36	13
IV	28	70	41	71	73	46	41	2
V	1	23	4	21	24	6	4	0
POG Harvest	0	853,270	462,880	1,042,428	1,402,800	670,270	475,000	-414,000
B. 1995 Panels								
I	13	0	5		0			
II	20	5	18		3			
III	18	11	16		9			
IV	43	30	51		29			
V	8	54	10		60			
POG Harvest	0	1,106,670	572,300		1,402,800			
C. Range Between Outcomes I + II and I + II + III								
Panel Year								
1997	>40, <71	>0, <8	>10, <55	>0, <8	>0, <4	>14, <48	>18, <55	>85, <98
1995	>33, <51	>5, <16	>23, <39		>3, <12			

¹ Mean likelihood outcome scores for the endemic mammal group by evaluators on the Other Terrestrial Mammals Assessment Panel in 1997 are shown in A. Scores from the 1995 panel also are shown in B. for alternatives common to both rating periods. Alternatives 1 and 9' are identical in features and acres of POG harvested. Alternatives 2 and 5 are identical in features but with fewer acres of POG harvested. A range for all alternatives is shown in C. for the likelihood of maintaining habitat to support viable and well distributed endemic mammal populations. Only 'after' scores are shown. The -414,000 value for POG harvest under Historic represents the acreage harvested since 1954.

B. Measures Added to Alternative 11 In Response to Panel Assessments

Results of risk assessment panels indicated moderate levels of concern for marten and small, endemic and widely-distributed mammals, a lower level of concern for goshawk, and a much lower concern for the wolf and brown bear. In response to these concerns for the mammal groups, marten and goshawk, and to further reduce risks to these species, protective measures were added to strengthen Alternative 11.

For endemic mammals, surveys will be conducted in project areas prior to management activities that would significantly alter habitat. Where distinct taxa are located, measures will be taken to provide for their continued persistence. Ongoing research into endemic mammals will be continued, and in some cases be accelerated, in order to refine the application of this "survey and manage" measure. This measure supplements previous steps taken to benefit endemic mammals, including the removal of islands of less than 1,000 acres from the timber base. A complete description of this measure is included in the Forest Plan, Chapter 4, Forest-wide Standards and Guidelines for Wildlife, XVII. Endemic Terrestrial Mammals.

A general landscape connectivity standard and guideline is designed to provide benefit for all taxa but particularly for the small mammals and other terrestrial vertebrates with limited dispersal capabilities. This measure will supplement existing provisions for connectivity through riparian and beach fringe buffers, and other land allocations that maintain the old-growth forest. Wherever those measures are inadequate to provide connectivity of old-growth forest between reserves, management will take additional steps to ensure that connectivity is maintained where it exists. A complete description of this measure is included in the Forest Plan, Chapter 4, Forest-wide Standards and Guidelines for Wildlife, XVIII. Landscape Connectivity.

Habitat management measures to further reduce risks to marten are directed at high value habitat in five biogeographic provinces where risks are judged to be higher due primarily to large amounts of young conifer forest (second growth) having little or no remaining forest structure important to martens. The overall objective is to avoid the creation of additional, significant gaps in marten habitat with resulting limitations on population interactions. In value comparison units (VCU's) where more than 33 percent of the original productive old growth has been converted to young forest, the objective is to avoid further significant fragmentation of high value marten habitat resulting from timber harvest. High value marten habitat is high volume strata productive old-growth forest below 1,500' elevation. This objective is met by restricting harvest units to less than 2 acres and using a 200-year rotation or, in larger units, maintaining significant canopy cover and coarse woody debris. In VCU's where productive old growth is less fragmented (i.e., less than 33 percent of the original productive old growth has been harvested), the objective of the mitigation is to retain structures that will allow harvested units to regain value as marten habitat in a relatively short time. This is accomplished by retaining coarse woody debris and green trees to act as a source of coarse woody debris during the next rotation. A complete description of this measure is included in the Forest Plan, Chapter 4, Forest-wide Standards and Guidelines for Wildlife, XVIII. Landscape Connectivity.

Additional habitat management measures for the northern goshawk are intended to provide benefit in areas on Prince of Wales Island where risks to goshawks are highest of all regions in southeast Alaska, and in VCU's where over 33 percent of the productive old growth has been converted to young forest. The objective is to maintain some canopy closure and large tree structure in harvest units to minimize further significant fragmentation of habitat in harvest units over two acres in size. A complete description of this measure is included in the Forest Plan, Chapter 4, Forest-wide Standards and Guidelines for Threatened, Endangered, and Sensitive Species, J. Northern Goshawk.

Details of these measures, the basis for their inclusion in Alternative 11, and their effects on species are described in the section below.

C. Effects of Added Habitat Management Measures

1. Other Terrestrial Mammals

a. Background

The other terrestrial mammals associated with productive old-growth have been broadly divided into two groups: widely-distributed species and endemic species. A total of 26 taxa within these 2 groups were explicitly considered by the panels asked to provide judgments for the other terrestrial mammals (Chapter 3). Two of these 26 taxa, northern flying squirrel and river otter, were the focus of specific measures in the original VPOP strategy. Small HCA's were adopted by the VPOP committee to provide for distribution of northern flying squirrels in every major watershed (i.e., every 10,000 acres). The size of these HCA's was intended to allow them to support 20 to 40 squirrels. VPOP also recommended that travel corridors be maintained between patches of flying squirrel habitat. They considered beach fringe and riparian zone to be suitable corridors, and recommended that additional corridors be designated in areas where these did not provide adequate connectivity.

The Prince of Wales river otter is strongly associated with saltwater beach fringe and freshwater riparian habitats (Larsen 1983, Noll 1988, Woolington 1984). VPOP's conservation recommendation for river otter was maintenance of beach fringe, estuary fringe, and riparian habitat associated with streams and lakes.

The review of Kiester and Eckhardt (1994) provided little comment on this aspect of the VPOP strategy. However, one of the common themes of many of the reviews was the lack of knowledge of all the taxa present on the Tongass and the distribution of species among islands. Kiester and Eckhardt (1994) recommended a thorough biological survey of the Tongass, and an evolutionary analysis of small mammals. Lidicker (in Kiester and Eckhardt 1994) recommended that no timber harvest take place on islands less than 1,000 acres or those that could be considered unique because of their isolation or known presence of endemics.

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b. Panel Assessments

A discussion of the panel evaluations is contained in section III. A. of this appendix, and the planning record contains the full reports. In the 1995 evaluation, the VPOP strategy, most fully embodied in Alternative 3, was assessed as having the third highest likelihood, of those alternatives that propose continuing timber harvest, of maintaining both the widely-distributed and the endemic groups of mammals. In this assessment, substantial likelihoods of not maintaining species well-distributed were projected for all alternatives, including Alternative 1 which calls for no further timber harvest. These results were based, at least in part, on effects of past harvest, lack of knowledge of many of the mammal species, and risks inherent to endemic species. Alternative 11, as evaluated in the 1997 panel assessments, differed in several important ways from Alternative 3. It eliminated all islands less than 1,000 acres from the timber base as recommended by Lidicker (in Kiester and Eckhardt 1994). It extended the beach fringe to 1,000 feet, but also relied more heavily on short-rotation clearcutting than did Alternative 3. Of the alternatives evaluated in 1997 that propose continued timber harvest, it ranked second highest in likelihood of maintaining viable populations of the widely-distributed and endemic mammals. Despite its favorable ranking relative to the other alternatives, it still was projected to have substantial likelihood of not maintaining well-distributed populations. Alternative components that were viewed favorably by this panel included the presence of a reserve system, the amount of old-growth that would be retained in the matrix, and a process for site-specific analysis particularly related to endemic mammals.

c. Strengthening Alternative 11 to Reduce Risk

In response to the 1977 panel assessment, additional guidelines were added to Alternative 11 to increase the likelihood that viable populations of endemic mammals would be maintained. These guidelines require that surveys for endemic mammals be completed prior to projects that would substantially alter vegetation on islands of 50,000 acres or less. Surveys will also be conducted on larger islands if an initial assessment indicates high likelihood that endemic mammals are present on the site. Where endemic taxa are detected by the surveys, projects will be designed to provide for continued persistence of the taxa. As an additional measure, ongoing research of endemic taxa on the Tongass will be accelerated.

Other guidelines added to Alternative 11 in response to the panel assessments would also benefit both the endemic and widely-distributed mammals. The connectivity guideline will provide additional measures to maintain connectivity of large and small reserves and other non-development LUD's in places where beach fringe and riparian habitat management areas do not provide adequate connectivity. Guidelines for structural retention for goshawk and marten habitat will also benefit other mammal species.

d. Effects of Implementation

As noted in Chapter 3, the Prince of Wales flying squirrel may be of greatest viability concern among the endemic mammals that were specifically considered by the panels, and the northern flying squirrel may be of greatest concern among the widely-distributed mammals. According to Carey (1991), habitat factors important to northern flying squirrels include large, live trees; large snags; fallen trees; multilayered canopies; and connectedness of habitat either through large contiguous areas of habitat or through corridors of suitable habitat. Alternative 11 will provide these features through its system of large and medium HCA's interconnected with small reserves and matrix habitats. Each large HCA should have the capability to support 100 or more northern flying squirrels, medium HCA's to support more than 50 squirrels, and small HCA's to support 20 to 40 squirrels. These individual populations should have the capability to persist over short to intermediate periods of time. Interactions among these populations through the matrix would allow them to function as a metapopulation conferring high probability of long-term persistence. Dispersal through the matrix will be facilitated by the beach fringe and riparian habitat management areas, by the overall amount of old forest remaining in the matrix, and by additional measures prescribed under Alternative 11 to provide for connectivity. These additional measures could include relocating small reserves to better serve a role as connectors, thus providing for small squirrel populations at locations intermediate between the larger populations.

These same components of Alternative 11 will also reduce risks to the endemic species and the Prince of Wales flying squirrel. In addition, the 200,000 acre reserve designated on Prince of Wales Island will, by itself, support a moderately large population of squirrels. Another feature of Alternative 11 that will further reduce risk to Prince of Wales flying squirrels is the requirement to survey for endemic mammals on islands of 50,000 acres or less, or in other areas where there is a high likelihood of species presence. Application of this measure to Prince of Wales Island is likely to result in additional project-specific measures reducing risk to the squirrels. Finally, implementation of mitigation measures for goshawk and marten on Prince of Wales Island will result in the retention of structural features important to flying squirrels such as snags, logs, and large live trees.

Implementation of the survey requirement will substantially reduce risks to other endemic species. This requirement, in combination with the ongoing research on endemic taxa, is responsive to Kiester and Eckhardt's (1994) recommendation to conduct a biological survey on the Tongass.

2. American Marten

a. Background

American martens were one of the primary species considered in the design of the original VPOP strategy. By design, each large HCA was intended to support at least 25 female martens, medium HCA's to support at least 5 female martens, and small HCA's at least 1 female. Each large HCA was designed to support a population with high likelihood of at least short-term persistence. The design distance between large HCA's was 25 miles, approximating the maximum dispersal distance recorded for marten, and medium and small HCA's were spaced more closely. Forested corridors were to provide for dispersal among HCA's. All corridors were to be at least 330 feet wide, and riparian and beach fringe habitats were considered appropriate corridors where they provided connections among the HCA's. This network of interconnected HCA's was intended to support a number of local populations that could interact as a metapopulation, thus providing for long-term viability.

Three of the scientists involved in the Kiester and Eckhardt (1994) review identified limitations in this strategy for marten. Benkman, Lidicker, and Powell questioned the use of the maximum marten dispersal distance to establish spacing among HCA's. Benkman cautioned that this strategy would only work if the medium and small HCA's provided connections among the large HCA's. Lidicker added that the condition of the matrix ought to be considered when establishing distances among HCA's. Powell indicated that marten would generally not travel directly between HCA's, so the actual distances they would have to cover would exceed the design distance. None of these reviewers commented directly on the size of large or medium HCA's, but both Benkman and Powell noted that the small HCA's would be unlikely to support even one pair of marten. A number of the reviewers in Kiester and Eckhardt (1994) commented in general that the utility of corridors for wildlife dispersal had not been demonstrated. None of these comments were specific to marten, possibly because marten are known to make extensive use of riparian zones (Bissonette et al. 1989; Clark et al. 1987).

b. Panel Assessments

The VPOP strategy is most fully represented in Alternative 3. The risk assessment panel convened in 1995 rated this alternative intermediate between Alternative 1 (no further harvest) and Alternative 9 (continuation of the existing plan). They indicated that there was a better than equal likelihood that implementation of this alternative for 100 years would result in significant gaps in marten habitat distribution on the Tongass. They projected no likelihood that marten would be extirpated from the entire forest under this alternative.

The risk assessment panel convened in 1997 gave Alternative 11 a similar risk rating to that given to Alternative 3 in 1995. Alternative 11, as rated by the panel, provides for a wider beach fringe buffer than Alternative 3, but it also relies more heavily on even-aged management in the matrix. Panelists noted that the projected matrix conditions had a significant influence on their ratings. The panelists convened in 1997 also clarified their interpretation of the outcomes that were used as the basis for risk assessment. Outcome III, defined as providing habitat to maintain breeding populations but with significant gaps in historic

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distribution, was interpreted as an array of conditions. At one end of this array was any condition where gaps in habitat existed as small as the territory of a single marten. At the other end this array could include conditions with broad gaps in habitat distribution and significant limitations on population interactions. The panelists considered some part of this array of conditions as meeting the definition of viable and well-distributed. The panelists assigned a total of 91 likelihood outcome points to the sum of Outcomes I + II + III. This included 38 likelihood points in Outcomes I and II, which they considered to represent a viable and well distributed condition. It also includes 55 likelihood points in Outcome III, some portion of which represents a viable and well distributed condition. The panelists indicated there was a very low likelihood that marten would exist only in refugia or be extirpated from the Tongass after 100 years of Forest Plan implementation with a combined Outcome IV and V score of 9. The panelists indicated that matrix management was the feature of Alternative 11, as rated, that contributed to the assignment of likelihood points to outcomes that were not well-distributed. They indicated that clearcut silviculture on a 100-year rotation would result in further fragmentation of marten habitat.

c. Strengthening of Alternative 11 To Reduce Risk

Alternative 11 was strengthened subsequent to the panel assessment because that assessment indicated a level of concern about the likelihood of marten populations remaining well-distributed across the Tongass for at least 100 years. The measures used to strengthen the alternative were based on comments provided by the panelists, information drawn from past studies on marten, and information on existing habitat conditions on the Tongass. Three different measures were applied to Alternative 11 to improve the likelihood of maintaining habitat to support well-distributed populations of marten.

The first directs the management of high quality marten habitat in five biogeographic provinces where marten habitat is currently considered to be at higher risk. These five biogeographic provinces were identified by the VPOP risk assessment as the highest risk provinces of the 21 provinces across the Tongass National Forest (Suring et al. 1993). High value habitat is defined in the Interagency Marten Habitat Capability Model (Suring et al. 1993) as consisting of high volume old-growth stands at elevations below 1500 feet. Within the high risk provinces, these stands will be managed under practices other than clearcutting. In VCU's where 33 percent or more of the productive old-growth has been or is projected to be harvested, further harvest in any high value marten habitat will retain at least 30 percent canopy closure, 8 large live trees per acre, 3 large decadent trees per acre and 3 logs per acre. Where less than 33 percent of productive old-growth has been harvested, further harvest in high value marten habitat will retain 10-20 percent canopy closure, 4 large live trees per acre, 3 large decadent trees per acre, and 3 logs per acre. These habitat management measures were based on studies showing marten use higher in partially logged areas than clearcut areas (Soutiere 1979); a recent study by Hargis and Bissonette (in press) indicating that the proportion of clearcut harvesting at a landscape scale is a key determinant of marten success; and numerous studies showing the importance of large wood structure to marten (Baker 1992, Buskirk et al. 1989, Corn and Raphael 1992, Raphael and Jones (in press)).

The second measure provides for access management to reduce marten mortality in areas where mortality rates due to trapping/hunting have been identified as a serious risk to marten populations. The third measure provides additional assurance of maintaining connections between habitat blocks throughout the Tongass. It requires an analysis of the effectiveness of features such as small reserves, beach fringe and riparian buffers in providing for connection between old-growth blocks in medium and large reserves and other natural setting LUD's. Where these measures do not provide for full connectivity, additional habitat will be allocated to provide for connectivity of old-growth habitats.

d. Effects of Implementation

With all measures in place, Alternative 11 will provide for a network of large and medium-sized HCA's, capable, respectively, of supporting 25 and 5 female marten each. Connection between HCA's will be provided by protected habitats in riparian and beach fringes, small HCA's, and additional old-growth habitat designated for connectivity where these protected habitats are not adequate. Connections through the riparian and beach fringe are likely to be effective for marten based on studies that have shown preferential use by marten of riparian zones (Buskirk et al. 1989, Raphael and Jones (in press), Spencer and Zielinski

1983). The matrix between the reserves will also contain significant, although fragmented, old-growth habitat. An average of 57 percent of the pre-1954 productive old growth will remain unharvested in the matrix areas through the planning horizon of 100 years. The percent of old growth remaining in the matrix will vary by province, but in those provinces considered at highest risk the additional habitat measures described above will be applied in the matrix. In addition to all of the above habitat measures, road access will be managed to reduce marten mortality where mortality has been identified as a significant risk.

Full implementation of the above strategy should increase the likelihood of maintaining habitat that will support well-distributed marten populations. While there will likely be gaps in this distribution, there is low likelihood that there will be significant isolation among marten populations resulting from implementation of Alternative 11.

3. Northern Goshawk

a. Background

Section IV. C. of this appendix presents a detailed analysis of the effects of the proposed plan on northern goshawks, so only a brief summary on goshawks is presented here. The 1997 panel ratings of Alternative 11 for goshawk assigned 71 likelihood points to the sum of Outcomes I and II, and 97 likelihood points to the sum of Outcomes I, II and III. This rating was second highest of all alternatives that proposed to continue timber harvest, only slightly lower than the rating given to Alternative 5. Conversely, Alternative 11 was rated as having very low likelihood of goshawks existing in refugia or being extirpated from the Tongass after 100 years of Forest Plan implementation with a combined Outcome IV and V score of 3. However, because the goshawk has been considered for listing under the Endangered Species Act, Alternative 11 was reviewed to determine if features of the alternative could be modified to improve the projected outcome.

b. Strengthening of Alternative 11 To Reduce Risk

The conservation assessment for northern goshawk (Iverson et al. 1996) evaluated the effect of various management practices on goshawk nesting and foraging habitat, and also identified specific geographic locations where goshawk habitat has been highly fragmented. Based on this information, an additional measure for goshawk habitat was prescribed for Prince of Wales Island where productive old-growth has been fragmented by past management actions. This measure applies in VCU's where over 33 percent of productive old-growth has been converted to young stands by past management. In those VCU's, any additional management of productive old-growth will either be restricted to two-acre clearcuts or be managed to leave significant structure in harvested stands.

c. Effects of Implementation

This standard and guideline will apply to management activities in 28 VCU's on Prince of Wales Island. Approximately 55 percent of the total original productive old-growth has been converted to young forest in these VCU's. For any additional harvest of productive old-growth in these VCU's, the standard and guideline will have the effect of either implementing a 200-year uneven-aged management regime or leaving structure equivalent to 30 percent of the cover of the original stand. Neither of these practices is expected to produce high value nesting habitat, but they will result in moderate to high value foraging habitat (Iverson et al. 1996). This structure, in combination with matrix management provisions for beach fringe and riparian management areas, will facilitate goshawk dispersal among large and medium reserves on Prince of Wales island. Goshawk will also be benefited in other provinces by the measures put in place for marten and for connectivity. Again, these will have the effect of facilitating dispersal among goshawk populations in reserves. Taken in combination with other measures already in place in Alternative 11, these will increase the already high likelihood of providing habitat sufficient to maintain viable and well-distributed goshawk populations.

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4. Effects of Additional Measures on Timber Availability

The potential effects of these additional standards and guidelines on the calculated allowable sale quantity (ASQ) have been considered. Overall, the net effect of the additional habitat management measures discussed in this appendix are expected to be sufficiently small that recalculation of the ASQ for Alternative 11 as presented in the FEIS is not necessary.

The habitat management measure for connectivity is projected to have very little if any effect on timber availability. An analysis was conducted at the regional scale and identified possibly three areas where connectivity limitations may be encountered. Even if local analysis identifies more areas where application of this connectivity measure is needed, the total number of areas will be small and the effect on timber availability negligible. Furthermore, the Old-growth Habitat LUD provides for the reexamination of the current placement of small old growth habitat reserves that are designed, in part, to maintain landscape connectivity. Where connectivity may be insufficient, small reserves may be adjusted to provide needed connectivity, with little or no net change in timber availability anticipated.

The survey and management measure for endemic mammals requires surveys prior to timber harvest on smaller islands and where appropriate on larger islands. Based upon results of these surveys, some harvest plans may have to be altered. However, the acreage of programmed timber harvest is expected to be small. The effect of this measure is expected to be small relative to the total ASQ for the Tongass.

Habitat management measures for the goshawk and marten will limit the use of clearcutting and require the use of alternative silvicultural techniques on a portion of the suitable timber land base, primarily on northern and central Prince of Wales Island and in certain other biogeographic provinces. Where applied and found necessary, the effect will be to approximately double the rotation age, and reduce the volume available for harvest in any time period by about half. Moreover, some of the alternative silvicultural techniques required in the marten and goshawk standards and guidelines have already been accounted for in ASQ calculations; these habitat management measures simply serve as additional guidance where such techniques may be necessary to address risk to marten and goshawks. Overall, the net reduction in available timber is expected to be small relative to the total ASQ for the Tongass.

IV. Forest Plan Old-Growth Habitat Strategy and Additional Analysis for Species of Special Management Concern

A. Old-Growth Forest Habitat Strategy

1. Overview

An integrated old-growth forest habitat conservation strategy has been developed as part of the revised Forest Plan. The old-growth strategy has two basic components. The first is a forest-wide reserve network that protects the integrity of the old-growth forest. The old-growth reserves include a system of large, medium, and small Habitat Conservation Areas allocated to the Old-growth Habitat Land Use Designation (LUD), and full protection of all islands less than 1,000 acres in size. The reserve network also includes all other non-development LUD's. These include Wilderness, Legislated LUD II, Wild River, Remote and Semi-remote Recreation, Research Natural Area, Municipal Watershed, and all other LUD's that essentially maintain the integrity of the old-growth ecosystem. The second component of the old growth habitat conservation strategy is management of the matrix, e.g., the lands with LUD allocations where commercial timber harvest may occur. Within the matrix, components of the old-growth ecosystem are maintained by standards and guidelines to protect important areas and provide old-growth forest habitat connectivity. The following analysis describes the rationale for the strategy and its specific components.

Development of the old-growth strategy has relied on several key scientific documents that provided the basic foundation for addressing wildlife viability. These include the Interagency Viable Population Committee (VPOP) Conservation Strategy (Suring et al. 1993), the PNW Peer Review of the VPOP Strategy (Kiestler and Eckhardt 1994) and the VPOP Response to the PNW Peer Review (Suring et al.

1994). In addition, the Alexander Archipelago Wolf (Person et al. 1996) and Northern Goshawk (Iverson, et al. 1996) conservation assessments provided the basis for design of some components of the strategy as well as a basis for examining whether the old-growth strategy would sustain viable and well distributed populations of these two species. A detailed analysis is presented for each of these species in Sections IV. B. and IV. C. Section A provides a discussion of the major features, findings, and recommendations of each of the three conservation planning (VPOP related) documents, a consideration of features and recommendations in each document, and the integration of features in the deliberative process to arrive at an overall strategy to address viability of old-growth associated species. A description of the resulting old-growth strategy is provided, followed by a quantitative analysis of features of the strategy

The appendices referenced throughout this section are listed at the end of the document.

2. VPOP Strategy

There is a substantial science base for an old-growth habitat reserve approach for addressing wildlife viability (See FEIS Chapter 2 - Wildlife Viability and Chapter 3 - Biodiversity and Wildlife). The Interagency Viable Population Committee (VPOP) (Suring et al. 1993) performed pioneering work in designing a landscape conservation strategy to address wildlife viability. VPOP was commissioned by the Tongass Land Management Plan (TLMP) Revision Team to provide recommendations for sustaining habitat to help ensure the maintenance of well-distributed viable populations of all old-growth associated wildlife species across the Tongass. VPOP systematically screened all wildlife species and identified those old-growth associated species they considered to be most sensitive to habitat loss and fragmentation of the old-growth ecosystem. Their 'coarse filter' landscape strategy designed to consider the entire complement of old-growth associated species, included a system of large (40,000-acre) and medium (10,000-acre) Habitat Conservation Areas (HCA's) with spacing and habitat composition requirements well distributed across the Tongass. Small (1,600-acre) HCA's in each major watershed (> 10,000 acres) and individual species-specific management guidelines also were recommended.

Landscape connectivity was an integral feature of the original VPOP landscape conservation strategy (Suring et al. 1993). VPOP reviewed the available literature and concluded that there was limited empirical support for corridors but that this should not preclude their inclusion in landscape conservation planning. They reasoned that landscape habitat connectivity was an important component of conservation planning to facilitate animal dispersal and movement, whether specifically designed as corridors or through overall management of a habitat matrix. They recommended (p. 30) a 500-foot beach fringe buffer forest-wide and 200-foot buffers on anadromous fish streams. Breaks in these buffer corridors should be less than 65 feet to facilitate flying squirrel dispersal.

VPOP mapped the large and medium reserves and provided guidance for locating the small reserves, stating that their mapping effort represented only one possible application of the old-growth reserve system across the forest. VPOP concluded that their strategy represented "the minimum amount and distribution of habitat necessary to assure a high likelihood of maintaining viable, well-distributed populations of old-growth associated wildlife species across the Tongass National Forest" (p. 37). Their strategy and extensive supporting analysis are contained in *A Proposed Strategy for Maintaining Well-Distributed, Viable Populations of Wildlife Associated With Old-Growth Forests in Southeast Alaska*.

3. PNW Review

The Forest Service Pacific Northwest Research Station was requested by the Alaska Region to conduct an independent scientific peer review of the VPOP strategy. Kiester and Eckhardt (1994) obtained technical reviews from 18 scientists from North America with substantial knowledge and experience in species ecology or conservation biology. Kiester and Eckhardt (1994) synthesized these technical reviews and published all reports in the document *Review of Wildlife Management and Conservation Biology on the Tongass National Forest: A Synthesis with Recommendations* (PNW Review).

The general concepts in VPOP's multiscale habitat conservation strategy received positive support from the scientists involved in the PNW Review: Beckman (p. 37): "The proposal of HCA's of three sizes somewhat

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uniformly scattered across the landscape seems like a reasonable strategy...”; Forsman (p. 48): “...proposed network of conservation areas is a reasonable start in combination with protection of known (goshawk) nest areas within the matrix.”; Hansen (p. 50): “The core approach of this report (strategy) is scientifically sound and generally consistent with modern conservation biology.”; Jarvis (p. 71): “The strategy is an innovative and bold attempt to apply species, community, and ecosystem concepts to applied management.”; Lande (p. 78): “...a good initial attempt to develop a strategy for maintaining biodiversity.”; Lidicker (p. 87): “The strategy outlined is a giant step in the right direction, but improvements are needed...”; Marcot (p. 101): “...the process and basis for the proposed conservation strategy is scientifically sound given our current knowledge base...”; and Walters (p.194): “...the overall management strategy that considers landscape level features is excellent. The approach is well-grounded in the best current information in conservation biology...”. Kiester and Eckhardt (p. 5) concluded in their summary review that “the Strategy (VPOP) receives high marks. It represents a solid attempt to integrate species viability concerns with the Habitat Conservation Area approach.”

The PNW Review identified several weaknesses in the VPOP strategy. For example, corridors were considered inadequate, there was insufficient attention directed to the matrix lands, and Habitat Conservation Areas’ (HCA’s) were considered to be too small by many scientists. Kiester and Eckhardt (1994 p. 5) concluded that “the particular pattern of Habitat Conservation Areas that it [the VPOP strategy] suggests will not ensure viability of all species”—although no individual species were specifically identified. Careful examination of all reports by the 18 scientists that participated in the PNW Review revealed repeated concerns relative to brown bears and wolves (Lande p. 82; Lidicker p. 91; McLellan p. 132, Paquet p. 143; Pletscher p. 147; Powell p. 156, and in the summary by Kiester and Eckhardt, p. 16, 17)) and that 40,000-acre large HCA’s recommended by VPOP were too small to sustain populations of these wide-ranging species. Lande recommended that at least one very large HCA be maintained in each ecological province or island (p.81); Lidicker recommended a “few large areas, one per island or island group” (p. 91); McCullough (p. 116) recommended fewer but larger HCA’s to support continuous populations; and Pletscher (p. 147) suggested an “inverse HCA” concept of very large preserved landscapes with small areas allocated for timber harvest.

Importantly, Kiester and Eckhardt (1994, p.3) noted that the PNW Review only considered the network of mapped VPOP large and medium HCA’s and Congressionally protected areas such as Wilderness, Monuments and Legislated LUD II areas. The VPOP reserve network was not examined in the context of the entire forest plan or a fully articulated planning alternative containing the strategy. The scientists were unable to consider other Land Use Designations (LUD’s) that effectively function as reserves and conserve the old-growth ecosystem—a very important component incorporated into the development of the old-growth habitat conservation strategy in the revised Forest Plan and this analysis.

Corridors and landscape connectivity received considerable attention among the scientists involved in the PNW Review, and somewhat differing opinions emerged regarding how to address landscape connectivity. Lidicker recommended 1,000-foot corridors (p. 91), while Lande (p. 82) recommended corridors of up to 4,000 feet wide. Other scientists questioned the value of explicitly designed corridors. McCullough (p. 116) noted that “corridors are of considerable debate” and recommended larger reserves to minimize reliance on dispersal corridors; Paquet (p. 137) stated “there are few controlled data with which to assess the conservation role of corridors, thus it is difficult to support or refute their value” but added “...maintenance or restoration of connectivity in the landscape is a prudent strategy”; Pletscher (p 147) stated “There are few empirical studies documenting the value of narrow corridors” and recommended more attention be focused on overall management of the matrix; and Powell (p. 154) agreed with VPOP regarding uncertainty of corridors and recommended more attention be given to the intervening landscape matrix to facilitate wildlife movement and dispersal. Kiester and Eckhardt (p. 17) stated that overall landscape connectivity was an essential component of an old growth conservation strategy and wider corridors were necessary (especially for marten), particularly relative to ecological pinch points, but cautioned that corridors are “virtually untested in practice.”

In their summary chapter, Kiester and Eckhardt (1994) provided many recommendations that specifically relate to forest planning and features of landscape design:

- ♦ The existing largest blocks of contiguous high volume old-growth forest should not be further fragmented by timber harvesting or road building.
- ♦ Incorporate larger reserves.
- ♦ Incorporate wider corridors.
- ♦ Do not differentially cut low altitude, high volume old-growth
- ♦ Consider an inverse habitat conservation area concept.

They provided many other sound management recommendations not directly related to landscape planning design, such as adaptive management, biological inventory, gap analysis, and population viability analyses.

4. VPOP Response

Suring et al. (1994) specifically responded to individual recommendations made in the Kiester and Eckhardt (1994) review of the VPOP Conservation Strategy in the document: *Response to the Peer Review of: A Proposed Strategy for Maintaining Well-distributed, Viable Populations of Wildlife Associated with Old-Growth Forests in Southeast Alaska* (VPOP Response). In this brief (11 pages with appendices) response, Suring et al. (1994) indicated that the document represented an “initial response” outlining additional elements that would be considered in their preparation of a final Conservation Strategy as provided for in the peer review process, stating “additional support will be needed by the Committee (VPOP) from the Forest Service to adequately incorporate the recommendations of the peer reviewers into our manuscript and to publish that manuscript” (Suring et al. 1994, p. 3).

Within the VPOP Response, seven specific recommendations were made that were responsive to PNW Review comments. All recommendations were considered during the Viability Synthesis Workshop (Iverson and Rene, 1997) to identify building block concepts for forest plan alternative development. All VPOP Response recommendations were analyzed spatially and quantitatively (Iverson 1996a). In doing so, the Forest Plan interdisciplinary team (IDT) concluded that the features described in the recommendations would not collectively represent a fundamentally different alternative than existed within the range for forest plan alternatives considered in the Revision planning process and that general concepts recommended (e.g., larger reserves and wider corridors) were already addressed.

Specifically, from the PNW Review recommendation to “keep landscape options open, and do not further fragment existing large blocks of high volume old-growth,” the VPOP Response generated the following recommendation: “it is important that the largest remaining patches not be fragmented. This may (emphasis added) be accomplished by restricting logging and road building to areas other than the 3 largest old-growth forest patches within each ecological province” (p.8). The PNW Review referred to blocks of old growth while the VPOP response referenced “patches”; the PNW Review recommendation specifically mentioned “high volume” old growth—VPOP did not; the VPOP Response only recommended that the three largest old-growth forest patches be protected—the PNW Review suggested all blocks. Despite slight but important differences between these two recommendations, we concluded that minimizing additional fragmentation of large areas of old-growth forest with a focus on the high volume class strata was the basic intent of the recommendations.

Noting the limitations in their original conservation strategy identified by the PNW Review, the VPOP Response considered the diversity of opinion among the scientists concerning corridors and provided a series of explicit corridor recommendations. They recommended that a beach fringe corridor of 3,300 feet be established forest-wide within which only selective uneven-aged management could be applied. They also recommended that 1,000-foot and 1,600-foot no harvest corridors be designated to connect medium and large HCA's, respectively. These corridors should be located below 800 feet in elevation.

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5. Old-Growth Forest Habitat Conservation Strategy

The TLMP IDT carefully reviewed the landscape design recommendations contained in the documents discussed above. In consideration of all multiple-use issues and concerns, they designed a habitat strategy that is responsive to the recommendations discussed above. This strategy represents the integration of many elements, some of which are specific to addressing wildlife viability (see below), others of which respond to other issues, such as Congressional legislation (Wilderness, National Monument, and Legislated LUD II), riparian habitat management from the Anadromous Fish Habitat Assessment, or the allocation of lands to Remote and Semi-remote Recreation in recognition of recreation and tourism uses.

After considering the PNW Review by prominent scientists and considering all other available information, the IDT incorporated the VPOP HCA strategy as the cornerstone of the old-growth forest habitat strategy in the revised Forest Plan. This represents a fundamental 'coarse filter' approach to addressing wildlife viability and the conservation of biodiversity (See FEIS - Biodiversity and Wildlife Sections for a discussion of the 'coarse' and 'fine' conservation approaches). Species specific standards recommended by VPOP (e.g. brown bear, goshawk, wolf, great blue heron, etc.) have been fully considered in light of additional information such as conservation assessments, panel assessment results, etc. and appropriate standards and guidelines have been incorporated into the Threatened, Endangered, and Sensitive Species and Wildlife sections of the Forest Plan.

a. Habitat Reserves

The mapped system of 149 large and medium HCA's originally designed by VPOP as "one possible application of the proposed strategy" was integrated into Forest Plan through allocation to the Old Growth Land Use Designation (LUD). Spatial modifications to the original VPOP large and medium HCA's have been made for the revised Forest Plan. This is provided for in the VPOP report as long as HCA design criteria for size, spacing, and composition are maintained (Suring et al. 1993, p. 30). In their HCA composition analysis, Suring et al (1993) also identified limitations in their mapped strategy. Subsequent modifications have been made to large and medium HCA's to correct limitations. Modifications have been made for several reasons:

- ◆ the original VPOP delineation did not meet minimum HCA criteria (e.g., St. James Bay Large HCA);
- ◆ the original delineation incorporated large amounts of fragmented clearcut landscape (e.g., Couverden and Kelp Bay Large HCA's);
- ◆ the original VPOP delineation exceeded minimum criteria (Ratz Harbor, Aaron's Creek medium HCA's);
- ◆ the integrity of the original HCA was substantially compromised by recent timber harvest that was inconsistent with HCA objectives (Game Creek Large HCA);
- ◆ reserve location was adjusted to achieve multiple use objectives such as timber harvest.

Even after these modifications, large and medium HCA's may still not precisely match the specific VPOP size, spacing and habitat composition design criteria. A detailed analysis has been conducted of how well the original mapped VPOP reserves and the design criteria are integrated into the Forest Plan (Iverson 1997). Considering the spacing criteria, VPOP found that over 90 percent of the 149 HCA's they mapped forest-wide met the minimum spacing criteria, and those that did not were generally isolated islands or within Wilderness (Suring et al. 1993, Table 8, 9). Very few HCA's have been completely moved (Iverson, 1997), thus the current location of mapped reserves is considered in general compliance with the original VPOP design. While site-specific compliance is not always perfect, either exceeding or occasionally deficient in VPOP design criteria, fine-tuning application of the strategy would take many iterations. As VPOP concluded, "a 'perfect' application of this conservation strategy does not exist" (Suring et al. 1993, p. 35). Furthermore, standards and guidelines in the Old Growth LUD provide for the examination of the size, spacing, and composition criteria for each reserve at the project level and provides for necessary adjustments to ensure minimum design criteria are met.

Small (1,600-acre) HCA's in each 10,000-acre watershed were recommended by VPOP, to be mapped during project implementation. VPOP identified two objectives for small HCA's (Suring et al. 1993, p. 28): "to provide temporary functional habitat for animals dispersing between large and medium HCA's and to

ensure that species of concern have a relatively high likelihood of occurring in each 10,000+ acre watershed.” The IDT identified and explicitly mapped the small reserves in the Forest Plan as part of the Old-growth LUD. These small reserves also contribute to the overall landscape matrix outside large and medium HCA’s (see b. Matrix Management). Approximately 237 small reserves were mapped. These included nearly 267,000 acres of productive old-growth forest within a total of 480,000 acres (Appendix 1). These reserves represent an important component of the forest-wide old-growth habitat conservation strategy.

The need for larger habitat reserves (larger than provided by VPOP) and minimizing fragmentation, in general, and specifically for brown bears and wolves, was a consistent recommendation expressed by the PNW Review scientists. The Forest Plan, in response to observations of the PNW Review scientists and management considerations contained in the interagency wolf conservation assessment (see Alexander Archipelago Wolf below), contains at least one very large reserve within each of the 21 biogeographic provinces across the Tongass to address large scale distribution of large old growth reserves (Appendix 5). This action is specifically responsive to Lande’s recommendation (p. 81, in Kiester and Eckhardt 1994) of one large reserve per province and to other scientist’s concerns that VPOP’s HCA’s were too small. A quantitative definition of large was not provided in any reference, however, multiples in excess of the VPOP large HCA’s of 40,000-acres may be considered as ‘large’ (1-2 times as large) or ‘very large’ (3 or more times as large).

The VPOP Response also recommended the following: “it **may** (emphasis added) also be necessary to establish 0.5- to 1-mile buffers around all Large and Medium HCA’s as a “special management zone” permitting removal of up to 25 percent of the standing volume in 5-acre units using uneven-aged timber management. This recommendation relates to the need for larger old-growth forest reserves. This feature has been incorporated into the Forest Plan in a different way than proposed in the VPOP Response. As discussed above, at least one very large reserve per province has been allocated. Furthermore, the VPOP Response recommendation would have permitted substantial harvest (up to 25 percent) of the expanded area. The Forest Plan protects entire reserves without selective harvest and associated additional reduction of old-growth forest.

Both the PNW Review and VPOP Response expressed concern for disproportionate harvest of higher volume old growth stands. VPOP Response specifically recommended (p. 9) that “it is necessary to defer logging and road building in volume class 6 and 7 old-growth forest (as determined by field reconnaissance) below 800 ft. elevation until a biological survey is completed.” The IDT recognized the concern for higher volume stands and has taken a broader approach toward protecting larger reserves and intact landscapes, which necessarily include higher volume stands (See d. Identifying and Mapping Old-Growth Reserves) The IDT did not believe that a focus on protecting small isolated stands of the former volume class 6 and 7 that may be imbedded within a mosaic of clearcuts, susceptible to windthrow, was a prudent management approach to addressing conservation of old-growth associated species.

The final fine-scale component of the reserve strategy addresses potentially endemic taxa (species or sub-species) that may exist on small islands. MacDonald and Cook (1994) reported 27 mammal taxa endemic to Southeast Alaska. Many may have limited dispersal capabilities and are restricted to individual islands (e.g., Coronation Island vole); some may also be susceptible to loss and fragmentation of old-growth habitat. Populations existing on small islands (oceanic or habitat fragments) are more susceptible to local extinction (Wilcove et al. 1986, Burkey 1995). The archipelago of Southeast Alaska contains over 22,000 islands (Iverson 1996b) and uncertain but likely high levels of biotic endemism (MacDonald and Cook 1994). Lidicker (in Kiester and Eckhardt, 1994, p. 91) identified a concern for small island endemic taxa and recommended that no logging occur on islands of less than 1,000 acres to reduce risks to these taxa, and further recommended that at least one reserve be maintained on larger islands. The Other Mammal Assessment Panel expressed similar concerns relative to endemic taxa (Julin, 1996).

In response to these concerns about endemic taxa with possibly unique gene pools that may be restricted to small islands, the Forest Plan protects all islands less than 1,000 acres from additional harvest of old-growth forest, in direct response to the Lidicker recommendation and concern expressed by the Other Mammal Assessment Panel.

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b. Matrix Management

The second component of the old-growth forest habitat conservation strategy is management of the area outside reserves (the “matrix”) that is subject to timber harvest. This topic was of notable concern to the PNW Review scientists who suggested that more attention be directed to this component of landscape conservation planning. They particularly noted the need to provide enhanced landscape connectivity and to manage human disturbance of the land similar to natural disturbance regimes (Kiestler and Eckhardt 1994: Hansen p. 52; Lande p. 82; Lidicker p. 87; McCullough p. 109; McClellan p. 133).

Some management protections within the matrix are spatially explicit, such as the 1,000-foot beach and estuary fringe, and the riparian buffers for maintaining the integrity of the aquatic and riparian ecosystems. Other forest-wide standards and guidelines preclude or significantly limit timber harvest in areas of high hazard soils, steep slopes, karst terrain, visually sensitive travel routes and use areas, and in timber stands technically not feasible to harvest.

Beach and estuary fringe, and riparian habitats, have special importance as components of old-growth forests, serving as wildlife travel corridors, providing unique wildlife habitats, and providing a forest interface with marine or riverine influences that may distinguish them as separate ecosystems within the larger old-growth forest ecosystem. Riparian areas are important for fisheries in providing, among other resources, the source of large woody debris that creates pools for rearing habitat, and in controlling stream temperatures and the amount of sediment reaching streams. Riparian areas provide habitat for terrestrial species associated with aquatic environments (amphibians, for instance, or mammals such as river otter and beaver), and for terrestrial species for which fish from streams are important food (brown and black bears). Considering the dendritic nature of riparian systems that begin high in watersheds, these riparian areas provide forested corridors connecting higher elevation regions in upper watersheds with lower elevation forests in valley bottoms. Riparian areas often contain plant species which can live only where water is available year-round. Riparian soils often support large spruce trees and some of the most highly-productive stands of old growth.

The beach fringe, the forested area adjacent to salt-water shorelines, is thought to be an important wildlife travel corridor, a transition zone between interior forest and salt water influences, and a unique habitat (or micro-climate) in itself. The beach fringe is a very important feature on the Tongass given the extensive amount of shoreline (more than 13,000 miles) that exists on the more than 22,000 islands. The beach fringe provides horizontal or low-elevation connectivity between watersheds, many of which otherwise have very steep sides and/or non-forested ridgetops. In conjunction with riparian areas, which provide connectivity within watersheds, the beach fringe is thought to be a component of the major travel corridor system used by many resident wildlife species.

Interagency habitat capability models developed for management indicator species of the Tongass indicate that the highest habitat suitability value was assigned to productive old-growth forests within the 500-foot beach fringe zone for the bald eagle, marten, and river otter (Suring 1993). The beach fringe was rated second only to the 1,000-foot estuary fringe for brown and black bears in overall habitat quality, and higher deer habitat values generally occur in high-volume old-growth below 800-foot elevation, much of which occurs in the beach zone with a moderating maritime-influenced microclimate. A revised marten habitat capability model rated the beach fringe old-growth forests highest among all habitat components (Flynn, 1995).

There are indications that the value of the beach zone habitat may extend beyond 500 feet. Gende et al. (in press) reported reduced bald eagle nesting densities and success in landscapes adjacent to clearcuts and recommended a beach buffer zone of at least 1,000 feet. The 1,000-foot beach fringe also is used frequently by radio-marked goshawks (Iverson et al. 1996). The importance of the beach fringe zone has long been recognized, and was a component of the Retention Factor Method used in the 1979 Tongass Plan, as amended (USDA Forest Service, 1986) (specifically recognizing the importance of the 1,000-foot beach fringe for brown/black bear, 600-foot for furbearers, and ¼-mile inland from the beach for deer winter range).

In developing the old-growth forest habitat strategy, the information described above and the available literature relative to Southeast Alaska were carefully examined. The IDT concluded that explicit corridors should be a component of a landscape conservation strategy, that a 1,000-foot beach and estuary fringe corridor was clearly justified by the available information but that no evidence supported a 3,300-foot buffer recommended by the VPOP Response. The IDT further reasoned that a 1,000-foot no harvest beach and estuary fringe corridor was comparable or possibly superior to a 3,300-foot corridor that permitted up to 25 percent of the volume removed in 5-acre patch cuts as recommended by the VPOP Response.

Accordingly, the Forest Plan establishes a Beach and Estuary Fringe Forest-wide Standard and Guideline that prevents timber harvest within 1,000 feet inland from mean high tide. The 1,000-foot beach fringe serves many functions: providing more effective landscape linkages between habitat reserves, protecting long-term bald eagle habitat capability, buffering the primary beach fringe zone (0 -- 500 feet) from windthrow (Hodges 1982, Harris 1989), maintaining a functional interior forest condition within the entire primary beach fringe (Concannon 1995), and sustaining very important habitat for goshawks (Iverson et al. 1996).

In addition, the Forest Plan incorporated, as a minimum, the riparian habitat recommendations in the Anadromous Habitat Fish Assessment (AFHA 1995). Riparian habitat buffers also provide elevational corridors within forested watersheds. Mapping the small old growth habitat reserves (see above) also provides additional landscape connectivity. Together, the beach and riparian habitat management features and the mapping of small reserves represent a substantial response to the landscape linkage element of conservation planning and significantly contribute to management of the overall matrix among habitat reserves.). Finally, the Forest Plan contains a standard and guideline that provides for the maintenance of a contiguous forested corridor, where it exists, connecting each large or medium habitat reserve to at least one other reserve.

Stand level habitat management objectives, that will also contribute to maintaining features of old growth forest within the matrix, have been established in the Forest Plan to reduce the adverse effects of clearcut timber harvest to marten and goshawk habitat use by retaining important forest structure during harvest. These habitat management measures have been added to the Forest Plan in response to panel assessments (see Section III.B. In the North and Central Prince of Wales Biogeographic province, where current risks to sustaining goshawks was greatest (Iverson et al. 1996), standards and guidelines provide for the retention of forest structure during harvest in VCU's where over 33 percent of the original productive old growth has been harvested and harvest units are over two acres. This management standard and guidelines maintains an average of at least 30 percent canopy closure after harvest and requires that an average of at least 8 large (20-30" DBH) trees/acre are retained at harvest. The objective of this provision is to retain some foraging habitat value during harvest; silvicultural prescriptions that retain this amount of material are superior to clearcut harvest (Iverson et al. 1996).

Similar stand level structural retention standards and guidelines in the Forest Plan have been established to manage high value marten habitat. These standards and guidelines apply to the five higher risk biogeographic provinces identified by VPOP (Suring et al. 1993, p. 41) (East Chichagof, Kupreanof/Mitkof, Etolin Island and Vicinity (except Zarembo), Revilladagado Island and Vicinity, and North and Central Prince of Wales Island). In VCU's within these provinces where over 33 percent of the original productive old growth has been harvested, including additional future harvest, high value marten habitat will be managed to retain important forest structure for marten. Harvest units over two acres in size in high value marten habitat (e.g. high volume timber strata and below 1500' in elevation) will retain after harvest: an average of over 30 percent canopy closure, an average of at least 8 large trees/acre (20-30" DBH), an average of at least 3 large decadent (20-30" DBH dead or dying trees) trees/acre, and an average of at least 3 pieces/acres of large (20-30" DBH) down logs. For all other VCU's within these five provinces, the following structure will be retained in harvest units in high value marten habitat. Approximately 10-20 percent of original stand structure will be retained with an average of 4 large trees/acre (20-30" DBH), an average of 3 large decadent trees/acre (20-30" DBH), and an average of at least 3 pieces/acres of large (20-30" DBH) down logs.

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For both the goshawk and marten stand management standards and guidelines above, harvest units under 2 acres do not need to maintain any of the prescribed amounts of forest stand structure. However, to provide for retention of important forest structure, the effective silvicultural rotation is increased to 200 years.

6. Analysis of the Old-Growth Strategy

a. Amount and Distribution of Old-Growth Forest

The first and most prominent feature of the old-growth habitat strategy in the Forest Plan is the substantial amount of productive old-growth forest that will be protected forest-wide in both the matrix allocated to timber management and the reserves (3,551,482 acres in reserves - Appendix 3 and 1,038,492 acres in the matrix - Appendix 8). A total of 84 percent of the productive old growth that was present in 1954 (5,441,557 acres - Appendix 3) would be present in 2095 assuming full implementation of the Forest Plan for 100 years. This is equivalent to an estimated 90 percent of existing productive old-growth (5,063,571 acres - Appendix 3).

Within protected reserves, a total of 70 percent (3,551,482 acres) of the existing productive old-growth on the Tongass is protected in reserves in “non-development” LUD’s (Appendix 3). Adequate distribution of old growth habitats, and not necessarily the forest-wide total amounts, was a principal element of the VPOP conservation strategy (Suring et al. 1993). The proportion of old-growth protected in reserves varies by biogeographic province, but ranges from 38 percent (Kupreanof/Mitkof Province) to 100 percent (Admiralty and West Chichagof Provinces). Within protected old-growth forests, all volume classes of productive old-growth have been protected as well. High volume old growth generally contains the largest trees and averages 35,000 board feet per acre (Julin and Caouette, 1997). For example, an average of 44 percent of the productive old growth in reserves is high volume, whereas 43 percent of the old growth forest-wide is high volume. The proportion of high volume old growth in reserves in 18 of 21 provinces equals or exceeds the proportion present in the province as a whole (Appendix 3).

The Forest Plan exceeds the minimum strategy recommended by VPOP relative to sustaining viable wildlife populations. While fully integrating the large and medium VPOP HCA’s and the mapping of the small reserves, the Forest Plan protects substantial additional productive old-growth forest to further reduce risks to wildlife viability and enhance protection of biological diversity. For comparison, reserves allocated in the Forest Plan with at least 5,000 contiguous acres of productive old-growth (the minimum productive old-growth requirement for VPOP medium HCA’s) exceed the amount recommended by VPOP by 147 percent forest-wide (Appendix 2). Old-growth allocated to reserves exceeds the amount recommended by VPOP in 20 of 21 biogeographic provinces, ranging from 9 to 460 percent over VPOP recommendations. This comparison is conservative: it does not include old-growth forest in contiguous reserves with less than 5,000 acres of productive old-growth, and does not include the substantial old-growth forest that will remain in areas outside of reserves where timber harvest can occur (see A. 5 b. Matrix Management).

The old growth strategy contains at least one large contiguous reserve relative to the province size in each of the 21 biogeographic provinces across the Tongass to address large scale distribution of large old growth reserves (Appendix 5). Seventeen of the 21 provinces have at least 1 very large reserve (e.g. over 180,000 contiguous acres). For example, in the North Central Prince of Wales Province, a contiguous reserve of 200,584 acres (Honker/Sarkar/Karta) is provided in the Forest Plan -- 5 times larger than a VPOP large HCA (40,000 acres). Two provinces have a large reserve exceeding 75,000 acres; the two remaining provinces are intermediate sized-islands or aggregates of smaller islands and have contiguous reserves of from 30-40,000 acres and virtually all federal lands within the province are in a reserve land allocation (Dall Island and Southern Outer Islands).

High quality old-growth forest has been mapped in the largest reserves as well. The proportion of high volume old growth (used as one indirect measure of old-growth habitat quality) in the largest reserves is equal to or greater than the proportion of high volume old growth throughout the province in 16 of 21 provinces forest-wide (Appendix 5). Many of these reserves previously existed (e.g., Admiralty and Misty

Fiords National Monuments), while others were explicitly created to achieve this objective (South and Central Prince of Wales Island, Kupreanof/Miktof and East Chichagof Island).

The comprehensive old-growth habitat strategy in the Forest Plan also is responsive to the PNW Review recommendation to not further fragment existing blocks of high volume old growth by incorporating many existing roadless areas in reserves. An average of 89 percent (range 55-100 percent in each of 21 biogeographic provinces) of the Tongass is roadless (Appendix 4), an indirect measure of unfragmented (from clearcut harvest) landscapes. An average of 84 percent of the currently roadless acreage on the Tongass is allocated to “non-development” LUD’s in the Forest Plan and will thus retain the roadless and unfragmented character of the landscape. A substantial portion of the Tongass will remain roadless and unfragmented in the Forest Plan

PNW Review scientist Pletscher (Kiestner and Eckhardt, 1994, p. 147) offered that an “inverse HCA” concept should be considered, in which large protected reserves would dominate the landscape and small “reserves” would be allocated for timber management. One way to examine this concept is the proportion of the existing productive old-growth in each biogeographic province allocated to timber management emphasis. Nineteen of the 21 provinces have equal to or greater than 50 percent of the existing productive old-growth forest allocated to a protective status (Appendix 2), suggestive of an inverse HCA concept. Ten provinces (48 percent) have over 75 percent of the existing productive old growth protected in reserves. Again, high quality old-growth forest has been protected; the proportion of high volume old-growth was generally equal to or greater than the proportion in the total province.

Additional concerns regarding habitat fragmentation were expressed by the VPOP Response that recommended that the 3 largest old-growth forest patches within each ecological province should be protected from logging and roadbuilding. We examined how well the old-growth strategy in the Forest Plan responded to these general recommendations to maintain large blocks of old-growth forest. However, there are various ways to define forest blocks or “patches”. Without some patch definition restrictions, virtually all old-growth forest on any island could be considered one contiguous and interconnected patch.

Two analyses were conducted to examine the recommendation regarding preservation of large blocks of old-growth forest. The first examined the concept of contiguous blocks of interior old-growth forest (DeGayner and Iverson, Old Growth Block Inventory, In prep.). Interior forest was defined as greater than 300 feet into the forest from the productive/nonproductive forest edge. The resulting five largest interior forest blocks in each biogeographic province were compared to the Forest Plan land allocations to determine the proportion of these blocks protected in a reserve. Forest-wide, 73 percent of the area of these 5 largest interior old-growth blocks was protected for a total of 476,000 acres (Appendix 6). A small portion of these acres may not longer meet the definition of interior forest acres after full implementation of the Forest Plan for 100 years. The proportion varied by province, from 38 percent protected in the East Baranof Biogeographic Province to 100 percent on West Chichagof, Admiralty, and North and South Misty Fiords Biogeographic Provinces.

A second analysis examined the largest contiguous blocks of only high volume old-growth forest and the proportion protected in reserves in the Forest Plan (Appendix 6). Overall, within a biogeographic province, these high volume blocks were much smaller than the interior forest blocks of all productive old growth (Appendix 6 and Appendix 7). Forest-wide, an average of 83 percent (province range 36 to 100 percent) of the five largest contiguous high volume blocks in each province was protected in reserves for a total of 225,000 acres (Appendix 6). These first two methods of many possible delineations of “large blocks” provided somewhat different results. There is no analysis to support the “3 largest old-growth forest patches” recommendation—certainly nothing compared to the in-depth analysis VPOP contributed in their initial conservation strategy (278 pp.) or the scientific reviews provided by the PNW Review 18 scientists (282 pp.). Nonetheless, the Forest Plan provides substantial (73 to 83 percent) protection to old-growth blocks considered in this analysis.

The allocation of forest stands and landscapes to some form of timber harvest within the matrix does not mean that all trees and stands will be harvested leaving only a continuous “sea of second growth.” There are numerous standards and guidelines limiting timber harvest in these matrix lands to protect specific

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resource and landscape components. An average of at least 57 percent (Appendix 8) of the original (pre-1954) productive old growth in these landscapes (the three timber harvest LUD's) would not be harvested and would remain standing throughout the planning horizon of 100 years, even with application of the maximum allowable timber harvest under the Forest Plan. A total of 69 percent of all existing productive old-growth in the matrix would remain after full plan implementation.

The relative quality of habitat within the three principal features of the matrix, the beach and estuary fringe, riparian habitat management areas, and other lands not available for timber harvest, are identified at both the province (Appendix 9) and VCU (Appendix 10) spatial scales. The beach and estuary fringe accounts for 15 percent of the productive old growth protected in the matrix; riparian habitat accounts for about 24 percent, and the "other lands" account for the remaining 61 percent. As discussed earlier, the proportion of high volume old growth is one measure of habitat quality: the beach fringe averages 45 percent and the riparian areas average 43 percent high volume old-growth forest.

Due to less restrictive management standards in the past, there has been some harvest in these areas: 27,000 acres in the beach and 54,000 acres in the riparian areas forest-wide. The "other" lands not available for timber harvest are not as spatially explicit as the beach and riparian. These include over half a million acres of productive old growth, averaging 31 percent high volume, protected in areas where future timber harvest will otherwise be permitted. Over half of this old growth is below 1,000 feet in elevation, the area where most past timber harvest has occurred. Note that where provinces and VCU's are completely reserved (i.e., where commercial timber harvest is prohibited), such as in semi-remote Recreation or Wilderness LUD's, there is no "matrix" (Appendix 9 and 10).

b. Island Effects

The potential risk to island endemic species that may be closely associated with old-growth forests was evaluated by conducting an analysis of islands of varying sizes (Iverson 1996b) revealed a very low risk to islands ranging in size from 1,000 to 10,000-acres in Southeast Alaska. There are a total of 58 islands of this size range, but only 8 had productive old-growth forest that was suitable for timber harvest in the Forest Plan representing only 2.2 percent of the productive old-growth on these islands (Table 7). However, long-term risk may be elevated on some of these 8 islands considering past as well as potential additional harvest (e.g., Shelikof, Sokolof, Marble, and Orr Islands).

Risks were slightly higher for islands ranging from 10,000-100,000 acres, with 7 of 19 having suitable productive old growth potentially available for harvest. Hecata Island is the largest island in this category (41,000 acres of federal land) with POG suitable for timber harvest. Several of these islands may also have elevated risks due to the cumulative effects of past as well as potential additional harvest (e.g., Tuxekan, Catherine, Suemez, and Hecata Islands). However, most productive old growth (92 percent) and most scheduled for timber harvest (95 percent) occurs on the largest islands exceeding 100,000 acres. The Forest Plan will not add additional risk to islands under 1,000 acres and will minimize risks to islands under 50,000 acres, with a cumulative maximum of 2,100 acres of old-growth forest that may be harvested over the next 100 years. This analysis assumes maximum allowable harvest every decade for 100 years under the Forest Plan. Furthermore, the analysis assumes a potential harvest of nearly 600,000 acres of productive old-growth, whereas only 474,000 acres are actually scheduled for potential harvest.

Table 7.

Analysis of the range of island sizes across the Tongass National Forest and the amount of productive old-growth (POG) at potential risk.¹

Island Size ² (acres)	No. of Islands	Total Area	Total POG	No. Islands w/POG Suitable for Harvest	Acres POG	% POG	1995 Second Growth
1-1,000	461	68,807	43,201	0	0	0	3,660
1,001 - 10,000	58	196,503	95,647	8	2,105	2.2	13,659
10,001 -100,000	19	502,271	272,552	7	25,759	9.5	29,710
Over 100,000	19	16,018,366	4,652,201	18	579,064	12.4	356,440
Total	557	16,785,947	5,063,601	33	606,928⁽³⁾	12.0	403,469

¹ The proportion of the productive old-growth (POG) that is suitable for timber harvest over the next 100 years in the Forest Plan is a measure of relative risk to potential island endemic taxa that may be associated with old-growth forests.

² Includes only federal lands.

³ Only 474,000 (80 percent) of these suitable acres are scheduled for harvest over the 100-year planning period.

In recognition of the uncertainty about island endemic species and their vulnerability, the Forest Plan contains a “survey and manage” standard and guideline designed to substantially reduce the risk to endemic mammals on these islands. If surveys indicate the presence of these taxa, proposed projects will be designed to ensure their long-term persistence on the island.

c. Habitat Connectivity

There is general agreement among scientists that habitat connectivity is an important component of a landscape conservation strategy (Kiestler and Eckhardt 1994, Lidicker 1995). There is, however, uncertainty regarding how connectivity should be achieved in an integrated conservation strategy: through explicitly designed corridors; by designing larger reserves thereby decreasing dispersal distances and facilitating population interchange; or by using an overall matrix management design (e.g. the “50-40-11” matrix prescription designed to provide marginal foraging habitat between reserves for dispersing northern spotted owls (Thomas et al. 1990)).

In light of the uncertainty regarding a variety of approaches to provide landscape connectivity, a further review and analysis was conducted by the IDT. Thus, the TLMP Revision has incorporated a combination of all three landscape conservation design approaches to address landscape connectivity. It has not relied on a single strategy. Beach and riparian corridors of specific widths have been established that provide significant within-island habitat connectivity; habitat reserves have been enlarged (see Old-Growth Habitat Reserves above) often minimizing dispersal distances between many reserves; and standards and guidelines that govern management of the matrix outside reserves (including beach and riparian buffers) contribute to retaining a substantial old-growth forest component to provide connectivity. If site-specific project analyses identify deficiencies in landscape connectivity, the Forest Plan Old Growth Habitat LUD provides the opportunity to re-examine small habitat reserves, which may be adjusted to provide the necessary connectivity (see Small Old-Growth Habitat Reserves, below).

An additional approach to achieve landscape connectivity is to use timber harvest practices that retains some forest structure within the stand after harvest. Application of the marten and goshawk stand level management standard and guidelines will contribute to maintenance of potentially important stand structure in landscapes with substantial amounts of even-aged clearcut harvest with little within-stand residual structure. The goshawk management standard and guideline will be applied to the 28 heavily harvested and fragmented VCU's on Prince of Wales Island. The marten standard and guideline will apply in these same 28 VCU's plus an additional 3 VCU's on North and Central POW and 2 VCU's on the Revilla/Cleveland and vicinity province. Since the marten standard and guideline applies to VCU's that currently exceed 33 percent of POG harvested as well as VCU's that will exceed that amount through future projects, this standard and guideline may apply to additional VCU's in the near future. Considering the likely timber harvests in the first decade of forest plan implementation, this management may apply to 1 VCU on East

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Chichagof, 37 VCU's on Prince of Wales Island, and 3 VCU's on Revilla/Cleveland province: Retention of this substantial amounts of within-stand structure should serve to minimize the adverse impacts of additional timber harvest.

Another feature of connectivity identified by the PNW Review were critical links or "pinchpoints" connecting major landscapes within islands (Marcot in Kiester and Eckhardt 1994, p. 103). Such pinchpoints must be carefully protected (Kiester and Eckhardt 1994, p. 17). The IDT identified six such landscape pinchpoints, all relatively narrow areas between larger land units where future alterations in habitat could significantly reduce natural connectivity and limit the ability of land-based species to disperse or migrate. These areas and their degree of protection include:

1. The portage between Tenakee Inlet and West Port Frederick on Chichagof Island is a narrow neck of land connecting northeast Chichagof Island to the main body of the rest of the island. This is in the East Chichagof biogeographic province. This area is completely protected with a large old-growth habitat reserve using the Old Growth Habitat LUD.
2. The area connecting Lisianski Inlet with the North Arm of Peril Strait is a narrow region that connects two major portions of Chichagof Island. This area is fully protected as a Legislated LUD II area.
3. The area between Port Camden, Bay of Pillars, and Three-Mile Arm on Kuiu Island (Kuiu Island biogeographic province), a narrow neck of land connecting the northern and eastern part of the island to the rest of Kuiu Island. This area is protected with the Old Growth Habitat LUD through a combination of several adjacent small old growth habitat reserves.
4. The narrow area between Lindenburg Peninsula and the remainder of Kupreanof Island is largely protected by the Petersburg Creek Duncan Salt Chuck Wilderness. The remaining small area not included in the Wilderness between Portage Bay and Duncan Salt Chuck is primarily peatland; the 1,000-foot beach fringe provides additional connectivity.
5. The Neck Lake area between Whale Passage and El Capitan Passage on Prince of Wales Island (North Central Prince of Wales biogeographic province) has had significant past and on-going forest management activities. It also is a relatively narrow piece of land connecting the extreme northern end of Prince of Wales Island to the remainder of the island. A cross-island connection is nearly protected with a small reserve around Neck Lake and fully protected further south with the very large natural setting reserve around Sarkar Lakes. Connectivity is also provided on both sides of the narrow pinchpoint with the 1,000-foot beach fringe corridor.
6. Sulzer Portage is between West Arm Cholmondeley Sound and Portage Bay at the head of Hetta Inlet on Prince of Wales Island. This relatively narrow neck of land joins the southeast part of Prince of Wales Island to the remainder of the island, connecting North Central and South Prince of Wales biogeographic provinces. This area has had considerable timber harvesting on both National Forest and adjacent private lands. Due to a recent transfer of land ownership the area is now all private land, dividing the northcentral and south portions of Prince of Wales Island with a non-National Forest strip 1-2 miles wide. Continued timber harvesting is anticipated on these private lands, with the potential of creating dispersal barriers. However, clearcuts and advanced second growth forests (50-100 years old) are unlikely to create complete barriers to movement for deer, wolves, marten and squirrels or other species of concern.

d. Identification and Mapping of Old-Growth Forest Reserves

The focus of most wildlife conservation measures in this strategy is the productive old-growth forest component of the terrestrial ecosystem. The Land and Timber Type map (TIMTYP) was used to quantify the abundance of productive old-growth and to identify old-growth reserves. Lands mapped as productive old-growth met two criteria. First, they had to qualify as productive forest, defined as stands of commercial value capable of producing at least 20 cubic feet of wood fiber per acre per year or has 8,000 board feet/per

acre and has at least 10 percent tree cover. The second criterion was that the land be classified as old-growth sawtimber. This is one of the four size classes defined for the Tongass TIMTYP forest inventory. Among other items, such as volume class, stand stocking, and stand decadence rating; this inventory breaks the productive forest into four size classes:

1. seedling and sapling, under 5" diameter at breast height (DBH)
2. pole timber; 5"-9" DBH
3. young-growth sawtimber; 9"+ and less than 150 years old.
4. old-growth sawtimber; 9" DBH and over 150 years

These classes were identified for the TIMTYP inventory using aerial photo interpretation. Tree heights and canopy characteristics were the primary size class interpretation criteria. Actual tree age was not a mapping criterion and age was inferred from other stand features. Generally, the size class 4 stands were identified by high tree-to-tree variation in canopy size, an uneven or coarse canopy structure, and the presence of large trees. These features are indicative of old-growth forest characteristics that also includes a multilayered canopy, large trees for the site, large standing and down trees, and multiple age classes. For the Forest Plan analyses, size class 4 stands are used to identify productive old-growth forest. This is a reasonable assumption for the following reasons:

1. Stands that are at or near the age of 150 years of age are relatively rare on the Tongass, so the average age of stands classified as size class 4 is much greater than 150 years. Farr et al. (1976) examined 1,234 trees 11.0" DBH and larger. They found average age at breast height to be 282 years old in mixed hemlock/spruce stands. Three trees were greater than 600 years old. The oldest tree in the study was 775 years old. Due to natural disturbance factors (heart rot, insects, wind) this study indicated that trees over 500 years old are not common.
2. The majority of the size class 4 stands are also mapped as wellstocked and as having a high decadence rating. This indicates that these stands are relatively old, uneven aged, and contain old growth characteristics. For example, annual tree mortality exceeded by nearly 3 times the annual growth for the 1.2 million acres of timber lands on the Stikine area (Rogers and van Hees, 1984).

The map of old-growth developed for the Tongass reveals that expansive, contiguous stands of productive old-growth occur only rarely. The forest is generally a mosaic of many forest types and volume classes with significant within stand heterogeneity. Because of the variable nature of the landscape it is not possible to map large reserves of pure or nearly pure productive old-growth forest. Rather, large reserves tend to reflect the overall composition of the landscape, especially high volume old growth. Biologically, mapping entire landscapes has the advantage of including the full range of ecological conditions present in an area. Such large reserves, mapped at the landscape scale, are more likely to support a greater array of the life history requirements of species and to fully represent the elements of biodiversity. Creating reserves around individual old-growth stands might increase the proportion of high volume productive old-growth in the reserves, but would not necessarily accomplish the objectives of providing for species viability and diversity.

Efforts were made to map reserves that contained as high a proportion of productive old-growth forest as possible given the other criteria (size and spacing) of the reserve system. The resulting mapped reserves incorporated the largest remaining intact old-growth blocks, and they were on average superior to surrounding landscapes when comparing the proportion of high volume old growth.

7. Summary

In summary, the IDT concluded that the original VPOP strategy was a sound and effective landscape approach to address the long-term conservation of old-growth associated wildlife species. VPOP used a coarse filter conservation planning approach to develop a comprehensive, multi-scale landscape conservation strategy. They incorporated the entire community of old-growth associated species into their analysis and focused on those species with the greatest viability or distribution concerns in the development of their strategy. Additional scientific information, such as conservation assessments and recommendations

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contained in the PNW Review, have been incorporated in the Forest Plan to further strengthen the original VPOP strategy. The VPOP Response was considered as a brief “initial response” of some possible considerations that may have been integrated into a final report. While VPOP Response recommendations have not been explicitly incorporated, many of the elements of the VPOP Response have been addressed in concept in the Forest Plan (wider corridors, larger reserves, protection of high volume old-growth, etc.).

The old-growth habitat conservation strategy in the Forest Plan was carefully crafted in response to these fundamental conservation planning documents. Based upon an consideration of the best available information related to conservation planning, the Forest Plan provides a sufficient amount and distribution of habitat to maintain viable populations of old-growth associated species after 100 years of Plan implementation. Due largely to uncertainty, the Forest Plan does not, however, represent a “no risk” conservation strategy; rather it represents a balance of wildlife conservation measures that consider the best available scientific information and reflect an acceptable level of risk for continued species viability.

B. Alexander Archipelago Wolf

1. Introduction

An interagency conservation assessment, *The Alexander Archipelago Wolf: A Conservation Assessment* (Person et al. 1996) (Wolf Assessment), was developed mutually by the Alaska Department of Fish and Game (ADF&G), Forest Service (FS), and Fish and Wildlife Service (FWS) to synthesize the best available information on this wolf subspecies and to address wolf conservation. Using the major findings contained within the Wolf Assessment as a benchmark for analysis, we conclude that the Forest Plan provides habitat conservation elements that will result in a high likelihood of maintaining habitat to sustain viable wolf populations in Southeast Alaska.

The Wolf Assessment identifies three principle management considerations to address both near-term and long-term wolf viability: 1) long-term deer habitat capability; 2) habitat reserves; and 3) wolf mortality management. Wolves occur on the mainland and on the islands of Southeast Alaska, except for Admiralty, Baranof and Chichagof Islands. The greatest potential concerns exist in two areas with large amounts of past and current timber harvest and road construction. The first is Prince of Wales (POW) and Kosciusko Islands in ADF&G Game Management Unit (GMU) 2 and the second is on Kuiu, Kupreanof, and Mitkof Islands in GMU 3. These two areas were the focus of our wolf viability analysis. There is limited reference to other literature given the comprehensive nature of the Wolf Assessment.

2. Deer Habitat Capability

Sitka black-tailed deer are the principal prey of Alexander Archipelago wolves and long-term viability of wolves is directly related to long-term deer habitat capability, a point of common agreement among members of the Wolf Assessment Panel (Iverson 1996d) and Person et al. (1996). Timber harvest of important deer winter range reduces deer habitat capability (Suring et al. 1993, DeGayner 1996). Fragmentation of deer habitats also may increase deer vulnerability to predators, especially in winters of heavy snowfall (McCullough in Kiester and Eckhardt, 1994, p.119). However, after a review of deer habitat relationships, the Deer Assessment Panel did not include “patch size” as a variable practical for the development of a deer habitat capability model (DeGayner, 1995). Further, “patch size” was not suggested to be added as a variable during the subsequent interagency deer model workshops (DeGayner 1996). The deer model primarily addresses deer forage biomass and associated factors affecting forage availability (forest type, elevation, aspect, canopy show interception capability, etc.). Patch size may affect wolf predation rates (increased predation efficiency); however, predation does not influence deer vegetation habitat capability, only the potential number of deer ultimately available to humans.

To estimate long-term deer habitat capability for the Forest Plan, the interagency deer habitat capability model was applied. The model was originally developed by Suring et al. (1988). This model was evaluated and revised during the Deer Panel Assessment meeting (DeGayner 1995). It was again reviewed and jointly revised during interagency (FWS, ADF&G and FS) meetings in May 1996 (DeGayner 1996). In general, the

model assumes that winter habitat is limiting and that lower elevations and southerly aspects have the highest habitat capabilities, particularly in heavy snow regions of Southeast Alaska. Stand level features considered important for deer winter range include an abundance of understory forage and a canopy structure capable of intercepting snow so that forage remains available during deep snow conditions. Stands considered as important deer winter range have a net volume of at least 20,000 (Hanley and Rose 1987) to 25,000 (Kirchhoff and Schoen 1987) board feet/acre. These stand volumes are represented in *both* the medium (average = 25,000 board/acre) and high (average = 35,000 board feet/acre) volume strata used in the Forest Plan and this report.

Using this revised model, current deer habitat capability was estimated, as was the capability in year 2095 after full implementation of the Forest Plan for 100 years. *The habitat capability model only estimates relative long-term habitat carrying capacity, and although this is expressed as number of deer, it is not an estimate of actual deer populations.* Habitat is only one of many factors that determine actual deer populations. Actual deer populations are subject to factors other than habitat such as severe winters, disease, predation, and hunting. While some uncertainty associated with the interagency deer habitat capability model exists, it presently represents the best scientifically-based tool available to estimate effects of management activities on deer habitat.

Immediate concerns focus on the cumulative effects of past timber harvest on the reduction in deer habitat capability on POW/Kosciusko Islands, where modeled deer habitat capability has declined over 20 percent since 1954 in 12 of 25 ADF&G Wildlife Analysis Areas (WAA's) (Appendix 12). In 3 WAA's capability has declined over 40 percent (Appendix 12).

Analysis of the deer habitat capability factor, assuming maximum allowable timber harvest every decade for 100 years of implementation of the Forest Plan, suggests that this factor leads to a relatively low risk to wolves. Kirchhoff (1993) recommended that a long-term carrying capacity of 5 deer/mile² was necessary to sustain a deer/wolf equilibrium in GMU 2. This estimate was revised by Person et al. (1996), who suggested that an average long-term carrying capacity of 13 deer/mile² would reduce long-term risks to wolf viability, sustain wolves, and maintain current levels of deer harvest by humans. Deer densities less than 13 deer/mile² but greater than 5 deer/mile² may indicate that wolves are viable but that human deer harvest could decline.

Of the 25 WAA's on POW/Kosciusko Islands, the deer habitat capability model estimated that the Forest Plan would support 13 deer/mile² in 20 WAA's in 2095 (Appendix 12). Of the 18 WAA's on Kuiu/Kupreanof/ Mitkof Islands, 14 WAA's would support at least 13 deer/mi² assuming maximum allowable timber harvest every decade for 100 years. Thus model outputs indicate that 34 of the 43 WAA's in the region of some concern for wolf viability in Southeast Alaska (portions of GMU 2 and 3 identified above) will maintain long-term (100 years) deer habitat that is likely to both support wolves and current human deer harvest. Model outputs for the same regions in 2095 also indicate that all 43 WAA's would maintain habitat capable of producing at least 5 deer/mile² and thus maintain current wolf populations. Note that 6 of the 9 WAA's that will support less than 13 deer/mile² in 2095 are not capable of supporting this estimated habitat capability density in 1995 (Appendix 12). We conclude that either these WAA's are currently at increased risk of not sustaining current wolf populations or current human deer harvest levels or both.

Furthermore, the Wolf Assessment concluded that sustaining the current estimated wolf population on POW/Kosciusko Island would require a deer population of from 42,500 to 54,000 for a 95 percent probability of equilibrium given current human deer harvest levels. The current estimated deer habitat capability on POW/Kosciusko is 48,743 (Appendix 12), within 10 percent of the 55,000 habitat capability reported in the Wolf Assessment using an earlier version of the interagency deer model. The estimated deer habitat capability on POW/Kosciusko projected for 2095 is 42,045 (Appendix 12), essentially the lower estimate of deer populations necessary to support the current wolf population, current wolf harvest, and current human deer harvest levels. This analysis conservatively assumes no deer habitat capability on private, state, or municipal lands, thereby probably underestimating the actual habitat capability for many landscapes.

The estimates of deer habitat capability from the interagency model (deer/mile²) are generally comparable to or less than published estimated densities of other black-tailed deer populations in coastal forests of

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northwestern North America (Table 8). For example, the estimated current capability of deer on POW/Kosciusko island is 19 deer/mile² and is less than densities typically reported in the literature. Many WAA's have reduced estimated deer density (habitat capability) due to past timber harvest. However, even relatively unfragmented and unroaded WAA's, such as in Honker Divide (WAA 1319) on central POW Island, have an estimated habitat capability of 20 deer/mile² which is well below published estimates. Note, however, that the deer habitat capability estimates do not have any estimate of variability.

Table 8.

Comparison of estimated densities of black-tailed deer in various locations within the coastal forests of British Columbia and Alaska with Tongass National Forest interagency deer habitat capability model estimates.

Location	Deer/mile ²	Conditions	Source
Reported Deer Density			
Northern Southeast Alaska	32	Mostly < 800 feet elevation, old-growth forest	Wallmo and Schoen, 1980
Finger Mountain, Chichagof Island, Southeast Alaska	89	Mostly < 800 feet elevation, old-growth forest	Kirchhoff, 1994
Northern Vancouver Island	75-150	Coastal old-growth forest	Smith and Davies, 1975 (in Herbert, 1979)
East coast and central and northern Vancouver Island	25 -- 60	Mature coastal forest	Herbert, 1979
Nanaimo River Watershed, Vancouver Island	49	Mosaic of old-growth and early successional coastal forest	McNay and Doyle, 1987
Deer model estimated habitat capability			
POW/Kosciusko Island (most of GMU 2)	19 ⁽¹⁾	Mosaic of old-growth and early successional forest; > 75 percent of original old-growth remaining.	Appendix 12. 1995 habitat capability estimate
Kuiu, Kupreanof, Mitkof Islands (most of GMU 3)	21 ⁽¹⁾	Mosaic of old-growth and early successional forest; > 90 percent of original old-growth remaining.	Appendix 12. 1995 habitat capability estimate

¹ includes a 36 percent reduction for the effect of wolves

The Forest Plan provides for maintaining deer habitat capability sufficient to sustain both wolf populations and current levels of human deer use. The plan guideline, which is generally 13 deer/mi² where deer are the principal prey of wolves (based upon Person et al. 1996 as described above), should preclude declines in deer habitat capability that would adversely affect the equilibrium. However, other factors in addition to habitat may affect the current equilibrium including changes in wolf harvest or human harvest of the deer resource. Because deer model outputs have not been validated through research and the equilibrium level of 13 deer/mi² is a professional working hypothesis, this TLMP Revision analysis indicates areas of potential concerns relative to the current situation rather than an absolute management threshold.

Wolf populations appear to be more resilient in GMU 3 than GMU 2 and may possibly persist under relatively low deer densities. Deer model results for three of the WAA's on Kupreanof Island show that these WAA's do not currently support the estimated minimum level of 13 deer/mile² and yet they apparently support a viable wolf population. Furthermore, wolves persisted in this region (GMU 3) through the consecutive severe winters from 1969-1972 and resulting extremely low deer densities in the 1970's and early 1980s, and have survived over 50 years of bounties paid for all wolves taken in the region (ADF&G 1996). Furthermore, Smith et al. (1986) reported that 78 of 80 wolf scats located near the den of a wolf pack on Revilla Island were dominated by beaver hair and bones and that 70 percent of telemetry relocations were within the vicinity of active beaver colonies. Apparent wolf population resiliency may in

part be explained by a more diverse prey base on the mainland (Person et al. 1996) and possibly in GMU 3, one less directly related to deer abundance. Thus, the estimate of 13 deer/mile² level from Person et al. (1996) may be primarily applicable to POW/Kosciusko Islands where the data originated to conduct the analysis.

The estimated ability of the Forest Plan to provide deer habitat to sustain wolf populations on POW/Kosciusko Islands and current levels of human harvest of deer is conservative for the following reasons:

- a. Estimated deer habitat capability numbers (Appendix 12) are reduced 36 percent where wolves occur to account for wolf predation, e.g., the portion of the deer habitat capability (component of the deer population) consumed by wolves (DeGayner 1996). These reduced deer densities are then used to assess areas that support at least 13 deer/mile², a density estimated necessary to support both wolves and human deer harvest. Using this approach, wolf deer prey needs have been provided for twice: once in the 36 percent reduction in density and once in the 13 deer/mile² density estimate.
- b. The deer model estimates long-term deer habitat carrying capacity and assumes that winter range is the limiting factor to deer populations in Southeast Alaska. Thus, deer habitat capability is essentially the population that could be sustained each year through the most restricted period of the year, generally mid-to-late winter. The model does not consider annual deer demographics and does not include the 'annual increment' of annual spring fawn production that may represent a 20-40 percent increase in population size until mid-to-late winter. This deer biomass is available to wolves essentially throughout the year but is not represented in the above analysis.
- c. Habitat capability from non-federal land is not included in the estimated density estimates as a worst case analysis, thereby understating the actual habitat capability available to wolves. Appendix 12 displays the abundance of non-federal lands and the estimated deer habitat capability in each WAA.
- d. The 13 deer/mile² level provides for both wolf viability and current levels of human deer harvest. Deer densities may have to be much lower to trigger a viability concern if human deer harvest rates decline.
- e. The estimated deer densities generated by the deer model are less than those reported as actual densities in similar habitat, thereby making it likely that we are underestimating deer habitat capability.

In conclusion, maintaining habitat to support current relatively high wolf populations and current human deer harvest is unlikely a viability issue for wolves. This analysis indicates that after 100 years of implementation of the Forest Plan, at least 80 percent of the WAA's on POW/Kosciusko and Kuiu/Kupreanof/ Mitkof will have estimated deer habitat capability densities that meet or exceed 13 deer/mile². Thus, for 20 percent of the WAA's in this region, there is some elevated risk of either not sustaining current wolf populations (estimated at 250-300 wolves) or current annual levels of human deer harvest or both, and there is a slightly elevated long-term risk that any existing current equilibrium may be disrupted.

In a more recent analysis, Person (1997) clarified that the 13 deer/mile² square value published in the Wolf Assessment was predicated upon a deer reproduction rate of 30 percent annually. To achieve this level of annual reproduction, he suggested that the population must be at about 75 percent of carrying capacity. The 13 deer/mile² recommendation in the Wolf Assessment equates to 17 deer/mile² for a deer population at carrying capacity. Therefore, Person recommends that analyses relying upon habitat capability model outputs relative to the Wolf Assessment equilibrium model should use the recommended 17 deer/mile².

The WAA analysis above using the 13 deer/mile² was repeated using the recommended 17 deer/mile² value. Thirteen of the 25 WAA's on POW/Kosciusko and 11 of the 18 WAA's on Kuiu/Kupreanof/Mitkof will be capable of supporting 17 or more deer/mile² mile after 100 years of full forest plan implementation in 2095 based upon deer model outputs (Appendix 12). Thus 24 or 43 WAA's (56 percent) will have sufficient

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deer habitat capability in 100 years to maintain the current deer, wolf, and human deer harvest equilibrium; a reduction from the 80 percent of the WAA's that will sustain the equilibrium as identified above.

We note again, however, that using this higher threshold, a total of 11 of 43 WAA's (26 percent) do not currently have habitat to support 17 deer/mile². Thus, using Person's revised recommendation to sustain the current equilibrium, there is currently insufficient deer habitat to sustain this new modeled habitat capability threshold in over a quarter of the wolf range in GMU's 2 and 3. As concluded above, either these 11 WAA's are currently at increased risk of not sustaining current wolf populations or current human deer harvest levels or both. Alternatively, variability and uncertainty in the equilibrium model or deer habitat capability may be large enough such that these WAA's may in fact sustain the current equilibrium. Because of variability in model inputs and uncertainty of how close current deer populations are to carrying capacity, this revised recommendation of 17 deer/mile² mile, in addition of the lower 13 deer/mile², may serve to express a range of relative risk, rather than an absolute threshold necessary to support the current equilibrium.

Deer populations declined significantly in parts of GMU 3 (especially Kuiu, Kupreanof, and Mitkof Islands) from 1969 to 1972 as a result of heavy and long-lasting snowfall; deer hunting was closed for 18 years. Extremely severe winters are apparently periodic and may occur every 15-20 years in Southeast Alaska (Juday 1984). Wolf populations persisted, at least in low densities, in spite of significant deer population declines. Wolves (and perhaps black bears) apparently factored heavily in limiting deer population recovery, which took nearly 20 years in some areas such as Mitkof Island. Other regions of GMU 3 still have low deer densities, well below the carrying capacity (e.g., Kuiu Island) that the existing habitat could support.

The periodic nature of these severe winter events suggests that during the next 10-15 years there is a high likelihood of such an event occurring again in Southeast Alaska. Within the longer 100-year period, perhaps 3-5 such events could be expected. As deer habitat capability is reduced from timber harvest, the magnitude of deer population declines resulting from these events will possibly increase. Population recovery times also may increase and thus could directly affect wolf populations where deer are the primary prey on the islands of GMU 2 and 3. As such, maintenance of long-term deer habitat capability would reduce the frequency and magnitude of periodic reductions in deer populations. Risks to wolves elsewhere within the wolf range in Southeast Alaska (GMU's 1a, b, c or the remainder of 3) are lower because of lower levels of anticipated timber harvest and increased prey diversity. However, continued reductions in deer winter range coupled with the likelihood of another periodic severe winter could increase the likelihood of deer populations declines: these declines could be as dramatic as those experienced in Kuiu/Kupreanof/Mitkof Islands in 1968-1971.

3. Habitat Reserves

The Wolf Assessment (Person et al. 1996) concluded that to reduce long-term risks to wolf viability, large roadless and unfragmented reserves should be established in biogeographic provinces where extensive timber harvesting is planned. An area of approximately 50,000 acres of limited human access and timber harvest per 192,000 acres of landscape was considered necessary to support relatively secure core wolf populations. These more secure wolf populations would provide surplus individuals to disperse and support less secure populations in non-reserved lands within the matrix. Spacing among reserves was not judged a critical criterion due to extensive mobility of wolves. On POW/Kosciusko Island they suggested nine 50,000-acre reserves totaling 437,000 acres. Applying the same design criterion, an estimated seven reserves totaling 350,000 acres would be needed on Mitkof, Kupreanof and Kuiu Islands (representing most of GMU 3). The assessment also concluded that each reserve should have enough high quality habitat to be capable of producing an estimated 18 deer/mile².

Biogeographic provinces may not always represent the most meaningful level of ecological stratification relative to wolf ecology, and thus some provinces were not included in this analysis for several reasons: 1) they were not discussed extensively in the Wolf Assessment due to lower viability concerns (e.g., mainland provinces); 2) sustainable wolf packs may not exist in provinces that are aggregates of smaller islands (e.g., Outer Islands); or 3) provinces may be aggregates of intermediate sized islands that may support

sustainable wolf populations but are individually smaller than the modeled amount of 192,000 acres (e.g., Wrangell and Zarembo Islands in the Etolin and Vicinity Province). Etolin Island is 219,000 acres and has one contiguous reserve covering 75,695 acres, which exceeds by nearly 50 percent the minimum suggested size of 50,000 acres. However, Zarembo Island is 117,000 acres and Wrangell Island is 134,000 acres, each well below the 192,000-acre identified for a 50,000 acre reserve. Reserves needed for these landscapes are unknown. Because data was available for the POW/Kosciusko region and there were heightened viability concerns there, Person et al. (1996) focused on that region and did not address intermediate sized islands or other biogeographic provinces.

In the portions of GMU 2 and 3 analyzed in detail, the total number of acres in at least 50,000-acre contiguous reserves in the Forest Plan exceeds by 5 percent (POW/Kosciusko) and 8 percent (Kuiu/Kupreanof/Mitkof) the number of acres suggested for that region in the Wolf Assessment (Table 9). In addition, every reserve approaches or exceeds the level of deer habitat capability of 18 deer/mile square as a relative indication of good quality habitat. The reserves are also dispersed throughout these two areas

A few of these reserves represent new Old-growth LUD allocations and may have some roads from previous management activity (e.g., Central POW reserve). Continued use of these roads will be examined using site-specific information, consistent with direction in the Old-growth Habitat LUD and Forest-wide Standards and Guidelines for Wolves.

Table 9.
The number of reserves in portions of Game Management Units 2 (Kosciusko and Prince of Wales Island) and 3 (Kuiu, Mitkof, and Kupreanof Islands) needed, according to Person et al. (1996), to reduce long-term risks to wolf viability.¹

Area	Reserves needed	Acres needed	Reserves present	Total acres	Deer habitat capability deer/mi ²
Prince of Wales/ Kosciusko	9	437,000	Calder Holdbrook	56,546	22.8
			Honker/Karta	200,584	17.8
			South POW	199,945	21.4
Total				457,075	
Kupreanof/Mitkof/Kuiu	7	350,000	Tebenkof/South Kuiu	233,346	29.6
			Petersburg/Salt Chuck	91,747	17.3
			Wilderness		
			East Rocky Pass	52,297	21.2
Total				377,390	

¹ Contiguous reserves are listed with their respective total area in acres. The estimated current deer habitat capability is also presented for each reserve.

4. Wolf Mortality

The third consideration relative to wolf viability is any potentially unsustainable human-induced wolf mortality. The Wolf Assessment identified open road access as a contributing factor to excessive mortality, stating that reported wolf kills increased substantially where open road density exceeded 0.7 miles of road per square mile of landscape. Wolf mortality concerns are primarily focused on POW and Kosciusko Island (most of ADF&G GMU 2) due to the relatively high existing road densities that contribute to greater trapping/hunting access. Wolf mortality results from natural events, legal hunting and trapping, and illegal kills. Human access to large portions of the wolf range on POW increases wolf vulnerability to legal and illegal mortality.

GMU 2 deer and wolf populations have been generally increasing since the severe winters in the late 1960's. Legal wolf harvests from hunting and trapping also have increased dramatically in GMU 2 over the last 19 years (Table 10). The average annual legal wolf harvest from 1977/78 to 1981/82 in GMU 2 was 19

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and increased nearly five fold to an annual average harvest of 96 wolves from 1991/92 to 1995/96. Similar increases occurred in GMU 3 where an average of 13 wolves was harvested from 1977/78 to 1981/82 and increased to an average of 43 wolves during 1991/92 to 1995/96 (Table 10).

In the remainder of the wolf range from Skagway to Dixon Entrance on the mainland, short-term viability concerns in response to management activities are lower despite lower apparent wolf and deer densities. This difference is due to the generally unroaded nature of the mainland, difficulty of hunter access, minimal past and anticipated future timber harvest, relatively minor anticipated reductions in deer habitat capability, and a more diverse prey base upon which wolves depend. Further, wolf harvest has been relatively stable over past 19 years (Table 10) in GMU 1a, b, and c, at least indirectly suggesting a temporary equilibrium between harvest mortality and net habitat capability. Wolf harvest rates in GMU 3 were low but stable before 1991, but have increased during the last five years, possibly in response to recovering deer populations.

Table 10.
Annual legal wolf harvest from hunting and trapping in Region 1 (Southeast Alaska) during the past 19 years

Year	GMU 2 ⁽¹⁾	GMU 3 ⁽¹⁾	GMU 1a, b, & c ⁽¹⁾	Total Region 1
1977/78	23	10	42	75
1978/79	10	16	60	86
1979/80	11	16	45	72
1980/81	34	10	44	88
1981/82	19	14	35	68
1982/83	15	17	48	80
1983/84	27	17	59	103
1984/85	43	7	54	104
1985/86	18	9	52	79
1986/87	39	10	63	112
1987/88	55	9	58	122
1988/89	45	10	42	97
1989/90	32	22	82	136
1990/91	66	18	44	128
1991/92	86	51	59	196
1992/93	105	26	62	193
1993/94	103	48	74	225
1994/95	85	54	80	219
1995/96	99	36	67	202

¹ Game Management Unit (GMU) 2 is Prince of Wales and surrounding Islands and GMU 3 is Kuiu, Kupreanof, Mitkof Wrangell, Zarembo and Etolin Islands. GMU 1 is the entire mainland. Data provided by ADF&G.

The Forest Plan contains a forest-wide standard and guideline that outlines a cooperative interagency analysis to identify regions where wolf mortality is apparently excessive. In such areas we would attempt to determine if the mortality is unsustainable and identify the probable causal factors of the excessive mortality. If road access and specific roads are identified as contributing to excessive mortality, then road closures or access management recommendations can be made and actions taken. In addition, seasons, harvest methods and bag limits need to be considered as population management tools by the ADF&G and Federal Subsistence Board as a cooperative approach to managing wolf mortality at a sustainable level.

The Forest Plan, a programmatic forest plan, does not prescribe a rigid open road density limit. The Wolf Assessment Panel recommended not using a specific road density "rule of thumb." This was contrary to Kirchhoff (1993) and Pletscher (1994) who recommended a road density limit of no more than one mile of open road/square mile. Appendix 13 lists WAA's that currently exceed the 0.7 mile road density identified in the Wolf Assessment and the miles of existing road that would have to be closed to reduce road densities to

within these identified limits. Establishing a rigid road density level, and arbitrarily closing roads to meet this density, provides no management assurance that wolf conservation objectives would be achieved, and may unnecessarily limit overall public use of an established road system that may otherwise have no specific adverse impact on wolf mortality. Management recommendations for road and access management, if necessary, would result from the site-specific analysis discussed above that would identify a problem requiring a local and cooperative management resolution. Open road densities above or indeed below these referenced densities may be appropriate to effectively manage road-access related wolf mortality. This approach is taken by the Forest Plan.

5. Other Considerations

Both short-term and long-term viability concerns for wolves should be considered in light of a recent review by Fritts and Carbyn (1995) that examined wolf viability and conservation relative to nature reserves. They reviewed information on many wolf populations throughout North America and Europe and concluded that data on survival of actual wolf populations might suggest that wolves are more resilient than is indicated by classic population viability analysis theory. In fact, many populations that they examined were smaller than the estimated populations on POW/Kosciusko Islands and these smaller populations appeared to be stable or increasing. They remained concerned, however, about fringe populations and rare subspecies, especially those located in the southern part of the species' range.

6. Summary

The Forest Plan provides a combination of land allocations and forest-wide standards and guidelines that provides sufficient habitat to maintain viable and well distributed wolf populations on the Tongass for 100 years of application of the Forest Plan. This addresses the requirements of the NFMA regulations and purposes of the Interagency Memorandum of Understanding among the FWS, FS, and ADF&G to conserve species with viability concerns and help prevent the need for listing under the ESA (MOU 1994). This conclusion is based upon the following findings using the Wolf Assessment as a basis of analysis.

- a. Habitat reserves in excess of the total indicated in the Wolf Assessment will be maintained on POW/Kosciusko Islands and Kuiu/Kupreanof/Mitkof Islands to provide secure refugia for persistent core wolf packs and increased likelihood of long-term wolf viability. Furthermore, the reserves include high quality old-growth habitat necessary to support the recommended density of 18 deer/mile².
- b. In our conservative analysis, the deer habitat capability of 13 deer/mile², indicated in the Wolf Assessment to sustain the current wolf population that is in apparent equilibrium between current human deer harvest levels and deer habitat capability, is maintained in 80 percent of the WAA's on POW/Kosciusko and Kuiu/Kupreanof/Mitkof in 100 years
- c. Wolf mortality and access management will be addressed through a reasoned, site-specific analysis process to be conducted in cooperation with the FWS and ADF&G. This is a standard and guideline in the Forest Plan and solutions may include road access management.

C. Queen Charlotte Goshawk

1. Introduction

An interagency assessment, *The Conservation Assessment for the Northern Goshawk in Southeast Alaska* (Iverson et al. 1996) (Goshawk Assessment) was prepared jointly by the FS, FWS, and ADF&G to synthesize the best available science information regarding goshawk ecology and to understand the conservation status and provide management considerations for long-term sustainable populations of this raptor in Southeast Alaska. The assessment contained results of a comprehensive literature review, goshawk inventories, Tongass goshawk research information, risk analysis and integrated management

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considerations. This assessment represents the standard of analysis for evaluating the overall landscape management strategy in the Forest Plan relative to sustaining viable goshawk populations.

Based upon the information synthesized in the Goshawk Assessment, implementing the Forest Plan for 100 years will 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. This conclusion is based upon the following analysis at both the landscape and stand level scales: 1) landscapes (VCU's) are examined forest-wide by projecting the abundance of habitat present in 2095, with the assumption that landscapes inconsistent with a 300-year rotation are at elevated risk of not sustaining goshawks, and 2) stand level analyses identify the proportion of goshawk relocation sites and goshawk nest areas that are at risk from timber harvest.

There is limited reference to other literature given the comprehensive nature (including a thorough literature review) of the recent Goshawk Assessment. Brief reference is made to findings of the Goshawk Panel Assessment (Iverson, 1996e).

2. Landscape Level Analysis -- 300-Year Rotation

One of the primary conclusions of the Goshawk Assessment is that if all landscapes were managed using a 300-year rotation schedule on all productive old-growth forests, the resulting set of forest age classes would provide a high likelihood of sustaining well distributed viable goshawk populations across the Tongass. A key finding used to support this conclusion was the significant selection by goshawks of productive old-growth forests (68 percent of all goshawk telemetry relocations) and relatively little use or avoidance (relative to availability) of all other available habitat types. It was also found that goshawks disproportionately use mature sawtimber in the 100-200 year stand age class. Given what is known about goshawk habitat use relative to stand structure, it was concluded that this forest age class was intermediate in value as goshawk habitat and contributes to sustaining goshawks.

There is an important difference between a harvest "rotation" applied to all old growth (an 'ecological' rotation) as a means to express age class distributions within a forested landscape, and a silvicultural timber harvest rotation applied only to suitable acres scheduled for timber harvest. In this analysis we considered an 'ecological' rotation applied to all productive old growth (as in the Goshawk Assessment) because goshawks use a variety of habitats apparently independent of administrative delineations relative to timber harvest capability. Productive old growth habitats not considered available for timber harvest were used by an estimated 46 percent of goshawk relocations (reported in the Goshawk Assessment), and thus the contribution of these habitats must be included in an assessment of overall risk to sustainability of goshawk habitat.

Application of a 300-year 'ecological' rotation generally results in 1/3 of the productive forest landscape in 0-100 year old stands (low value to goshawks), 1/3 in 100-200 year old stands (moderate value to goshawks), and 1/3 in 200-300 or older (old-growth) stands (highest value to goshawks). As described in the Goshawk Assessment, these proportions of habitat within the scale of goshawk use areas (i.e., median home range of approximately 10,000-acres) across a large landscape would provide habitats with a high likelihood of sustaining well distributed populations. The Goshawk Assessment also concluded that habitat reserves are necessary in regions where past timber harvest precluded the opportunity to fully achieve a 300-year ecological rotation.

The concept of extended rotations, like the 300-year rotation, was viewed favorably by members of the Goshawk Assessment Panel for sustaining long-term goshawk habitat (Iverson, 1996e). Panel members, as did authors of the Goshawk Assessment, concluded that maintaining conifer stands in intermediate age stand structure from 100 to 200 years would, in part, supply stand structure for goshawk prey production, and thus goshawk foraging opportunities.

We conducted a risk analysis at the Value Comparison Unit (VCU) level to compare the Forest Plan with this 300-year rotation landscape design; the closer the Forest Plan came to meeting this design, the higher the likelihood of long-term, well distributed goshawk persistence. The proportion of productive old-growth

forest remaining in each VCU across the Tongass in 2095 assuming full implementation of the Forest Plan was estimated. The analysis was conducted at the VCU level because the Goshawk Assessment identified this scale as a measure of potentially well-distributed populations and because VCU's generally approximate the size of median adult goshawk use areas (10,000-acres) on the Tongass.

A 300-year ecological rotation results in an average of 3.3 percent of the productive old-growth harvested per decade over the 300-year period. At this 300-year rotation rate of harvest, and accounting for all timber harvest since year 1954, VCU's should have no more than 47 percent (14 decades times 3.3 percent) of the productive old-growth harvested at year 2095. If a VCU exceeds 47 percent harvest in 2095, productive old-growth would have been harvested at a faster rate than that of a 300-year ecological rotation, and possibly result in excessive amounts of early-aged (0-100 years old) forest. According to the Goshawk Assessment, this could result in an increased risk of not sustaining goshawks in that VCU or local landscape. We concluded that up to 33 percent of the productive old-growth in a VCU in early seral forest (0-100 years old) was consistent with a strategy to sustain goshawk habitat based upon a working hypothesis of a 300-year rotation. Those VCU's with between 33 and 47 percent of the total productive old-growth in early seral forest structure represents a slightly increased risk of not supporting goshawks.

To estimate forest-wide risk to goshawks with application of the Forest Plan until the year 2095, the number of VCU's with greater than 47 percent and between 33 and 47 percent of the productive old-growth harvested since 1954 was divided by the number of landscapes (VCU's) across the Tongass that might support goshawks. Many of the 926 VCU's forest-wide are composed largely of unsuitable goshawk habitat, including rock, ice, and peatland. The analysis only included the 678 VCU's that have at least 2,300 acres of productive old-growth forest, an estimate of the minimum amount necessary to support goshawks. This acreage amount was used because the median adult goshawk home range size is 10,000-acres and the least amount of productive old-growth within any goshawk use area reported in the Goshawk Assessment was 23 percent. Under these assumptions, this analysis is considered conservative because it does not include the over 280,000 acres of productive old-growth in 248 VCU's forest-wide having less than 2,300 acres of productive old-growth per VCU. There is a high likelihood that these VCU's collectively support some goshawks.

Using only percentages of productive old-growth harvested may be misleading in some instances, and absolute amounts of productive old-growth may be an important consideration in a VCU-based risk analysis. Specifically, even though a VCU may exceed a certain proportions of productive old-growth harvested (e.g., 33 percent, between 33-47 percent, or greater than 47 percent), the resulting landscape may still contain a substantial total amount of suitable habitat, and thus the overall risk to goshawks may be less. This situation could occur in very large VCU's or VCU's that originally had a substantial proportion of productive old-growth before timber harvest began in 1954. An example is VCU 588. Originally, it had 20,668 acres of productive old-growth and now has 10,942 acres for a 47 percent reduction—yet despite the magnitude of reduction, the 10,942 acres may be sufficient to support goshawks within that VCU. Thus, those VCU's that would contain greater than 6,700 acres of productive old-growth in 2095 were not considered at elevated risk, despite exceeding an absolute proportional level (33 percent or 47 percent), because we assumed they would have sufficient habitat to sustain goshawks. This amount of old-growth is 67 percent (2/3's of a landscape in suitable habitat condition) of the 10,000-acre median goshawk use area size. This is a conservative estimate for two reasons. First, the Goshawk Assessment concluded that up to 1/3 of a landscape may be in an intermediate value stand condition (100-200 years old) and this analysis allocates this 1/3 to high quality productive old-growth forest. Second, the analysis assumes that 100 percent of the use area is productive old-growth, which never occurred (Goshawk Assessment, Appendix 1).

Results of this analysis indicated that a total of 35 VCU's across the forest currently (1995) exceed 33 percent of the productive old-growth harvested. Thus, approximately 5 percent of the range of the goshawk habitat across the entire Tongass (35 of 678 VCU's) is at an elevated risk (e.g., > 33 percent)(Appendix 14). Twenty-six of these 35 VCU's (74 percent) are aggregated in the North Prince of Wales biogeographic province. This finding is consistent with a risk analysis presented in the Goshawk Assessment. No other province among the 21 provinces on the Tongass had more than 3 VCU's with elevated risk, suggesting that any remaining risk is minimally dispersed forest-wide.

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Full implementation of the Forest Plan in 2095 would result in 51 VCU's with over 47 percent of the productive old-growth harvested, representing an elevated risk of not maintaining a high likelihood of sustaining habitat to support goshawks across 7.5 percent of the species' range on the Tongass (Appendix 15). Again, most risk occurs on the North Prince of Wales biogeographic province where 29 VCU's (57 percent) exceed a harvest of 47 percent of the productive old-growth. Of the remaining 22 VCU's, no more than 5 that exceed 47 percent occur in one province, indicating a generally dispersed risk across the other 8 provinces forest-wide that have at least 1 VCU in excess of 47 percent of the productive old-growth harvested. An additional 64 VCU's forest-wide (9 percent) would have between 33 and 47 percent of the productive old-growth harvested in 2095, indicating a slightly elevated risk (Appendix 16). Again, most of these VCU's would occur in the North Prince of Wales province (25 VCU's or 39 percent). A total of 10 VCU's (16 percent) would occur in the East Chichagof Island province.

The likelihood of sustaining a satisfactory distribution of habitat at the VCU spatial scale to support goshawks may be reduced in some localized regions where timber harvest in aggregates of VCU's exceeds the habitat capability of a 300-year rotation. This is especially true for the North Prince of Wales Island. However, risks may be compensated by several factors:

- a. The Goshawk Assessment concluded that where past timber harvest had exceeded the harvest rate to achieve the age class distribution of a 300-year rotation, large reserves in those landscapes would compensate for the habitat loss due to timber harvest. They also concluded that insufficient information existed to prescribe the design of a reserve-based strategy to sustain goshawks. The Forest Plan does, however, provide at least one very large reserve in each biogeographic province (Appendix 5). In the Prince of Wales Island area, most notable are the Sarkar/Honker Divide/Karta Wilderness reserve that totals over 200,000 acres, the 200,000-acre reserve on South Prince of Wales, and a 56,000-acre reserve at Mt. Calder/Mt. Holbrook on Kosciusko Island. A 40,000-acre HCA generally was considered too small to sustain more than one or two pairs of goshawks by Goshawk Assessment Panel members (Iverson 1996e). The panelists did not judge reserves greater than 40,000 acres. The two 200,000-acre reserves are each 5 times larger than the V-POP recommended large HCA of 40,000-acres and should certainly contribute to goshawk viability. We concluded that, in addition to these very large reserves, other smaller reserves (e.g., 10-50,000 acres, Appendix 2) also should contribute to reducing overall risk to goshawks in localized areas by providing some goshawk habitat.
- b. The Forest Plan also contains a specific protective standard and guideline to address goshawk habitat in VCU's where more than 33 percent of the productive old growth forest goshawk foraging habitat has been converted to young conifer stands (i.e. those VCU's that do not meet the effective 300-year rotation). In these VCU's, additional timber harvest units over 2 acres in size must maintain forest stand structure characteristics beneficial to goshawks. These include maintaining an average of 30 percent canopy closure and an average of at least 8 large trees per acre. Where harvest units are less than 2 acres, structural retention is not required, but overall stand removal is limited to the equivalent of a 200 year silvicultural rotation.
- c. High quality goshawk habitat is retained in areas where timber harvest is permitted. As discussed above (Old-growth—Matrix), not all acres of productive old-growth in the matrix will be harvested: an average of 57 percent of the original productive old-growth will remain in 100 years. Specifically, standards and guidelines protect riparian areas and the 1,000-foot beach and estuary fringe buffers. These areas are particularly important as goshawk habitat, since riparian habitats receive about 25 percent of all goshawk habitat use as reported in the Goshawk Assessment, and beach fringe areas an average of 15 percent of the total goshawk habitat use.
- d. The distribution of reserves will provide habitat for core populations of nesting goshawks. Goshawks can disperse and recolonize habitats within aggregations of greater at-risk landscapes. While no true juvenile dispersal distances are available for Southeast Alaska, we assume population interchange may also be maintained by adult movements between subsequent nesting areas. The Goshawk Assessment reported that four adult female goshawks moved from 2.3 to 26.9 miles between subsequent nesting seasons. ADF&G (1997) reported that six adult females moved an

average of about 14 miles between nests. The three large referenced reserves on POW are located such that nearly all matrix habitats outside these reserves and other protected areas are within this reported dispersal distance, thus increasing the likelihood of recolonization of landscapes that may be at elevated risk of currently supporting goshawks.

- e. A goshawk nest protection Forest-wide Standard and Guideline protects an area of 100 acres of high volume old growth forest around goshawks nests. This does not represent a comprehensive conservation strategy, but rather serves to conserve identified goshawk nesting habitat sites with different characteristics of stand structure and landscape position. Nest site protection is only one important part of a broader landscape strategy. The Goshawk Assessment also revealed that goshawk nest sites were a nonrandom subset of the landscape with a higher proportion of productive old-growth surrounding the nest. A nesting habitat protection Forest-wide Standard and Guideline serves to protect these local stand level features important to goshawks.

3. Stand Level Analyses—Goshawk Telemetry Relocations and Lands Available for Timber Harvest

Another approach to assess relative long-term risk to goshawk viability is to examine the vulnerability of known goshawk habitats to modifications from timber harvest at the stand scale. In an assessment of the current (1979) Forest Plan, the Goshawk Assessment reported that about 46 percent of goshawk relocations in productive old-growth occurred in sites or stands that were not available for timber harvest (riparian buffers, isolated stands, unstable soils, etc.).

We re-examined the goshawk telemetry relocations reported in the Goshawk Assessment relative to potential timber harvest permitted by land use designations and standards and guidelines in the Forest Plan (Table 11). This analysis is biased towards birds that occur in landscapes allocated to timber harvest because most goshawk nests are discovered during activities related to timber harvest sale preparation, as noted in the Goshawk Assessment. The proportion of goshawk relocations in areas available for timber harvest, and thus at adverse risk to sustaining goshawks, are likely overestimated in this forest-wide estimate of risk to goshawk habitat.

Table 11.
Analysis of goshawk telemetry relocations compared to sites that are available for timber harvest according to the Forest Plan.¹

	All Bird Relocations			Adult Only Relocations		
	Total	Available for Timber Harvest	Percent Available	Total	Available for Timber Harvest	Percent Available
Development LUD's	1559	202	12.9	1230	179	14.5
Non-development LUD's	801	2	0.2	725	0	0
Total	2360	204	8.6	1955	179	9.1

¹ Radio-marked goshawks were separated into those that were captured and tracked in landscapes allocated predominantly to timber harvest land use designations (development LUD's) (e.g., Prince of Wales Island, Kuiu Island) and those captured and followed predominantly in regions where timber harvest is not permitted (non-development LUD's) (e.g., Juneau and Douglas Island). Available refers to relocations that occurred in sites where timber harvest was permitted.

This analysis revealed that among all goshawk relocations, nearly 91 percent occurred on lands not available for timber harvest. Thus on average, approximately 9 percent of habitats of known use by goshawks may be at risk due to possible timber harvest over the next 100 years. Risk increases to 14.5 percent for adults only captured and monitored in landscapes predominantly allocated to management prescriptions that do not exclude timber harvest. This low risk is consistent with the observation that much of goshawk habitat use occurs in sites that are protected from timber harvest. Nearly 70 percent of all productive old-growth forest is in some form of reserved status where timber harvest is excluded, and an average of 57 percent of the original productive old growth will be sustained in areas where timber harvest

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will be permitted. Importantly, the Goshawk Assessment reported nearly 40 percent of goshawk relocations occurred in the beach fringe and riparian habitat, areas specifically protected in the Forest Plan.

We also examined the relationship between known goshawk habitat use patterns and the VPOP Response recommendation to fully protect the three largest old-growth reserves in each biogeographic province. This recommendation, while conceptually attractive for other reasons such as biodiversity, has little apparent relationship with goshawk habitat use patterns. A specific 'forest edge' and 'clearcut edge' analysis in the Goshawk Assessment did not detect any significant relationship between these structurally different ecotones and goshawk habitat use patterns. Based upon telemetry relocations, goshawks neither avoided nor selected these two ecotones, suggesting they may not be sensitive to the difference between natural forest edge and that caused by timber harvest. Further analysis of 'interior' versus 'edge' forest did not detect any selection or avoidance for interior old-growth forest (defined as greater than 300 feet from a forest edge). Based upon results reported in the Goshawk Assessment, protection of the three largest old-growth forest patches would not substantially contribute to critical landscape features important to goshawk habitat use (as compared to selection for beach and riparian habitats that may be prey rich, versus possibly less diverse interior forest conditions).

The spatial relationship between the five largest interior old-growth forest patches in each biogeographic province (Appendix 6) was examined relative to goshawk telemetry relocations (Goshawk Assessment). Forest-wide, only 7 percent (174 of a total of 2,363) of all goshawk relocations occurred within these forest interior old-growth blocks. For comparison, nearly 13 percent of the productive old growth across the Tongass occurs within the entire sample of interior old growth blocks (Appendix 6). This analysis is generally consistent with findings in the Goshawk Assessment that goshawks apparently do not select for interior portions of large blocks of old-growth forest. Based upon these data, the largest interior blocks of old-growth forest do not appear to provide a significant contribution to a goshawk habitat conservation strategy.

4. Goshawk Nesting Habitat

The second component of the stand level analysis was to examine past timber harvest at various spatial scales around known goshawk nests. We also examined additional future risk to known goshawk nesting areas compared to land allocations and standards and guidelines in the Forest Plan. The sample of 36 known goshawk nest areas in Southeast Alaska referenced in the Goshawk Assessment was used for this analysis. As concluded in the Goshawk Assessment, this sample of nests is biased towards goshawks discovered in landscapes predominantly allocated to timber management and may not necessarily be representative of the entire goshawk population in Southeast Alaska.

Relatively little productive old growth has been harvested around known goshawk nests. The proportion harvested increased with distance from the nest, with 3 percent (range 0 -- 50 percent) within the ¼ mile radius (radius area = 140 acres), 12 percent (range 0 -- 57 percent) within a 1-mile radius (radius area = 2040 acres), and 14 percent (range 0 -- 61 percent) within a 3-mile radius (radius area = 18,000 acres) (Appendix 17). Only 2 of 36 nests (6 percent) had any harvest within the 140-acre area around the nest and only 60 acres within the ¼ mile radius had been harvested after the nest was discovered. Forest Service management direction has generally prohibited harvest within this small region around known goshawk nests (USDA Forest Service 1992). Similarly, only 160 acres at 3 nests has been harvested within a 1-mile radius once the nest was located.

There is substantial protection of old growth habitats around known goshawk nests resulting from land allocations in the Forest Plan. A total of 20 of 36 (56 percent) known goshawk nest sites occur in a protected natural setting LUD in the Forest Plan (Appendix 18). Nearly 40 percent of the entire area of all three spatial analysis areas (1/4, 1, and 3 mile radii from the nest) would be protected in a reserve in the Forest Plan, despite being a biased sample toward landscapes predominantly allocated to timber harvest. This compares to the estimated 70 percent forest-wide average of all productive old growth that will be protected in reserves. This analysis includes only those lands protected in a reserve status, and does not include the proportion of old growth that would remain in the matrix lands (see above), an average of 57 percent of the original productive old growth.

5. Evaluation of Cumulative Effects of Non-Federal Ownerships

There are nearly 950,000 acres of state, municipal and private lands in Southeast Alaska (not including Glacier Bay National Park). This represents approximately 5 percent of the total land acreage of Southeast Alaska. The ability of these lands to provide goshawk habitat is generally unknown, which makes factoring in the effects of non-federal lands on overall goshawk viability difficult.

In this analysis (and other previous work developed for the TLMP Revision), the effects of non-Federal lands were considered in several ways: 1) the stand level nest site buffer analysis described above adopted a scenario which assumed all non-Federal lands would be subjected to timber harvest; 2) virtually all goshawk telemetry relocations on non-Federal land occurred in the Juneau-Douglas area and these lands were assumed to be in a natural setting habitat condition; and 3) the VCU by VCU long-term risk analysis was an index of goshawk habitat and risks solely for Tongass National Forest lands.

The conclusion of this analysis is that there is, and should continue to be, sufficient habitat on Federal lands well-distributed across the Tongass in 100 years to attain a moderately high likelihood of sustaining viable goshawk populations. With only 5 percent of Southeast Alaska in non-Federal ownership, there is little reason to alter this conclusion. The Goshawk Assessment provided a “crude estimate” of 15-20 percent current reduction in goshawk habitat capability throughout Southeast Alaska considering all ownerships. A generalization may be made that in those biogeographic provinces with little or no long-term risk (no or only a small number of VCU's exceeding 47 percent of the productive old growth harvested in 2095), there would be little if any additional overall risk from factors attributed to land management activities on non-Federal lands in those provinces. However, in the few provinces with some aggregated risks to goshawk habitats anticipated from potential timber harvest on federal lands (e.g., North Central POW), a high proportion of non-federal land in those provinces (North Central POW, for instance, has 255,000 acres or 17 percent) could add localized risk to goshawks. This further emphasizes the importance of habitat features protected on Federal lands (e.g., beach and riparian buffers and very large reserves in higher risk landscapes). However, again this would not fundamentally alter the conclusion that there is sufficient habitat on Federal lands to maintain well-distributed goshawk populations.

6. Summary

Based upon these analyses, the Forest Plan will provide a sufficient amount and distribution of habitat to maintaining viable and well distributed goshawk populations across the Tongass after 100 years of Forest Plan implementation. These analyses assumed maximum allowable timber harvest every decade for 100 years of implementation of the Forest Plan. This conclusion addresses the NFMA regulations concerning wildlife population viability and purposes of the interagency MOU (MOU, 1994). Several specific analyses support this conclusion:

- a. An estimated 95 percent of the goshawk range on the Tongass currently has a high likelihood of sustaining goshawk habitat (< 33 percent of old-growth harvested).
- b. An estimated 93 percent of the goshawk range on the Tongass would have less than 47 percent of the productive old growth harvested in 2095, and would maintain a high likelihood of sustaining goshawks.
- c. An estimated 9 percent of the goshawk range on the Tongass would have a slightly elevated risk of not having optional habitat for sustaining goshawks, with between 33 and 47 percent of the old-growth harvested in 2095.
- d. Most elevated risk landscapes would be aggregated on North Prince of Wales Island. This province only represents 9 percent of the goshawk range on the Tongass.
- e. Where risks would be elevated by matrix management intensity, remaining very high quality goshawks habitats would be protected by forest-wide standards and guidelines (Beach and Estuary

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Fringe, and Riparian), and very large reserves would be maintained as a compensatory landscape conservation strategy.

- f. There is no detectable relationship between the largest interior forest blocks and important goshawk habitat capability.
- g. An estimated 85-91 percent of goshawk telemetry relocations occur in sites that would not be at risk from timber harvest.
- h. In landscapes allocated to timber harvest, based upon a limited sample of 16 goshawks nests found in areas predominantly allocated to timber harvest, an average of 75 percent (40 percent fully protected as reserves plus an average of 57 percent of the remaining 60 percent subject to timber harvest) of the productive old growth within an area (3-mile radii) around known goshawk nesting areas would receive protection in 100 years in the Forest Plan.
- i. In VCU's currently not consistent with a 300-year rotation on Prince of Wales Island, timber harvest will retain within stand forest structure to reduce the adverse effects of even-aged clearcut timber harvest and retain some foraging habitat value for goshawks.

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VI. Appendices

Note: The appendices to Appendix N are not included with this printed version. They are included in the planning record and are available for review upon request.

Appendix 1. Small old-growth reserves in Forest Plan.

Appendix 2. Listing of all contiguous reserves over 5,000 acres by biogeographic provinces in Forest Plan and a comparison with VPOP large and medium Habitat Conservation Area requirements.

Appendix 3. Total productive old-growth forest protected in reserves by each biogeographic province.

Appendix 4. Existing inventoried roadless acres in each biogeographic province.

Appendix 5. List of the single largest contiguous reserve in each biogeographic province.

Appendix 6. Size and composition of the 5 largest contiguous interior old-growth blocks in each biogeographic province and the proportion of each protected in reserves.

Appendix 7. Size of the 5 largest contiguous blocks of high volume old-growth in each biogeographic province and the proportion protected in reserves.

Appendix 8. Amount and composition of productive old-growth forest in the matrix in 1954 and 2095 by biogeographic province.

Appendix 9. Characterization of the productive old-growth forest within the beach, riparian and other lands not suitable for timber harvest in the matrix that will remain in 2095 after full implementation of the Forest Plan by biogeographic province.

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Appendix 10. Characterization of the productive old-growth forest within the beach, riparian and other lands not suitable for timber harvest in the matrix that will remain in 2095 after full implementation of the Forest Plan by value comparison unit.

Appendix 11. Old-growth habitat reserve criteria.

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Appendix 17. Analysis of the amount of timber harvested within $\frac{1}{4}$, 1 and 3 mile radii around goshawk nest areas in southeast Alaska.

Appendix 18. Analysis of habitat protection within $\frac{1}{4}$, 1 and 3 mile radii around goshawk nest areas in southeast Alaska under the Forest Plan.



United States
Department of
Agriculture

Forest Service
R10-MB-736c

June 2013



Big Thorne Project Thorne Bay Ranger District, Tongass National Forest

Final Environmental Impact Statement

Volume I



3 Environment and Effects

the North Central Prince of Wales Island biogeographic province, and habitat is protected under the Forest Plan conservation strategy, the effects of the Big Thorne Project in combination with past, present, and foreseeable activities may adversely impact individuals, but are not likely to result in a loss of viability in the Planning Area, nor cause a trend toward Federal listing. Forest Plan conservation strategy maintains habitat for goshawks.

Subsistence

Direct and Indirect Effects – All Alternatives

ANILCA requires that any analysis of project-related effects on Federal lands within Alaska take into account, 1) subsistence resource distribution and abundance, 2) access to these resources by subsistence users, and 3) competition for the use of these subsistence resources. This is because changes in access to subsistence resources due to project-related activities can affect the level of effort required, time involved, and the effectiveness of harvesting these resources. Altered distributions and abundance of subsistence resources can effect competition between subsistence and non-subsistence user, as well as competition between individual subsistence users.

Road building associated with timber harvesting is an important agent of change in Southeast Alaska. These road networks provide greater access to areas previously not accessible and can affect subsistence both positively and negatively by providing access, dispersing hunting and fishing pressure, and creating the potential for increased competition for favored hunting areas among communities connected by the existing road system (USDA Forest Service 2008b).

None of the Big Thorne Project alternatives would present “a significant possibility of a significant restriction” of subsistence uses for most subsistence resources (fish and marine invertebrates, food plants, personal use timber, upland game birds and waterfowl, furbearers, and marine mammals). These resources are briefly discussed below.

The direct and indirect effects of the Big Thorne Project alternatives may have a significant possibility of a significant restriction for subsistence uses of deer in the project area WAAs (USDA Forest Service 2008c). As noted above, deer are considered the “indicator” for potential subsistence resource consequences concerning the abundance and distribution of the resources, given their association with old-growth forest habitat and that they are the largest terrestrial component of subsistence food resources (USDA Forest Service 2008b); therefore, they are the only species addressed in detail in this analysis.

Sitka Black-tailed Deer

Abundance and Distribution

The abundance and distribution of deer is generally based on assessing the number and location of deer available for hunter harvest. After timber harvest, deer may shift their patterns of activity in response to forest succession, and the density of deer may decline as even-aged young-growth stands progress beyond shrub and sapling stages to stem-exclusion forests (Wallmo and Schoen 1980). As described in the Deer Effects section, implementation of the action alternatives would locally reduce deer winter habitat capability; which, over the long-term, could result in a reduction in deer numbers.

Alternatives that result in the greatest reduction in deer habitat capability would be expected to have the greatest effect to deer abundance and distribution.

Access

Road building associated with timber harvesting is an important agent of change in Southeast Alaska. These road networks provide greater access to areas previously not accessible and can affect subsistence both positively and negatively by providing access, dispersing hunting pressure, and creating the potential for increased competition for favored hunting areas among communities connected by the existing road system (USDA Forest Service 2008b). New proposed roads would be closed and stored 1 to 5 years after timber harvest activities are completed, under all alternatives; during the 1 to 5 year period, they would be open seasonally (from May 1 to November 30) to High Clearance Vehicles to allow for firewood removal and other incidental uses and would improve access (see the Transportation section for more information on road management objectives).

Alternatives that would result in the greatest increase in the road system would be expected to result in the greatest increase in access to both subsistence and non-subsistence hunters. The greatest increase in road access would occur during project implementation when temporary and new roads are in use. Road access would decrease as road closures are applied, making them no longer available for use by motorized vehicles. Historical access would remain available under all the alternatives. Under all action alternatives there would be temporary restrictions in road access to subsistence during active logging operations as a safety precaution. As this project would occur over 10-years, all proposed timber operations, and temporary road closures would not occur simultaneously.

Timber harvest would also increase access to deer over the short term, due to the clearing of dense vegetation which makes them more visible to hunters. In a study of the influence of industrial logging on deer harvest on Prince of Wales Island, Brinkman et al. (2009) determined that hunters preferred habitats with open terrain, low vegetative cover, and high visibility (i.e., clearcuts). However, shrub and trees establishment in harvested areas associated with the transition of the forest to the stem exclusion stage creates undesirable hunting conditions (i.e., low visibility). Young-growth stands were least popular for hunting because they impeded the hunters' ability to see deer and were thought to contain fewer deer (Brinkman et al. 2009). Young-growth management, proposed under Alternatives 3, 4, and 5, may locally improve hunter access to deer over the long term.

Competition

Competition for subsistence resources is a result the distribution and fluctuation in population levels of game species, harvest regulations, mobility, and access provided to rural communities in the form of roads, ferries, and commercial air carriers. The Big Thorne project area is commonly used by subsistence hunters from a number of local communities for harvesting deer and other subsistence resources. The road network on Prince of Wales Island connects most of the communities on the island to the project area, and has allowed communities access to the area for hunting and other subsistence activities. Non-subsistence users (e.g., those from Ketchikan and Juneau, as well as out-of-state hunters) also hunt in the project area.

3 Environment and Effects

Timber harvest can influence competition for resources through new road construction, particularly near communities potentially generating competition from outside communities with lower abundance of the same resources. Habitat alternations that reduce carrying capacity, which could in turn reduce deer densities, will also increase competition for deer if allowable levels of harvest remain the same but available subsistence resources are diminished. Indirectly, displacement of subsistence hunters from areas with active timber harvest operations could temporarily increase competition in other subsistence use areas. Alternatives resulting in the greatest reduction in deer carrying capacity and increase in the road system would be expected to result in the greatest likelihood of increasing competition for resources.

Other Subsistence Resources

Fish and Marine Invertebrates

The Big Thorne Project would not affect the abundance and distribution of or competition for anadromous or marine fish and marine invertebrates. The risk of project-related impacts to fish populations due to timber harvest would be minimal because of Tongass Timber Reform Act (TTRA) stream buffers, and Forest Plan beach and estuary, riparian, and fish standards and guidelines which maintain water quality and fish habitat (See Issue 4 for detailed assessment). Although the project may adversely affect Freshwater Essential Fish Habitat (EFH) and Marine EFH, effects would be temporary and localized. Fishing and marine invertebrate harvesting occurs primarily from boats, on beaches, and along estuaries. No activity associated with the Big Thorne Project is expected to occur in the marine environment that would preclude access to these resources. Freshwater fisheries are accessed by the road system, with motorized vehicles and OHVs. New roads under Alternatives 2, 3, 4, and 5, some of which would remain open for a period of years, may temporarily increase access to streams used for subsistence fishing. Some existing roads would be closed to public use for safety reasons during active timber harvesting, but any reduction in access would be temporary and localized.

Food Plants and Personal Use Timber

None of the alternatives are expected to negatively affect the abundance or distribution of subsistence plants gathered for food, because these resources are abundant along roads and in previously harvested areas. They are also expected to increase in harvested stands during the early successional stage, declining thereafter. The Big Thorne Project would also not preclude Alaska residents from obtaining timber and firewood for personal use. New roads under Alternatives 2, 3, 4, and 5, some of which would remain open for a period of years, may temporarily increase access to areas where food plants and firewood can be gathered. Some existing roads would be closed to public use for safety reasons during active timber harvesting, but any reduction in access would be temporary and localized. Given that any beneficial changes in the abundance and distribution of food plants, and temporary effects to access, would be distributed throughout the project area over time (i.e., over the 10-year project period and beyond), no changes in competition for food plants or personal use timber would be expected.

Upland Game Birds and Waterfowl

All action alternatives would reduce upland game bird habitat (e.g., POG) and have the potential to increase vulnerability to harvest associated with increased access (see

discussion of spruce grouse above). The presence of OGRs in the Big Thorne project area and implementation of standards and guidelines that maintain connectivity within matrix lands (e.g., various buffer requirements) would help sustain local populations. No measurable effects to waterfowl would occur, given that most species occur in the project area only during migration on lakes and in bays and estuaries (an exception is the Vancouver Canada goose which uses forested and non-forested wetlands), and thus would be minimally exposed to project-related activities in the vicinity of these areas. Thus no changes in the abundance or distribution of upland game birds and waterfowl are anticipated under any of the alternatives. The number of hunters may temporarily increase in the project area due to increased access along project roads, but competition would likely remain the same because upland birds and waterfowl do not contribute a large percentage of the foods for the subsistence communities in the project area.

Furbearers

Estuary, riparian, and forested coastal habitats that receive the greatest use by furbearers such as river otters, beavers, and ermine are protected under Forest Plan conservation strategy. Therefore, the Big Thorne Project would not affect the abundance or distribution of these species.

Timber harvest (through the removal of POG and associated fragmentation) and road building (increased access) could affect the local distribution of marten (see Marten discussion above). Marten may become more vulnerable to harvest due to increased trapper access along project roads. This could increase competition among local communities, particularly if increased access in currently accessible areas were to lead to overharvest. However, these effects would be somewhat mitigated through project road closure and closures under the Prince of Wales Island ATM.

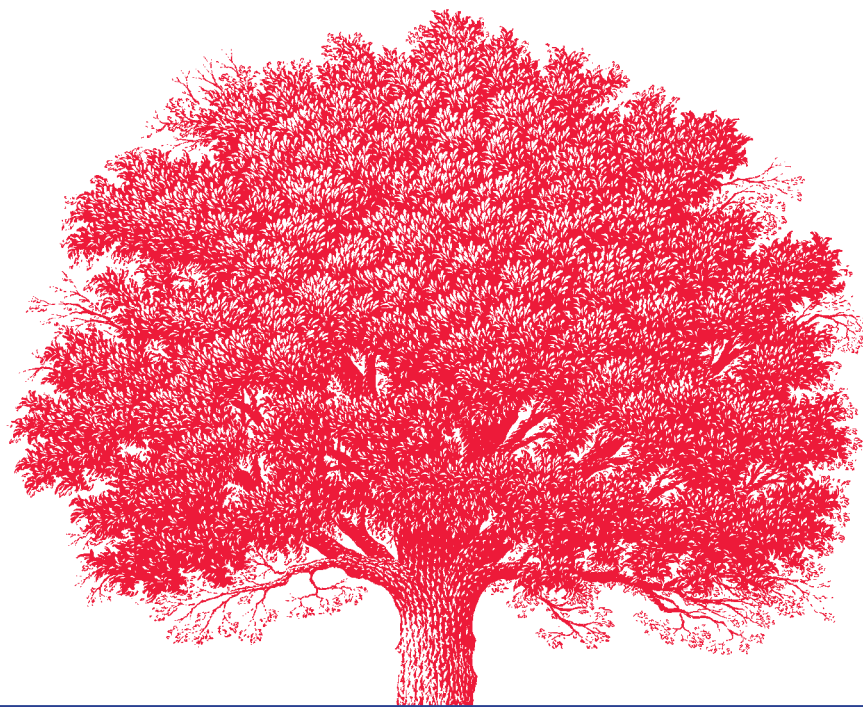
Marine Mammals

Marine mammals have the potential to be exposed to disturbance and noise associated with marine access facilities (MAFs) activity, potential collisions with vessels, and fuel or oil spills associated with vessel traffic. Alternatives 2, 3, 4, and 5 have the potential to result in a minor increase in vessel activity at the existing MAFs and in association with the export of logs. However, vessel activity would be infrequent, and would be spread over 10 years. Vessels used to transport logs are not likely to affect the abundance or distribution of marine mammals in Clarence Strait, given the transient nature of these species and the fact that such vessels typically operate at low, constant speeds, giving the marine mammal species time for avoidance, and would operate at infrequent intervals. Additionally, it is assumed that all vessels operating on behalf of the Big Thorne Project would adhere to Marine Mammal Protection Act, Endangered Species Act (ESA), and National Marine Fisheries Service (NMFS) guidelines for approaching marine mammals, as required under the Forest Plan. Therefore, no change in access to, or competition for, marine mammals would occur as a result of the project.



United States Department of Agriculture

The U.S. Forest Carbon Accounting Framework: Stocks and Stock Change, 1990-2016



Forest
Service

Northern
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AbSTRACT

As a signatory to the United Nations Framework Convention on Climate Change, the United States annually prepares an inventory of carbon that has been emitted and sequestered among sectors (e.g., energy, agriculture, and forests). For many years, the United States developed an inventory of forest carbon by comparing contemporary forest inventories to inventories that were collected using different techniques and definitions from more than 20 years ago. Recognizing the need to improve the U.S. forest carbon inventory budget, the United States is adopting the Forest Carbon Accounting Framework, a new approach that removes this older inventory information from the accounting procedures and enables the delineation of forest carbon accumulation by forest growth, land use change, and natural disturbances such as fire. By using the new accounting approach with consistent inventory information, it was found that net land use change is a substantial contributor to the United States forest carbon sink, with the entire forest sink offsetting approximately 15 percent of annual U.S. carbon dioxide emissions from the burning of fossil fuels. The new framework adheres to accounting guidelines set forth by the Intergovernmental Panel on Climate Change while charting a path forward for the incorporation of emerging research, data, and the needs of stakeholders (e.g., reporting at small scales and boreal forest carbon).

Quality Assurance

This publication conforms to the Northern Research Station's Quality Assurance Implementation Plan which requires technical and policy review for all scientific publications produced or funded by the Station. The process included a blind technical review by at least two reviewers, who were selected by the Assistant Director for Research and unknown to the author. This review policy promotes the Forest Service guiding principles of using the best scientific knowledge, striving for quality and excellence, maintaining high ethical and professional standards, and being responsible and accountable for what we do.

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The U.S. Forest Carbon Accounting Framework: Stocks and Stock Change, 1990-2016

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Author Contributions

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C.W. Woodall, J.W. Coulston, G.M. Domke, B.J. Clough, M.C. Nichols, C.H. Perry, and M.B. Russell developed the initial framework for carbon accounting at a workshop in October 2014.

J.W. Coulston and D.N. Wear developed the R code and techniques for projecting annual forest inventory, separating land use change from forests remaining forest and attribution to disturbance.

G.M. Domke developed new techniques for estimating litter and soil organic carbon.

B.F. Walters conducted the majority of the FIA database development for this project and created infographics and maps.

J.E. Smith contributed writing material.

H.-E. Andersen contributed information on Alaska's carbon accounting.

B.J. Clough contributed the Bayesian uncertainty description.

W.B. Cohen contributed the Landsat/LiDAR research description.

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I.S. Hanou contributed to the description and development of the phone and tablet carbon application.

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PREFACE

A Modeling System That Moves Annual Forest Inventory Data through Time and Attributes Changes to Disturbances and Land Use

The United States is currently in the process of adopting a new approach to forest carbon accounting. The Forest Carbon Accounting Framework (FCAF) will incorporate the most consistently measured annual forest inventories (including all the pools of forest carbon) while aligning with projections of forest resources. Such an approach will reduce inconsistencies, and thus uncertainty, associated with the U.S. forest carbon baseline while empowering policy makers in light of potential future greenhouse gas emission reduction targets.

One role for the new framework is meeting the reporting commitments for the United States under the United Nations Framework Convention on Climate Change (UNFCCC). The forest ecosystem carbon estimates contained herein are initial estimates from the new FCAF that is in development for official release as part of the National Greenhouse Gas Inventory submission of the United States to the UNFCCC in 2016. The United Nations Intergovernmental Panel on Climate Change documents Good Practice Guidance (IPCC 2006) for several attributes that national carbon inventories should aspire to: transparency, consistency, comparability, completeness, and accuracy. In this context transparency means that the data sources, assumptions, and methodologies



Forest Inventory and Analysis field crew measuring a plot in southeast Alaska. Photo by U.S. Forest Service.

are clearly documented. Consistency assures the estimates for all reported inventory years account for changes in data or methods over time. Forest carbon inventories should also be comparable across Nations, an attribute that is empowered by clear documentation. Completeness refers to the identification of all appropriate carbon in forest ecosystems (i.e., pools). Accuracy is attained by removing bias and minimizing uncertainty as much as is practically possible. The new FCAF of the United States seeks to embrace all these tenets through the development of a novel accounting approach that addresses attribution (i.e., disturbances) and land use change and incorporates emerging science and diverse data sources, all while providing clear documentation such as we have done in this first publication.

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INTRODUCTION

Carbon dioxide is one of the most important greenhouse gases that contributes to the warming of our planet via the greenhouse gas effect. Carbon is emitted through the combustion of fossil fuels and through the decay and combustion of organic material such as wood. In contrast, carbon can be sequestered through the growth of trees. Recognizing the need to monitor the emission and sequestration of carbon on Earth, the United Nations Framework Convention on Climate Change (UNFCCC) called for the annual monitoring of carbon among signatory Nations. This annual monitoring mechanism is known as a National Greenhouse Gas Inventory (NGHGI) which contains accounting of carbon emissions and removals (i.e., sequestration). The United States is a signatory to the UNFCCC whereby annual inventory reports of carbon are developed. This document provides additional information on the context of the U.S. forest carbon cycle, a brief history of carbon accounting efforts, and a vision for the future of forest carbon accounting in the United States.

Of all the land uses across the United States (e.g., settlements, croplands, or wetlands), forests sequester the vast majority of carbon from the atmosphere, which partially offsets carbon emissions from sources such as fossil fuel combustion. Due to this important role of forests in the carbon budget, there is a continuous effort to improve the accounting of forest carbon across the diverse ecosystems and ownerships of the United States. In this document we introduce a new approach to forest carbon accounting in the United States, the Forest Carbon Accounting Framework (FCAF). Across this broader document you will gain access

to preliminary estimates from the 2016 carbon inventory of U.S. forests using the FCAF along with contextual analysis of these estimates. In addition, because new data and scientific advances occur annually, planned inventory improvements and promising research directions will be outlined as a potential roadmap for the future.

The U.S. Forest Carbon Cycle in Context

Currently, annual net sequestration of carbon in managed U.S. forests offsets approximately 15 percent of the annual emissions of carbon that result from the combustion of fossil fuels (Fig. 1). In addition, forests contain substantial stores of carbon which have accumulated in some pools (e.g., soils) for millennia. The amount of carbon stored in U.S. forests represents more than 67 years of fossil fuel emissions at today's rate of combustion (see Forest Carbon Vital Signs on page 7). However, just as there are numerous sources of fossil fuel emissions, including electrical generation and transportation, the forest also has numerous carbon pools that emit carbon through decay and combustion. An important difference is that forest carbon pools also serve as active sinks of carbon, in strong contrast to fossil fuels which can only serve as an emission source. New biomass that arises from forest growth and expansion that is not emitted via decay or combustion can serve as a longer-term store of carbon as a wood product, by being assimilated into the forest floor or soils, or by remaining in their constituent pool (i.e., old growth forests). Without the continued expansion and growth of forests, their ability to serve as a substantial offset of U.S. fossil fuel emissions will be diminished.

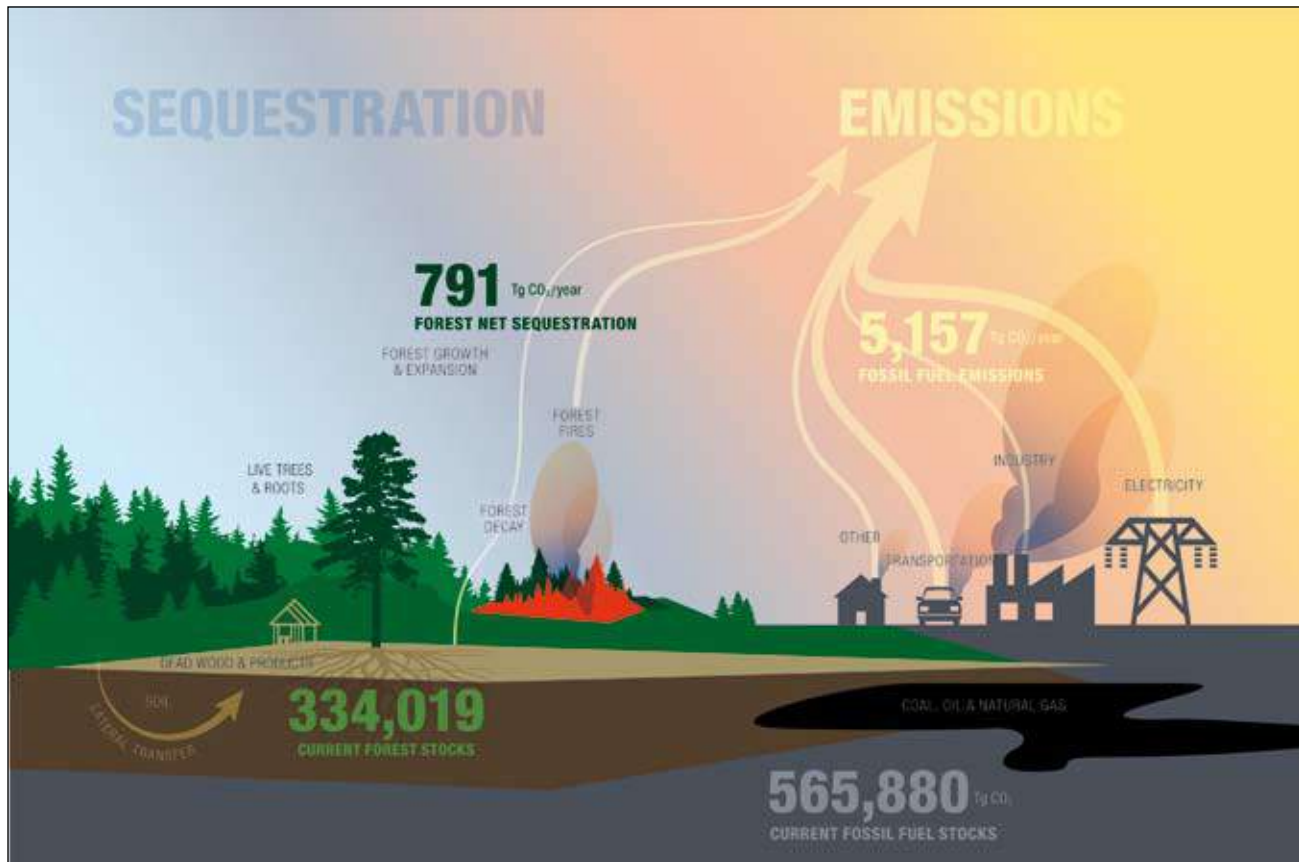


Figure 1.—The components of the U.S. forest carbon cycle (2016 estimates, pools, and flow) in the context of fossil fuel emissions (values for fuel emission estimates from USEPA 2015a). Diagram courtesy of Perry et al. (in press).

Forest Carbon Inventories: A History of Improvements

In the United States, monitoring forest carbon has been a process of continuous improvement as data (both field and remotely sensed) have accumulated in the face of emerging research (e.g., carbon pool science) (Fig. 2). In the 1990s, Birdsey (1992) converted a compendium of periodic forest inventories into carbon assessments using numerous assumptions about volume to carbon conversions. In the 2000s, Heath and Smith ushered in a new era of carbon reporting (Smith et al. 2010) that focused on comparing the nationally consistent annual forest inventories to past periodic inventories to estimate carbon change. In the 2010s, carbon monitoring (Woodall 2012) has focused on improving pool estimation using the full breadth of the national forest inventory system (e.g., including soil

measurements) while developing approaches to incorporate emerging remotely sensed information (e.g., Landsat and LiDAR) and aligning with projection systems.

The Forest Carbon Accounting Framework Vision

In response to calls for improved terrestrial carbon accounting in the United States stemming from the Agricultural Act of 2014, also known as the 2014 Farm Bill (Agricultural Act 2014), and the President's 2013 Climate Action Plan (U.S. Executive Office of President 2013), a cohesive carbon accounting framework (the FCAF) was envisioned that linked the Forest Inventory and Analysis (FIA) annual inventory system of all forest carbon pools to modules that compile predictions of carbon stocks and stock changes back to the 1990

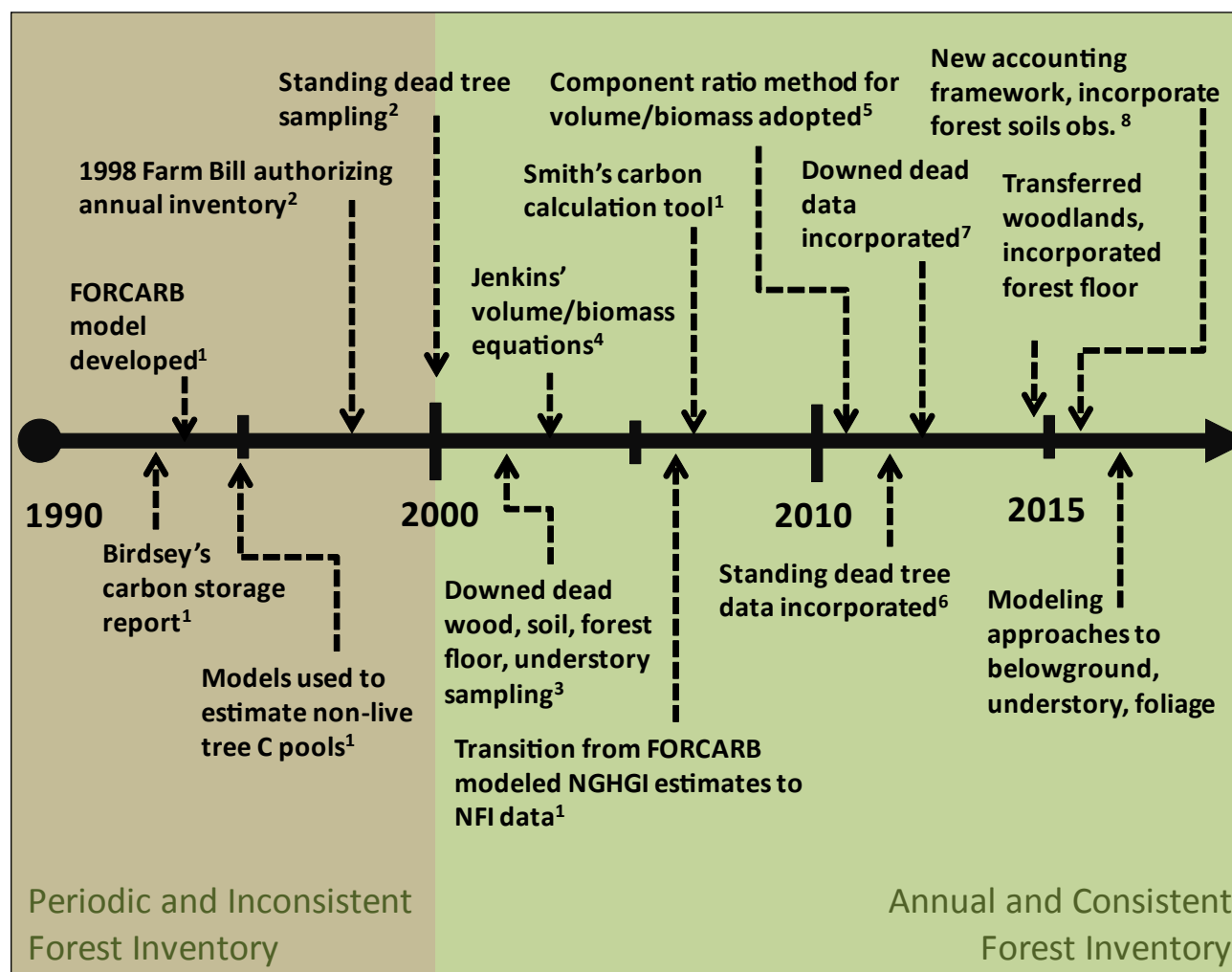


Figure 2.—Timeline of the development of national greenhouse gas inventories for U.S. forests showing the phasing out and replacement of periodic forest inventories with annual forest inventories. References include: ¹(Birdsey 1992, Birdsey and Heath 1995, Birdsey 1996, Heath et al. 1996, Smith et al. 2010); ²(U.S. Forest Service 2014a, U.S. Forest Service 2015a); ³(Woodall et al. 2011a); ⁴(Jenkins et al. 2003); ⁵(Woodall et al. 2011b); ⁶(Woodall et al. 2012); ⁷(Domke et al. 2013); ⁸(See this publication; Domke et al., in prep.). NGHGI = National Greenhouse Gas Inventory; NFI = National Forest Inventory.

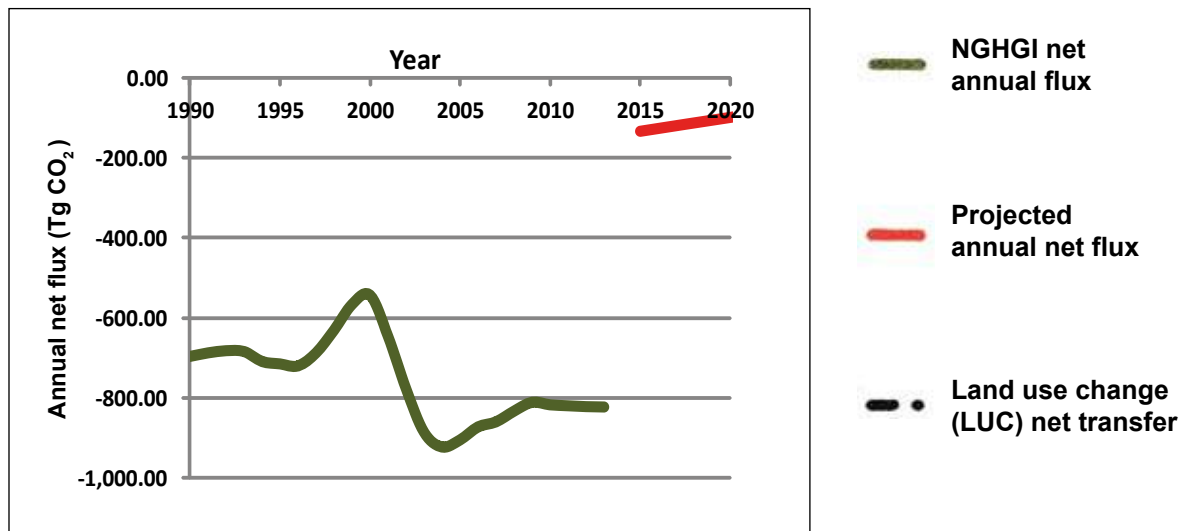
baseline and forward to user-defined time horizons. Recognizing the host of obligatory forest carbon reporting needs (e.g., United Nations Framework Convention on Climate Change [UNFCCC 2015a], Global Forest Resources Assessments [UN FAO FRA 2015], United Nations Framework Convention on Climate Change Biennial Reports [UNFCCC 2015b], Montréal Process Criteria and Indicators [Montréal Process Working Group, n.d.], and U.S. Forest Service Climate Change Scorecard [U.S. Forest Service 2015b]), the new framework had to be able to estimate the carbon implications of

disturbances and management and disaggregate land use change into deforestation versus afforestation effects on carbon stocks and stock changes at national and regional scales (Fig. 3). Past approaches (Fig. 3a) often depended on reconciling differences between two different U.S. forest inventory systems, which had a higher probability of creating carbon flux estimates stemming from differences in sample design rather than changes in forest ecosystems. Furthermore, this previous accounting approach did not easily enable linkage to forecasting mechanisms (Fig. 3a). The new, data-driven accounting

framework (Fig. 3b) has already been designed for implementation at the strategic scale using the national forest inventory of the United States, and with the appropriate data the framework can be used by partners interested in carbon accounting at other spatial scales of interest. Beyond the peer review and

publication of all technical aspects of this vision, an outreach and extension component still needs to be developed to interpret the results of the new accounting system for policy makers, land managers, and citizens.

a Where We've Been
Periodic Data Artifacts and Unaligned Projections



b Where We're Headed
Modeling Annual Data across Space/Time with LUC and Attribution

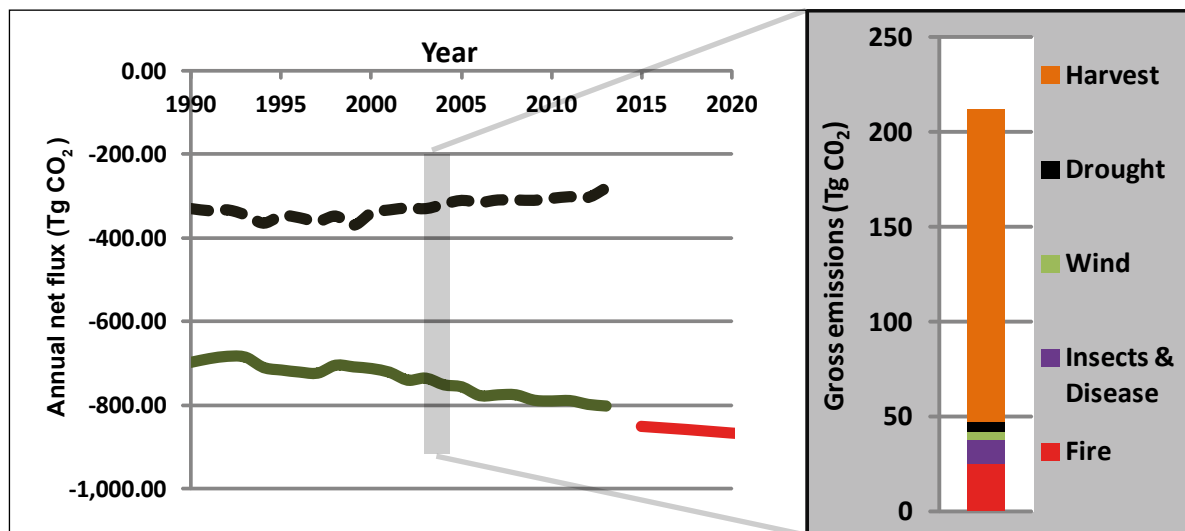


Figure 3.—Hypothetical carbon baselines that illustrate past issues with forest carbon accounting techniques, namely (a) misalignment between current baselines and future projections in addition to a lack of attribution to disturbance. It is expected that (b) future forest carbon baselines using the techniques described in this document will align baselines with projections while affording attribution to disturbance.

? How do the Forest Carbon Estimates in this Report Differ from Previous Greenhouse Gas Inventories?

- Older, periodic inventories which did not cover all managed forest land and were inconsistent with current annual inventories were removed from the accounting system, thus removing inconsistencies and reducing carbon baseline uncertainty.
- A new modeling approach was used to generate estimates of forest carbon derived from the annual inventory system both backward (to 1990) and forward (to 2016) through time to satisfy UNFCCC requirements.
- Repeated measures of the hundreds of thousands of permanent plot locations were used to inform land use change and disturbance effects on carbon stocks.
- In the eastern United States, remeasured individual plots were used to estimate carbon stocks and change. For the western states, the FIA annual inventory panel design was divided into two distinct time periods, with the older and more recent periods representing two independent estimates of the forest carbon population. In the future, as annual plots are remeasured in the western states, this approach can be replaced with remeasured annual plots, per the technique adopted for eastern states.
- Harvested wood products were not included in this forest ecosystem carbon assessment but will be included in the upcoming UNFCCC submission.
- This analysis focuses solely on the forest sector, so carbon transfers to other land uses were subtracted from the forest carbon inventory but were not reconciled with estimates made independently for other land sectors as will be required for the United States submission under the UNFCCC.
- A new approach for estimating soil organic carbon, the largest pool of carbon in U.S. forests, was included in this analysis (Domke et al., in prep.). The approach builds on the

thousands of in situ observations from across U.S. forests in conjunction with modeling refinements developed in coordination with the International Soil Carbon Network (ISCN; <http://iscn.fluxdata.org/Pages/default.aspx>).

? What is a Forest?

The UNFCCC does not prescribe to a specific definition for forest, but instead each country determines its own classification. Starting with the 2015 National Greenhouse Gas Inventory report (USEPA 2015a, b) and for this report, forest land is defined as: Land at least 120 feet (37 m) wide and at least 1 acre (0.5 ha) in size with at least 10 percent cover (or equivalent stocking) by live trees, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 m) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and nonforest lands, that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads, trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 m) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use (Oswalt et al. 2014: 31).



Forest and hayfield in southern Indiana. Photo by Christopher Woodall, U.S. Forest Service.

? How Much Forest in the United States is Managed?

Approximately 34 percent (310 million ha) of the U.S. land area is estimated to be forested (Oswalt et al. 2014). The most recent forest carbon inventories from each of the conterminous 48 states (U.S. Forest Service 2014a, b) includes an estimated 264 million ha (Oswalt et al. 2014) of forest land that are considered managed (Ogle et al., in prep.) and are included in this inventory. An additional 6 million ha of southeast and south central Alaskan forest are inventoried and are included in this analysis. Annual forest inventory data are not yet available for Hawaii and interior Alaska, but estimates for these areas are included in Oswalt et al. (2014).



Standing dead tree in Superior National Forest in Minnesota. Photo by Christopher Woodall, U.S. Forest Service.

? What is in a Forest Carbon Pool?

Carbon estimates obtained directly from an inventory or from inventory-based models are classified to account for all forest ecosystem organic carbon and fall into the following distinct, non-overlapping, forest ecosystem carbon pools which can be arrayed in various combinations for domestic or international (e.g., UNFCCC) reporting:



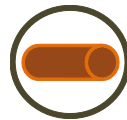
Live tree biomass—biomass of all live trees with a diameter of 2.5 cm and greater measured 1.37 m above the forest floor (diameter at breast height; d.b.h.) including stem, stump, branches, bark, and belowground coarse living roots with a diameter greater than 2 mm.



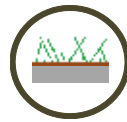
Understory vegetation—all live biomass including woody shrubs and trees smaller than the above tree classification, specifically less than 2.5-cm d.b.h.



Standing dead trees—entire aboveground and belowground portions of standing dead trees with a d.b.h. of 12.7 cm and greater.



Downed dead wood—all nonliving woody material lying on the ground and having a diameter greater than 7.5 cm at transect intersection. This pool also includes stumps (both aboveground and belowground portions).



Forest floor or litter—includes the duff, humus, and fine woody debris located above the mineral soil, and all nonliving woody biomass with a diameter less than 7.5 cm at transect intersection, lying on the ground.



Soil organic carbon (SOC)—all organic material in soil to a depth of 1 m, including fine roots but excluding the coarse roots of the belowground pools.

FOREST CARBON INDICATORS

Forest Carbon Vital Signs

A number of key statistics regarding U.S. forest carbon using the new FCAF are presented in Figure 4. It is useful to policy makers to evaluate

forest carbon rates relative to other sectors such as fossil fuel emissions. Please refer to the Carbon Stocks and Stock Change section on page 12 for complete national results.

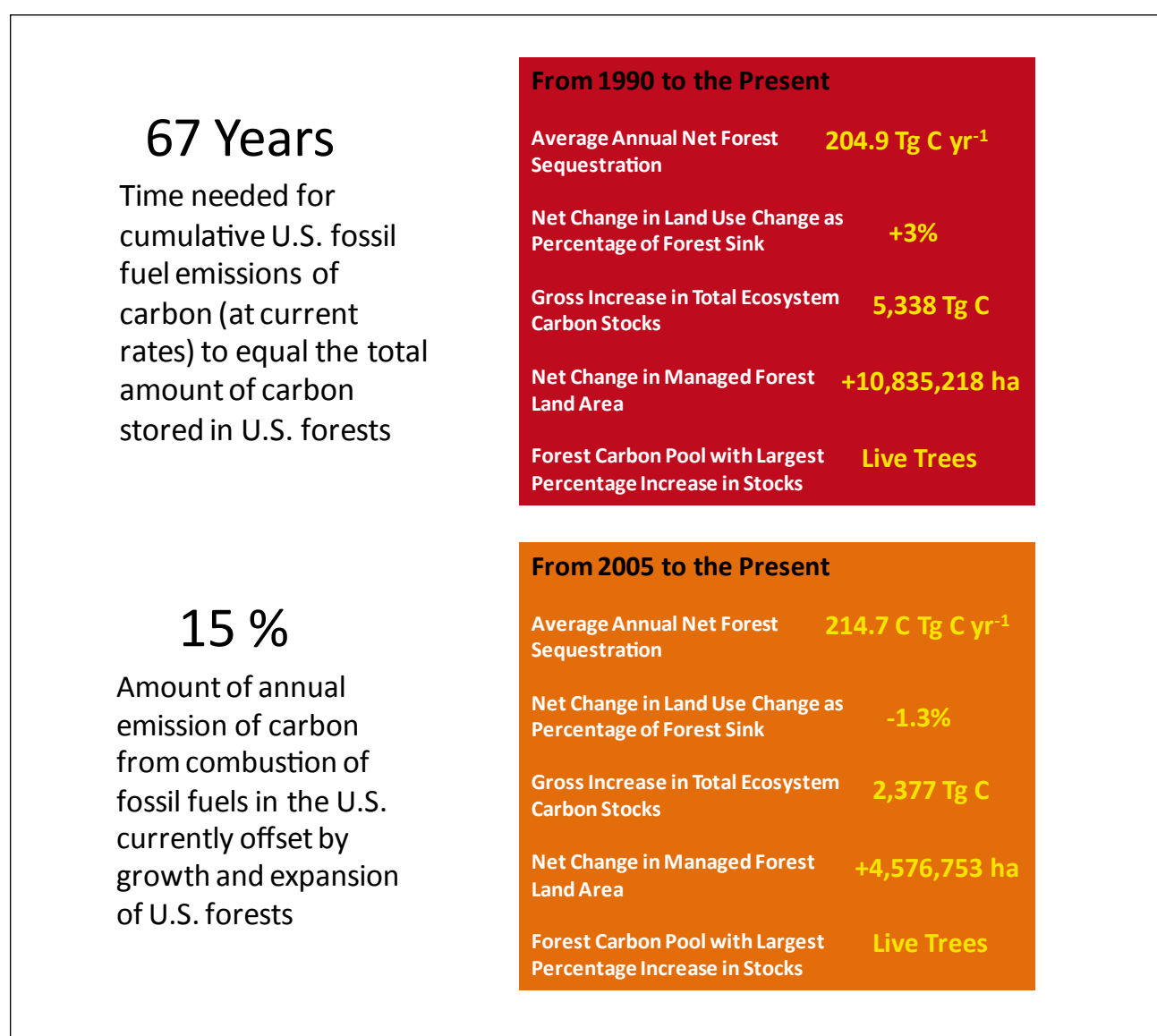


Figure 4.—Key statistics for annual U.S. forest carbon monitoring derived from the new Forest Carbon Accounting Framework introduced in this document.

The U.S. Forest Carbon Baseline

Overall, the total net carbon stock change (i.e., net sequestration) provided by U.S. forests has been trending above 200 Tg C yr⁻¹ since the Great Recession began in 2007 (Fig. 5a). There has been more fluctuation in net forest sequestration (i.e., net

growth) due to the effects of variations in regional harvest patterns which have a stronger effect on sequestration than wildfire (Fig. 5b). Land use change has been a steady net positive contributor to the forest carbon sink, with a slight decrease in the positive rate of change in recent years (Fig. 5a).

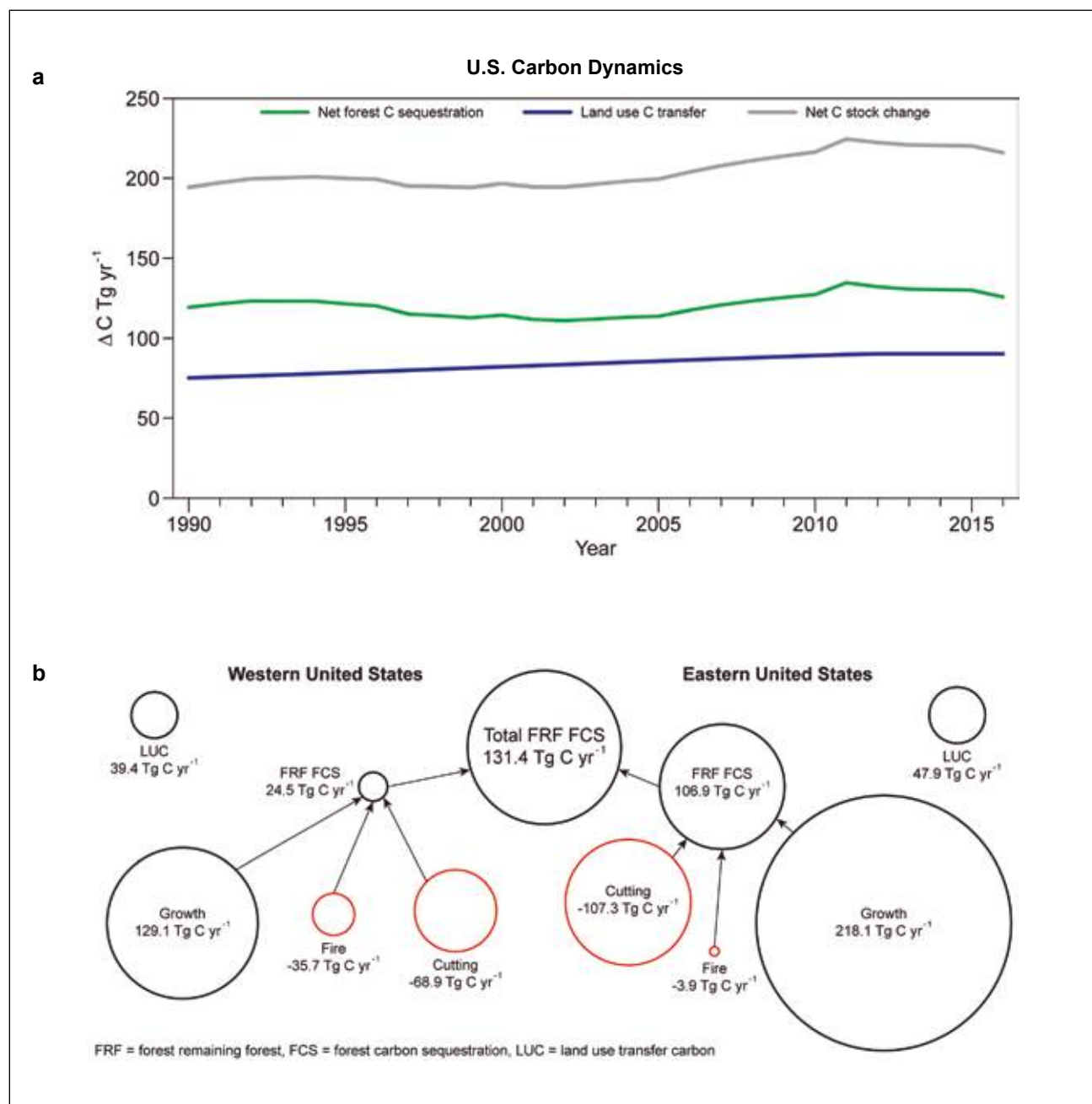


Figure 5.—The 1990–2016 forest carbon baseline (a) and 2011 attribution to disturbance (b), including delineation between forests remaining forest and land use change, obtained from the new Forest Carbon Accounting Framework in managed forests of the United States.

The Carbon Baseline in Context

Although trends in land use and net forest growth in relation to the forest carbon baseline have only marginally varied over the past couple of decades, more conclusions can be drawn when viewing these trends relative to the total forest sector and fossil fuel emissions (Fig. 6). As carbon from U.S. fossil fuel emissions has slightly diminished over the past few

years, the offset from both land use change and net forest growth have increased, from lows of 5.3 and 7.2 percent in the early 2000s, to recent highs of 6.4 and 9.3 percent, respectively. Relative to the entire forest ecosystem sector, net forest growth since the Great Recession has represented a larger proportion of the forest ecosystem sink than carbon transfers resulting from net land use change to forests.

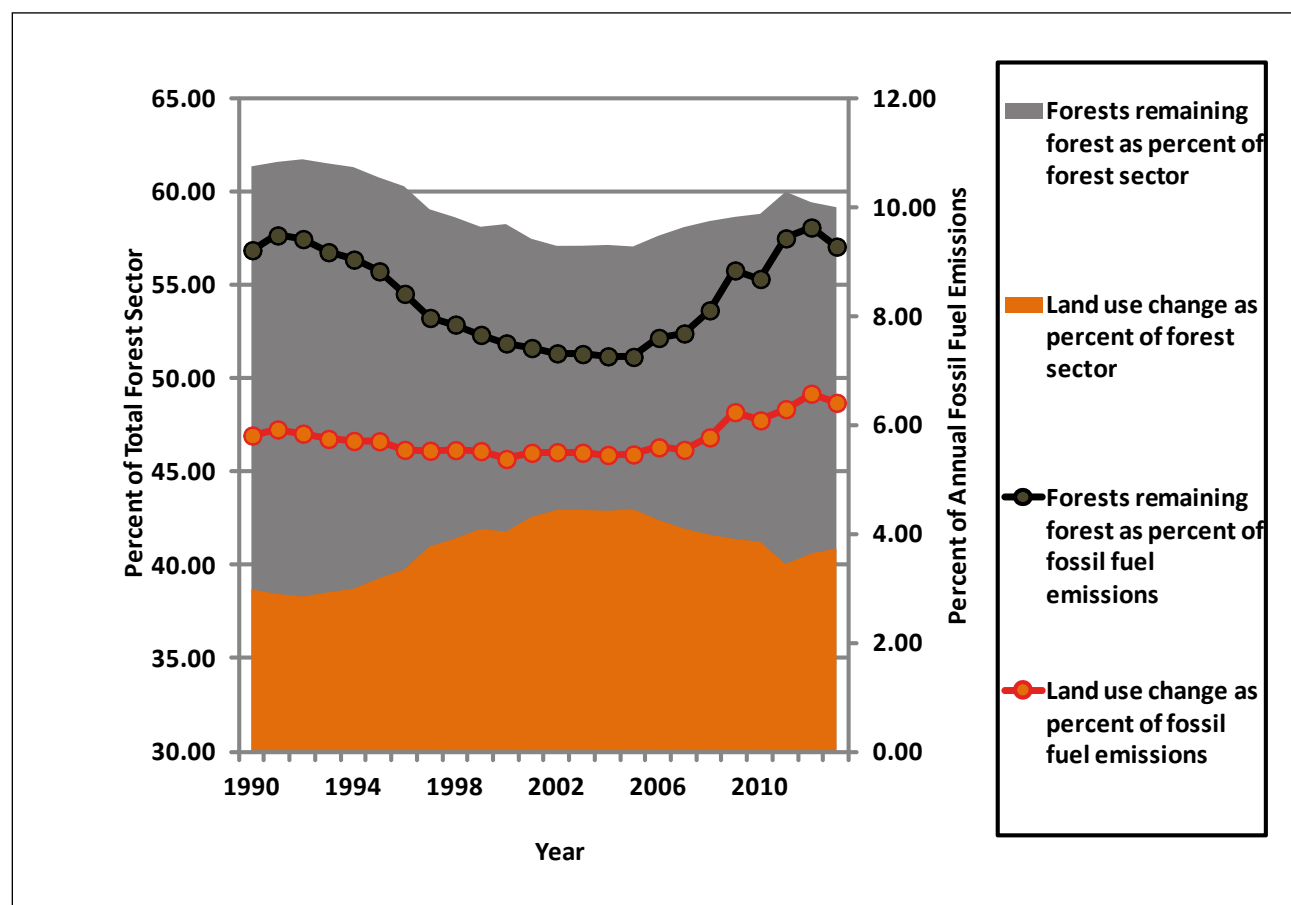


Figure 6.—Net annual sequestration resulting from forests remaining forest (i.e., net forest growth) versus land use change (i.e., net carbon transferred into forests from other land uses) relative to the forest ecosystem carbon sink and carbon from fossil fuel emissions.

Forest Carbon Stocks and Pools

Carbon pools are the individual, nonoverlapping categories where carbon resides in a forest, such as soils or live trees. Stocks are the amount of carbon in each particular pool. Figure 7 displays the proportion

of U.S. carbon stocks by pool and as a coal equivalent, and also shows the spatial delineation of each carbon pool across the United States. In some regions, such as the upper Great Lakes, the majority of forest carbon resides in the soils pool.

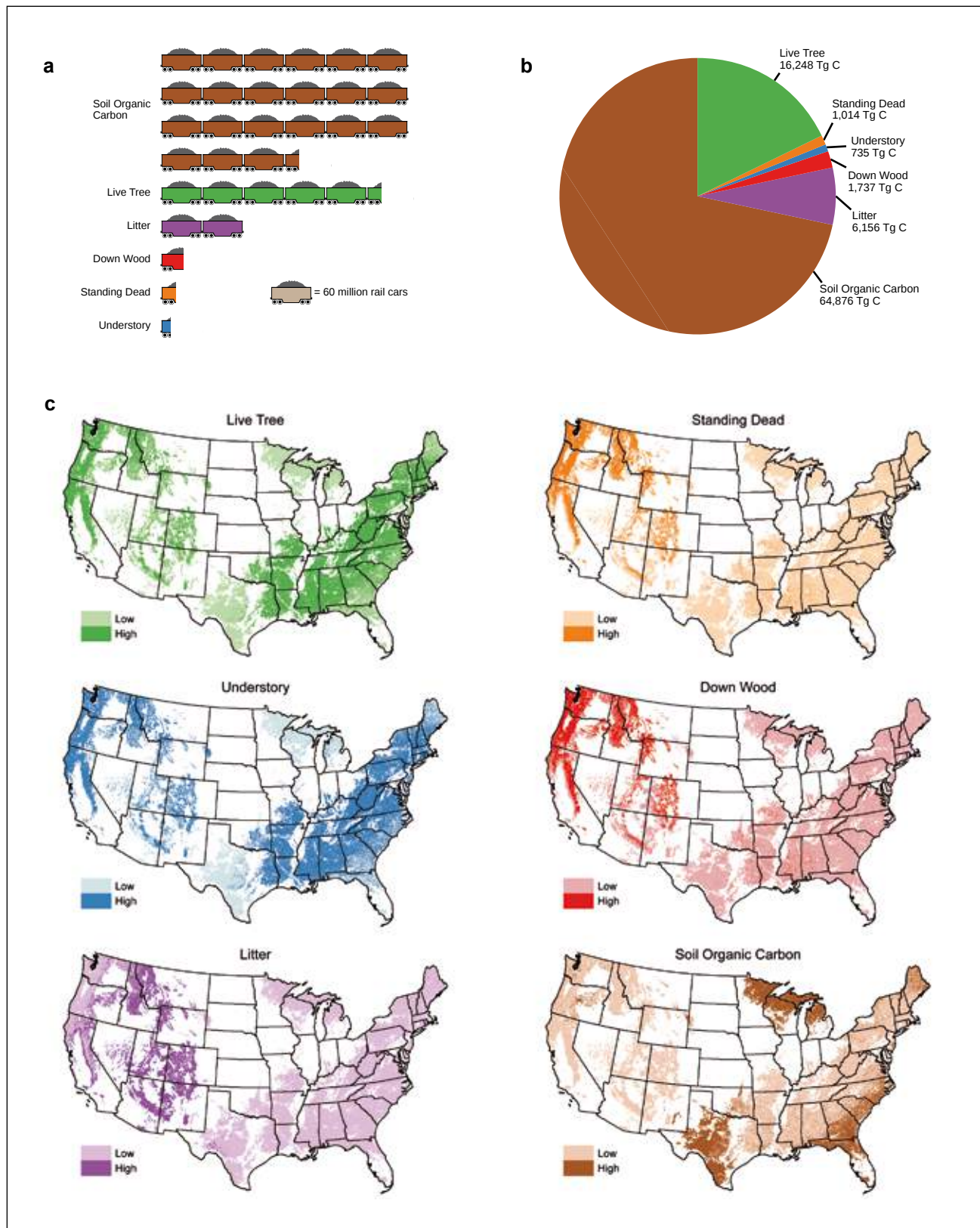


Figure 7.—Coal equivalents (a) and proportion of forest carbon stocks by pool (b) along with preponderance maps (c) by pool across the conterminous United States. Note: Pool preponderance maps from Wilson et al. (2013) will eventually be updated per emerging pool estimation techniques (e.g., Domke et al, in review).

Change in Forest Stocks by Pool

In the period from 1990 to 2016, the most dynamic forest carbon pools included those most closely associated with tree growth, removals, and mortality: live, standing dead, and downed dead trees.

However, not all net carbon sequestration occurs in forests remaining forests across the reporting period as there is net accumulation of forest, and hence, the movement of carbon from other land uses and pools into forests. As a case study, Woodall et al. (2015)

examined the movement of carbon from pools in other land uses to forests for the eastern United States over the period 2000 to 2012 (Fig. 8). For the soil organic carbon pool, more than 60 percent of carbon accumulation resulted from net positive carbon transfer into forests from other land uses (e.g., agriculture or developed). In contrast, for the aboveground live tree carbon pool only ~18 percent of carbon accumulation resulted from net land use transfers.

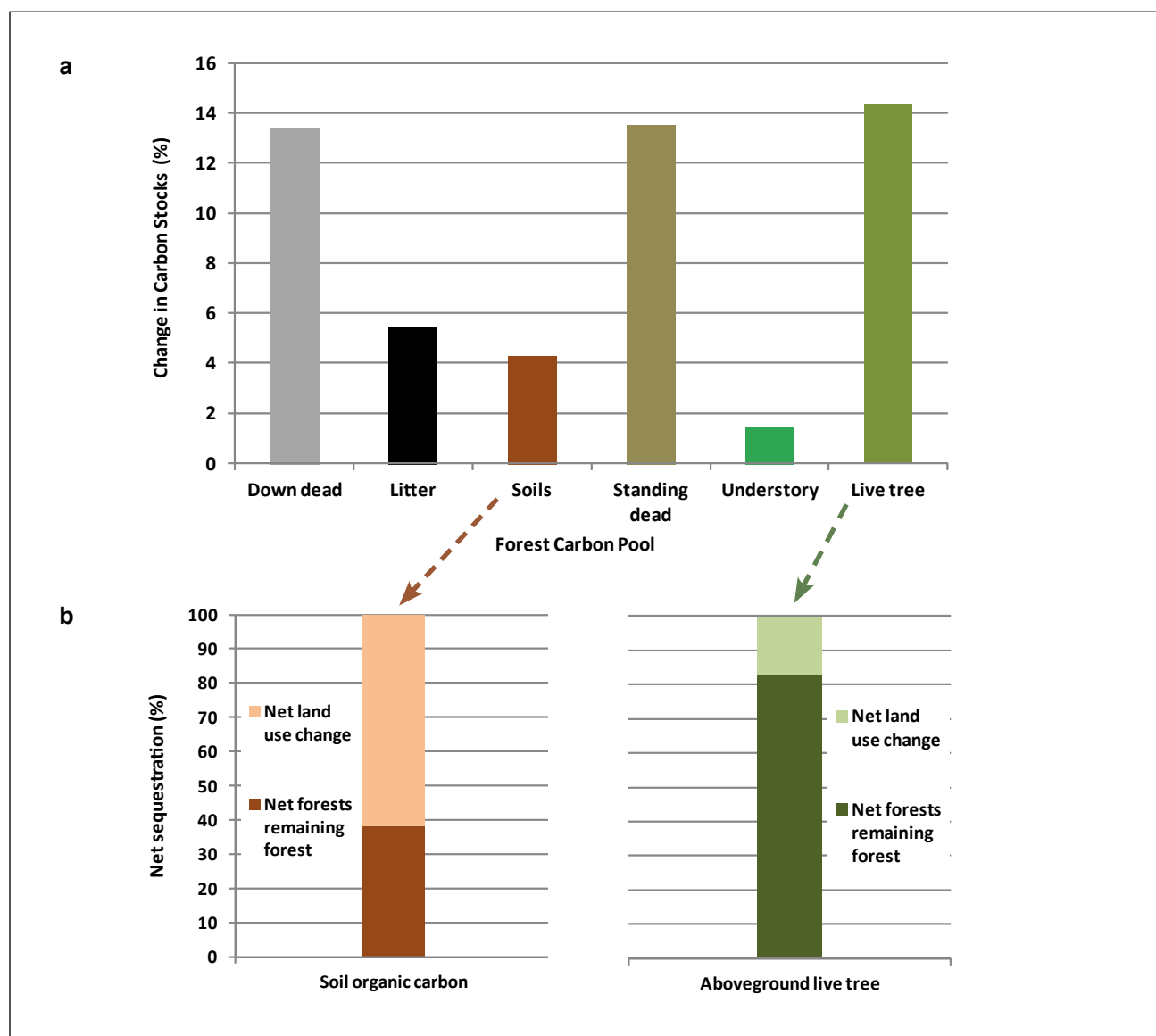


Figure 8.—FCAF results for changes in forest carbon stocks by pool from 1990-2016 in managed U.S. forests (a), and a case study examination (b) of land use change and carbon accretion for the two largest stocks, soil organic carbon and aboveground live trees, in eastern U.S. forests, 2000-2012 (Woodall et al. 2015).

CARBON STOCKS AND STOCK CHANGE

Regional Forest Carbon Estimates

Forest carbon stocks increased across all regions of the United States (Fig. 9). In forests that remained forest, carbon accumulation from net forest growth resulted in a net annual accumulation in all regions. Trends in net forest growth were variable across the baseline period, with the North, South, and Pacific Coast regions demonstrating an increasing rate of net forest growth while the Rocky Mountain region had a decreasing (but still positive) rate of carbon accumulation. Due to the availability of remeasured annual plots in the eastern United States, there is

greater resolution of the effects of land use change, with the effect of net transfers of land into forest representing a portion of the total sink nearly equal to that of net forest growth. In this documentation, general assumptions about rates of land use change in western states were adopted based on initial results from examining split annual inventory cycles (see Methods section on page 16). If resources permit continued remeasurement of annual plots in the western United States, then FCAF outputs can refine these regional land use baselines in the future as remeasured data become available.

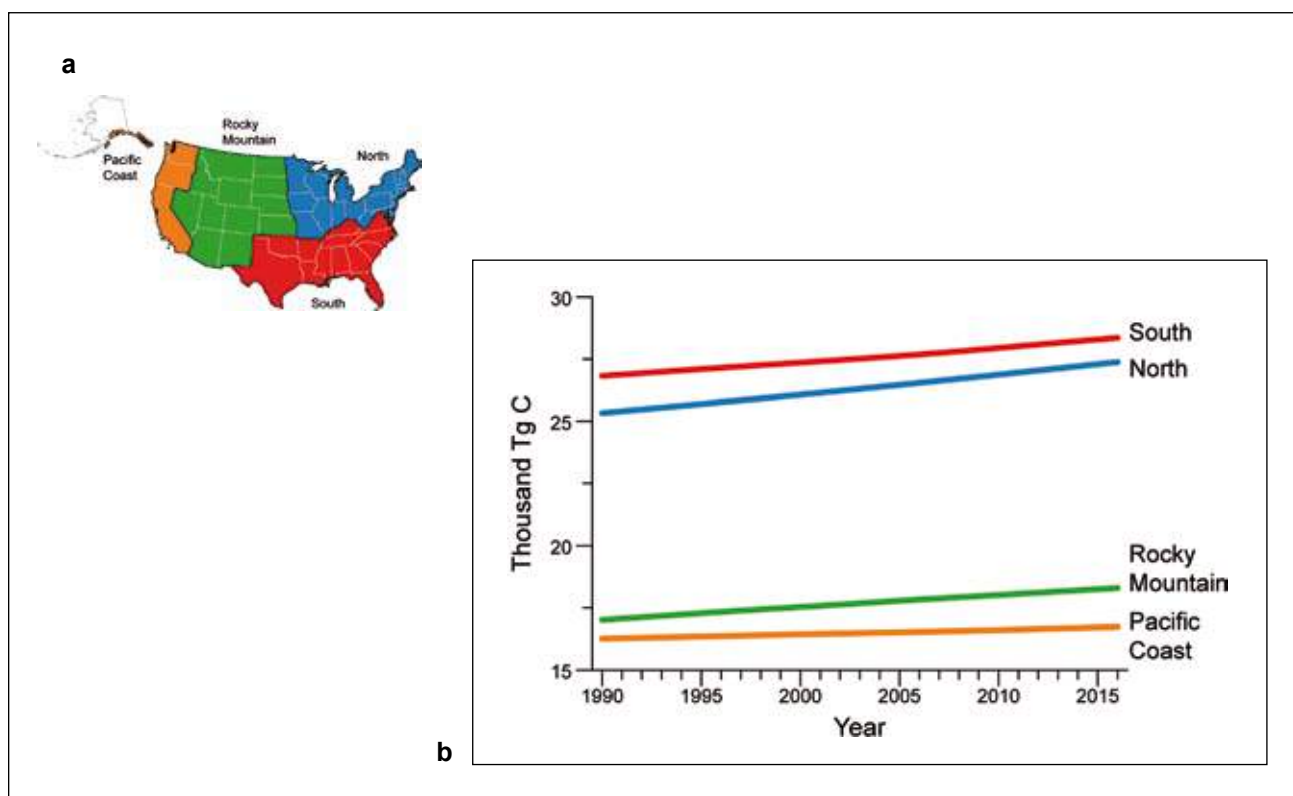


Figure 9.—Regional disaggregation of forest carbon analysis, 1990-2016: (a) regional delineations, (b) U.S. forest carbon stocks, and (c) annual forest carbon flux delineated by forests remaining forest (net forest carbon accretion) and land use change (net carbon transfer into forest land use) by region.

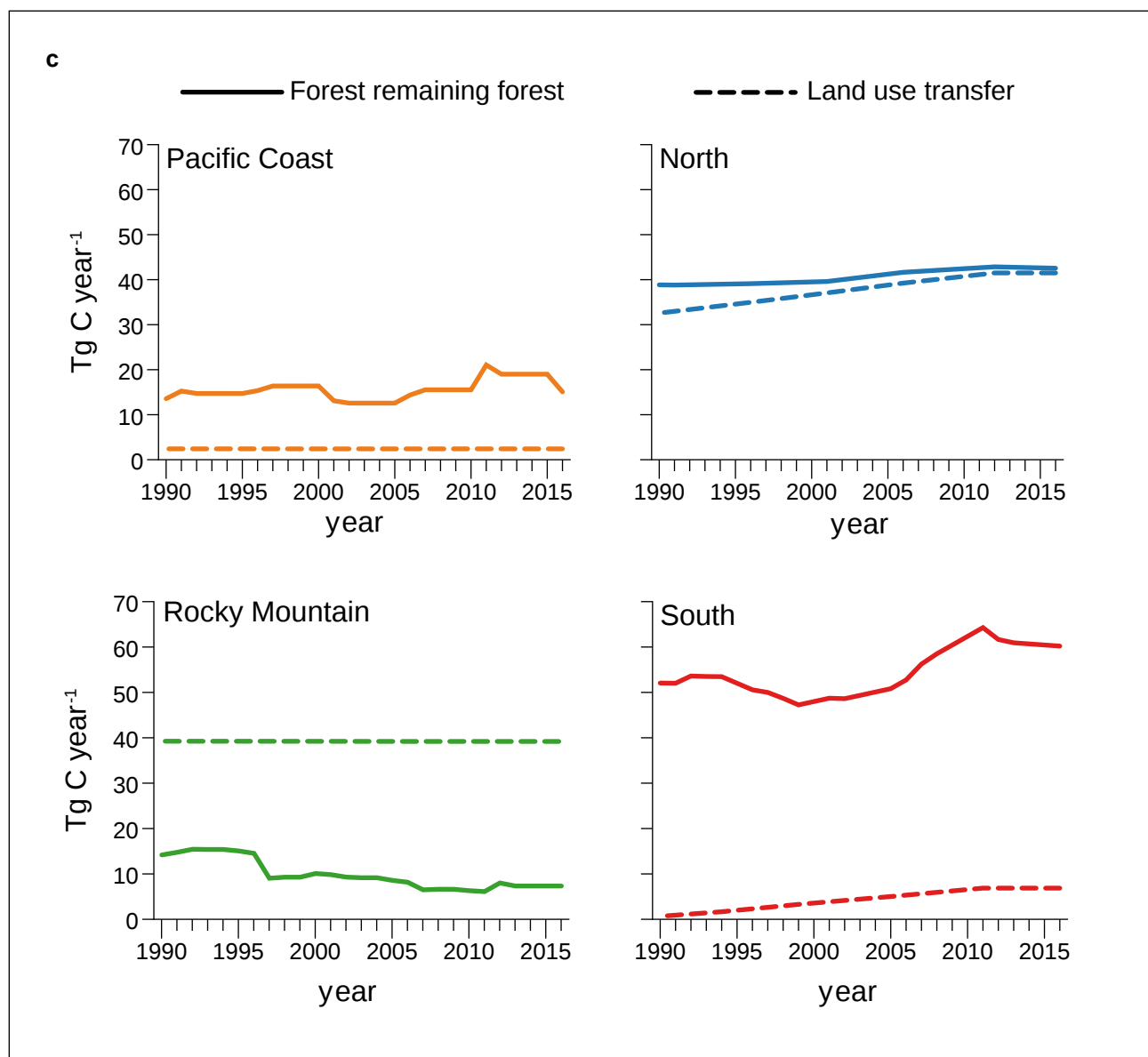


Figure 9 (continued).—Regional disaggregation of forest carbon analysis, 1990-2016: (a) regional delineations, (b) U.S. forest carbon stocks, and (c) annual forest carbon flux delineated by forests remaining forest (net forest carbon accretion) and land use change (net carbon transfer into forest land use) by region.

National Forest Carbon Estimates

Since 1990, forests in the United States have contributed from 194.4 to 224.5 Tg C·yr⁻¹ toward the net sequestration of atmospheric carbon (Table 1). Net land use change (nonforest converted to forest after subtracting forest converted to

nonforest) accounted for a substantial portion of net sequestration although forest growth (i.e., growth in forest remaining forest) continued to be the major component of net sequestration. The total U.S. forest carbon stock was tremendous at over 90,000 Tg C (Table 2).

Table 1.—Annual carbon flux (Tg C·yr⁻¹) by net land use change, forests remaining forest, and total net sequestration in managed U.S. forests, 1990-2016. Positive values indicate carbon removal from the atmosphere.

Year	Net land use change	Forests remaining forest	Net sequestration
1990	75.2	119.2	194.4
1991	75.8	121.4	197.2
1992	76.4	123.2	199.6
1993	77.1	123.1	200.2
1994	77.7	123.1	200.9
1995	78.5	121.4	199.9
1996	79.2	120.1	199.3
1997	79.9	115.2	195.1
1998	80.7	114.2	194.9
1999	81.4	112.9	194.3
2000	82.1	114.5	196.6
2001	82.8	111.8	194.6
2002	83.5	111.1	194.6
2003	84.2	112.0	196.3
2004	85.0	113.2	198.2
2005	85.7	113.8	199.4
2006	86.4	117.5	203.9
2007	87.1	120.7	207.8
2008	87.8	123.3	211.1
2009	88.5	125.4	213.9
2010	89.2	127.2	216.4
2011	89.9	134.6	224.5
2012	90.2	132.1	222.3
2013	90.2	130.6	220.8
2014	90.2	130.3	220.5
2015	90.2	130.0	220.2
2016	90.2	125.7	216.0

Table 2.—Forest carbon stocks (Tg C) by pool and year in managed U.S. forests, 1990-2016

Year	Downed dead wood ^a	Litter	Soil organic carbon	Standing dead ^a	Understory ^a	Live trees ^a	Total ecosystem stocks
1990	1,532.0	5,839.2	62,230.3	893.2	725.4	14,208.1	85,428.0
1991	1,538.9	5,852.2	62,323.5	895.9	725.3	14,289.4	85,625.2
1992	1,546.0	5,865.2	62,418.8	898.8	725.2	14,370.8	85,824.8
1993	1,553.2	5,878.2	62,514.5	901.7	725.2	14,452.2	86,025.0
1994	1,560.4	5,891.2	62,610.7	904.8	725.1	14,533.7	86,225.9
1995	1,567.7	5,904.2	62,707.3	907.8	725.1	14,613.7	86,425.8
1996	1,575.0	5,917.0	62,801.2	911.5	725.1	14,695.2	86,625.1
1997	1,582.7	5,928.6	62,897.9	917.5	725.5	14,768.1	86,820.2
1998	1,590.3	5,940.0	62,995.6	923.6	725.8	14,839.6	87,015.1
1999	1,598.0	5,951.5	63,094.0	929.8	726.3	14,909.9	87,209.4
2000	1,605.7	5,963.1	63,193.8	936.2	726.7	14,980.6	87,406.0
2001	1,612.9	5,973.5	63,300.2	942.3	727.6	15,044.1	87,600.6
2002	1,619.9	5,984.4	63,407.0	945.8	728.5	15,109.6	87,795.2
2003	1,627.1	5,995.4	63,514.3	949.3	729.4	15,176.0	87,991.5
2004	1,634.3	6,006.6	63,622.3	952.9	730.3	15,243.3	88,189.6
2005	1,641.6	6,017.9	63,730.8	956.1	731.2	15,311.5	88,389.1
2006	1,649.9	6,029.6	63,828.6	960.1	731.5	15,393.2	88,593.0
2007	1,658.1	6,041.2	63,929.7	964.9	731.9	15,474.8	88,800.8
2008	1,666.3	6,053.1	64,031.7	969.8	732.3	15,558.6	89,011.8
2009	1,674.7	6,065.1	64,134.5	974.7	732.7	15,644.0	89,225.7
2010	1,683.1	6,077.1	64,238.3	979.7	733.1	15,730.6	89,442.1
2011	1,692.1	6,090.7	64,345.9	984.9	733.4	15,819.6	89,666.6
2012	1,701.1	6,104.1	64,451.2	990.7	733.8	15,908.0	89,888.9
2013	1,710.1	6,117.3	64,556.6	996.7	734.1	15,994.8	90,109.7
2014	1,719.2	6,130.5	64,662.1	1,002.7	734.5	16,081.2	90,330.2
2015	1,728.4	6,143.6	64,767.6	1,008.7	734.9	16,167.3	90,550.4
2016	1,748.1	6,218.4	65,244.3	1,017.4	739.5	16,294.5	91,262.1

^a Includes aboveground and belowground components.

METHODS AND DATA SOURCES

FCAF Technical Specifications

Overview

The FCAF is fundamentally driven by the annual forest inventory system conducted by the Forest Inventory and Analysis program of the U.S. Forest Service (2014d, 2015a). The FIA program is considered to be the National Forest Inventory (NFI) for the United States, so these terms are used interchangeably. The FCAF system is comprised of a forest dynamics module and a land use dynamics module. The forest dynamics module assesses forest sequestration, forest aging, and disturbance effects (i.e., disturbances such as wind, fire, and floods identified by foresters on inventory plots). The land use dynamics module assesses carbon stock transfers associated with afforestation and deforestation. Both modules are developed from land use area statistics and carbon stock change or carbon stock transfer by age class. The required inputs are estimated from more than 625,000 forest and nonforest observations in the FIA national database (U.S. Forest Service 2014a, b, c). Model predictions for before or after the annual inventory period are constructed from the FCAF system using the annual observations. This modeling framework includes opportunities for user-defined scenarios to evaluate the impacts of land use change and disturbance rates on future carbon stocks and stock changes. The accounting system is flexible and can incorporate emerging inventory data (e.g., remeasured western plots and Alaskan lichen biomass), future image-based change estimation information (see Planned Improvements section on page 28), data from trends in burn severity (Eidenshink et al. 2007), and process model output (i.e., inform future forest carbon densities or land use dynamics). The future accounting system will be transparent and verifiable through open-source, publicly available R software that links with

the FIA database and associated distillations. The accounting system is scalable to allow other users to parameterize models at scales relevant to them, but inherently the framework is built for application at the strategic scale, using FIA data to parameterize the matrices. This introduction to the FCAF is just the first step in a process to engage the public and policy makers in interpreting forest carbon status and trends. Whether it is remeasuring western inventory plots, initiating an inventory of interior Alaska, or vetting emerging research, we expect years of refinements to the FCAF.

Data

Data from the FIA program are the basis for the FCAF and the U.S. forest carbon inventory program (U.S. Forest Service 2014a). The FIA program relies on a rotating panel statistical design with a sampling intensity of one 674.5 m² ground plot per 2,403 ha of land and water area. A multi-panel design, with a percentage of all field plots systematically distributed and measured each year within each panel, is used with a base federal measurement period of 7 years (i.e., 7 panels) in eastern states and 10 years (i.e., 10 panels) in western states. The interpenetrating hexagonal design across the U.S. landscape enables the sampling of plots at various intensities in a spatially and temporally unbiased manner. Typically, tree and site attributes are measured with a higher sample intensity while other ecosystem attributes such as downed dead wood are sampled during summer months at lower intensities. From the measurements taken on the field plots, carbon estimates are predicted for six pools: live trees (aboveground and belowground), understory vegetation, standing dead trees, downed dead wood, litter, and soil organic carbon. The techniques for estimating these pools are detailed in the recent

National Greenhouse Gas Inventory annexes (USEPA 2015b). An important refinement of these techniques is the adoption of a new approach (Domke et al., in prep.) for estimating soil organic carbon, whose preliminary results are included in this assessment.

Carbon in Soil Organic Matter

Soil organic carbon (SOC) is the largest terrestrial carbon sink, and management of this pool is a critical component of efforts to mitigate atmospheric carbon concentrations. Soil organic carbon also affects essential biological, chemical, and physical soil functions such as nutrient cycling, water retention, and soil structure (Jandl et al. 2014). Much of the SOC on earth is found in forest ecosystems and is thought to be relatively stable. However, there is growing evidence that SOC is sensitive to global change effects, particularly land use histories, resource management, and climate. Given the cost and time required to measure SOC, and particularly changes in SOC, many of the UNFCCC signatory nations report estimates of SOC stocks and stock changes using default values from the Intergovernmental Panel on Climate Change or country-specific models (Keith et al. 2009, Kurz and Apps 2006). Country-specific models are often developed from soil inventories that are not representative of all land uses and vegetation types, resulting in unquantified uncertainties. In the United States, SOC in forests is monitored by the national forest inventory conducted by the FIA program (O'Neill et al. 2005). The FIA program currently uses SOC predictions based, in part, on a model using the Soil Survey Geographic (SSURGO) and the State Soil Geographic (STATSGO) databases compiled by the Natural Resources Conservation Service (NRCS) (Amichev and Glabraith 2004), hereafter referred to as the country-specific (CS_{soc}) model. Most estimates of forest SOC found in the SSURGO and STATSGO databases are based primarily on expert opinion and lack systematic field observations, but these country-specific model predictions have been used in past UNFCCC reporting (USEPA 2015a, b). The FIA program has been consistently measuring soil attributes as

part of the inventory since 2001 and has amassed an extensive inventory of SOC in forest land in the conterminous United States and coastal Alaska (O'Neill et al. 2005). More than 5,000 profile observations of SOC on forest land from FIA and the International Soil Carbon Monitoring Network were used to develop and implement a modeling framework used for UNFCCC reporting that includes site-, stand-, and climate-specific variables that yield predictions of SOC stocks and stock changes specific to forest land in the United States. This section provides a summary of the methodology used to predict SOC for this report. A complete description of the approach is given in Domke et al. (in prep.).

The data used to develop the new modeling framework to predict SOC on forest land came from the FIA program and the ISCN. Since 2001, the FIA program has collected soil samples on every 16th base intensity plot distributed approximately every 38,848 ha, where at least one forested condition exists (Woodall et al. 2011a). On fully forested plots, mineral and organic soils were sampled adjacent to subplots 2, 3, and 4 by taking a single core at each location from two layers: 0 to 10.16 cm and 10.16 to 20.32 cm. The texture of each soil layer was estimated in the field, and physical and chemical properties were determined in the laboratory (U.S. Forest Service 2011). For this analysis, estimates of SOC from the FIA program were calculated following O'Neill et al. (2005):

$$\sum SOC_{FIA_TOTAL} = C_i \cdot BD_i \cdot t_i \cdot ucf \quad (1)$$

Where

$\sum SOC_{FIA_TOTAL}$ = total mass (Mg C ha⁻¹) of the mineral and organic soil carbon over all i th layers,

C_i = percent organic carbon in the i th layer,

BD_i = bulk density calculated as weight per unit volume of soil (g·cm⁻³) at the i th soil layer,

t_i = thickness (cm) of the i th soil layer (either 0 to 10.16 cm or 10.16 to 20.32 cm), and

ucf = unit conversion factor (100).

The SOC_{FIA_TOTAL} estimates from each plot were assigned and averaged by forest condition, resulting in 3,667 profiles with SOC layer observations at 0 to 10.16 and 10.16 to 20.32 cm depths. Since the United States has historically reported SOC estimates to a depth of 100 cm (USEPA 2015a), ISCN data from forests in the United States were harmonized with the FIA soil layer observations to develop models of SOC by soil order to a depth of 100 cm. All observations used from the ISCN were contributed by the Natural Resources Conservation Service. A total of 16,504 soil layers from 2,037 profiles were used from ISCN land uses defined as deciduous, evergreen, or mixed forest. The FIA-ISCN harmonized dataset used for model selection and prediction included a total of 5,704 profiles with 23,838 layer observations at depths ranging from 0 to 1,148 cm.

The modeling framework developed to predict SOC for this report was built around strategic-level forest and soil inventory information and auxiliary variables available for all FIA plots in the United States. The first phase of the new estimation approach involved fitting models using the midpoint of each soil layer from the harmonized dataset and SOC estimates at those midpoints. Several linear and nonlinear models were evaluated, and a log-log function provided the optimal fit to the harmonized data:

$$\log_{10} SOC_i = I + \log_{10} Depth \quad (2)$$

Where

$\log_{10} SOC_i$ = SOC density (Mg C ha⁻¹ cm depth⁻¹) at the midpoint depth,

I = intercept, and

$\log_{10} Depth$ = profile midpoint depth (cm).

The model was validated by partitioning the complete harmonized dataset multiple times into training and testing groups and then repeating this step for each soil order to evaluate model performance by soil order. Extra sum of squares

F tests were used to evaluate whether there were statistically significant differences between the model coefficients from the model fit to the complete harmonized dataset and models fit to subsets of the data by soil order. Model coefficients for each soil order were used to predict SOC for the 20.32 to 100 cm layer for all FIA plots with soil profile observations. Next, the SOC layer observations from the FIA and predictions over the 100 cm profile for each FIA plot were summed:

$$SOC_{100} = SOC_{FIA_TOTAL} + SOC_{20-100} \quad (3)$$

Where

SOC_{100} = total estimated SOC density from 0-100 cm for each forest condition with a soil sample in the FIA database,

SOC_{FIA_TOTAL} = as defined in model (1), and

SOC_{20-100} = predicted SOC from 20.32 to 100 cm from model (2).

Note that bias correction factors will be incorporated into the SOC_{20-100} predictions and evaluated in Domke et al. (in prep.) but were not included in the SOC_{100} estimates used in this analysis.

In the second phase of the modeling framework, SOC_{100} estimates for FIA plots were used to predict SOC for plots lacking SOC_{100} estimates using Random Forests (RF), a machine learning tool that uses bootstrap aggregating (i.e., bagging) to develop models to improve prediction (Breiman 2001). Random Forests also relies on random variable selection to develop a forest of uncorrelated regression trees. These trees recognize the relationship between a dependent variable, in this case SOC_{100} , and a set of predictor variables. All relevant predictor variables—those that may influence the formation, accumulation, and loss of SOC—from annual inventories collected on all base intensity plots and auxiliary climate, soil, and topographic variables obtained from the PRISM climate group (Northwest Alliance 2015), Natural Resources Conservation Service (NRCS

2015), and U.S. Geological Survey (Danielson and Gesch 2011), respectively, were included in the RF analysis. Due to regional differences in sampling protocols, many of the predictor variables included in the RF variable selection process were not available for all base intensity plots. To avoid problems with data limitations, pruning was used to reduce the RF models to the minimum number of relevant predictors (including both continuous and categorical variables) without substantial loss in explanatory power or increase in root mean squared error (RMSE). The general form of the full RF models were:

$$P(SOC) = f(lat, lon, elev, fortypgrp, ppt, tmax, gmi, order, surfgeo) + u \quad (4)$$

where *lat* = latitude, *lon* = longitude, *elev* = elevation, *fortypgrp* = forest type group, *ppt* = mean annual precipitation, *tmax* = average maximum temperature, *gmi* = the ratio of precipitation to potential evapotranspiration, *order* = soil order, *surfgeo* = surficial geological description, and *u* = the uncertainty in the prediction resulting from the sample-based estimates of the model parameters and observed residual variability around this prediction. For each replacement, *u* was independently and randomly generated from a $N(0, \sigma)$ distribution, with σ incorporating the variability from both sources. This process of randomly selecting and incorporating *u* may be considered an imputation. Each model prediction was replaced independently *m* times, and *m* separate estimates were combined following Rubin (1987):

$$\hat{\bar{C}} = \frac{1}{m} \sum_{k=1}^m \hat{C}^k \quad (5)$$

where $\hat{\bar{C}}$ is the estimate for the *k*th completion of the dataset. In this analysis, *m* = 1,000, which is markedly larger than the *m* recommended by Rubin (1987), but given the extremely high level of replacement in this study, it was deemed necessary (Bodner 2008).

The FIA dataset used to develop the full RF model was partitioned multiple times into training and testing groups, and the results were evaluated graphically and with a variety of statistical metrics, including RMSE and modeling efficiency (*EF*). This provided an index of model performance on a relative scale where 1 indicated a perfect fit, 0 suggested the model was no better than the mean, and negative values indicated a poor model fit. The RMSE for the full model was 32.78 Mg C ha⁻¹ and the *EF* was 0.36. The RF predictions from the full model were also evaluated against the SOC_{100} estimates using an equivalence testing framework (Wellek 2003). This method assumes the values are not equivalent unless the *P*(*SOC*) predictions and SOC_{100} estimates demonstrate they are similar to within a predefined tolerance. A region of indifference was defined as ± 25 percent, meaning the absolute value of the mean of the difference is less than 25 percent of the standard deviation. The SOC_{100} estimates and *P*(*SOC*) predictions were statistically equivalent with a mean difference of 0.95 (standard deviation = ± 15.53) Mg C ha⁻¹. The *P*(*SOC*) predictions represent an estimated 40 percent (42.52 ± 46.80 Mg C ha⁻¹) increase in carbon stocks per unit area relative to the county-specific predictions which have been used in previous UNFCCC reports. As a final step in this analysis, the *P*(*SOC*) predictions were compared to SOC estimates published in the recent literature. The *P*(*SOC*) predictions ranged from 47.90 to 374.57 Mg C ha⁻¹ with a mean of 105.40 Mg C ha⁻¹. These predictions are consistent with estimates from studies across forest types of the United States (Jobbagy and Jackson 2000, Lal 2005, Sun et al. 2004, Tan et al. 2004, Thompson and Kolka 2005, Woldelessie et al. 2012) and with estimates obtained from a large scale soil survey in European forests (De Vos et al. 2015).

Estimation of Other Pools

Techniques for estimating the carbon stocks of all other pools (other than SOC) are identical to those used in the previous NGHGI (USEPA 2015b). Briefly, forest inventory data are converted to carbon units or augmented by other ecological

data. Expansion factors are applied to the survey data at the scale of FIA inventory plots. The results are estimates of carbon density (Mg C ha^{-1}) for the various forest pools. Carbon density for live trees, standing dead trees, understory vegetation, downed dead wood, litter, and soil organic matter are estimated. All nonsoil pools except litter can be separated into aboveground and belowground components. The live tree and understory carbon pools have been pooled as biomass in the greenhouse gas inventory. Similarly, standing dead trees and downed dead wood have been pooled as dead wood. Regardless of the pool delineations used in this initial report, they can be summarized in various ways for varying reporting formats.

- **Live trees**—Live tree carbon pools include aboveground and belowground (coarse root) biomass of live trees with diameter at breast height of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates are made for aboveground and belowground biomass components. If inventory plots include data on individual trees, tree carbon is based on Woodall et al. (2011b) using the component ratio method (CRM), which is a function of volume, species, diameter, and, in some regions, tree height and site quality. The estimated sound volume (i.e., after rotten and missing tree volume have been deducted) provided in the tree table of the FIA database is the principal input to the CRM biomass calculation for each tree (Woodall et al. 2011b). The estimated volumes of wood and bark are converted to biomass based on the density of each. Additional components of the trees, such as tops, branches, and coarse roots, are estimated according to adjusted component estimates from Jenkins et al. (2003). Live trees with a d.b.h. of less than 12.7 cm do not have estimates of sound volume in the FIA database, and CRM biomass estimates follow a separate process (see Woodall et al. 2011b for details). An additional component of foliage, which is not explicitly included in Woodall et al. (2011b), was added to each tree following the same CRM method. Carbon was estimated by multiplying the estimated oven-dry biomass by a carbon constant of 0.5

because carbon is 50 percent of dry weight (IPCC 2006). Further discussion and example calculations are provided in Woodall et al. (2011b) and Domke et al. (2012).

- **Understory vegetation**—Understory vegetation is a minor component of total forest ecosystem biomass. Understory vegetation is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.5-cm d.b.h. Estimates of carbon density are based on Birdsey (1996), and calculation details are provided by the U.S. Environmental Protection Agency (2015b). The approach to quantifying carbon in this pool is expected to be revised in the near future.
- **Standing dead trees**—The standing dead tree estimates are primarily based on plot-level measurements (Domke et al. 2011, Woodall et al. 2012). This carbon pool includes aboveground and belowground (coarse root) mass and includes trees of at least 12.7-cm d.b.h. Calculations follow the basic CRM method applied to live trees (Woodall et al. 2011b) with additional modifications to account for decay and structural loss. In addition to the lack of foliage, two characteristics of standing dead trees that can substantially affect carbon mass are decay, which affects density and thus specific carbon content (Domke et al. 2011, Harmon et al. 2011), and structural loss such as missing branches and bark (Domke et al. 2011). Dry weight is converted to carbon mass by multiplying by 0.5.
- **Downed dead wood**—Downed dead wood, inclusive of logging residue, are sampled on a subset of FIA plots. Despite a reduced sampling intensity, empirical estimates of downed dead wood are used in combination with model predictions to compile a single downed woody material population estimate (Domke et al. 2013, Woodall et al. 2013) per state. Downed dead wood is defined as pieces of dead wood with a diameter greater than 7.5 cm at transect intersection, that are not attached to live or standing dead trees. It also includes stumps and roots of harvested trees.

Estimates for downed dead wood correspond to the region and forest type classifications described in Smith et al. (2003). An additional component of downed dead wood is a regional average estimate of logging residue based on Smith et al. (2006) applied at the plot level. These are based on a regional average carbon density at age zero and first order decay. These amounts are added to explicitly account for downed dead wood following harvest. The sum of these two components is then adjusted by the ratio of population totals; that is, the ratio of plot-based to modeled estimates (Domke et al. 2013). Details are provided in U.S. Environmental Protection Agency (2015b).

- **Litter**—Carbon in the litter layer is currently sampled on a subset of the FIA plots. Litter carbon is the pool of organic carbon (including material known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Because litter attributes are only collected on a subset of FIA plots, a model was developed to predict carbon density based on site-, stand-, and climate-specific variables from plots that lacked litter information (Domke et al., in review). Since the modeling framework used to obtain predictions of litter carbon is new this year, a more detailed overview of the methods is provided here, and a full description of the methods is described in Domke et al. (in review).

The first step in model development was to evaluate all relevant variables—those that may influence the formation, accumulation, and decay of litter organic matter—from annual inventories collected on base intensity plots. This was done using RF variable selection and litter carbon estimates from FIA plots ($n = 4,553$) where litter attributes were sampled from 2001-2012. Random Forests was used to evaluate the importance of all relevant predictor variables available on base intensity plots in the FIA. Due to regional differences in sampling protocols, many of the predictor variables included in the RF variable selection process were not available for all base intensity plots. To avoid

problems with data limitations, pruning was used to reduce the RF models to the minimum number of relevant predictors (including both continuous and categorical variables) without substantial loss in explanatory power or increase in RMSE. The general form of the full RF models was:

$$P(\text{Litter}) = f(\text{elev}, \text{lon}, \text{above}, \text{gmi}, \text{fortypgrp}, \text{ppt}, \text{tmax}, \text{lat}) + u \quad (6)$$

where $P(\text{Litter})$ = litter carbon (Mg C ha^{-1}), *above* = aboveground live tree carbon (trees $\geq 2.54\text{-cm}$ d.b.h.), and other variables are as defined for model (4). For each replacement, u was independently and randomly generated from a $N(0, \sigma)$ distribution with σ incorporating the variability from the sample-based estimates of the model parameters and observed residual variability around the predictions. Each model prediction was replaced independently m times, and m separate estimates were combined following Rubin (1987) using model (5). The FIA dataset used to develop the full RF model was partitioned multiple times into training and testing groups, and the results were evaluated graphically and with a variety of statistical metrics.

Attribution

Attribution is the separation of impacts of major disturbance from forest sequestration. In the eastern United States where remeasured data are available, this was done directly based on repeated observations (Coulston et al. 2015). In the western United States where only one measurement is available, a coarse-scale model was adopted (Coulston, in prep.). The coarse-scale model arises from a finer-scale model:

$$E(\delta C_{dp}) = E(C_{dp}) - E(C_{-dp}) \quad (7)$$

Where

$E(\)$ is the expected value,

δC_{dp} is the change in carbon for plot p with disturbance d ,

C_{dp} is the current carbon stock of plot p with disturbance d , and

C_{-dp} is the carbon stock for plot p without disturbance.

$E(C_{dp})$ may be developed from a model such as:

$$E(C_{dp}) = f(\text{fortypgrp}, C_{tree}, SD, SI \dots) \quad (8)$$

Where

C_{tree} = total live and standing dead tree carbon,

SD = stand density, and

SI = site index.

In simple terms this approach models δC_{dp} as the observed deviation from a carbon yield curve. However, the same general idea can be employed as a population model. Suppose that a disturbance or management activity occurs at random within a forest type (population). Under this assumption for each forest type:

$$E(\Delta C_d) = F_d * (D_d - D_u) \quad (9)$$

Where

ΔC_d = vector of population carbon change by pool associated with the disturbance,

F_d = area of the disturbance,

D_d = vector of carbon density (stock per unit area) by pool in disturbed areas, and

D_u = vector carbon density by pool in undisturbed areas.

The coarse-scale model was implemented for the western United States including west Texas and west Oklahoma. For fire disturbance D_{fire} was compared to D_u by forest type group. For cutting D_{cut} was compared to D_u by forest type group where D_u was restricted to observations between ages 5 and 105. This age restriction was based on a small set of remeasurements for the western United States where 90+ percent of all observed cutting occurred in stands between 5 and 105. Note that cutting includes a range of cutting types from timber stand improvement to clearcutting.

Projections: Moving Annual Inventory Data Backward and Forward in Time

Wear and Coulston (2015) and Coulston et al. (2015) provide the framework for the projection model. The overall objective is to estimate unmeasured

historical changes and future changes in forest carbon consistent with annual forest inventory measurements. For most regions, forest conditions are observed at time t_0 and at a subsequent time $t_1 = t_{0+s}$, where s is the time step (time measured in years) and is indexed by discrete (5 year) forest age classes. The inventory from t_0 is then backcasted to the year 1990 (on average about 16 years) and projected from t_1 to 2016 (about 5 years for the next inventory report). This backcasting/projection approach requires simulating changes in the age class distribution resulting from forest aging and disturbance events and then applying carbon density estimates for each age class. For the North, South (except for west Texas and west Oklahoma), and Rocky Mountains regions of the country, age class transition matrices are estimated from observed changes in age classes between t_0 and t_1 . In the remainder of the regions (Pacific Coast including Alaska, west Texas, and west Oklahoma), only one inventory was available (t_0) so transition matrices were derived from theory but informed by the condition of the observed inventory to backcast from t_0 to 1990 and project from t_0 to 2016.

Theoretical Age Transition Matrices

Without any mortality-inducing disturbance, a projection of forest conditions would proceed by increasing all forest ages by the length of the time step until all forest resided in a terminal age class where the forest is retained indefinitely (this is by assumption, where forest carbon per unit area reaches a stable maximum). For the most basic case, disturbances (e.g., wildfire or timber harvesting) can reset some of the forest to the first age class. Disturbance can also alter the age class in more subtle ways. If a portion of trees in a multiple-age forest dies, the trees comprising the average age calculation change, thereby shifting the average age higher or lower (generally by one age class).

With n age classes, the age transition matrix ($\mathbf{T}$) is an $n \times n$ matrix, and each element (T_{qr}) defines the proportion of forest area in class q transitioning to class r during the time step (s). The values of the elements of $\mathbf{T}$ depend on a number of factors,

including forest disturbances such as harvests, fire, and storms, and the value of s , especially relative to the span of the age classes. For example, holding area fixed, allowing for no mortality, defining the time step s equivalent to the span of age classes, and defining five age classes results in:

$$\mathbf{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{pmatrix} \quad (10)$$

where all forest area progresses to the next age class and forests within the terminal age class are retained forever. With this version of $\mathbf{T}$, after five time steps all forests would be in the terminal age class. Relaxing these assumptions changes the structure of $\mathbf{T}$. If all disturbances, including harvesting and fire, that result in stand regeneration are accounted for and stochastic elements in forest aging are allowed, $\mathbf{T}$ defines a traditional Lefkovitch matrix population model (e.g., Caswell 2001) and becomes:

$$\mathbf{T} = \begin{pmatrix} 1-t_1-d_1 & d_2 & d_3 & d_4 & d_5 \\ t_2 & 1-t_2-d_2 & 0 & 0 & 0 \\ 0 & t_3 & 1-t_3-d_3 & 0 & 0 \\ 0 & 0 & t_4 & 1-t_4-d_4 & 0 \\ 0 & 0 & 0 & t_5 & 1-d_5 \end{pmatrix} \quad (11)$$

Where

t_q is the proportion of forest of age class q transitioning to age class $q + 1$,

d_q is the proportion of age class q that experiences a stand-replacing disturbance, and

$(1 - t_q - d_q)$ is the proportion retained within age class q ($\mathbf{T}_{qr}$).

Projections and Backcast for Pacific Coast, Rocky Mountains, West Texas, and West Oklahoma

Projections of forest carbon in the Pacific Coast region (including Alaska), Rocky Mountains, west Texas and west Oklahoma are based on a life stage model:

$$\Delta C_t = C_{(t+m)} - C_t = (\mathbf{F}_t \mathbf{T} - \mathbf{F}_t) \cdot \mathbf{Den} + \mathbf{L}_t \cdot \mathbf{Den} \quad (12)$$

In this framework $\mathbf{T}$ is an age transition matrix

that shifts the age distribution of the forest $\mathbf{F}$. The difference in forest area by age class between time t and $t+s$ is $\mathbf{F}_t \mathbf{T} - \mathbf{F}_t$. This quantity is multiplied by carbon density by age class (**Den**) to estimate carbon stock change of forest remaining forest between t and $t+s$. Land use change is accounted for by the addition of $\mathbf{L}_t \cdot \mathbf{Den}$, where $\mathbf{L}_t$ identifies the age distribution of net land shifts into or out of forests. A query of the forest inventory databases provides estimates of $\mathbf{F}$ and **Den**, while inventory observations and modeling assumptions are used to estimate $\mathbf{T}$. By expanding **Den** to a matrix of carbon contained in all the constituent pools of forest carbon, projections for all pools are generated.

Land use change is incorporated as a $1 \times n$ vector $\mathbf{L}$, with positive entries indicating increased forest area and negative entries indicating loss of forest area, which provides insights of net change only. Implementing a forest area change requires some information and assumptions about the distribution of the change across age classes (the n dimension of $\mathbf{L}$). In the eastern states, projections are based on the projection of observed gross area changes by age class. In western states, total forest area changes are applied using rules. When net gains are positive, the area is added to the youngest forest age class; when negative, area is subtracted from all age classes in proportion to the area in each age class category.

Backcasting forest carbon inventories generally involves the same concepts as forecasting. An initial age class distribution is shifted at regular time steps backward through time, using a transition matrix (**B**):

$$\mathbf{F}_{t-s} = \mathbf{F}_t \cdot \mathbf{B} \quad (13)$$

$\mathbf{B}$ is constructed based on similar logic used for creating $\mathbf{T}$. The matrix cannot simply be derived as the inverse of $\mathbf{T}$ ($\mathbf{F}_{t-s} = \mathbf{F}_t \mathbf{T}^{-1}$) because of the accumulating final age class (i.e., $\mathbf{T}$ does not contain enough information to determine the proportion of the final age class derived from the $n-1$ age class and the proportion that is retained in age class n from the

previous time step).¹ However, $\mathbf{B}$ can be constructed using observed changes from the inventory and assumptions about transition/accumulation including nonstationary elements of the transition model:

$$\mathbf{B} = \begin{pmatrix} 1 - \sum d_i & b_2 & 0 & 0 & 0 \\ d_1 & 1 - b_2 & b_3 & 0 & 0 \\ d_2 & 0 & 1 - b_3 & b_4 & 0 \\ d_3 & 0 & 0 & 1 - b_4 & b_7 \\ d_4 & 0 & 0 & 0 & 1 - b_7 \end{pmatrix} \quad (14)$$

Forest area changes need to be accounted for in the backcasts as well:

$$\mathbf{F}_{t-s} = \mathbf{F}_t \mathbf{B} - \mathbf{L}_t \quad (15)$$

where $\mathbf{L}_t$ is the forest area change between t_1 and t_0 as previously defined.

In the Rocky Mountains, age class transition matrices were empirically derived from observed changes in age classes between t_0 and t_1 . The frequency of transitions was constructed between age classes observed at t_0 and t_1 to define $\mathbf{T}$ and between age classes t_1 and t_0 to define $\mathbf{B}$. In the Pacific Coast region, including Alaska, west Texas, and west Oklahoma, the theoretical life-stage models described by matrices 11 and 14 were applied. The disturbance factors (d) in both $\mathbf{T}$ and $\mathbf{B}$ are derived from the current inventory by assuming that the area of forest in age class 1 resulted from disturbance in the previous period, the area in age class 2 resulted from disturbance in the period before that, and so on. The source of disturbed forest was assumed to be proportional to the area of forest in each age class. For projections ($\mathbf{T}$), the average of implied disturbance for the previous two periods was applied. For the backcast ($\mathbf{B}$), we move the disturbance frequencies implied by the age class distribution for each time step. For areas with empirical transition matrices, change in forest area ($\mathbf{L}_t$) was backcasted/projected using the change in forest area observed for the period t_0 to t_1 . In the

Pacific Coast region, including Alaska, west Texas, and west Oklahoma, it was assumed that total forest land area remained constant for the time period examined.

Projections and Backcast for North, South, east Texas, and east Oklahoma

For the eastern United States a full set of remeasured plots were available. When remeasured data are available, the previously described approach is extended to estimate change more directly; in this case $\Delta \mathbf{C}_t = \mathbf{F}_t \cdot \delta \mathbf{C}$ where $\Delta \mathbf{C}$ is net stock change by pool within the analysis area, $\mathbf{F}$ is as previously defined, and $\delta \mathbf{C}$ is an $n \times cp$ matrix of per unit area forest carbon stock change per year by pool (cp) arrayed by forest age class. Inter-period forest carbon dynamics are previously described, and the age transition matrix ($\mathbf{T}$) is estimated from the observed data directly. Forest carbon change at the end of the next period is defined as: $\Delta \mathbf{C}_{t+s} = \mathbf{F}_t \cdot \mathbf{T} \cdot \delta \mathbf{C}$. Land use change and disturbances such as cutting, fire, weather, insects, and diseases were incorporated by generalizing to account for the change vectors and undisturbed forest remaining as undisturbed forest:

$$\Delta \mathbf{C}_{t+s} = \sum_{d \in L} (\mathbf{A}_{td} \cdot \mathbf{T}_d \cdot \delta \mathbf{C}_d) \quad (16)$$

Where

$\mathbf{A}_{td}$ = area by age class of each mutually exclusive land category in $\mathbf{L}$ which includes d disturbances at time t .

$L = (FF, NFF, FNF, F_{cut}, F_{fire}, F_{weather}, F_{id})$ where FF = undisturbed forest remaining as undisturbed forest, NFF = nonforest to forest conversion, FNF = forest to nonforest conversion, F_{cut} = cut forest remaining as forest, F_{fire} = forest remaining as forest disturbed by fire, $F_{weather}$ = forest remaining as forest disturbed by weather, and F_{id} = forest remaining as forest disturbed by insects and diseases.

In the case of land transfers (FNF and NFF), $\mathbf{T}_d$ is an $n \times n$ identity matrix and $\delta \mathbf{C}_d$ is a carbon stock transfer rate by age. Paired measurements for all plots in the inventory provide direct estimates of all elements of $\delta \mathbf{C}_d$, $\mathbf{T}_d$, and $\mathbf{A}_{td}$ matrices.

¹ Simulation experiments show that a population that evolves as a function of $\mathbf{T}$ can be precisely backcast using $\mathbf{T}^{-1}$. However, applying the inverse to a population that is not consistent with the long run outcomes of the transition model can result in projections of negative areas within some stage classes.

Projections are developed by specifying either F_{t+s} or A_{t+sd} for either a future or a past state. To move the system forward, T is specified so that the age transition probabilities are set up as the probability between a time 0 and a time 1 transition. To move the system backward, T is replaced by B so that the age transition probabilities are for transitions from time 1 to time 0. Forecasts were developed by assuming the observed land use transitions and disturbance rates would continue for the next 5 years. Backcasts were developed using a Markov Chain process for land use transitions, observed disturbance rates for fire, weather, and insects. Historical forest cutting was incorporated by using the relationship between the area of forest cutting estimated from the inventory plots and the volume of roundwood production from the Timber Products Output program (U.S. Forest Service 2014d). This relationship allowed for the modification of F_{cut}

such that it followed trends described by Oswalt et al. (2014).

Total Uncertainty

There are many input variables (e.g., aboveground live biomass, forest land area) in the FCAF (Fig. 10) and each input variable has uncertainty. Techniques to account for the total uncertainty associated with the FCAF output (i.e., annual C flux in Table 1) are still under development. As a first approximation we intend to use a Monte Carlo-based framework. Uncertainty parameters (e.g., distribution functions and variance) that best reflect the potential errors associated with each input variable will be defined. For each input variable, many realizations (e.g., $n_{mc} = 10,000$) will be randomly generated using the uncertainty parameters. The realizations for each input variable will then be used in the FCAF to produce a distribution of predictions, means, and standard deviations for the annual C flux.

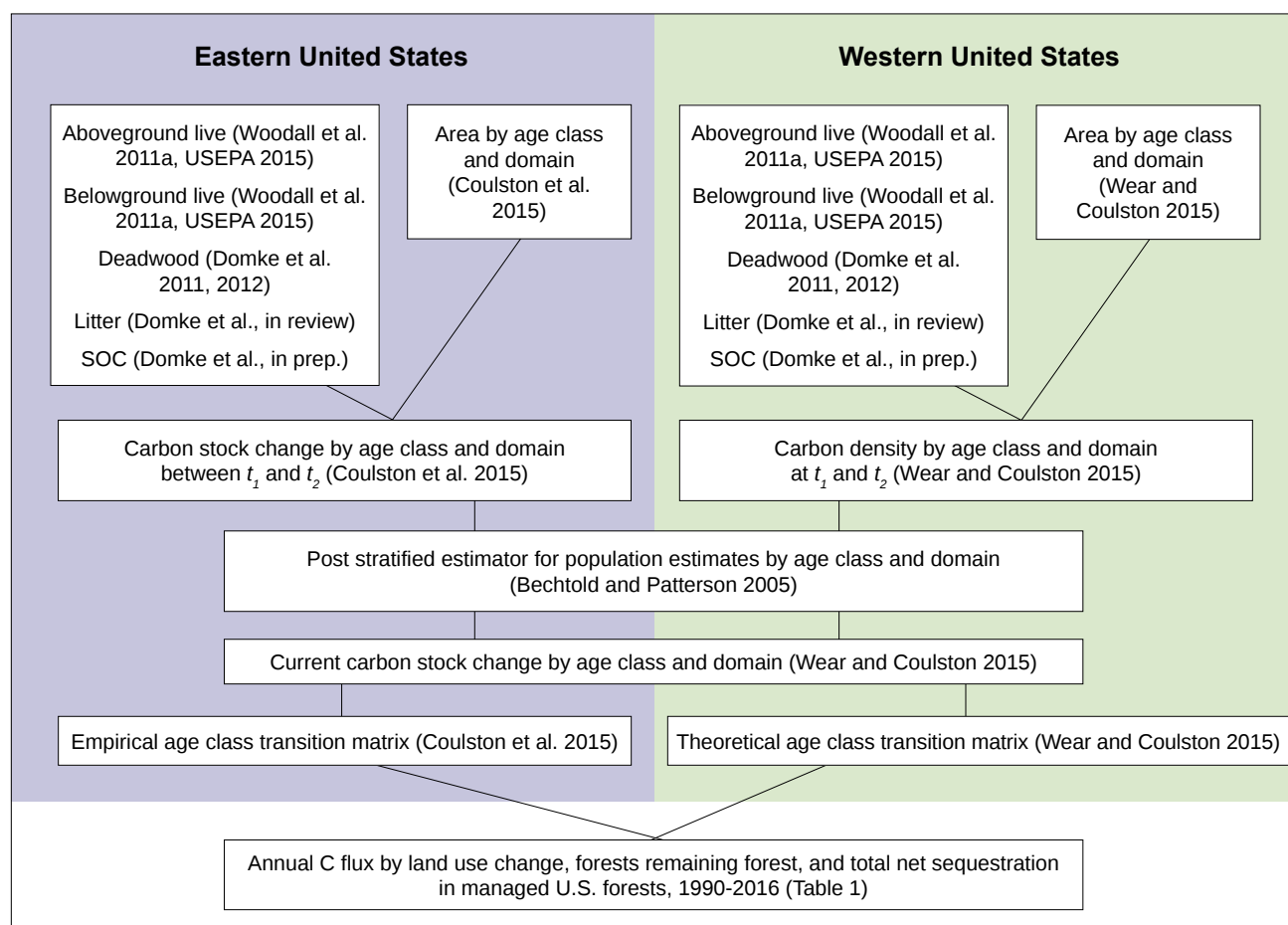


Figure 10.—Conceptual flowchart of the FCAF outlining the first approximation that is intended to measure total uncertainty for annual C flux predictions in the United States. Sources of uncertainty (with references) represent input variables that will be included in the total uncertainty assessment.

Annual Data Description

Contrary to past greenhouse gas inventories, periodic data were not used in the FCAF to develop national carbon baselines, instead we relied solely on annual FIA data (Tables 3 and 4). Annual FIA plots are consistently located across the United States in a spatially balanced and unbiased manner (Fig. 11). The base intensity of FIA plots is approximately one plot for every 2,428 ha. Strategic partners, such as states, have the opportunity to increase the base intensity by adding plots through direct or in-kind

contributions. Some of these added plots may be established and measured at one point in time but are then not subsequently remeasured. The FIA database is structured such that statistically valid samples of change can be derived owing to the hexagonal and panelized system across the United States (see Bechtold and Patterson 2005). The attribution and projection system of FCAF will be greatly improved once western annual plots are remeasured in the years ahead.

Table 3.—Inventory data used to develop forest carbon estimates presented in this report by state and time (time 1 and time 2) for states with remeasured annual plots. Valid population estimates were made using the two independent measurement cycles (otherwise known as evaluations, see U.S. Forest Service 2014a, b).

Remeasured annual plots			Remeasured annual plots		
State	Time 1 year range	Time 2 year range	State	Time 1 year range	Time 2 year range
Alabama	2001 - 2009	2006 - 2014	Nebraska	2004 - 2008	2009 - 2013
Arkansas	2000, 2002, 2004 - 2010	2009 - 2014	New Hampshire	2003 - 2008	2009 - 2013
Connecticut	2004 - 2008	2009 - 2013	New Jersey	2004 - 2008	2009 - 2013
Delaware	2004 - 2008	2009 - 2013	New York	2003 - 2008	2009 - 2013
Florida	2002 - 2004, 2006 - 2007	2009 - 2013	North Carolina	2002 - 2007	2003, 2005 - 2007, 2009 - 2014
Georgia	1998 - 2009	2005 - 2007, 2009 - 2013	North Dakota	2004 - 2009	2009 - 2014
Illinois	2004 - 2009	2009 - 2014	Ohio	2003 - 2008	2009 - 2013
Indiana	2004 - 2008	2009 - 2013	Oklahoma (East)	2008	2010 - 2013
Iowa	2004 - 2009	2009 - 2014	Pennsylvania	2004 - 2008	2009 - 2013
Kansas	2004 - 2009	2009 - 2014	Rhode Island	2004 - 2008	2009 - 2013
Kentucky	2000 - 2009	2005 - 2006, 2008 - 2012	South Carolina	2002 - 2010	2007 - 2013
Louisiana	2001 - 2005, 2008	2009 - 2013	South Dakota	2004 - 2009	2009 - 2014
Maine	2004 - 2008	2009 - 2013	Tennessee	2000 - 2009	2005 - 2012
Maryland	2004 - 2008	2009 - 2013	Texas (East)	2002 - 2008	2005, 2007 - 2012
Massachusetts	2004 - 2008	2009 - 2013	Vermont	2004 - 2008	2009 - 2013
Michigan	2004 - 2009	2009 - 2014	Virginia	2002 - 2003, 2005 - 2010	2008 - 2013
Minnesota	2005 - 2009	2010 - 2014	West Virginia	2004 - 2008	2009 - 2013
Mississippi	2006	2009 - 2014	Wisconsin	2004 - 2009	2009 - 2014
Missouri	2004 - 2009	2009 - 2014			

Table 4.—Inventory data used to develop forest carbon estimates presented in this report by state and time (time 1 and time 2) for states where an insufficient number of annual plots have been remeasured. A single cycle of annual plots was split into two statistically valid samples of the state's forest carbon at the start and end of the annual inventory cycle.

Split annual cycle plots			Split annual cycle plots		
State	Time 1 year range	Time 2 year range	State	Time 1 year range	Time 2 year range
Alaska (Coastal)	2004 - 2008	2009 - 2013	New Mexico	1999	2005 - 2013
Arizona	2004 - 2008	2009 - 2013	Oklahoma (West)	2009 - 2010	2011 - 2013
California	2003 - 2007	2008 - 2012	Oregon	2003 - 2007	2008 - 2012
Colorado	2004 - 2008	2009 - 2013	Texas (West)	2004 - 2007	2008 - 2012
Idaho	2004 - 2008	2009 - 2013	Utah	2004 - 2008	2009 - 2013
Montana	2004 - 2008	2009 - 2013	Washington	2003 - 2007	2008 - 2012
Nevada	2004 - 2008	2009 - 2013	Wyoming	2000	2011 - 2013

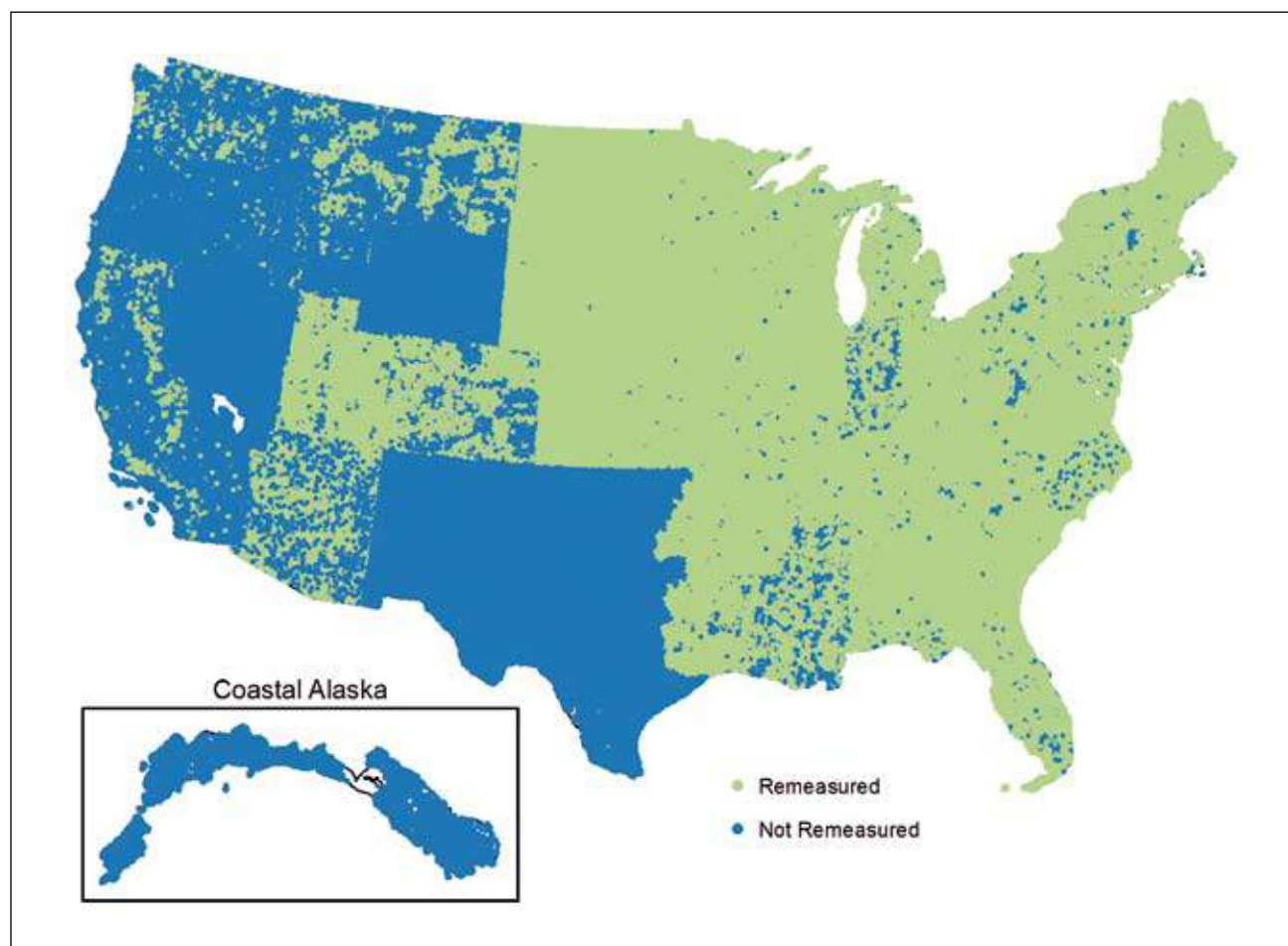


Figure 11.—Annual FIA plots (remeasured and not remeasured) across the United States including coastal Alaska through 2014. Note: Due to the vast number of plots, data points appear spatially contiguous when displayed in small maps. Source: FIA data.

PLANNED IMPROVEMENTS TO THE FOREST CARBON INVENTORY

Uncertainty

Estimates of uncertainty are not provided in this report as techniques for calculating uncertainty are still being developed for application in the United States' official submission to the UNFCCC, which requires such estimates. Good practice guidelines by UNFCCC (IPCC 2006) recognize multiple possible approaches to defining and quantifying uncertainty, and the documentation provides some guidance, particularly for lower tier estimates, but guidelines are not prescriptive. The primary role for uncertainty analysis is in model development and improving estimates by identifying the important sources of uncertainty in a country's report. Overall uncertainty in the current estimate of forest carbon change is a 95 percent confidence interval (USEPA 2015a), which is combined with the emission/sequestration estimates of other sectors. This uncertainty estimate enables comparability across Nations as it is required input to UNFCCC from all signatory Nations.

Uncertainty associated with forest carbon baselines can be substantial compared to other sectors, such as fossil fuel combustion, due to the numerous sources of error that all contribute to forest carbon uncertainty. Sampling error results from using sample plots to estimate the entire forest population (Fig. 12a). Estimates of forest carbon stores are also subject to error associated with the models used for calculating carbon (e.g., Melson et al. 2011), with model selection error, parameter estimation error, and residual error (Fig. 12b) being the primary sources. Finally, there is measurement error that arises in the field when collecting measurements such as tree height and diameter (Fig. 12c). Total uncertainty attempts to represent all of these sources of error simultaneously. Monte Carlo approaches have been used to simulate total uncertainty, and this approach for estimating uncertainty associated with the U.S. forest carbon inventory will be evaluated for application in the 2016 submission to the UNFCCC, as Bayesian approaches continue to be researched.

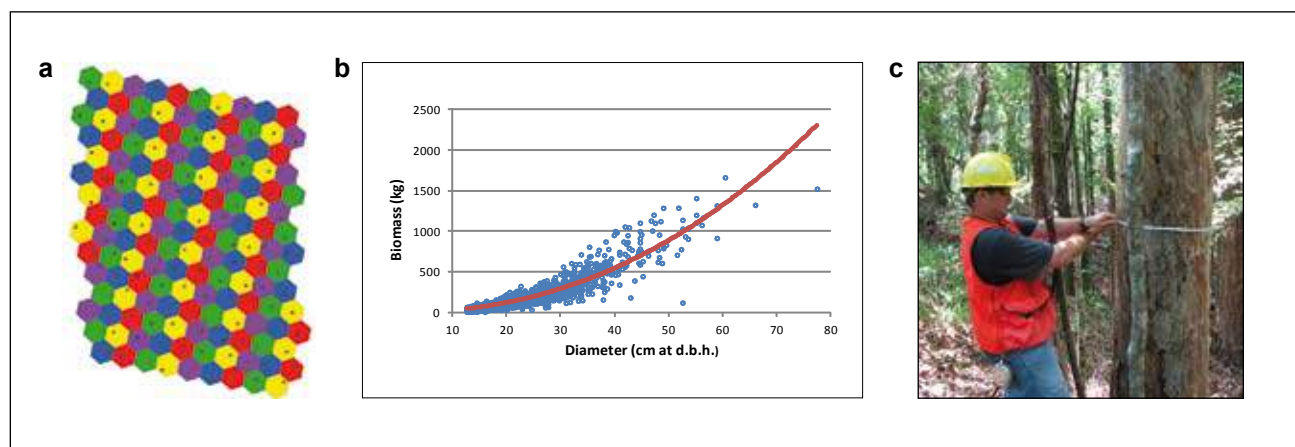


Figure 12.—Sources of forest carbon inventory uncertainty: (a) sampling error, (b) model error, and (c) measurement error. Photo by Kimberly Rowe, U.S. Forest Service.

More Data: Forests, Woodlands, and Urban Trees

The foundation of the forest carbon accounting system is the annual forest inventory. The ongoing annual surveys by FIA are expected to improve the accuracy and precision of forest carbon estimates as new state surveys become available (U.S. Forest Service 2014a), particularly in western states as the annual plot system is remeasured. Hawaii and U.S. territories will be included when appropriate forest carbon data are available (compiled Hawaii data from the annualized sampling design is anticipated in summer 2016) (Fig. 13). In addition, the more intensive sampling of fine woody debris, litter, and SOC on a subset of FIA plots continues and will

substantially improve resolution of carbon pools (Westfall et al. 2013). Increased sample intensity of some carbon pools and using annualized sampling data as it becomes available for those states that are not currently reporting on an annual basis are planned for future National Greenhouse Gas Inventories, which will greatly improve the FCAF. Beyond the monitoring of the forest land use, the FIA program is expanding its field measurements to other land uses of woodlands and settlements where tree resources are present. The U.S. Forest Service has been conducting inventories of urban tree carbon (Nowak et al. 2013) for a number of years, with a recent push to begin annual inventories in a number of cities. Carbon inventory-relevant information for these land uses will likely become increasingly available in the future.

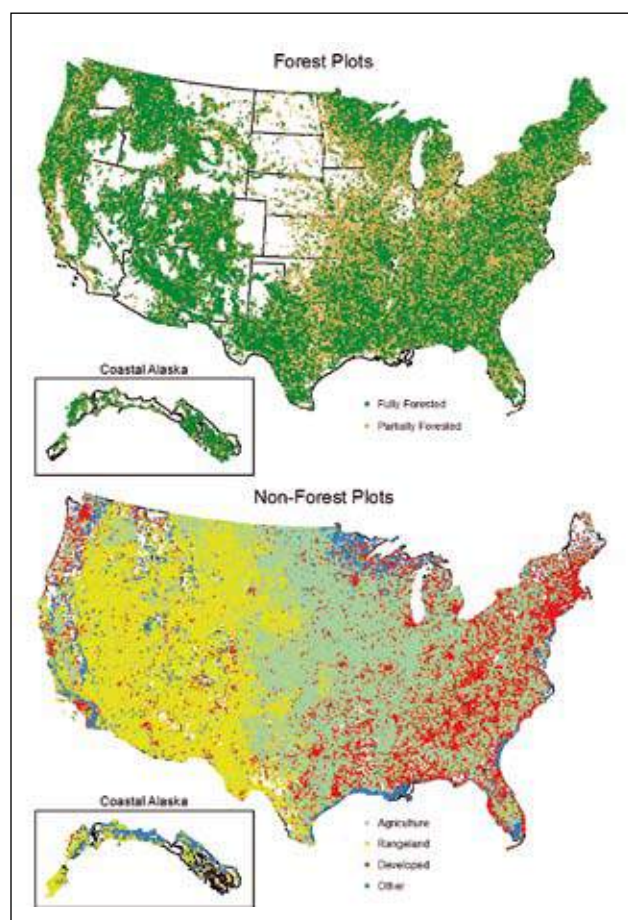


Figure 13.—FIA forest land use plots indicating fully and partially forested plots in contrast to FIA measurement of other land uses across the entire plot network. Note: Due to the vast number of plots, data points appear spatially contiguous when mapped. Source: FIA data.

Refined Land Use Assessment: The Image Change Estimation Program

The 2014 Farm Bill (Agricultural Act 2014; Subtitle D: SEC. 8301 (B) (9)) directs FIA to explore refined approaches to understanding and reporting on changes in land cover and use. In response to this, the FIA program has initiated the Image Change Estimation (ICE) program to interpret imagery from the USDA National Agricultural Imagery Program (NAIP) in a more rigorous manner. The FIA program already employs NAIP imagery to assist with identification of land use (e.g., forest or settlements) across the FIA plot network. However, ICE efforts will identify the land use on every FIA plot concurrent with the measurement cycle of NAIP imagery, which is often far shorter (2 to 3 years) than the typical FIA plot measurement cycle (5 to 10 years). The measurement of land use is not an automated cover interpretation (although a tandem cover assessment will be recorded); rather each FIA plot is manually reviewed by an experienced aerial photogrammetry interpreter. In addition, if change is identified on a plot, the agent of change will be identified if possible (e.g., forest converted to development) (Fig. 14). This program has the potential to greatly refine the monitoring of land use change as a component of the FCAF, as it will operate on the same national plot network.

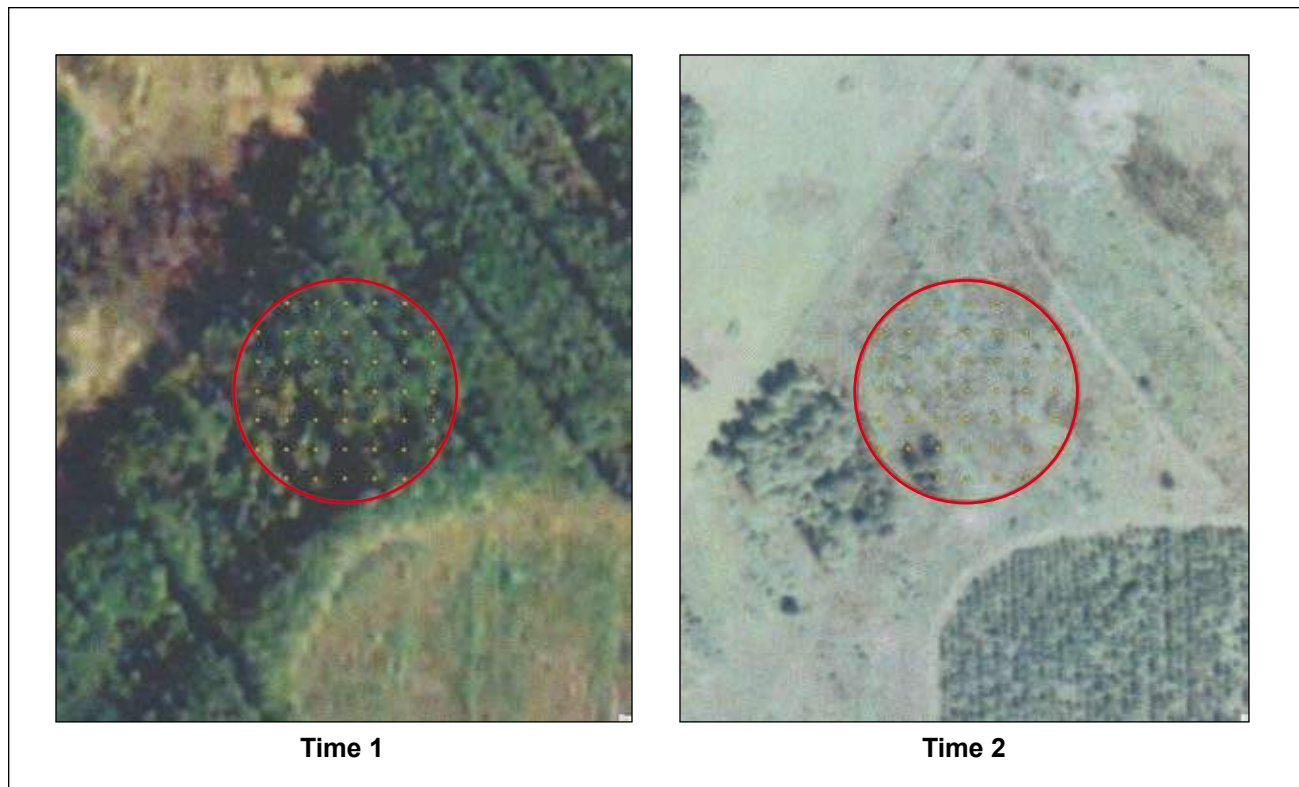


Figure 14.—Measuring land use and land cover changes from time 1 to time 2 on an FIA plot using Image Change Estimation protocols.

Reconciling Improvements to Forest Accounting with All Land Uses

The refinement of forest carbon accounting to benefit U.S. reporting to UNFCCC certainly is not conducted in isolation. Forest land use is part of a larger terrestrial sector entitled “Agriculture, Forestry, and Other Land Uses” (AFOLU), as land use is constantly changing across the United States (Fig. 15). If there is perfect alignment between the carbon accounting of agriculture and forests then the soil carbon associated with a deforested hectare of forest would potentially transfer to a hectare of agriculture, thus balancing out its transfer among land uses. Because land use change can have a substantial effect on the AFOLU carbon accounting, accurately representing the transfer of carbon by pool across the matrix of land use change is paramount. Forests account for the vast majority of terrestrial carbon flux in the United States, and thus it is logical that the refinement of forest carbon accounting should occur first, with subsequent

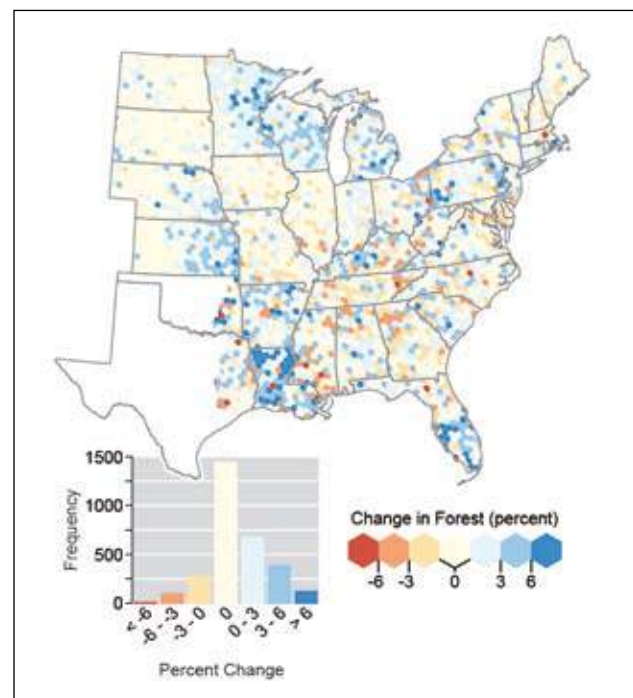


Figure 15.—Percent forest land use change in the eastern United States derived from FIA plot land use identification, 2002-2012 (Woodall et al. 2015).

cascading of carbon accounting improvements across the remaining land uses of AFOLU. It is envisioned that the initiation of a number of improvements, including the implementation of the Image Change Estimation program, refined soil carbon accounting and modeling across all land uses, refined integration between the U.S. Department of Agriculture Forest Inventory and Analysis forest monitoring and Natural Resources Inventory cropland monitoring programs, and expanded monitoring of urban trees and agroforestry systems, will greatly enable refined accounting across the breadth of AFOLU.

Pool Estimation

In an effort to reduce the uncertainty associated with the estimation of individual forest carbon pools, the empirical data and associated models for each pool are being evaluated for potential improvement (Woodall 2012). In the 1990 through 2010 UNFCCC submission, the approach to tree volume/biomass

estimation was evaluated and refined (Domke et al. 2012). In the 1990 through 2011 UNFCCC submission, the standing dead tree carbon model was replaced with a nationwide inventory and associated empirical estimation techniques (Domke et al. 2011, Harmon et al. 2011, Woodall et al. 2012). In the 1990 through 2012 Inventory report (2013 NGHGI), the downed dead tree carbon model was refined by incorporation of a national field inventory of downed dead wood (Domke et al. 2013, Woodall et al. 2013). In the current Inventory report (2015 NGHGI), the litter carbon density model was refined with a nearly nationwide field inventory (Domke et al., in review). In this report, a new approach to estimating soil organic carbon is included (Domke et al., in prep.). Components of other pools, such as carbon in belowground biomass (Russell et al. 2015) (Fig. 16), understory vegetation (Russell et al. 2014), and foliage (Clough et al., in review) are being explored for application in future submissions.

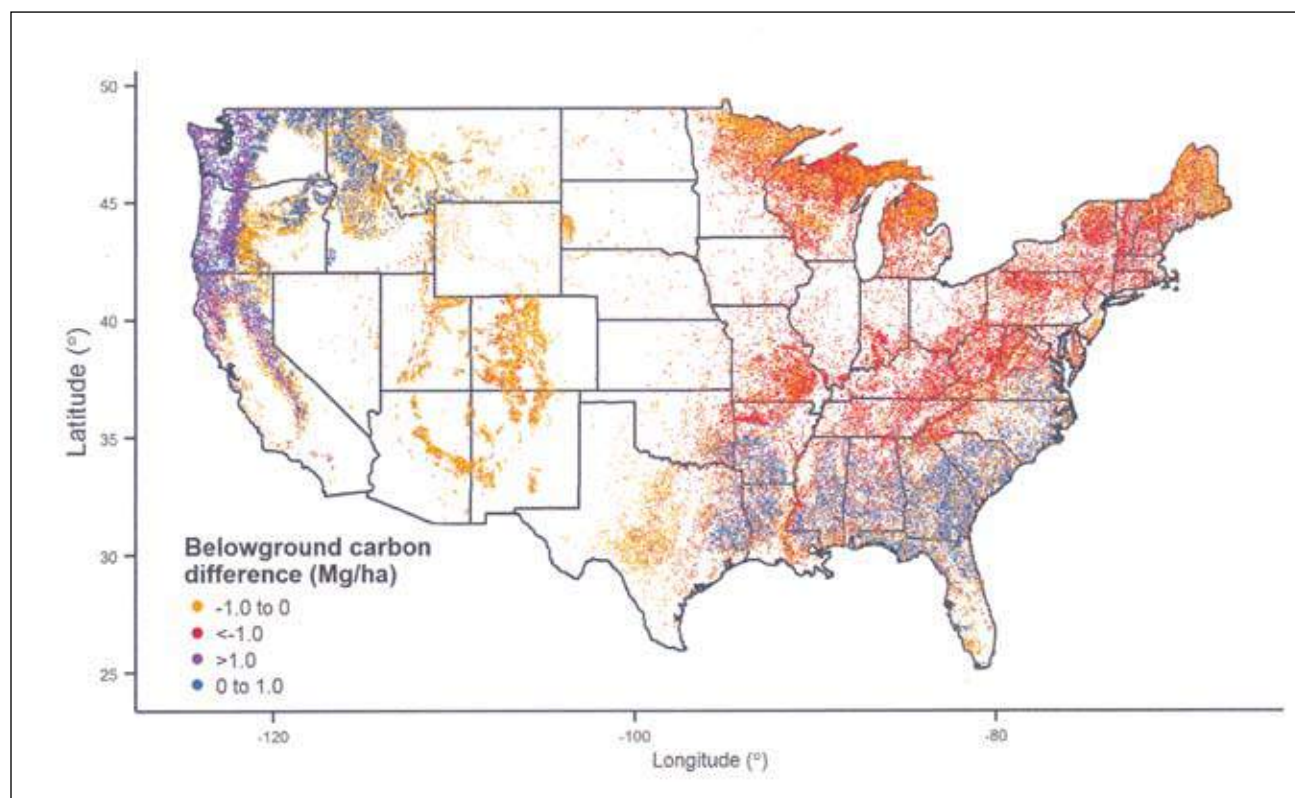


Figure 16.—Distribution of differences between live tree belowground C estimates from the current U.S. National Greenhouse Gas Inventory and refined estimates ($\text{Mg}\cdot\text{ha}^{-1}$). Red colors indicate higher estimated C and purple colors indicate less C (Russell et al. 2015).

The Boreal Forests of Interior Alaska

A national system of field inventory plots is the primary data source for the annual assessment of U.S. forest carbon stocks and stock change to meet reporting requirements under the UNFCCC. The only area of potentially managed forests included under UNFCCC reporting that is not sampled by the national plot network is the boreal forest of interior Alaska (Fig. 17). A preliminary analysis suggests that these forests may represent over a third of all forest carbon in the conterminous United States (Zhu and McGuire, in review), hence the assessment of their carbon balance is critical to the monitoring of the U.S. terrestrial carbon sink. Furthermore, it is the nonlive biomass carbon pools, namely the forest floor, lichen/moss mats, and soils, which may



A vast stretch of boreal forest reaches along the Tanana River in interior Alaska. Photo by Christopher Woodall, U.S. Forest Service.

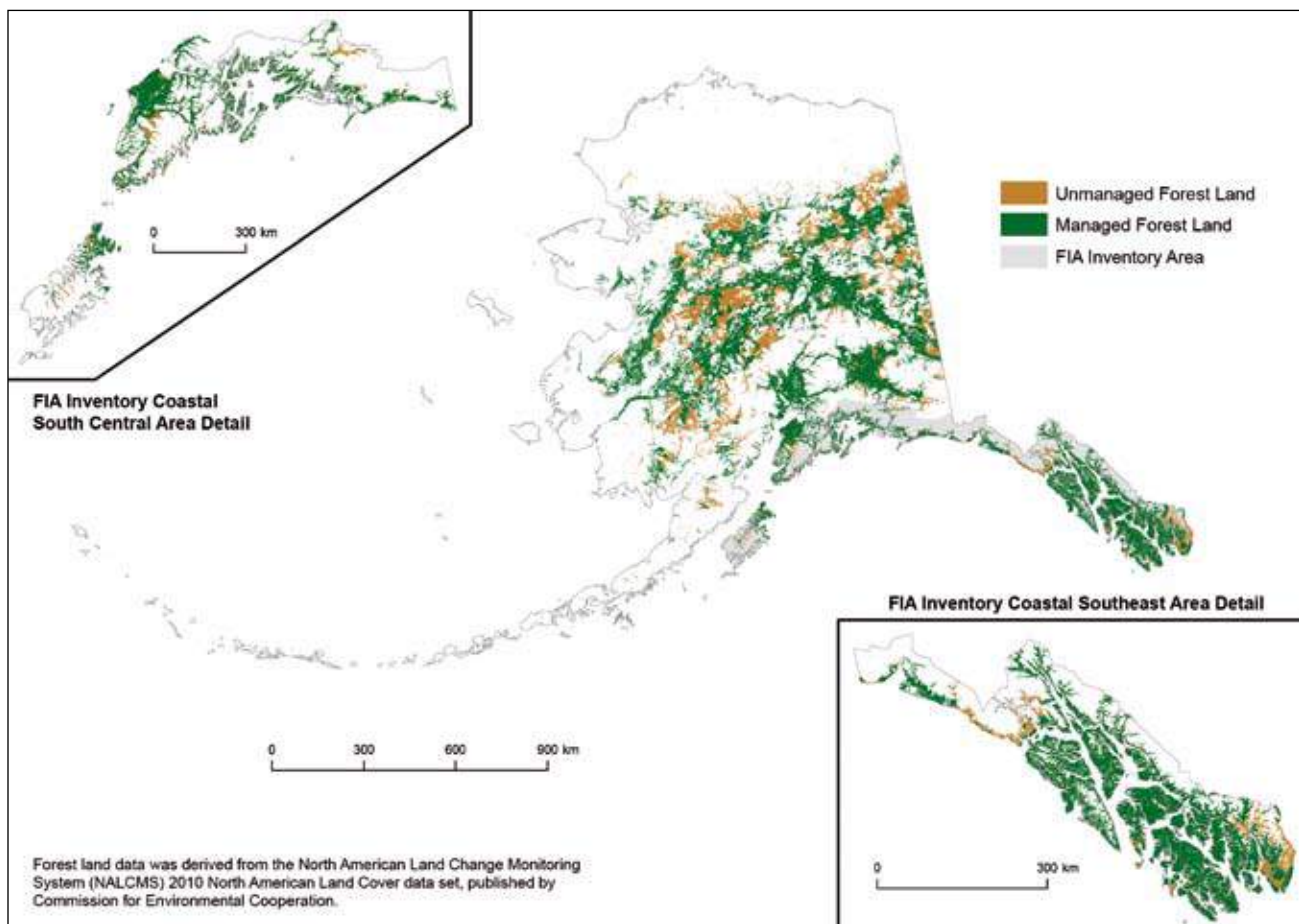


Figure 17.—Delineation of managed and unmanaged forest land in Alaska. Currently south central and southeast coastal Alaska are inventoried by FIA, but interior Alaska remains the only area not sampled by the national plot network.

account for the majority of Alaska's carbon stock that cannot be quantified using remote sensing products alone. A variety of field and research efforts are currently underway to ameliorate these knowledge gaps. In the interim, a managed land analysis has been completed for interior Alaska (Ogle et al., in prep.) which identifies tens of millions of acres of forest that can be considered influenced by humans, and hence deemed managed per UNFCCC good practice guidance.

Disaggregation

The FCAF is designed to monitor carbon to satisfy UNFCCC reporting requirements while monitoring progress towards future commitments. Such a framework aligns well with the FIA inventory as it is intended to address strategic-level questions about forest resources across large geographic areas under a design-based mode of inference (Bechtold and Patterson 2005). Undoubtedly,

there is increasing interest in using this information for smaller-scale reporting within the population. The FCAF is also applicable in this case, but the base FIA data may not be sufficiently dense to parameterize the system. By using auxiliary variables from data collected for all population units, such as those obtained from remote sensors, and shifting to a model-based mode of inference, dramatic gains in the precision of estimates can be achieved for disaggregated areas, though possibly at the expense of violating the unbiasedness assumption for the estimators (Gregoire 1998). Through the application of a model-based approach, Wilson et al. (2013) developed spatially extant estimates of forest carbon density for the conterminous United States using FIA and auxiliary data (e.g., multi-temporal satellite imagery from the National Aeronautics and Space Administration [NASA]) (Fig. 18). The relationship between the auxiliary and FIA data was defined using an

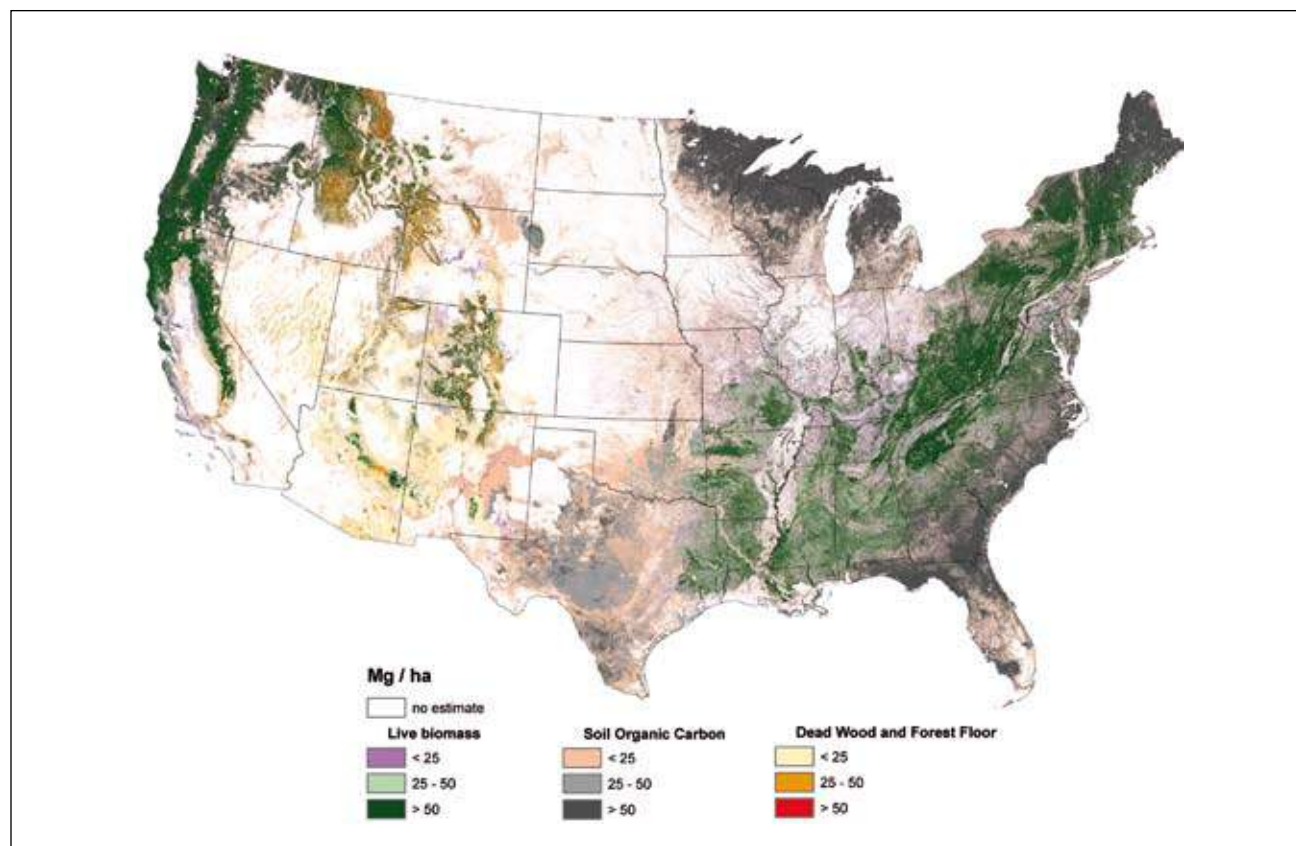


Figure 18.—Forest carbon pool which constitute the plurality of forest carbon at each pixel across the conterminous U.S.: live biomass, soil organic carbon, or detritus (dead wood and forest floor) (Wilson et al. 2013).

ecological ordination model enabled by a k nearest neighbor estimator (Eskelson et al. 2009). It provides an estimate for each unsampled unit in the population as a weighted average of the observed response variable for the k -nearest sample units in the feature space. Research is currently underway to incorporate finer spatial resolution imagery (e.g., Landsat time series) using a similar modeling approach. Although the new accounting framework is designed to meet national scale monitoring needs, it is hoped through research partnerships with stakeholders (e.g., national forests or states) that valid downscaling techniques can be developed to disaggregate national results to the entity level. These finer scale estimates of carbon density and land use may be used to parameterize the FCAF so that smaller areas can be monitored.

Harvested Wood Products

Carbon stored in long-term harvested wood products (HWP) is an important driver of carbon sequestration within the forest sector and as such is included when estimating the contribution of the forest sector to greenhouse gas sources and sinks. For example, in 2013 the accumulation of carbon in

HWP was $19.3 \text{ Tg}\cdot\text{yr}^{-1}$ (USEPA 2015a), which was as large as accumulation rates in litter, standing dead trees, and understory pools combined. However, the HWP estimates through the Woodcarb II model (Skog 2008) are currently exogenous to the FCAF. Efforts to more directly incorporate HWP within FCAF will further increase the analytical capacity to assess carbon dynamics in the United States and provide for consistent scenario-based projections.

The key link between FCAF inventory estimates and HWP estimates is domestic harvest. Domestic harvest simultaneously influences sequestration within the forest and material moving into durable wood products. The attribution of forest carbon dynamics allows for the development of relationships between harvest effects witnessed in the inventory and quantities of wood products observed from a census of mills. These two sources of information exhibit a strong relationship (ordinary linear regression; $R^2 = 0.98$) when observed at an aggregate scale (Fig. 19). Further research is needed to determine the relationship among products, imports, and exports. As these relationships are quantified, the FCAF will also support a HWP module.

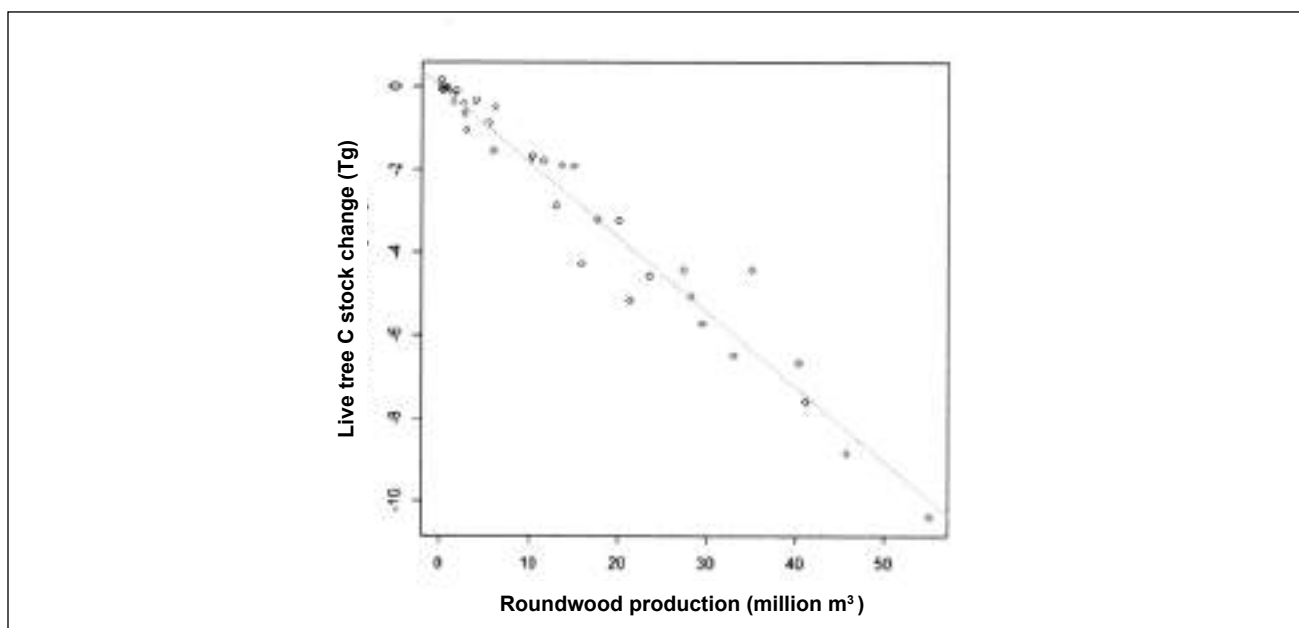


Figure 19.—The relationship between live tree C stock change from cutting in the inventory and of roundwood production (m^3) from wood using facilities. The figure is based on the eastern United States where state-level production is compared to state-level changes in live tree carbon from cutting.

RESEARCH TO IMPROVE AND DISSEMINATE THE FOREST CARBON INVENTORY

National Volume/Biomass Study

National, regional, state and county estimates for both bioenergy and greenhouse gas analyses are derived from FIA field data that rely on individual tree species volume/biomass models. Recently, there has been an increasing need for tree biomass estimates, including various portions of the tree (e.g., merchantable bole and stumps), that requires not only a re-evaluation of older volume/biomass models but perhaps development of new modeling approaches. Unfortunately, there has been no consistent national source of individual tree volume/biomass measurements of all tree components. To ensure FIA estimates provide an accurate representation of forest resources and trends, comprehensive data on tree biomass are needed. These data would provide: (1) a means of assessing current FIA methods, and (2) a basis for nationally-consistent estimation of biomass/carbon. Unfortunately, obtaining such data is both time consuming and expensive, as very detailed measurements on individual trees are required.

To accomplish the considerable amount of work necessary, FIA has engaged a number of partners and stakeholders including: University of Maine, Potlatch Corporation, University of Montana, University of Georgia, Rayonier Inc., U.S. Forest Service Forest Management Service Center, Michigan State University, Oregon State University, National Council for Air and Stream Improvement Inc., Virginia Polytechnic Institute and State University, Weyerhaeuser NR Company, and U.S. Forest Service Forest Products Laboratory. The objective of this study is to collect data (Fig. 20) and develop methods for estimating the biomass/carbon content of individual trees (Weiskittel et al. 2015). Once developed, these methods will have wide-ranging application; however, the primary purpose is for application to trees measured by FIA. These methods will provide a nationally-consistent basis for assessments of current conditions and trends in forest resources. In addition to providing consistent methods and definitions nationwide, substantial increases in analytical flexibility will be realized.

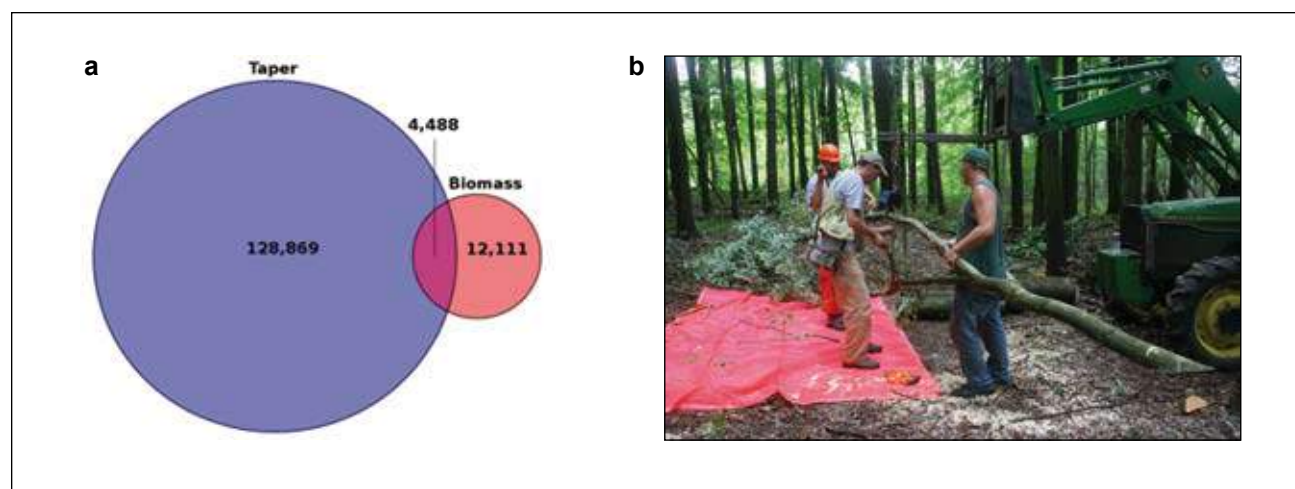


Figure 20.—The national volume study has already gathered thousands of legacy individual tree observations, such as taper and biomass data collected from often overlooked data files spanning nearly a century (a) in addition to contemporary felled tree studies (b) to augment gaps in the legacy dataset. Photo by David MacFarlane, Michigan State University, used with permission.

Remote Sensing of Forest Carbon

Remote sensing combined with field inventory data can provide spatially and temporally consistent biomass estimates. Strong statistical relationships between LiDAR forest structure metrics and field-measured biomass enable accurate spatial predictions of biomass well beyond the plot locations (e.g., Pflugmacher et al. 2014) (Fig. 21). But LiDAR data remain expensive and are limited historically. Landsat data are available everywhere since 1972 and can be linked to the LiDAR biomass estimates to extend those over space and time. A single date of Landsat data does not correlate well

with biomass over a wide range of biomass values; however, the strength of the Landsat data is in the time series. Because disturbance and recovery history are strong determinants of current biomass, history metrics (e.g., predisturbance reflectance trend, year of disturbance, causal agent and magnitude of disturbance, and recovery rate) derived from times series data transcend the weakness of the biomass to single-date Landsat relationship. The advantages are twofold: (1) high-quality current biomass maps can be derived for any locations where there are samples of LiDAR data (i.e., LiDAR strips) supported by field measurements; and (2) the annual statistical models can be walked back to an arbitrary date (e.g., 1990) using the history metrics prior to that date, thereby providing an annual time series of biomass maps using a consistent set of methods so that trend lines are devoid of artifacts associated with changes in sample design or approach. The basic methodology has been tested and published. A current NASA-Carbon Monitoring Systems research effort is extending the approach across six diverse forest areas (~22,500 km² each) of the conterminous United States.

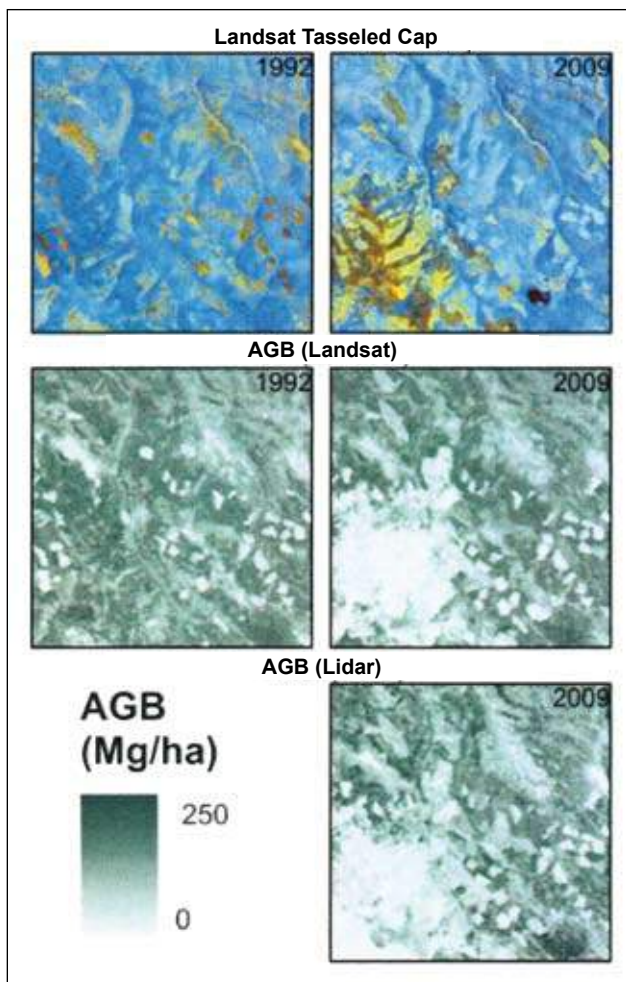


Figure 21.—Example of integrating Landsat and LiDAR information to create robust maps of aboveground live tree biomass that can reduce the lack of temporal sensitivity often associated with delays in remeasuring forest inventory plots following disturbances such as wildfire (Pflugmacher et al. 2014).

Inventorying Boreal Forest Carbon: The Tanana Experiment

The interior Alaska boreal forest biome represents one-fifth of the forest land in the entire United States. Despite the importance of these natural resources to local Alaskan communities, the ecological significance of changes in these resources and their role in the global energy, water, and carbon cycles, interior Alaska is the only forest ecosystem in the country that is not currently being funded for monitoring as part of the national Forest Inventory and Analysis program. A full inventory of interior Alaska could answer fundamental and pressing questions about this important landscape, including:

- What is the status and condition of forests in interior Alaska, and how can they be sustainably managed to provide woody biomass to support bioenergy production in remote communities?

- How are changes in forest composition and condition affecting the quality of wildlife habitat (e.g. caribou) and associated effects on subsistence economies?
- How much carbon is stored below ground in cold, moist soils?
- How vulnerable is this carbon reservoir to potential changes in the wildfire regime, insects, and disease?
- How can the FIA program draw from the local knowledge of natural resources, and in turn provide employment opportunities in these remote areas of the state?

The U.S. Forest Service initiated an inventory pilot in the Tanana Valley of interior Alaska in the summer of 2014 to evaluate a cost-effective inventory design utilizing a reduced sample of field plots and state-of-the-art airborne remote sensing which enables FIA to inventory the entire state at a cost level of \$25 million over 10 years—less than one-fifth the cost of the traditional FIA sampling design. Field measurement protocols specific to boreal forest conditions are being examined including: (1) ground cover measurements to

quantify biomass/carbon of lichens and mosses; (2) soil core sampling to quantify soil carbon content; (3) using two microplots (or one larger microplot) to increase sampling of small (2.54 to 12.7 cm) diameter trees; and (4) using high-precision global positioning system (GPS) to enable accurate registration of field plots to airborne remote sensing data. The U.S. Forest Service has built partnerships with a number of groups to leverage resources and expertise for this pilot work. NASA's Goddard Space Flight Center augmented the FIA sample with detailed measurements acquired from a newly-developed LiDAR-hyperspectral-thermal airborne remote sensing instrument (G-LiHT) (Cook et al. 2013) that provides detailed measurements of 3-D forest structure (tree heights), species composition, and condition (e.g., insect damage) (Fig. 22). The State of Alaska Division of Forestry (Tanana Valley State Forest) assisted with logistics planning and in-kind support. The University of Alaska, Fairbanks has been instrumental in logistics planning, protocol development, and ground-access field plot data collection. Finally, the U.S. Fish and Wildlife Service aided with protocol development and ground plot location in the Tetlin National Wildlife Refuge.

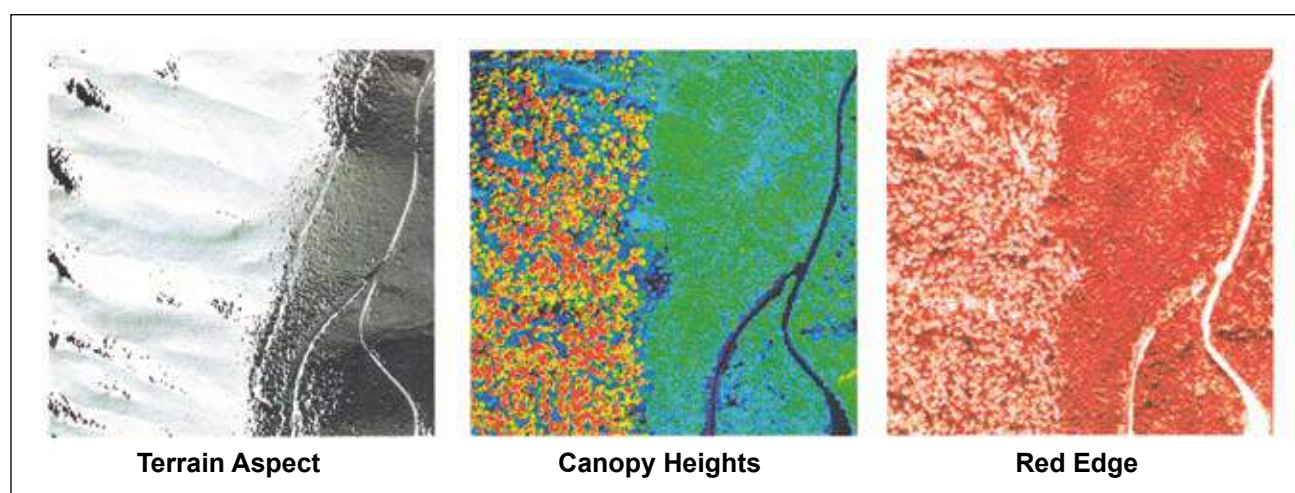


Figure 22.—Spatially explicit estimates of terrain aspect, tree canopy heights, and red edge (i.e., measure of canopy stress) derived from NASA Goddard's G-LiHT and hyperspectral data, 300 m swatch, interior Alaska, 2014.

Bayesian Hierarchical Models for Uncertainty

A key challenge of deriving national forest carbon stocks from the FIA database is capturing uncertainty that arises across different scales within the data (i.e., from tree to plot, from plot to Nation). Monte Carlo approaches to estimating total uncertainty provide initial estimates of uncertainty within FCAF (Fig. 10); however, other uncertainty procedures are being researched. For example, we are evaluating a hierarchical modeling framework, based on Bayesian statistical inference, to provide robust uncertainty estimation for national forest carbon stock estimates. This approach presents several key advantages when compared to other methods: (1) uncertainty is determined by observed data hence removing the need to make assumptions; (2) tree and plot scale errors are seamlessly aggregated, allowing for realistic reporting of uncertainty bounds around national forest carbon stocks; (3) the framework is easily expanded and updated as new data is collected; (4) a hierarchical structure integrates with satellite imagery and other remote sensing data which enables high resolution mapping of forest carbon; and (5) this approach accommodates prediction and uncertainty estimation across space and through time (Fig. 23).

Ongoing work is focused on foliage biomass (Clough et al., in review), which is a carbon pool that is difficult to quantify due to tremendous variability (see Pool Estimation section on page 31). Results show markedly higher uncertainty than has been previously reported, with important consequences for reporting stocks at the national level. Future work seeks to expand the framework to other biomass pools and will lead to the development of user-friendly tools to facilitate wider adoption of hierarchical models for quantifying forest carbon stocks and robust quantification of their associated uncertainty throughout the FCAF.

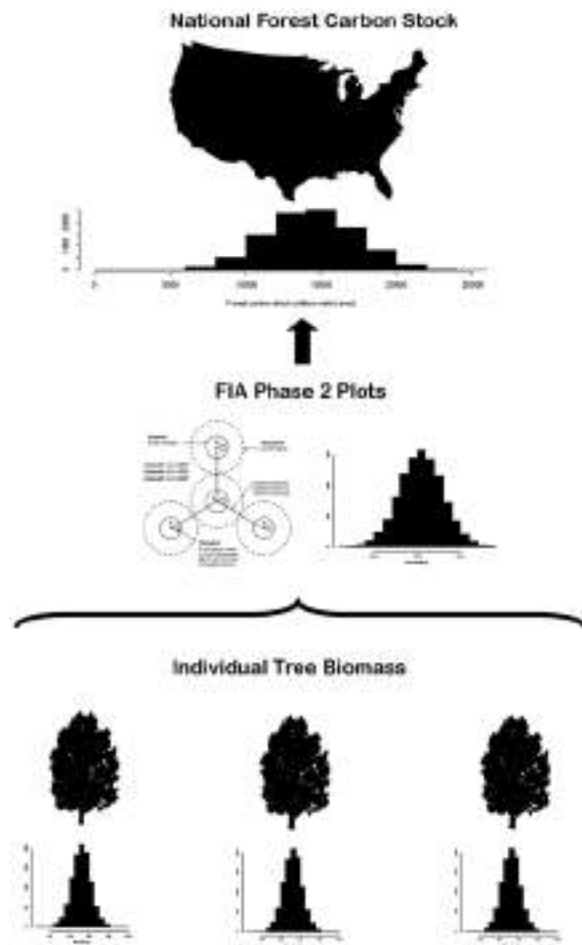


Figure 23.—Bayesian approaches to estimating uncertainty enable the integration of numerous error sources into final estimates of uncertainty.

Surf Forest Carbon with your Thumb: The Forest Carbon Xplorer

The FIA program conducts a systematic inventory of U.S. forests that serves as not only the primary source of national statistics but also supports informed forest management. This wealth of data has been analyzed to provide wall-to-wall spatial geographic information system (GIS) coverage of forest carbon estimates by pool across the lower 48 states to support carbon monitoring. Through

a research agreement and collaboration with the University of Minnesota, an online, mobile/web browser map application (app) has been developed that provides a 21st century digital experience of the distribution of the forest carbon estimation in the FIA program (Fig. 24). This web and mobile software tool (forestcarbonx.umn.edu) enables the public to learn about carbon and how much is stored in their vicinity by using the location of the user's phone or tablet. The data is presented interactively on a map along with charts, graphs, and links to related resources. The intended audience is anyone interested in exploring forest carbon information. The tool is a web browser map application for smartphones, tablets, and desktop use that primarily works online but that can also be used offline with simplified functionality. This provides any range of users with access to the carbon summaries in the field and at the desk.

Timely Attribution of Carbon Emissions by Disturbance

Funded under NASA's Carbon Monitoring System program, a team of researchers from Applied GeoSolutions, the Jet Propulsion Laboratory, Winrock International, the U.S. Forest Service, and NASA Ames Research Center has worked together to develop a methodology based on a combination of ground inventory and satellite observations to resolve the drivers of forest carbon emissions and sequestration at 1 ha spatial resolution in the continental United States for 2006 to 2010 (Fig. 25). Using this method, the team found that 75 percent of the carbon emissions committed during this period originated from anthropogenic sources, including harvest (69 percent) and land use change (6 percent). The remaining committed emissions were from natural sources, including fire (10 percent), wind

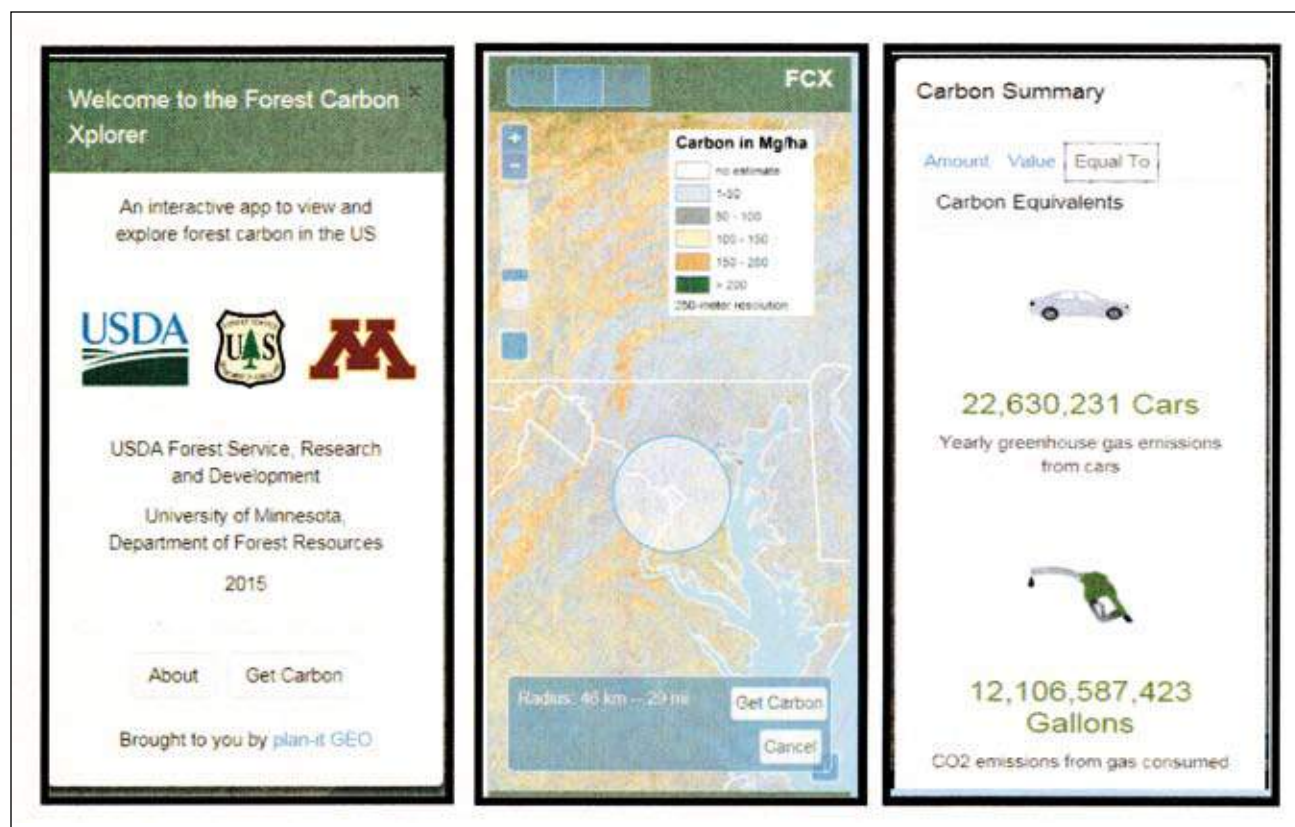


Figure 24.—Example screenshots from Forest Carbon Xplorer (forestcarbonx.umn.edu), a smartphone application that allows users to explore gridded forest carbon data and equivalents using their phone's location.

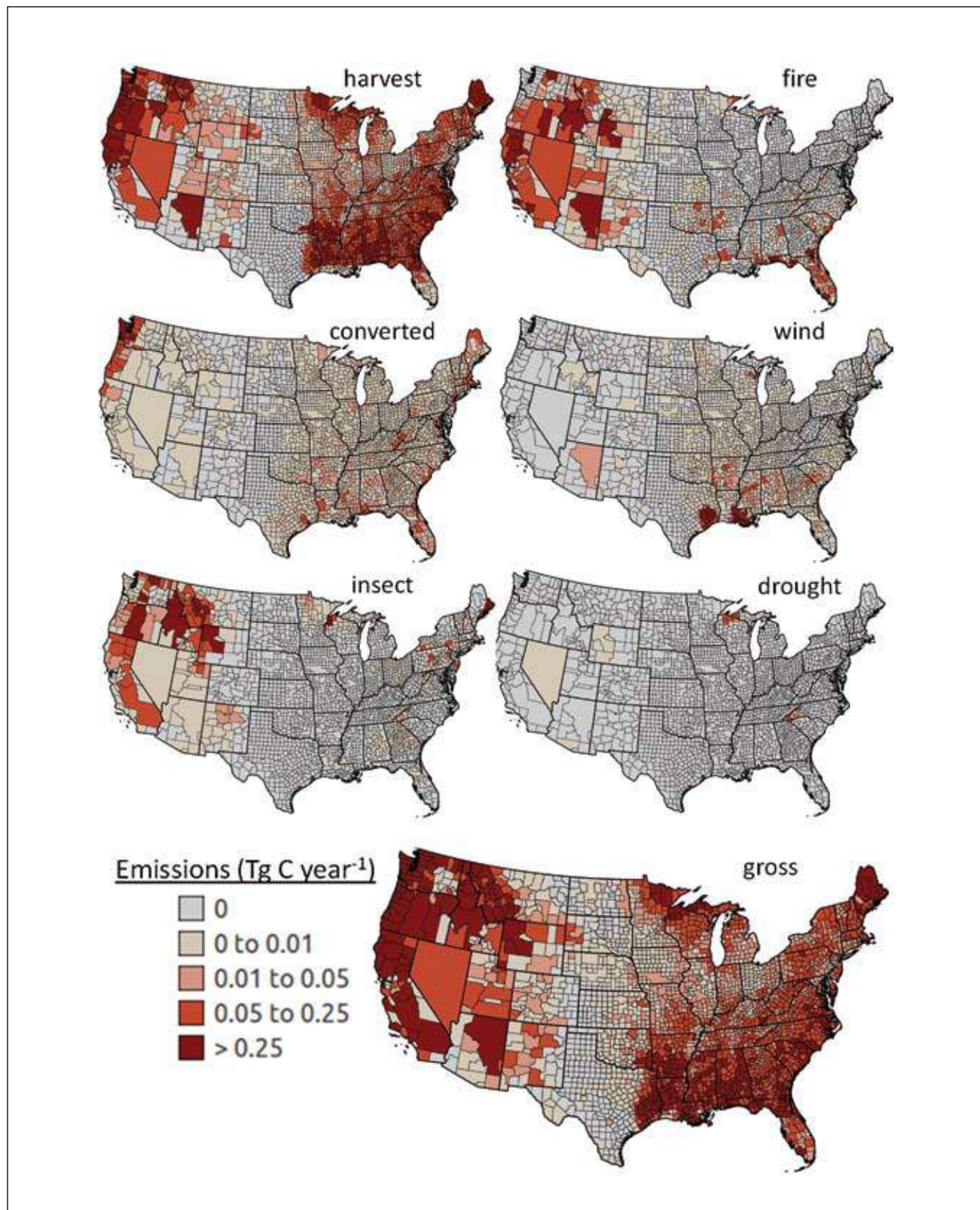


Figure 25.—Average annual committed emissions attributed to the most likely source and estimated at the county scale except where reduced observations necessitated combining counties. Combining these sources of emissions results in estimates of committed gross forest carbon emissions from disturbance occurring between 2006 and 2010.

(7 percent), insect outbreaks (7 percent), and droughts (<1 percent). This was accomplished by integrating the nationally consistent FIA database with a host of products derived from earth observation satellites, including fire from Monitoring Trends In Burn Severity (MTBS) (Eidenshink et. al. 2007), forest cover change (Hansen et. al. 2013), and the National Land Cover Database (NLCD) (Homer et. al. 2015).

The framework and accompanying results from this research represent a step towards enabling the disaggregation of natural and anthropogenic causes of carbon fluxes in forest land of the United States. The results also allow U.S. policy makers

and negotiators to better understand the drivers of forest carbon fluxes more completely so that they can participate more effectively in domestic policy discussions about forest management and monitoring as well as in the upcoming international negotiations. For example, the team found that timber harvesting, and not land use change or fire, was the largest source of gross emissions from U.S. forests between 2006 and 2010. Integration of results from this and other studies should further enable development of future U.S. carbon inventories that include disturbance attribution and full land use change accounting in expectation of post-2020 commitment requirements.

CONCLUSIONS

The annual monitoring of forest carbon in the United States is critical to both domestic and international needs for forest managers and policy makers alike as forests annually offset almost 15 percent of carbon dioxide from the combustion of fossil fuels in the United States. In an effort to improve the forest carbon inventory that the United States submits annually to the United Nations Framework Convention on Climate Change, a new accounting framework was introduced that moves the nationally consistent forest inventory backward and forward in time to meet reporting standards back to the 1990 baseline year while enabling forecasting of future forest carbon dynamics (per biennial reporting). Preliminary results from the new Forest Carbon

Accounting Framework demonstrate the ability of the new framework to both backcast the annual inventory system while attributing changes in forest carbon to disturbances and delineating land use change from forests remaining forest. Numerous improvements are planned, such as refining the estimation of individual carbon pools and land use change identification, which can be incorporated into the framework with future iterations. The National Greenhouse Gas Inventory will continue to be refined as new data become available and numerous areas of emerging research are identified that someday may substantially improve our ability to monitor forest carbon.

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English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Square meters (m ²)	10.76	Square feet
Kilograms (kg)	0.0011	Tons
Kilograms per cubic meter (kg m ⁻³)	0.0624	Pounds per cubic foot
Megagrams per hectare (Mg ha ⁻¹)	0.446	Tons per acre
Teragram (Tg)	1,102,311	Tons
Square meters per hectare (m ² /ha)	4.37	Square feet per acre

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As a signatory to the United Nations Framework Convention on Climate Change, the United States annually prepares an inventory of carbon that has been emitted and sequestered among sectors (e.g., energy, agriculture, and forests). For many years, the United States developed an inventory of forest carbon by comparing contemporary forest inventories to inventories that were collected using different techniques and definitions from more than 20 years ago. Recognizing the need to improve the U.S. forest carbon inventory budget, the United States is adopting the Forest Carbon Accounting Framework, a new approach that removes this older inventory information from the accounting procedures and enables the delineation of forest carbon accumulation by forest growth, land use change, and natural disturbances such as fire. By using the new accounting approach with consistent inventory information, it was found that net land use change is a substantial contributor to the United States forest carbon sink, with the entire forest sink offsetting approximately 15 percent of annual U.S. carbon dioxide emissions from the burning of fossil fuels. The new framework adheres to accounting guidelines set forth by the Intergovernmental Panel on Climate Change while charting a path forward for the incorporation of emerging research, data, and the needs of stakeholders (e.g., reporting at small scales and boreal forest carbon).

Key WORDS: forest, carbon accounting, baselines, attribution,
United Nations Framework Convention on Climate Change

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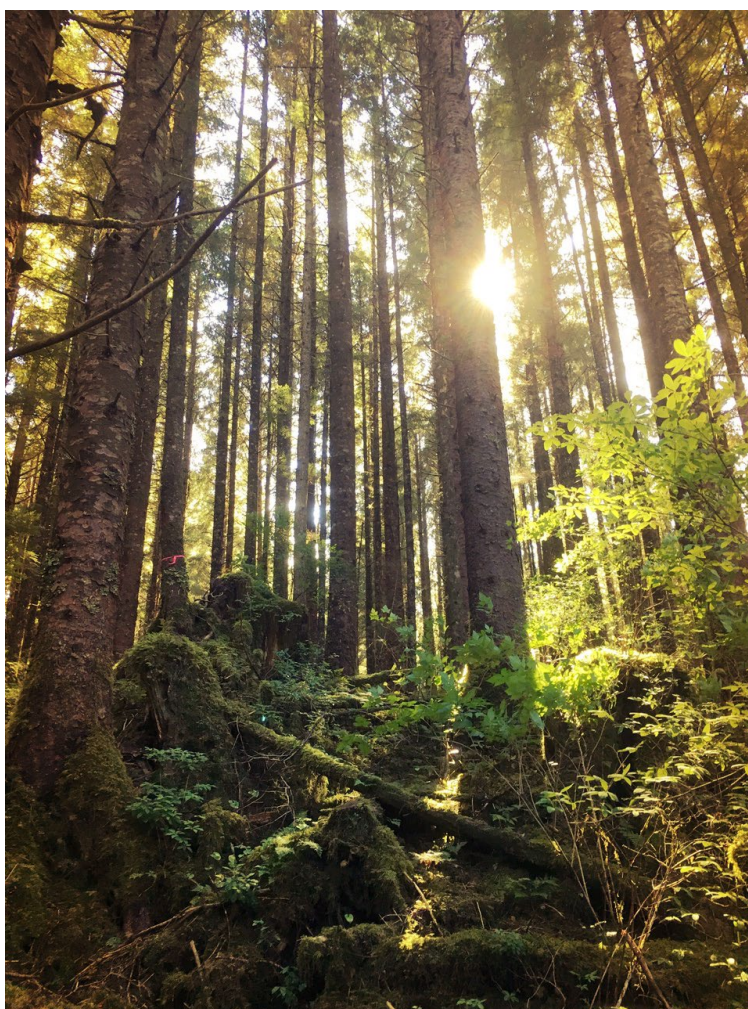
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United States Department of Agriculture

Forest Management and Timber Assessment

Tongass National Forest Plan Revision



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National Forest

June 2025

Cover Photo: Young-growth forest on Kosciusko Island by Sheila Spores.

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Forest Management and Timber Assessment

Tongass National Forest Plan Revision

Forest Service, Alaska Region

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Resource Importance

Forest management, including timber harvest and production, is an important tool for establishing and maintaining sustainable and diverse communities, economies, and ecological conditions. In Southeast Alaska, timber production is a valuable ecosystem service provided by the Tongass NF and other forest lands. It helps meet the demands of the public for products such as sawlogs, carving logs, firewood, and specialty products such as musical instrument wood, shakes and shingles, boat wood, posts and pilings, and high-quality construction materials. Timber harvest and production also contributes to social and economic sustainability by supporting employment opportunities and economic diversification in rural communities; providing markets for byproducts of forest restoration activities; supporting traditional and cultural use of the forest; and maintaining infrastructure that supports access for subsistence and other resource uses that contribute to community well-being (see also the Subsistence and Socioeconomic sections).

Resource History and Current Management Direction

Resource Context and History

Since establishment of the Tongass NF in 1907, forest management and timber harvest across the region have adapted to meet changing societal demands (Figure 1), from supplying primarily the needs of local residents and those of the fishing and mining industries in the early 1900s, to supporting airplane manufacturing with Sitka spruce during the first and second world wars, and supporting a regional pulp industry from the 1950s to the 1990s (for a succinct history of timber harvest and uses on the Tongass NF, see Morse 2000). Timber production on the Tongass has decreased substantially since the 1990s, corresponding with pulp mill and sawmill closures and changes in political, social, economic, and regulatory demands (Resource Development Council 2024, see also Figure 1 and Table 3).

Since completion of the 1997 Tongass NF Land and Resource Management Plan (Forest Plan) region-wide timber harvest including on State of Alaska lands (managed by the Division of Forestry, Alaska Mental Health Trust, and University of Alaska) and Native Corporation lands (managed by Sealaska, the Alaska Native Regional Corporation, as well as 13 Alaska Native Village Corporations) has declined from just over 500 MMBF to about 50 MMBF in 2021 (Figure 2).

Since establishment, approximately 400,000 acres of timber land on the Tongass NF have been harvested and have regenerated to young-growth forest. This equates to about 4% of the forested acres and 8% of the productive forest acres on the Tongass.

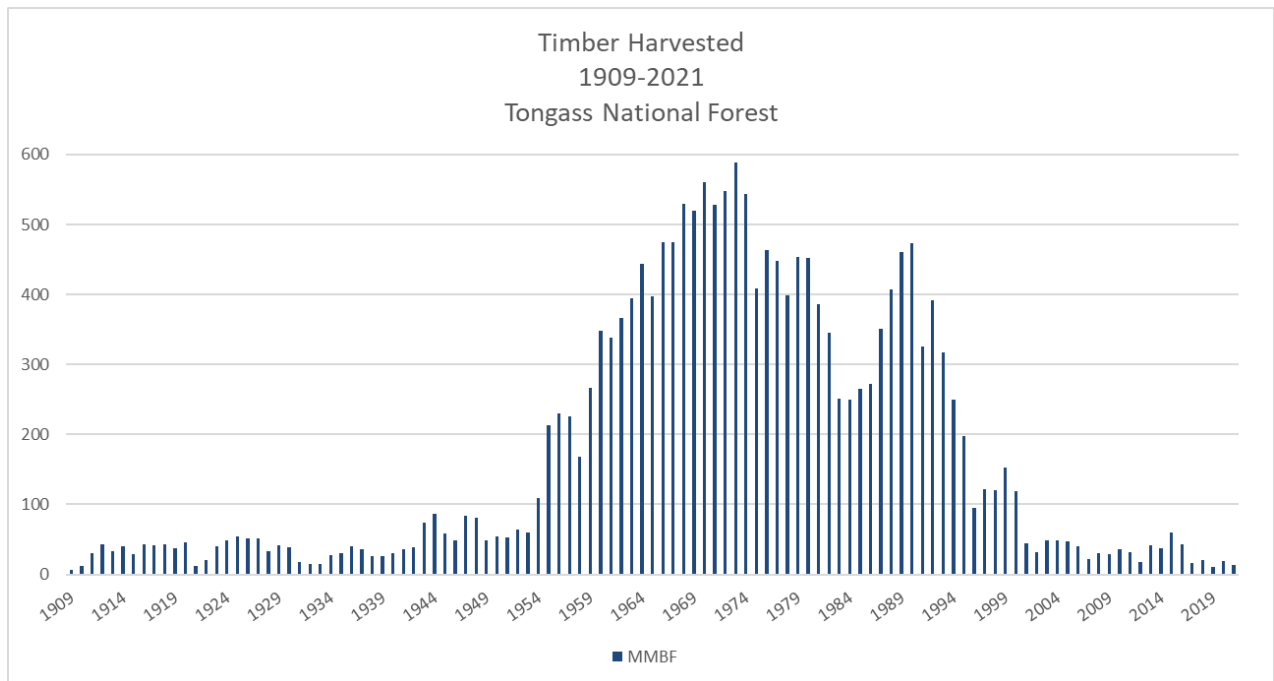


Figure 1. Tongass NF timber harvest history 1909-2021, in million board feet (Forest Management Reports and Accomplishments 2024.)

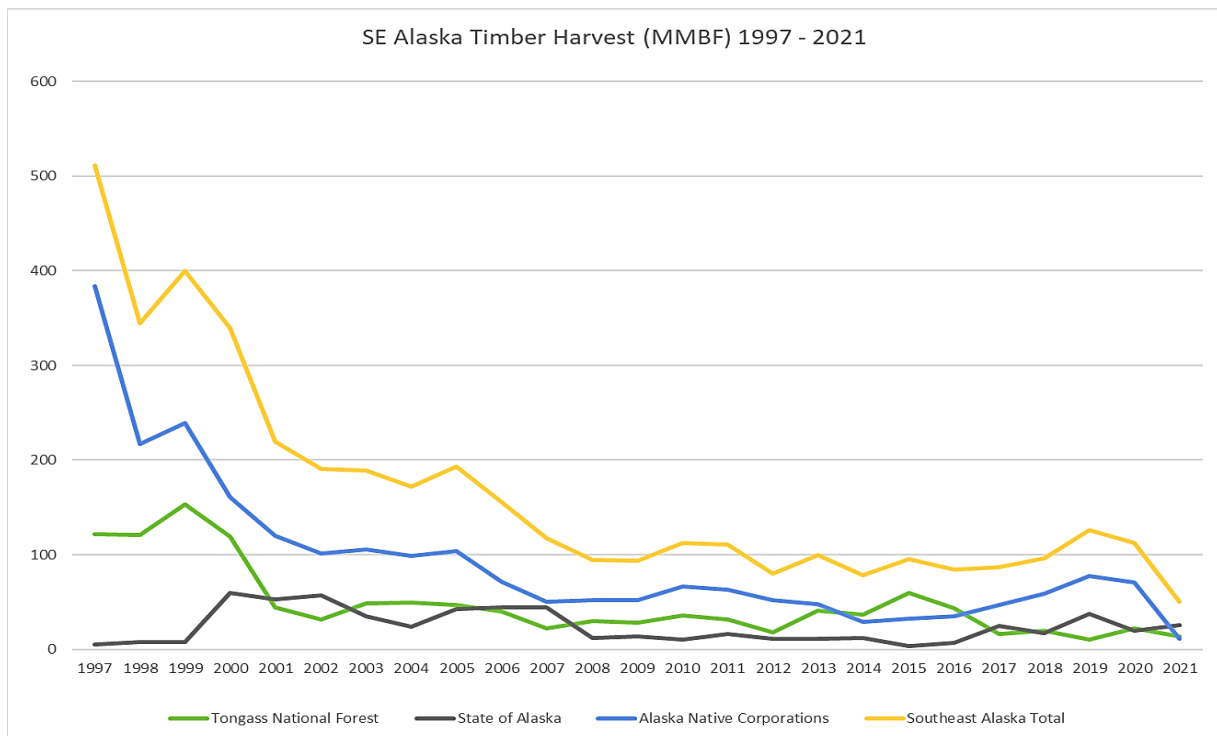


Figure 2. Southeast Alaska timber harvest volume, in million board feet (MMBF), 1997–2021

Public Feedback

Public engagement during the assessment phase highlighted the desire for sustainable timber management. Commenters recognized that sustainable timber management is beneficial for the local economy and personal use. Concerns were expressed regarding export of round logs and clearcutting. Public feedback also focused on the importance of intact, healthy, watersheds and salmon production and habitat.

There were varying perspectives with an emphasis on protecting old growth. Many comments did not support old growth harvest, with the exception of harvest of old growth trees for cultural uses. A few comments indicated otherwise, with support for utilizing mature trees, access to small specialty sales for high value / instrument wood, and concerns that preserving so much old growth forest would limit the response to and resiliency to climate change.

Comments suggest young growth harvest should be the priority, with an interest in harvesting young growth to improve deer habitat and small sales to support local mills and maintain availability of lumber.

Current Management Direction

Legal and Regulatory Compliance

The 1997 Tongass Land and Resource Management Plan, as amended in 2016 (generally referred to as the 2016 Forest Plan) provides the current land and resource management direction for the Tongass NF. The Forest Plan was amended in 2016 in response to a July 2013 memo issued by the Secretary of Agriculture (Memorandum 1044-009), “*Addressing Sustainable Forestry in Southeast Alaska*,” which directed the Forest Service to transition timber harvest on the Tongass National Forest from old growth to young growth over the next 10 to 15 years (USDA 2013, Tongass FEIS 2016). The timeframe was intended to conserve old growth forests while allowing the forestry industry time to adapt. The memo emphasized that the transition was necessary to conserve the Tongass NF under the principles of the Multiple-Use Sustained-Yield Act of 1960 and the Tongass Timber Reform Act while maintaining a viable timber industry to provide jobs and opportunities for residents of Southeast Alaska.

The Forest Service has envisioned transitioning the timber program on the Tongass towards harvest of young growth since it developed the 1997 Tongass Land and Resource Management Plan. The selected alternative in that plan revision (Alternative 11) showed a transition to young growth management occurring 40-50 years into the future (1997 FEIS, page 3-303). The 2008 Amended Land and Resource Management Plan also expressed support for moving the Tongass timber program to one based more on the harvest of young-growth stands, with careful review to ensure that that plan contained no provisions that might impede such a transition. It recognized that young growth could potentially comprise a substantial portion of the Tongass timber program in as little as three decades (2008 ROD, page 50). Despite the goal, concerns were expressed regarding the difficulty and likely failure of this transition, particularly if done too quickly. For instance, a panel presentation at the 2011 Society of American Forester conference shared several issues, such as the acres of young growth forest available for harvest (without restrictions), the impact of limiting regeneration harvest to stands that generally have reached the culmination of mean annual increment (CMAI) of growth, and the importance of old growth timber as a bridge during the transition period.

There are several challenges, opportunities, and uncertainties associated with this timber harvest shift. The current age class distribution of young-growth is challenging. Much of the harvest in the early part of

the transition will come from stands at the minimum age for commercial harvest (2016 FEIS, Appendix B, Figure B-3)¹². The young-growth supply is not yet viable (stands need more time to mature and reach commercial size) and also has lower wood quality relative to old growth (Meridian Institute 2023).

Other challenges highlighted as part of 5-year review (Meridian Institute 2023) include the unstable and uncertain timber supply (including concerns that old growth bridge timber was no longer offered to help with near-term supply), staffing/lack of skilled workforce, shifting management priorities, and litigation. This review noted a backlog of infrastructure maintenance (such as roads), lack of funds for “retooling”, and high transportation costs. It suggested that the Tongass needs a new Forest Plan focused on young growth utilization.

Direction in the 2016 Forest Plan includes timber production calculations required by the 2012 Planning Rule: Sustained Yield Limit (SYL), Lands Suitable and Not Suitable for Timber Production, Projected Wood Sale Quantity (PWSQ), and Projected Timber Sale Quantity (PTSQ) (Table 1, Table 2). In addition, the Tongass Old Growth Habitat Conservation Strategy and the Adaptive Management Plan for Timber remain key elements of the Forest Plan that pertain to timber production.

When a revised forest plan is developed, it will include potentially modified estimates of the area considered suitable for timber production, the planned vegetation management practices and associated timber sale program, and any applicable limitations on timber harvest. As part of Forest Plan Revision, Lands Suitable for Timber Production, SYL, PTSQ, and PWSQ values from the 2016 Forest Plan will be presented as the no action alternative in the EIS and values will be calculated for the proposed action and alternatives identified during the forest plan revision process. There is a need to update the Lands Suitable for Timber production inventory during the Forest Plan revision due to several changes in the National Forest land base and other factors including land exchanges, land selections, and land transfers that have occurred since 2016, as well as updated vegetation mapping and new available data.

The 2016 Forest Plan included several goals associated with forest management and timber harvest on the Tongass during the first 5 years of implementation and throughout the 15-year transition period. In 2022, Tongass NF staff completed a review of progress on the five 5-year commitments described in the 2016 Forest Plan and Record of Decision (Meridian Institute 2023). Tongass NF has been unable to achieve planned work at the intended pace outlined in the 2016 Forest Plan due to a variety of factors including budgets, staffing, shifting management priorities, and litigation.

¹ As described more in a later section, Public Law 113-291 of 2014 made provision for shorter rotations on a limited basis – allowing for harvest at ages less than 95 percent CMAI.

² As described in the 2016 FEIS (page 3-344), transitioning to young growth as fast as possible means it is important to harvest stands at the youngest age possible. Based on collective experience of timber managers on the Tongass and discussions with industry representatives, it was decided that in order for a young timber stand to have a chance of being economic, the majority of trees harvested need to produce two logs. Production of one log per tree not only increases logging costs relative to revenues substantially, but also creates a large amount of slash left behind, which can have negative effects on wildlife, scenery, economics and recreation. Based on analysis of yield tables it was decided that to produce two logs per tree for the majority of trees in a stand, a minimum age of 65 years would be used for modeling of high site stands and a minimum age of 75 years would be used for lower site stands.

Harvesting trees at 65 to 75 years of age is prior to their CMAI age, which is likely to be in the 90 to 110 year range. Although this would likely shorten the transition time, in the long term it should be recognized that it would result in lower growth rates and lower overall volumes produced.

Sustained Yield Limit (SYL)

The sustained yield limit (SYL) is the amount of timber that could be produced on all lands that may be suitable for timber production, assuming all these lands were managed to produce timber without considering other multiple uses or fiscal or organizational capability. The SYL is the amount of timber that can be removed annually in perpetuity on a sustained-yield basis from the applicable national forest.

The SYL for the Tongass NF under the current management direction of the 2016 Forest Plan is estimated to be 248 million board feet (MMBF) per year (USDA FS 2016, Appendix A; Table 1)³.

Lands Suitable for Timber Production

Lands suitable for timber production constitute the land base for vegetation management practices associated with timber production. The status of land as suitable for timber production does not necessarily mean that timber production is the primary purpose of management on those lands. Timber production may be a secondary use of the land and needs to be compatible with the achievement of desired conditions and objectives established by the plan for those lands (36 CFR 219.11(a)(1)(iii)), and some regular flow of timber products may be expected.

Suitability of lands is a determination made regarding the appropriateness of various lands within a plan area for various uses or activities, based on the desired conditions applicable to those lands. Identifying lands not suited for timber production is accomplished by following the process outlined in 36 CFR 219.11 and in Forest Service Handbook 1909.12, Chapter 60, Sections 61.11 to 61.14. In accordance with the 2012 planning rule, an analysis of lands suitable for timber production on the Tongass NF was completed as part of the 2016 Forest Plan Amendment. The inventory of lands suitable for timber production in the existing 2016 Forest Plan was about 568,000 acres (Line F of Table 2) (USDA FS Appendix A 2016). Model implementation reduction factors (MIRFs) were then applied to compensate for incomplete knowledge of on-the-ground conditions. Due to the expanse and terrain of the forested lands on the Tongass, a complete and current ground survey is not possible.

As described above, as part of forest plan revision, the area considered suitable for timber production may change. Lands currently considered suitable for timber production may change for a variety of reasons, such as changes in the National Forest land base that have occurred since 2016, updated mapping, or in concert with changes in the desired conditions and objectives for specific areas of the Forest.

While changes in climatic conditions could possibly lead to a change in what is determined suitable for timber production, stocking surveys as required by NFMA have not indicated any issues with regeneration on the Tongass. The Forest does not anticipate at this time that the area considered suitable for timber production would necessarily change due to changing climatic conditions.

The [Aquatic Ecosystems](#) assessment discusses karst and describes how steeper, higher elevation karst areas show less than desirable regeneration. Currently, as described in the 2016 Forest Plan Appendix A, page A-4, high vulnerability karst lands are not considered suitable for timber production.

³ The calculation of the SYL is not limited by land management plan desired condition, other plan components, or the planning unit's fiscal capability and organizational capacity. Calculation of the limit includes volume from lands that may be deemed not suitable for timber production after further analysis during the planning process. The 2016 plan allocates areas where the desired condition is not for the management of timber production but for other resources. 961,681 acres were considered as "may be suitable" for timber production, while only 568,033 acres were found suited for timber production because timber production was compatible with the desired conditions and objectives established by the plan, as seen in Table 2.

Table 1. 2016 Forest Plan Sustained Yield Limit (SYL), Projected timber sale quantity (PTSQ), and Projected wood sale quantity (PWSQ) (USDA FS 2016, Appendix A).

Planned Timber Sale Program, Tongass National Forest, including Annual Average Volume Outputs for 1st and 2nd Decade				
Sustained Yield Limit (SYL):	248 MMBF or 55 MMCF¹ per year			
	First Decade		Second Decade	
Timber Products				
	MMCF	MMBF	MMCF	MMBF
Lands suitable for timber production				
Sawtimber	10.3	46.0	16.0	71.8
Other products				
Lands not suitable for timber production				
Sawtimber				
Other products				
Projected Timber Sale Quantity (PTSQ)	10.3	46.0	16.0	71.8
Other Estimated Wood Products²				
	MMCF	Tons	MMCF	Tons
Fuelwood	0.5	10,000	1.0	20,000
Projected Wood Sale Quantity (PWSQ)	10.8		17.0	
¹ MMCF: Millions of cubic feet MMBF: Millions of board feet ² Does not include wood provided through the Tongass personal use firewood or free use timber programs.				

Table 2. Lands suitable for timber production (USDA FS 2016, Appendix A)

	Land Classification Category	Acres
A	Total National Forest System lands within the plan area	16,755,685
B	Lands not suited for timber production due to legal or technical reasons	15,794,004
C	Lands that <i>may</i> be suited for timber production (A-B)	961,681
D	Lands not suited for timber production because timber production is not compatible with the desired conditions and objectives established by the plan	393,648
E	Total lands not suited for timber production (B+D)	16,187,652
F	Total lands suited for timber production (mapped suitable) because timber production is compatible with the desired conditions and objectives established by the plan (C-D)	568,033
G	Model Implementation Reduction Factor (MIRF) Acreage	90,138
H	Estimated actual suitable acreage for timber production (F-G)	477,895
I	Scheduled suitable acreage (based on modeling)	326,623

Land acres suitable for timber production on the Tongass NF have declined with each revised or amended plan since 1979 due to transfer of lands to other owners and shifts in land management goals and objectives for the Tongass NF. Lands suitable for timber production have declined from over 2.4 million acres in 1979 to about 568,000 acres in 2016 (Figure 3). This represents a decrease in the percentage of the Tongass NF land suitable for timber production from 15 percent in 1979 to 10 percent in 1991 and 3 percent in 2016.

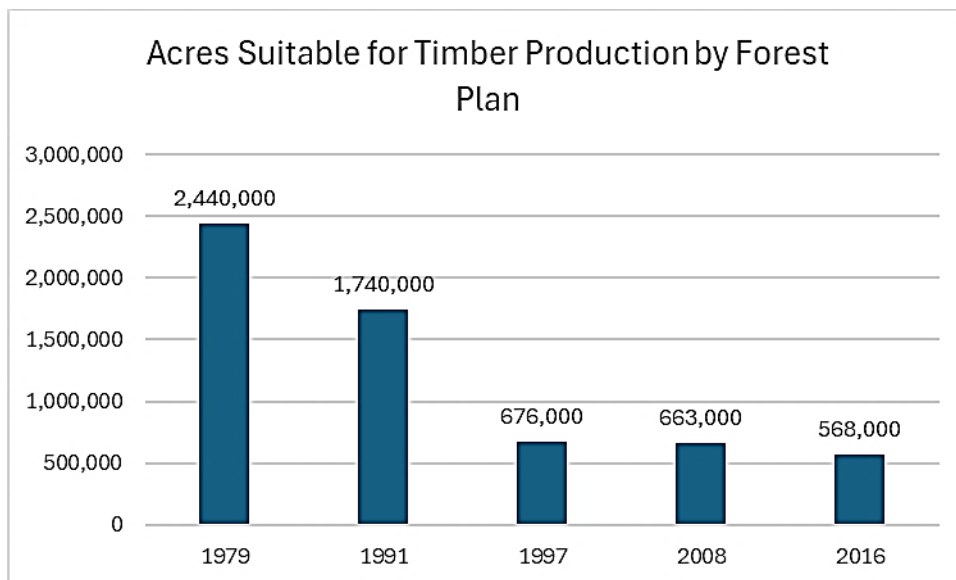


Figure 3. Acres suitable for timber production (rounded) for each Forest Plan and major amendment, by date

Projected Wood Sale Quantity (PWSQ)

The projected wood sale quantity (PWSQ) is an estimate of the volume of all timber and other wood products that is expected to be sold during the plan period from expected harvests for any purpose (except salvage harvest or sanitation harvest) on all lands in the plan area. The PWSQ includes all woody material likely to be sold from these harvests, whether the woody material meets the utilization standards¹. The estimation of both the PWSQ and the projected timber sale quantity (PTSQ) must consider the fiscal capability of the planning unit and be consistent with all plan components.

The PWSQ for the Tongass National Forest under the current management direction of the 2016 Forest Plan is estimated at 10.8 MMCF per year for the first decade and 17.0 MMCF per year for the second decade (USDA FS Appendix A 2016; Table 1).

Projected Timber Sale Quantity (PTSQ)

The projected timber sale quantity (PTSQ) is a subset of the PWSQ and is an estimate of the quantity of timber expected to be sold during the plan period. The volume in the PTSQ is the volume that meets utilization standards.⁴ The estimation of both the PWSQ and the PTSQ must consider the fiscal capability of the planning unit and be consistent with all plan components.

The PTSQ for the Tongass National Forest under the current management direction of the 2016 Forest Plan is estimated to be 46.0 MMBF per year for the first decade, increasing to 71.8 MMBF per year for the second decade, due to more young growth reaching harvestable age (USDA FS Appendix A 2016, Table 1)⁵.

⁴ Utilization Standards for commercial removal at time of the 2016 FP Amendment were minimum 9" diameter at breast height (DBH), net 12' piece length, net 6" top diameter of inside bark (DIB), and 33.33 percent sound. Since November 2018, the Regional Forester has issued interim direction to change utilization standards to better correspond with current utilization trends, market conditions, and appraisal pricing, to minimum 9" DBH, net 16' piece length, net 7" top DIB, and 33.33 percent sound.

⁵ As described in Appendix A of the 2016 plan, the PTSQ is not a target. A timber target is assigned, internally, as a part of accomplishing a national goal. This internal target is reflective of budget allocation and prioritization.

As young-growth volume increases, the volume of old growth decreases to 5 MMBF per year, for the life of the plan starting in the year 2031.

Old Growth Conservation Strategy

The 1997 Tongass Forest Plan included a comprehensive science-based strategy intended to provide for long-term viability of old growth associated wildlife, well-distributed across Southeast Alaska. This strategy, referred to as the Tongass Old-Growth Conservation Strategy, was retained with minor modifications through 2008 and 2016 amendments of the Forest Plan. The Strategy includes a network of habitat reserves linked by corridors of old growth forest and a collection of Standards and Guidelines that provide additional protection for vulnerable wildlife species. Elements of the Strategy are dispersed throughout the Forest Plan, with standards and guidelines intended to protect certain habitats such as beach and estuary fringe and old growth dependent species. Forest Plan components that comprise the Old Growth Conservation Strategy were compiled in a report to support the current revision effort (Brockman 2023).

Adaptive Management Plan for Timber

The 2008 Forest Plan introduced the Timber Sale Program Adaptive Management Strategy. This strategy divided the development LUDs, which allow timber harvest, in three phases. The strategy was aimed at reducing impacts to high-value, inventoried roadless areas of the Tongass. Under the 2008 Forest Plan, timber sales were allowed only in Phase 1 land base until the timber harvest rose to 100 mmbf for 2 consecutive years (Tongass FEIS ROD 2008), then could expand to Phase 2 lands. However, personal use of timber, microsales (timber sales of down or dead trees totaling no more than 50 thousand board feet, to supply small niche-market timber processors), salvage sales, small commercial timber sales generally less than 1 MMBF, young-growth management projects, and the roads associated with these activities, would be allowed in development LUDs outside of the Phase 1 portion of the land base (Tongass FEIS ROD 2008). The 2016 Plan Amendment changed implementation of the 2008 Adaptive Management Strategy to allow old growth timber harvest only in the Phase 1 portion of the land base (approximately 537,000 acres, of which 223,000 acres is old growth).

Tongass Timber Demand

In 1990, Congress passed the Tongass Timber Reform Act (TTRA). Among other provisions, the TTRA established the requirement to better understand demand for Tongass NF timber. It states:

Subject to appropriations, other applicable law, and the requirements of the National Forest Management Act of 1976 (P.L. 94-588), except as provided in subsection (d) of this section, the Secretary shall, to the extent consistent with providing for the multiple use and sustained yield of all renewable forest resources, seek to provide a supply of timber from the Tongass National Forest which (1) meets the annual market demand for timber from such forest and (2) meets the market demand from such forest for each planning cycle.

Under TTRA, the Forest Service must seek to provide a supply of timber to meet annual and planning cycle demand, subject to limitations such as available appropriations and multiple use and sustained yield of all renewable forest resources. Planning-cycle market demand studies have been conducted by the US Forest Service Pacific Northwest Research Station since 1990 (Brooks and Haynes 1990, 1994, 1997; Brackley et al. 2006, Daniels et al. 2016). Annual market demand is calculated and used to estimate timber sale offer target (i.e., timber supply) by translating long term timber demand projections into an annual estimate for timber sale offer targets (Grewe 2017).

Long-term timber demand analysis estimates the quantity of Tongass National Forest timber required to satisfy projected demand for forest products given harvest by other regional landowners and assumptions about future market conditions and prices. In the most recent long term timber demand study (Daniels et al. 2016), a baseline model based on projections and market shares for each market served by SE Alaska producers was developed for the period 2015-2030. The baseline model was used to construct three management scenarios representing alternative futures for timber harvest and markets in southeast Alaska: the Tongass NF young-growth transition, the Tongass NF young growth transition with expansion of bioenergy markets, and the Tongass NF young-growth transition with an increase in demand for wood products for construction. Estimates for demand from these three scenarios for the years 2015 to 2030 ranged from 40.8 MMBF to 76.4 MMBF per year (Daniels et al. 2016). Annual demand estimates for the Tongass NF for the years 2017 through 2023 range from 45 to 58 MMBF per year.

Several events have occurred since 2016 that have changed the circumstances for the planning cycle demand study. In 2021, the US Forest Service and Alaska Mental Health Trust finalized a land exchange. The exchange was required by the Alaska Mental Health Trust Land Exchange Act of 2017 and provided productive timber lands to the State of Alaska and valued recreational lands to the Tongass NF, enabling the State to provide a limited supply of old growth timber for local mills during the Tongass NF transition to young growth. Also in 2021, Sealaska Corporation announced plans to transition out of logging operations beginning in 2022, making lands available for selective harvesting, hunting, fishing and other recreation and tourism activities but decreasing the amount of timber volume harvested annually. These changes affect market and market share assumptions in the demand study. Finally, in July 2021, The US Department of Agriculture announced the Southeast Alaska Sustainability Strategy in order to help support a diverse economy, enhance community resilience, and conserve natural resources in Southeast Alaska (<https://go.usa.gov/xMNzF>). One of the components of the strategy called for ending large-scale, old growth timber harvest on the Tongass NF and focusing resources to support forest restoration, recreation, climate resilience, and sustainable young-growth forest management. The Southeast Alaska Sustainability Strategy does not represent law, regulation, directive, or a final agency action representing long-term management decisions on the forest; however, recent years have seen a reduction in old growth harvest on the Tongass NF to less than 5 MMBF per year. A new long term timber demand analysis is underway at the Pacific Northwest Research Station to support the current Tongass Forest Plan revision, but it has not been completed yet.

Scope and Scale of Assessment

This assessment identifies and evaluates available information about how timber management on the Tongass NF, including harvest and production, contribute to social, economic, and ecological sustainability. The scope for assessing the timber resource on the Tongass NF includes timber harvest and timber sold, harvest and treatment types, timber and forest product demand, and logging infrastructure and employment. Forest management on the Tongass NF has the potential to impact and influence communities and economies across various land ownerships more broadly, including the geographic region known as Southeast Alaska, the entire state of Alaska, the lower 48, and international markets. Information contained within this report is presented at a scale most appropriate for the topic being discussed.

Also note, this assessment is focused on existing conditions and trends. It is a precursor to and informs plan development. When a revised forest plan is developed in the future, it will include more information, such as potentially modified estimates of the area considered suitable for timber production, the planned silvicultural practices and associated timber sale program, and any applicable limitations on timber harvest.

Status and Trends

The following section will briefly discuss the status and trends of timber volume sold, commercial harvest, forest management, logging infrastructure, and economic considerations on the Tongass NF.

Since establishment, approximately 400,000 acres of timber land on the Tongass NF have been harvested and have regenerated to young-growth forest. This equates to about 4% of the forested acres and 8% of the productive forest acres on the Tongass. Though past timber harvest occurred on only about 4% of the forested area, it is not evenly distributed, but instead has been concentrated on high productivity, low elevation valley bottoms and hillslopes and mostly on the southern end of the Tongass⁶⁷⁸⁹¹⁰.

Tongass Timber Volume Offered, Sold, and Harvested

Timber volume offered, sold, and harvested was queried from a variety of Forest Service reports and databases. This information is presented in several tables and figures in this report. Metrics differ based on whether presented for each calendar year or fiscal year. They also vary between each other given, for example, volume that is sold in one year, may not be harvested until a future year. Table 3 shows the amount of timber volume offered, sold, and harvested by fiscal year (October 1 to September 30) for years 1994-2023. Volumes include sawtimber, fuelwood, pulpwood, non-sawtimber, and small roundwood products. National economic trends, National Forest funding levels, litigation, and local market conditions are some of drivers that affect the amount of timber harvest from the Tongass each year. Timber harvest on the Tongass was lowest in 2022 with 3 MMBF harvested (USDA Forest Service 2024a). The most recent 10-year sold average is 10 MMBF and the most recent 10-year harvest average is 21 MMBF. This is below the 2016 Forest Plan PTSQ of 46 MMBF and the SYL of 248 MMBF, with a 15-year schedule to reduce the old growth portion to 5 MMBF.

Table 3. Tongass NF Timber volume offered, sold, and harvested, 1994-2024 (MMBF)

Fiscal Year	Offered ¹	Sold ²	Harvest
1994	277	269	276
1995	290	261	221
1996	266	227	120
1997	162	152	107
1998	187	24	120
1999	115	61	146
2000	85	170	147
2001	68	50	48
2002	57	24	34
2003	89	36	51
2004	73	87	46
2005	110	65	50

⁶ Information about timber harvest and its impacts regarding habitat fragmentation and watersheds can be found in the [Terrestrial Ecosystems](#) assessment and the [Watershed Condition and Water Resources](#) assessment.

⁷ Information about timber harvest and its impacts regarding carbon can be found in the [Carbon Stocks](#) assessment.

⁸ Information about riparian timber harvest can be found in the [Terrestrial Ecosystems](#) assessment.

⁹ Information about timber harvest and its impacts on deer can be found in the [Subsistence and Other Harvest](#) (Non-Commercial) assessment.

¹⁰ More information about past timber harvest and its distribution can be found in the 2016 Plan Amendment FEIS, Biodiversity section. It includes tables of acreage of young-growth and original and remaining productive old growth by biogeographic province. See tables 3.9-5 and 3.9-6.

<u>Fiscal Year</u>	Offered¹	Sold²	Harvest
2006	25	85	43
2007	32	30	19
2008	42	5	28
2009	48	23	28
2010	46	46	35
2011	44	44	33
2012	53	52	21
2013	118	16	36
2014	111	106	39
2015	45	23	57
2016	44	14	45
2017	31	31	20
2018	34	9	20
2019	29	5	11
2020	2	4	15
2021	2	2	18
2022	5	4	3
2023	3	2	18
2024	1	2	4

¹Offer- Offered volume source: Periodic Timber Sale Accomplishment Report, total fiscal attainment including Gate 4 (advertised), Gate 5 (bid opening), Gate 6 (awarded), personal use permits and small commercial sales. Volume does not include re-offered sales, re-sold sales, or previous FY volume. PTSAR reports are available at <https://www.fs.usda.gov/forestmanagement/products/ptsar/index.shtml>

²Sold and Harvest- Sold and Harvested volume source: Forest Products Cut and Sold from the National Forests and Grasslands reports, all convertible products volume, including sawtimber, pulpwood, fuelwood, misc. convertible products, non-sawtimber, and small roundwood. Reports are available at <https://www.fs.usda.gov/forestmanagement/products/cut-sold/index.shtml>

Table 4 shows the amount of timber volume harvested by species on the Tongass NF by fiscal year (October 1 to September 30) for years 2013-2023. Volume includes sawtimber, fuelwood, pulpwood, non-sawtimber, and small roundwood products.

Table 4. Tongass National Forest timber harvest by species (MBF)

Fiscal Year	Alder	Sitka spruce	Softwood Other	Western Hemlock	Alaska Yellow-Cedar	Western Redcedar	Total
2013	6.0	9,854.2	0.0	22,566.1	2,379.6	2,474.6	37,280.5
2014	14.2	14,648.8	0.0	20,217.9	3,297.4	940.8	39,119.2
2015	5.0	14,783.6	0.0	34,909.0	2,266.3	4,918.7	56,882.6
2016	0.0	12,515.7	0.0	22,414.5	3,147.1	7,293.7	45,370.9
2017	0.1	3,899.1	0.0	9,817.1	2,162.0	4,132.1	20,010.3
2018	0.0	5,052.6	0.0	10,186.6	2,099.5	2,566.8	19,905.5
2019	0.0	1,999.7	0.0	5,278.5	1,802.7	2,625.0	11,705.9
2020	0.0	6,221.7	0.0	5,892.0	955.3	2,126.2	15,195.2
2021	1.5	10,844.9	59.3	4,718.7	768.1	1,446.8	17,839.3
2022	2.5	1,393.6	0.2	773.7	324.7	752.7	3,247.2

Fiscal Year	Alder	Sitka spruce	Softwood Other	Western Hemlock	Alaska Yellow-Cedar	Western Redcedar	Total
2023	0.2	14,394.5	22.6	2,831.4	115.4	688.5	18,052.6

Source: (Forest Management Reports and Accomplishments 2024- Forest Products Cut and Sold from the National Forests and Grasslands, Tongass National Forest)

Timber Sales

Young Growth and Old Growth

Timber sales on the Tongass NF can include a combination of young and old growth. Young growth exists in diverse stages, influenced by the harvest method used historically. Age of stand, past intermediate treatments such as thinning prior to harvest, and stand site quality and site productivity also influence the diversity present within young-growth stands. Beach logging was the most common practice many decades back, where some of the oldest stands of young growth can be found now.

The existing inventory of young growth on the Tongass NF is about 410,000 acres.¹¹ Of this, 8,750 acres is considered commercially viable in 2026 for a total of approximately 198 MMBF¹². One unique aspect of the 2016 Forest Plan is that to support the transition to young growth, it allows for the harvesting of trees prior to the culmination of mean annual increment (CMAI) of growth under the authority granted by Public Law (P.L.) 113–291, Sec. 3002, subsection (e)(4). This provision is valid until a total of 50,000 acres have been harvested prior to CMAI. As of this time, four projects have included young-growth forests that have or may include the CMAI exemption for a cumulative 4476 acres.

As of 2023, the Tongass NF has awarded 19 young-growth sales. In the most recent 5 years of data, 66 old growth and 14 young-growth sales were awarded, averaging 2,312 MBF and 777 MBF, respectively. (Table 5). Although several local sawmills have begun retooling and purchasing young-growth sales, preference for old growth timber remains (Daniels et al. 2023, Daniels et al. 2025).

Table 5. Number of timber sales and timber volume awarded for old growth and young growth on the Tongass:2010 to 2023., in thousand board feet (MBF)

Source: Tongass NF timber volume under contract reports, 2010-2023, Tongass sales gates worksheets module PRP101. Includes commercial fuelwood permits, does not include scaled timber sale overrun volume reported in the year

Tongass timber sale awarded	Old growth timber volume awarded (MBF)	Old growth number of sales	Young-growth timber volume awarded (MBF)	Young growth number of sales
2010	59,252	26	0	0
2011	29,637	22	7,557	1
2012	41,815	27	0	0
2013	12,943	26	0	0
2014	89,569	31	0	0

¹¹ In response to the TAC recommendations in the 2016 Forest Plan, the Tongass National Forest entered into an agreement with ADOF in 2016 to jointly conduct a forest-wide inventory of young-growth stands. The inventory data collected information covering over 42,000 acres of young growth. This information was incorporated into the Forest Planning and Projection System (FPS) that allows the inventory information to be tracked spatially and grown over time, allowing the data to not become stagnant. In addition to the actual data, the ADOF hired Terra Verde to conduct an extensive mapping exercise that subdivided all the Forest's young growth into ecological units and applied consistent vegetation labels on all polygons across the Forest. In 2021, the 2nd phase of this effort began, to include mapping of all young growth on non-National Forest System (NFS) land across SE Alaska. This effort will lead to one, unified young-growth map that can be modeled, allowing for cooperation across landowners in the region to plan for a sustainable and predictable flow of young-growth forest.

¹² From Management Basins and Near Term Merchantable YG Timber Supply presentation, S. Spores.

Tongass timber sale awarded	Old growth timber volume awarded (MBF)	Old growth number of sales	Young-growth timber volume awarded (MBF)	Young growth number of sales
2015	14,619	26	4,409	2
2016	12,655	32	0	0
2017	800	13	35,592	1
2018	9,962	15	44	1
2019	2,661	17	2,730	1
2020	2,236	11	43	2
2021	1,440	11	172	2
2022	3,475	12	269	5
2023	1,759	15	671	4

Microsales

A microsale is a timber sale consisting of dead or down timber of approximately 50 thousand board feet (MBF) or less that a District Ranger agrees to offer for bidding (Tongass Forest Plan 2016). Microsales have traditionally been dead and down old growth timber. Assuming they have the quality needed to meet the purchaser's desired product specifications, young-growth microsales could increase as younger trees blow down, likely along road corridors, and as the trees increase in size. These sales can be lucrative for local operators since they can produce value-added products such as music wood, shakes and shingles, molding, and high-value sawn building products. Some of these products require special characteristics. For example, music wood needs tight tree rings mainly found in old growth trees to achieve tonal quality.

Microsales are a primary sale type for many small operators, and the Tongass updates the Standard (advertised) Rates used for microsales annually based on recent bids, with a roll-back factor to encourage competition and ensure advertised rates are not too high for local bidders to afford.

Non-deficit Timber Sale Requirement

A Forest Service timber sale is comprised of different species and grades of timber, each of which is appraised according to the expected product yield. Per most of the annual appropriations laws since 2000, the Tongass NF may not offer a deficit timber sale. A deficit timber sale is defined as one where the value of the timber is not sufficient to cover all logging and stumpage costs and provide a normal profit and risk allowance under the Forest Service's appraisal process. Timber sale design and location greatly impact harvesting costs and subsequent ability to appraise positive.

Commercial Timber Harvest and Management Methods

Three main types of silvicultural systems are used for commercial timber harvest on the Tongass NF: even-aged regeneration harvest (such as clearcutting, clearcutting with reserves, and seed-tree cuts); two-aged regeneration harvest (clearcutting with reserves); uneven-aged regeneration harvest (such as group selection and single-tree selection); and intermediate harvest (such as commercial thinning).

Salvage or sanitation harvest is used to harvest dead, down, or dying trees that have been negatively affected by wind-events or insect and/or disease. The Tongass microsale program is based on the harvest of these trees but larger salvage harvest has also occurred over the years.

Future silvicultural practices will be determined as part of plan development.

Table 6. Acres of timber harvest, 1915 to 2023

Year of Harvest	Acres of even-aged harvest	Acres of uneven-aged harvest	Acres of 2-aged harvest	Acres Total Harvest
1915 and prior	1,001	1,275	NA	2,276
1916-1920	320	734	NA	1,054
1921-1925	1,775	600	NA	2,375
1926-1930	782	500	NA	1,282
1931-1935	822	148	NA	970
1936-1940	858	NA	NA	858
1941-1945	1,210	242	NA	1,452
1946-1950	2,231	817	NA	3,048
1951-1955	5,439	1,885	NA	7,324
1956-1960	20,928	182	NA	21,110
1961-1965	44,986	NA	227	45,213
1966-1970	60,981	31	NA	61,012
1971-1975	56,159	5	NA	56,164
1976-1980	47,370	24	NA	47,394
1981-1985	32,163	239	144	32,546
1986-1990	52,000	144	NA	52,144
1991-1995	46,721	NA	980	47,701
1996-2000	*41,468	1,517	1,063	44,048
2001-2005	5,668	1,544	1,158	8,370
2006-2010	2,889	1,672	1,205	5,766
2011-2015	4,462	3,635	539	8,636
2016-2020	3,141	1,473	51	4,665
2021-2023	1,153	56	169	1,378
Totals	434,527	16,723	5,536	456,786

Source: USDA Forest Service - Forest Service Activities Tracking System (FACTS) database.

*Approximately 22,000 acres of even-aged harvest in the 1995-2000 time period was done on non-Forest Service lands that were then transferred to the Forest Service (Cube Cove)

Even-Aged Management

The dominant silvicultural system used on the Tongass has been even-aged regeneration harvest, predominantly using clearcutting since the 1950s (USDA FS 2014). Clearcutting is used as the predominant harvest method as it is relatively economical, it is effective at removing diseased trees, reduces the risk of within stand windthrow, reduces the wounding of thin barked species, as well as encourages regeneration of spruce and cedars. In contrast, even-aged management can impact scenery and the associated recreational value of an area, as described more fully in the [Scenic Resource](#) assessment. Rotational harvest using even-aged management has been the predominant method considered for the future of the timber industry. For effective continued use of even-aged harvest on the Tongass NF, the Tongass Young Growth Management Strategy identified that the following should be considered (USDA FS 2014):

- The initial harvest consisted of primarily downhill cable yarding. Partial harvests using downhill cable is very complex, difficult, costly, and dangerous.

-
- It is expected that even maximizing timber with even-aged harvests would still produce a mosaic of openings across the landscape given plan direction for resource protection. For example, even-aged harvests and associated openings are scattered throughout the forest, and not adjacent to one another given direction to avoid and/or buffer around raptor, murrelet and heron nests and rookeries, riparian areas, sensitive plant locations, and high vulnerability karst, among others. Harvest is restricted in some areas, such as the Old-growth Habitat LUD. Any management created openings are also intermixed with unproductive forest types, other vegetation types, and areas considered unsuitable for timber production due to other factors such as soils or slope.
 - In order to harvest commercial-sized trees via thinning, the stand must be older to allow for the co-dominant trees to be the ones targeted. Studies conducted on the Forest demonstrate that taking the largest trees out during a thin can lead to unraveling of a stand through windthrow.

Uneven-Aged Management

The current forest plan allows for uneven-aged management, a silvicultural system that has been used on the Tongass for decades (see Table 6). It is used in some situations to create sale opportunities for local operators and sawmills and to provide diversity in the economy and community stability. One recent example was the Naukati Musicwood and Green Tree Small Sale. Other projects with a component of uneven-aged management included the Big Thorne and Tonka projects, among others.

The use of uneven-aged management of timber on the Tongass NF presents various operational and economic challenges that influence the availability of timber on the Tongass NF (USDA FS 2014 (Tongass Young Growth Management Strategy)). For instance, net present values are the lowest in stands that are managed using uneven-aged silvicultural systems such as group selection or single tree selection (McClellan 2004). There is also an unknown cost to be incurred in future stands made up of varying sized trees which will require different types of logging equipment than typically modeled. Logging feasibility in stands that have been partial cut may be a challenge in situations where specialized harvesting equipment is needed, as opposed to the common downhill yarding practices. Lastly, damage to thin barked trees is common with uneven-aged management and must be considered in selecting a management method.

Thinning

Thinning includes both commercial thinning and non-commercial thinning. Precommercial thinning is the cutting of trees not primarily for financial return but to accomplish stand improvement goals such as improving residual stand health, stand stability, or increasing the production and yield of usable wood. However, the distinction between commercial thinning and precommercial thinning can be fuzzy given the co-intent of many vegetation management projects done on the Forest. For instance, commercial thinning projects may be done for wildlife improvement purposes. Slash material from a precommercial thinning project could potentially support a commercial biomass venture.

Commercial thinning currently occurs at a small scale on the Forest. Operational feasibility of commercial thinning can be a challenge as it requires more modern equipment. Local purchasers haven't invested in this more modern equipment, making it difficult to implement commercial thinning on a large scale. In some cases, commercial thinning is cost prohibitive. In some areas the risk of windthrow restricts the use of commercial thinning.

Opportunities for commercial thinning on the Forest may be expanding given more research into the practice. For example, Crotteau et al. (2022) found that commercial thinning of young-growth forests in

SE Alaska dramatically affected overstory structure and dynamics through 10 years posttreatment, with thinning generally increasing tree diameter and volume growth and altering mortality rates. Other observations included abundant regeneration 10 years post thinning and incremental understory response, with cover, richness, and forage successively increasing after 5 and 10 years¹³. A simple browse analysis showed that thinned units were being used for forage more than the unthinned young-growth control and had more anecdotal deer sightings.

As discussed above, precommercial thinning (PCT) is the cutting of trees not primarily for financial return but to accomplish stand improvement goals such as improving residual stand health, stand stability, or increasing the production and yield of usable wood. PCT facilitates earlier economical timber sale opportunities by allowing the residual stand to grow larger, faster, and with preferred species. PCT operations can also generate valuable resource benefits such as aquatic and wildlife habitat improvements that provide important subsistence resources for Southeast Alaskans (Meridian Institute 2020). PCT is also critical in even-aged stands in areas managed for old growth objectives by creating growing conditions that accelerate development of structural and plant species heterogeneity, allowing for the growth of large trees and eventual recruitment of large snags and logs, features important to wildlife species on the Tongass NF.

An analysis of how to transition forest management on the Tongass NF to young growth more quickly shows that viable commercial thinning opportunities will generally be found in stands that are at least age 60 or greater if they have been precommercially thinned or at least age 70 or greater if unthinned (USDA FS 2014 (Tongass Young Growth Management Strategy)). Precommercially thinned stands tend to be more stable with sturdier boles and healthy crowns, increasing their resilience to disturbance such as windthrow, giving land managers more options for treatment (USDA FS 2014 (Tongass Young Growth Management Strategy)).

Current 2016 Forest Plan objective for precommercial thinning is:

- O-YG-03: Annually, pre-commercially thin 4,000 to 7,000 acres of young-growth stands and refers to (USDA FS 2014 (Tongass Young Growth Management Strategy)) for precommercial treatment prioritization and scheduling.

Even-aged timber harvest during the pulp mill era (1960s-1990s) in Southeast Alaska grew back to stands of thick young growth that are overstocked and in need of density management for stand health via thinning. These areas in need of thinning are estimated at 85,000 acres across the Tongass NF (Meridian Institute 2020).

On the Tongass NF, programmatic thinning did not start until the late 1970s. From 1979 until 1997, an average of 5,600 acres were precommercially thinned per year (USDA FS 2014). From 1998 through 2007, an average of 4,650 acres were precommercially thinned per year (USDA FS 2014). To address the thinning backlog and ongoing need, about 6,000-8,000 acres per year of PCT is needed. The amount of precommercial thinning in the future will be determined as part of plan development.

Future exploration and understanding of thinning practices as it relates to wood quality is an observed need for the long-term sustainability of the young growth transition. Currently, there is lack of scientific information of thinning prescriptions implications on Alaska Second Growth.

¹³ Variability was too high and replication too low to demonstrate pervasive statistical differences in richness and forage availability by treatment.

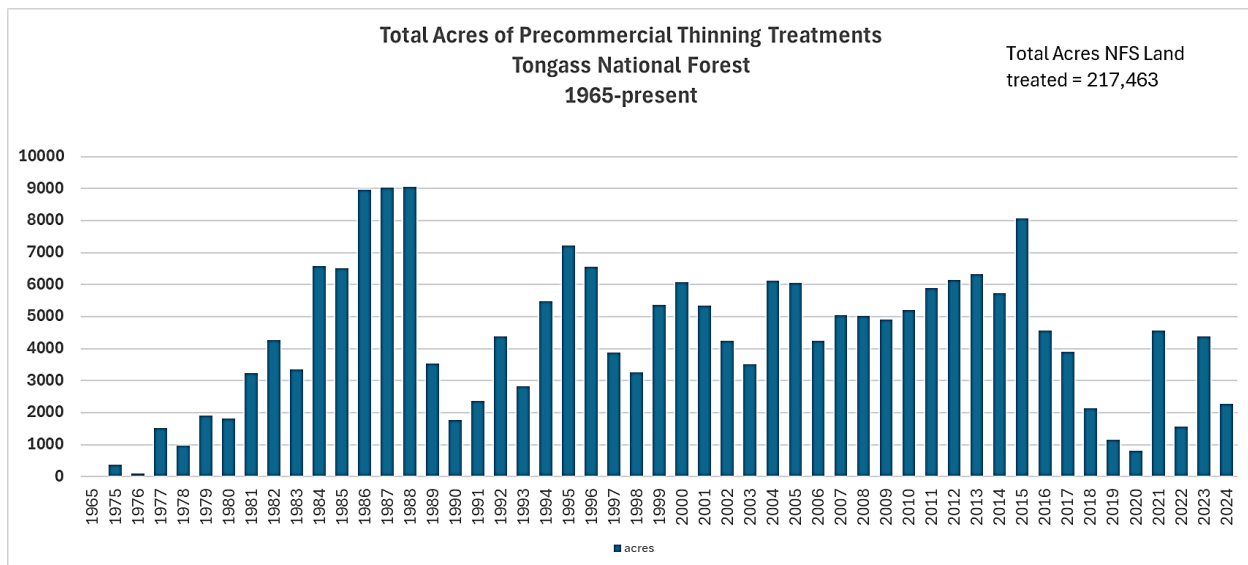


Figure 4. Acres of precommercial thinning treatments, Tongass National Forest, 1965 to 2024

In Southeast Alaska, old growth forests are generally considered to be greater than 150 years old and characterized by: multiple canopy layers; an interspersed of trees of multiple age classes; the presence of snags, decadent trees, and fallen trees; presence of forbs; and variation in the amounts and distribution of live trees (Capp et al. 1992). Public interest has been expressed in the use of thinning or other harvest methods to accelerate the development of old-growth forest structure and function. Thinning has been shown to increase understory biomass relative to unthinned young-growth stands in southeast Alaska (Crotteau et al. 2020). In general, restoration of old-growth structure and function is an area where more local research is needed.

Salvage Harvest

Existing forest plan direction is unclear, impacting the ability for salvage operations to address windthrow and emergent forest health issues from insect and disease outbreaks and the amount of timber that could be harvested. The ability to salvage threatened, infected, dying, and recently dead trees can recoup the value of the wood.

Regeneration and Desired Species Composition

The National Forest Management Act (NFMA) of 1976 requires all forested lands in the National Forest System be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stands designed to secure maximum benefits of multiple-use sustained yield management in accordance with land management plans (NFMA 1976). These regulations do not specify that harvested units be regenerated with the identical species composition that existed before harvest. The current 2016 Tongass Forest Plan defers to site-specific silvicultural prescriptions to determine the appropriate species mix based on the potential of the site as indicated by plant associations and adjacent stand conditions, emphasizing the need to regenerate and maintain particular species such as Alaska yellow-cedar and western redcedar where appropriate for the site. The National Reforestation Strategy also provides guidance on reforestation regimes that foster broader adaptations to create more efficient implementation plans that will result in the greatest benefit to forest stands and trees species in the future (National Reforestation Strategy 2024).

Natural regeneration is abundant on the Tongass, accounting for nearly 99 percent of the reforestation that occurs on forest. Interplanting for species diversity accounts for the remaining 1 percent of reforestation, not for the purposes of meeting restocking requirements but to promote a particular species composition on the landscape (National Reforestation Strategy 2024). To the extent practical, land managers prescribe regeneration harvests designed to create microclimates that favor the establishment of less shade-tolerant western redcedar, Alaska yellow-cedar, and Sitka spruce. Yet western hemlock regenerates far more than other species following harvest because of differences in soil and light requirements, seed production, seed dispersal distance, seed dormancy requirements, and other factors. Western hemlock can thrive on organic or mineral soil and in a variety of light conditions. Alaska yellow-cedar can grow in a variety of mineral and organic soils, in fully open or partially shaded environments.

Natural regeneration and recruitment of Alaska yellow cedar can be difficult and sporadic. Germination of Alaska yellow-cedar seed requires an extensive and complex stratification that consists of warm and cold periods (Hennon et al. 2016). If stratification requirements are not met, then seeds will not germinate the first year after seed dispersal. Remaining seed may germinate the next year if stratification requirements are met and if the seeds are not consumed by birds or rodents or decayed by fungi. Future climate projections for Southeast Alaska indicate a warmer and wetter environment, influencing the establishment, survival, and appropriateness of sites for desirable tree species to naturally regenerate, influencing the species composition found across the landscape.

Commercial Wood Permits

Permits that offer wood for commercial use are primarily firewood permits. Many homes in Southeast Alaska use wood as a secondary source of heat in the winter, through fewer and fewer homes use wood as a primary heat source as time progresses. Since 1997, commercial use of wood via permit has averaged 115 MBF per year and varied from a minimum of about 20 MBF to a maximum of 387 MBF per year (<https://www.fs.usda.gov/forestmanagement/products/ptsar/index.shtml>).

Alaska Free Use Program

On the Tongass NF, various products (green or dead standing timber) are available for harvest for personal use (but not for sale), providing residents of Southeast Alaska economic, cultural, and spiritual benefits. Under the Alaska Free Use Timber Program (36 CFR § 223.10), all Alaska residents are entitled to 10,000 board feet of sawtimber and 25 cords of firewood annually. In FY2023, 218 permits were issued for free use timber on the Tongass, amounting to 1,609 CCF of sawtimber and firewood.

Table 7. Tongass NF free-use sawtimber and fuelwood from free use reports (Source: Region 10 - Resource Management (usda.gov))

Fiscal Year	Number of Permits	Volume (CCF)
2009	303	1,841.8
2010	289	1,609.28
2011	249	1,445.71
2012	318	1,133.4
2013	427	1,423.27
2014	266	1,025.09
2015	285	1,393.26
2016	204	968.09
2017	142	757.68
2018	150	867.87
2019	140	1,007.61
2020	125	710.08
2021	167	1,172.34
2022	168	1,289.61
2023	218	1,609.14

Cultural Use

Alaska Natives have used western redcedar and Alaska yellow-cedar species for cultural products for centuries. Today, Southeast Alaska tribes continue to use trees from their traditional territories within the Tongass NF for cultural and traditional purposes. Cedars provide logs for totem and mortuary poles, longhouses, housing, dugout canoes and cedar canoe paddles, and bark for traditional woven baskets, hats and weaving (Johnson and Cervený 2022). Other items made from Alaska yellow-cedar trees include masks, boxes, bowls, halibut hooks, tools, mats, and hats (Johnson et al 2021). Specific trees needed for totems and canoes are known as monument trees. These trees are usually 450 - 600 years old, have tight grain and small growth rings, stand tall and straight, and are relatively free of defects or too many branches (Riley and Anderson 2021, see also [The Tongass: An Indigenous Place](#) assessment section). Trees with these characteristics are increasingly rare across the Tongass (Riley and Anderson 2021). Alaska Native people need a permit to harvest trees for their cultural traditions, which many say is a challenging process to navigate (Johnson and Cervený 2022).

As described more thoroughly in [The Tongass: An Indigenous Place](#) assessment, there is high economic and cultural impact from carving and raising a totem pole or dugout canoe on a community. Local demand for cultural use trees, as well as quantification of local and regional economic impact of the Alaska Native arts economy, is undervalued and needs further research. Carving and raising a totem pole can have a significant economic impact on a rural community through employment of master carvers and apprentices, renting a carving studio, buying the log, paying for elders guidance and stories, as well as transporting and erecting the pole.

Cultural use of non-timber forest products, including gathering and foraging of wild fungi, berries, and plants, harvesting of spruce roots for weaving (Johnson et al 2021), as well as hunting, trapping, and fishing (Wilmer et al 2024) are discussed in other sections of the Assessment (See, e.g., [Subsistence and other Non-Commercial Harvest](#)). Not only do these objects have cultural meaning for the tribes, the act of harvesting, preparing, processing, and producing cultural products is a part of heritage and cultural identity and belonging (Johnson and Cervený 2022). Cultural market demand for wood products on the

Tongass NF includes recognition of community significance, associated jobs and income associated with wood used for cultural artforms in Southeast Alaska, and community requirements for maintaining and promoting culture and heritage activities (Johnson et al 2021). The production and sale of wood products increases tourism-related opportunities for community residents and provides a sense of sharing something meaningful with visitors (Johnson and Cervený 2022). Carving and weaving also provide an important source of income (Johnson and Cervený 2022).



Figure 5. Totem tree being cut on the Ketchikan-Misty Fjords Ranger District

Special Forest Products

Special forest products are products or natural resources derived from non-timber biological resources that are used for subsistence, personal, spiritual, educational, commercial, and scientific use. Examples of special forest products include resins, oils, leaves, bark, fungi, boughs, Christmas trees, ferns, moss, burls, berries, cones, conks, herbs, roots, and wildflowers. Resources excluded from special forest products include saw-timber, pulpwood, cull logs, small round-wood, house logs, utility poles, minerals, animals, animal parts, rocks, water and soil. Special forest products can provide an opportunity to diversify the wood products industry and create or expand markets for niche products.

Table 8 shows the quantity of special forest products by type cut on the Tongass NF from 2016-2023. Cut amounts and demand for these products are variable year to year.

Table 8. Special forest products cut by type by fiscal year on the Tongass NF

Special forest product	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023
Foliage, limbs, boughs, pounds	0	100	1,000	0	0	0	0	263
Christmas trees, each	100	0	0	0	0	0	30	30
Mushrooms, pounds	50	120	30	0	0	820	100	0
Miscellaneous, pounds	0	0	402	268	400	0	0	0

Source: Cut and Sold Reports- Tongass NF, cut quantity of non-convertible products (<https://www.fs.usda.gov/forestmanagement/products/cut-sold/index.shtml>)

Timber in the Broader Landscape

The Tongass NF is one source of timber available to Southeast Alaska timber operators.

Figure 6 below is from Simmons et al. (2024) and shows timberland area, sawtimber volume, and 2019 harvest by ownership.

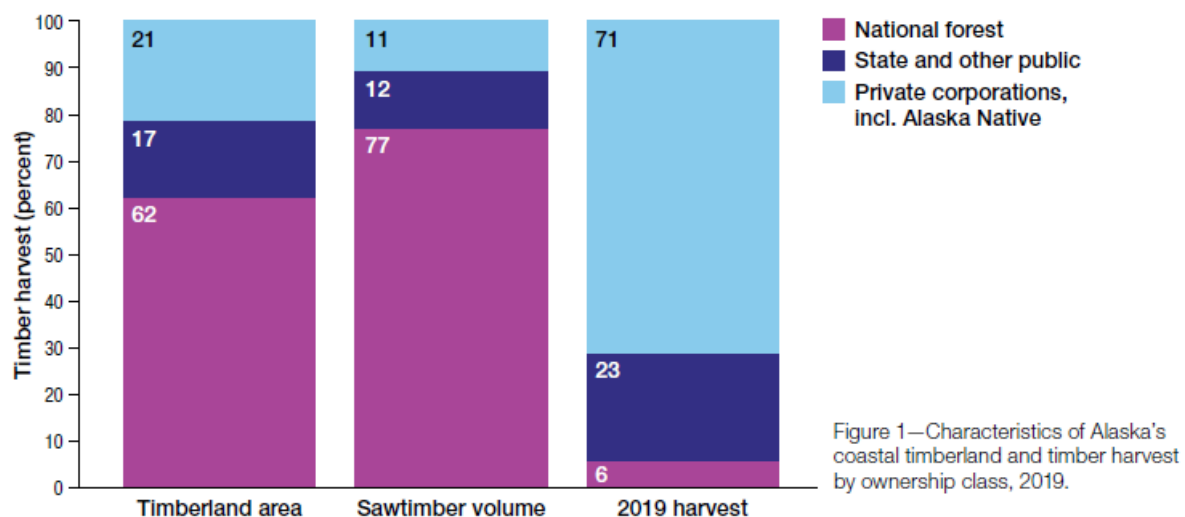


Figure 6. Characteristics of Alaska's coastal timberland and timber harvest by ownership, 2019, as shown in Simmons et al. (2024).

Volume has come from Alaska Native Corporations¹⁴ and State of Alaska lands including the Division of Forestry lands, the Alaska Mental Health Land Trust, and the University of Alaska. A 100 mmbf contract was harvested from Alaska Mental Health Trust lands on Prince of Wales Island in 2019 and 2020. Another 100 mmbf is in a contract near Ketchikan on Revillagigedo Island near Shelter Cove in 2022. Both of these parcels of lands were part of the Alaska Mental Health Trust Land Exchange for Forest Service lands which occurred in two phases and completed in 2020 (AK DNR MHTLO 2020). These landowners have plans that direct their activities – for instance, the Alaska Department of Natural

¹⁴ Information about timber harvest on Alaska Native Corporation lands and the Sealaska Entitlement bill can be found in [The Tongass: An Indigenous Place](#) Assessment.

Resources has the Prince of Wales Island Area Plan (AKDNR 1998) and Prince of Wales Island Area Plan Amendment (AKDNR 2008). Planned timber harvest information available includes five-year schedules of timber harvest. For example, the Alaska Division of Forestry, Southern Southeast Alaska area plans to offer nearly 62 million board feet from state-owned lands over the next five years. (AK DNR 2024 Table 1).

There are impacts to other lands when the Tongass timber program is reduced. For example, there has been an increase in timber harvest by the State of Alaska in the most recent years to meet demand and bridge the lack of timber available to mills during the transition.

Logging Infrastructure

Critical infrastructure to support all aspects of logging operations includes log transfer facilities, operators, roads and bridges, sawmills, and biomass facilities.

Log Transfer Facilities

A log transfer facility (LTF) is a type of marine access facility that is constructed in marine waters and is utilized for the purpose of transferring commercially harvested logs to or from a vessel or log raft, including the formation of a log raft. Also included are constructed facilities such as sort yards, equipment loading ramps, docks, floats, buoys, booms, log rafts, pilings, and anchors. Management of LTFs across the Forest varies widely. LTFs are often not single use infrastructure – while originally created for timber use, they often are used for other purposes such as recreation and subsistence access. Changes in use may occur when an LTF changes ownership or as demand for other uses such as recreation and tourism change over time. In some cases, LTFs constructed as logging infrastructure have been converted or shifted to recreational facilities and may no longer be available to support logging. This creates inefficiencies in the timber industry transportation network by requiring longer hauling and marine towing distances to more distant LTFs still available for industrial use.

Logging infrastructure also includes the service providers such as third-party log scalers, dock workers, fuel providers, and barging and towing services. Established facilities to load export ships have declined, such as the KIDCO dock on Klawock Island which was recently converted to tourism use. These trends can be traced back to the closure of the region's pulp mills in the 1990s. The primary helicopter logging contractor has recently sold their Alaska equipment and demobilized from the region.

In some parts of Southeast Alaska, larger operators shutting down could have ripple effects on the overall viability of smaller operators and contractors (i.e., loggers, small mills, longshoremen) because many of the smaller operators benefit from the larger operators that maintain the foundations of the remaining existing infrastructure (Huber-Stearns et al 2020).

Roads and Bridges

Most of the roads on the Tongass National Forest were built and maintained to access and remove timber. As the number of timber sales have decreased so have the miles of roads being maintained. Many roads have been in storage status for so long that it is nearly cost-prohibitive to reopen them for logging access. Roads were often built in valley bottom locations that provide access challenges for modern logging equipment or in locations that increase maintenance needs and the risk for sediment from the road surface to enter adjacent streams. As described in the [Infrastructure](#) assessment, many of the bridges across the Tongass NF were constructed to support the timber program and are over 40 years old, with the oldest bridges no longer in compliance with best management practices.

Sawmill Capacity and Production

The number and distribution of sawmills that process timber has social and economic impacts on many Southeast Alaska communities. Since 2000, the USFS Alaska Regional Office has conducted annual surveys of sawmills across the Tongass NF to gather information regarding sawmill operations including total estimated production capacity, actual production, wood supply source, forest products, market destinations, and general business challenges (Daniels et al. 2023, Daniels et al. 2025)¹⁵. When the survey was initiated in 2000, 20 medium- (producing 1.0-5.0 MMBF annually) to large-scale sawmills (producing > 5.0 MMBF annually) operated across the Tongass National Forest with the greatest concentration located in southern Southeast Alaska (Daniels et al. 2025). Between 2000 and 2019, more than half (59 percent) of these sawmills were closed and uninstalled and sawmill capacity had contracted to produce a fraction of their 2000 output (Daniels et al. 2025)¹⁶. No new sawmills of equal size classification have been established to date. The mill survey conducted for 2019 found that of the original pool of sawmills, four were operating and five were idle; thus, the entire Southeast Alaska wood products industry was being represented by four active mills. To improve the representation of small mills in the region, the sawmill survey pool was expanded in 2021 to include seven additional mills selected based on a combination of three criteria: a history of purchasing timber from the Tongass National Forest, a valid Alaska business license to manufacture wood products, and a recommendation from Tongass timber management staff. Sawmill capacity remained significantly underutilized in 2023; regional capacity utilization rate, based on an installed capacity of 135,556 MBF, is 13 percent (Daniels et al. 2025). Sawmill employment fell from 80 full time equivalents (FTEs) in 2021 to 76 FTEs in 2023, including owners, operators, and other employees (Daniels et al. 2025).

The high cost of fuel is also a limiting factor for sawmills to expand their operations; many sawmills depend on diesel-generated power to run their milling equipment and diesel fuel is expensive in the rural areas of Southeast Alaska.

Biomass Facilities

Biomass facility is a broad term used to describe facilities that utilize biomass in different ways. Biomass in terms of this report is wood for heat. Currently the biomass facilities installed to produce heat operate on cordwood or chips or pellets. Biomass utilization facilities provide a viable market and heating source for businesses, schools, and other centers while also providing employment and a use for byproducts of sawmill processing and logging residue. Industrial and nonindustrial biomass facilities impact the social and economic well-being of communities by creating paying, low-skill jobs which offers economic opportunity and job training opportunities. Cordwood facilities also create a local market for cordwood, wood that has been cut into uniform lengths, typically used as firewood, allowing individuals to supplement their income by selling firewood, and importantly, keeping money within the local

¹⁵ Note that the largest producer in the region has not provided data since 2021. Production data for that mill has been held constant since. See Daniels et al. 2023.

¹⁶

Southeast Alaska's forest product industry peaked in the 1950's through the mid 1970's when intensive harvest of easily accessible timber was not regulated. In addition, the Forest Service ceased offering long-term timber sale contracts in the mid 1990's, making timber supply less reliable and impeding the ability of industry to invest in retooling for young growth. In addition, the industry has also been negatively impacted by changes in global timber markets, high labor costs, long distances from markets, high transportation costs, and workforce shortages. The industry is also impacted by shifting demand in export markets as new suppliers move into Pacific Rim markets. As a result of all of these factors, and others such as shifting management priorities, litigation, and challenges with the transition to young growth discussed above, timber offered and sold on the Tongass has declined and this has impacted the sawmill industry and the associated workforce.

community. The largest cordwood burning system in Southeast Alaska burns on average of 200 cords of wood a year, the largest chip system burns about 2,000 tons of wood chips a year.

Biomass utilization facilities can create a market and use for the byproducts of sawmilling, efficiently utilizing the entirety of the harvested timber. At least 16 biomass facilities have been installed across 13 communities in Southeast Alaska (Alaska Wood Energy 2024). These facilities are primarily located in schools, but also heat other private and public facilities such as an airport, a senior center, two office buildings, a pool, and housing units. Another 18 projects have undergone a pre-feasibility study by the State of Alaska's Alaska Wood Energy Development Task Group and are in various stages of consideration or development (Alaska Energy Authority 2024). These facilities are impacted when local mills close.

Economic Contributions and Considerations

Timber harvest contributes to local economies and rural community well-being by supplying raw materials, generating local jobs and income, and stimulating economic activity in supporting sectors. The Tongass NF is an economic contributor to Southeast Alaska communities directly as an employer by supporting jobs through stewardship and service contracts and permits, timber sales, grants and agreements and through federal payments to the states. Timber harvesting for wood production supports traditional forest industries such as logging and milling. In addition, tree cutting and timber harvest are often activities included in contracts, grants, and agreements to accomplish restoration to achieve forest health and restoration goals. These direct economic contributions expand more widely as the ripple effect of job creation and money spent circulates throughout the related industries and economic sectors. These contributions are especially important to rural economies where there may be few opportunities.

Commercial Use of Wood and Local Use Lumber

Commercial harvest of products from the Tongass NF provides a source of employment and labor income across Southeast Alaska. Special forest products and timber resources that are sold, processed for sale, or used in business operations are considered commercial use. Examples include mushrooms, boughs and greenery, and Christmas trees. Wood harvested from the Tongass NF is used to manufacture a variety of primary products. Primary products are wood products directly manufactured from timber and include dimensional lumber, firewood, timbers, house logs, log furniture, molding stock, cedar products (mostly shingles), and tonewood blanks used to make musical instruments.

Western hemlock is used for pilings, poles, railway ties, windowsills, doors, and construction lumber, and has been an important fiber source for pulp (Tongass FEIS 2016). Sitka spruce is used for lumber and commodity products, as well as specialty products, such as piano sounding boards, guitar faces, oars, planking, masts, and spars for custom-made or traditional boats (Tongass FEIS 2016). Today, redcedar is primarily used as a roofing, siding, and decking material and Alaska yellow-cedar has many uses including boats, utility poles, heavy flooring, framing, and marine decking and piling (Tongass FEIS 2016).

To expand domestic marketing opportunities for Alaska-produced wood products, the Local Use Lumber Program was enacted in 2023 (AK DNR 2023). The intent of the program is to provide small mills an opportunity to enter home construction markets, address housing shortages, and increase management opportunities of Alaskan forest resources (Douse 2023).

Local Jobs and Industry

Although many communities have diversified or completely shifted their economic bases from timber to other industries such as tourism, or recreation, timber is still a culturally, socially, and economically important industry for communities in Southeast Alaska.

Overall, timber sector employment has declined by 65 percent from 2005 to 2021, with losses in forestry and logging (72 percent), and wood product manufacturing (49 percent) (Table 9).

The expanding use of Forest Service authorities to engage in “goods for services” stewardship contracting and Good Neighbor Authority agreements to achieve ecological restoration goals is reflected in the support services employment trends. By providing opportunities for living wage jobs through local contracting and workforce development, management activities on the Tongass NF contribute to economic opportunities in the communities in Southeast Alaska.

Table 9 shows employment in logging and sawmill operations in Southeast Alaska from 2005-2021. Data for total logging and sawmill jobs in Southeast Alaska was acquired from the Alaska Department of Labor and Workforce Development. The number of logging jobs attributable to timber projects on the Tongass National Forest was calculated by adjusting total Southeast Alaska logging jobs by the ratio of Tongass timber harvest to total Southeast Alaska timber harvest. Tongass National Forest sawmill employment was calculated by adjusting total Southeast Alaska sawmill employment by the ratio of sources of wood (Federal versus total) from annual regional mill study reports.

Table 9. Employment in the wood products industry in Southeast Alaska, 2005-2021 (number of fulltime employees)

Year	Tongass Logging	Other Logging	Logging Total	Tongass Sawmill	Other Sawmill	Sawmill Total	Total Industry Employment
2005	88	263	351	96	52	148	499
2006	81	217	298	77	46	123	421
2007	44	225	269	70	63	133	402
2008	52	118	170	70	24	94	265
2009	48	110	158	39	17	56	216
2010	61	133	194	46	4	50	241
2011	60	152	212	47	3	50	264
2012	39	147	186	47	11	58	244
2013	75	106	181	48	14	62	243
2014	86	96	182	60	7	67	249
2015	104	63	167	58	12	70	237
2016	81	76	157	70	1	71	228
2017	25	108	133	37	32	69	202
2018	25	94	119	37	37	74	193
2019	14	148	162	37	31	68	230
2020	19	92	111	36	32	68	179
2021	26	71	97	19	57	76	173
5 year average	22	103	124	33	38	71	195

On the Tongass NF, labor income from the Forest Products program area was \$8,844,000 with 90 direct and 190 total jobs supported by forest management activities in 2019 (USDA FS 2019). Across Southeast Alaska, total employment-related earnings in the timber industry by year were \$17,050,899 (2013), \$18,764,683 (2018), \$19,352,720 (2022), and \$19,241,564 (2023), contributing 295 total jobs in the timber sector in 2022 (Southeast Conference 2023).

Timber Industry Workforce Availability

Timber industry employment has been in decline for decades, with an estimated 3,500 jobs lost in the 1990s (Alexander and Gorte 2014). Broadly, the timber industry workforce demographic is aging, and a lack of skilled workforce (e.g., equipment operators, logging engineers) is ongoing (Meridian Institute 2023). Larger operators rely on a seasonal workforce that come from out of state and need housing which can be costly and challenging to find. As larger operators age towards retirement, there has not been a younger demographic willing to come in to replace them. Most small sawmills are family owned and operated, relying on family members to run operations, and not really interested in growing their labor force.

To meet future opportunities and fill employment demand in the industry, the maintenance of a trained timber and restoration workforce is critical. Several workforce development and training programs have been implemented to help recruit, train, and retain local employees (Meridian Institute 2023). Examples of these include agreements with the State of Alaska Division of Forestry, Prince of Wales Vocational & Technical Education Center, Alaska Youth Stewards, the 2016 Forest Academy, hiring initiatives through the ANILCA, and various community native forest partnerships such as Hoonah Native Forest Partnership, Klawock Indigenous Stewards Forest Partnership, and Keex' Kwaan Community Forest Partnership.

Authorities with Emphasis on Restoration and Collaboration

To address challenges with providing an adequate supply of timber from the Tongass NF, emphasis has been placed on collaboration using an all-lands approach with the region's timber land managers.

Good Neighbor Authority

The Good Neighbor Authority (GNA) is a multi-faceted approach with the State of Alaska Division of Forestry to manage forests for multiple benefits. In 2016, the U.S. Forest Service and Alaska Department of Natural Resources entered into a Master Good Neighbor Agreement, under which two Supplemental Project Agreements have been executed. These GNA agreements between the State of Alaska and the Tongass NF, both of which included young-growth harvest, include working across land ownership boundaries and combining timber sales with restoration work (Huber-Stearns et al 2020). Under GNA, revenue generated from the sale of Federal timber remains with the forest to be used to complete additional authorized restoration work that otherwise may not have been funded through annual appropriations.

Stewardship Contracting Authority

Stewardship Contracting includes natural resource management practices that contribute to the development of sustainable rural communities, restore and maintain healthy forest ecosystems, and provide a continuing source of local income and employment. From 2011-2015, the Tongass NF had an active Stewardship Contracting program, which required an emphasis on restoration and informal collaboration with partners. Stewardship authority continues to evolve and remains a viable tool that is still in use today at a smaller scale.

Emphasis on restoration and collaboration is expected to continue, as extensive restoration needs exist on the Tongass NF, based around young-growth management and stand restoration through thinning activities. Restoration treatments can help support a more efficient and effective transition to young-growth management of timber on the Tongass NF.

Limited Export Policy

The forest products industry is a global industry, where it is common for both unprocessed and processed products to be bought and sold to competitive international markets, supply chains, and customers.

The Tongass National Forest is unique because its Limited Export Policy makes it the only national forest west of the 100th meridian of the United States authorized to export unprocessed timber to international destinations (Daniels et al. 2025). Sale of unprocessed timber from Alaska to destinations in the Lower 48 is considered interstate shipment but is often termed export because primary manufacture occurs outside of Alaska. Export of unprocessed timber to locations outside of Alaska is an important component of the Tongass timber economy as it allows for more complete utilization of timber harvested in areas logged primarily for local manufacture (36 CFR 223.201). Timber harvested from the Tongass is bound by 36 CFR 223.201 and associated Forest Service Alaska Regional Office Limited Export Policy (USDA FS 2015 Annual Review and Update of R10 Limited Export Policy letter). Log exports represent another market available to purchasers of timber throughout the region (Daniels et al. 2025). Tongass timber purchasers can choose to process timber into forest products, buy and sell logs among each other, or apply for a permit from the Regional Forester to divert wood into log export markets to respond to economic conditions and fluctuating product prices. Log exports support jobs in logging, transportation, and shipping (Daniels et al. 2023).

Figure 7 shows the volume of Tongass National Forest log exports to international and Lower 48 destinations by calendar year. Sitka spruce and western hemlock of very high quality have been exported in the form of logs, lumber and timbers into the Pacific Rim for the past 5 decades (Resource Development Council 2024). Log export and timber harvest data from lands managed by the Tongass NF indicate that export percentages have fluctuated year to year, likely due to declining harvest of old growth coupled with an increased harvest of young-growth trees of which the primary market is export. Year-to-year export percentages depend on global markets, transport logistics, and other factors (Huber-Stearns et al 2020).

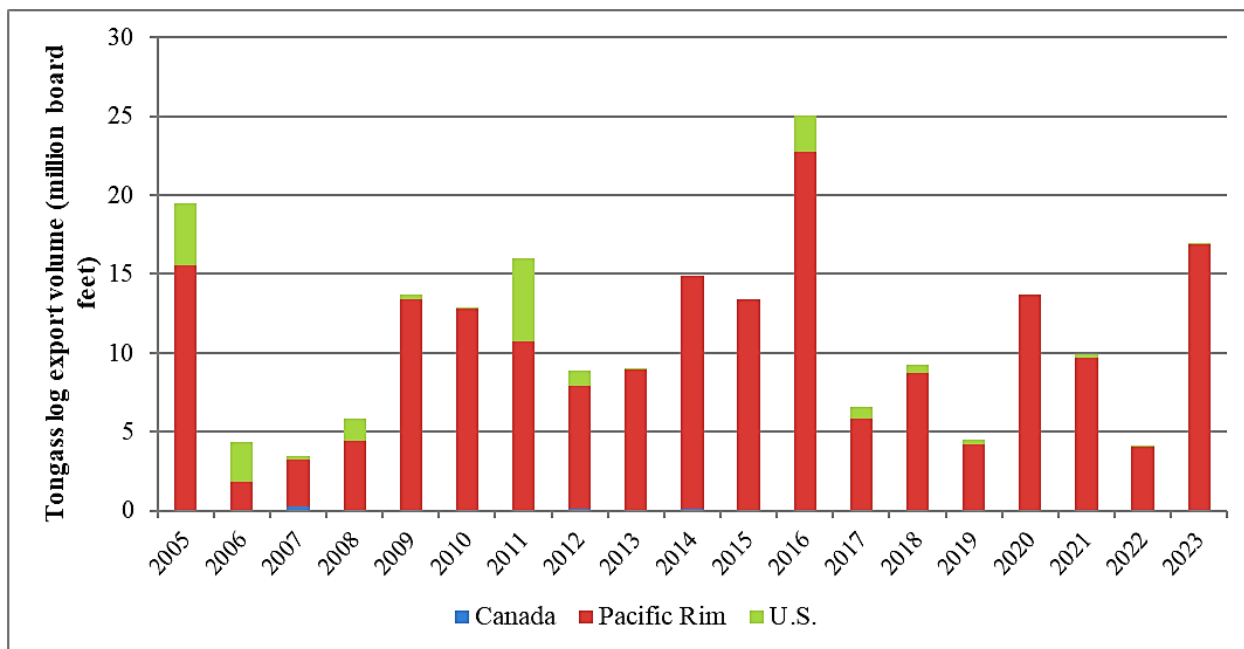


Figure 7. Volume of log export permits by destination, 2005-2023

At this time, the only established large-scale market for young-growth Tongass timber is export destinations; export percentages are expected to remain high unless processors establish new domestic markets for young-growth products in Southeast Alaska.

As mentioned in the public feedback section, the public expressed concerns regarding export and interstate shipment of round logs from Alaska. While the volume of log export permits in Figure 7 is not broken out by old growth and young growth, in general, the vast majority of young growth harvested to date has been exported. Sawmills harvesting old growth may divert a portion of their volume made up of lower quality logs into export markets to increase utilization of the resource and maintain long-term profitability. This allows the region's timber producers to shift harvested volume to different markets in response to changing economic conditions and fluctuating product prices. Timber markets are often volatile, with a multitude of different elements affecting them – trade policies, shipping costs, housing trends, and others. Flexibility to respond to market volatility through multiple market opportunities continues to be important for local producers.

Young-growth Transition and Milling Equipment

Timber harvest trends have been influenced by the direction to transition timber harvest on the Tongass NF to primarily young growth. The desired condition for suitable young-growth acres scheduled for timber production is that timber products from young-growth stands are available on an even-flow, long-term sustained yield. Due to the extent of past harvest since the 1950s, large acreages of young growth will become ready for rotational harvest over a relatively short period of time starting around 2030. Various studies have been used to develop management schemes that produce the highest potential future returns on stand treatments (USDA FS 2014).

Markets for young growth processed or sawn in Southeast Alaska are still developing. There is notable mixed interest in investing in infrastructure for young-growth processing due to uncertain timber supply, limited economically viable options for young-growth utilization, and modest success with selling young-

growth products to date (Huber-Stearns et al 2020). There are equipment challenges in producing finished lumber from young growth (planed and kiln-dried) and sawmills may not have those facilities installed or operating. The 2023 survey of mill operators indicates milling of young growth is occurring in their overall production (Daniels, et al. 2023, Daniels et al. 2025). The small mills added to the survey in 2021 averaged 18 percent in terms of the young growth percentage of total sawmill production and the original sawmills in the survey averaged 2 percent young growth percentage of total production (Daniels et al. 2025).

The Tongass Transition Collaborative (TTC), a third-party collaborative group focused on forest management work on the Tongass NF, conducted work sessions in 2022 and 2023 and results indicate there is a perception that young-growth wood quality is inferior to, and not a replacement for, the quality of old growth wood (Meridian Institute 2023). However, young-growth wood from the Tongass NF is of higher quality than most second growth in the Lower 48 due to its strong, small knots that holds up well in construction (Meridian Institute 2023). Higher grade products such as shop lumber, cants and timbers, and niche products are typically sourced from old growth and generally command a price premium. Conversely, dimension lumber, generally sourced from young growth, is a commodity product for structural use that is highly price competitive and Alaska's distance to established markets puts local producers at a competitive disadvantage (Daniels et al. 2023).

Discussions with operators about young-growth timber revealed that several had no desire to ever purchase young growth, but several others would purchase more if offered, primarily because logs were more uniform in size, had less defect than old growth, and met local customer needs for rough cut dimension lumber (Daniels et al. 2023, 2025). Some small mills are retooling to more efficiently process young growth. Some assistance is being provided in support of the transition to young growth. Three grants awarded by the Forest Service in 2022 brought \$1.1 million into Southeast Alaska to fund a containerized pellet mill near Ketchikan as well as purchase equipment to support value added and young-growth milling in Hoonah and Tenakee Springs (Daniels et al. 2023). Three grants awarded by the Forest Service in 2023 brought almost \$775,000 into Southeast Alaska to fund a one-pass log sawmill in Petersburg¹⁷, a community firewood distribution program in Klawock, and a wood fired boiler to heat kilns at a sawmill in Thorne Bay (Daniels et al. 2025). Market competition for finished products can be challenging due to high costs of transportation as bulk shipments of construction lumber are barged into rural communities from large suppliers in the Lower 48 (Huber-Stearns et al 2020).

Factors Affecting Timber Sale Economics and Project Design

Alaska is inherently a high cost operating environment, making prudent project design of timber projects imperative to their overall implementation success. In some cases, aspects of the project design (such as high-cost yarding systems, limited treatment area sizes, or necessary road construction for access) or the physical characteristics of the area can make most of the acres economically infeasible. Project location and whether it is connected to a community by road or at a remote location and requiring a logging camp also affects timber sale economics, as well as transportation logistics (such as marine towing, which is

¹⁷ <https://www.fs.usda.gov/sites/default/files/success-story-alaska-mill-sustainable-processing.pdf>

discussed in the Logging Infrastructure section below)¹⁸¹⁹. Timber harvest on non-federal lands is not subject to the same constraints as on federal lands; As such, non-federal landowners may have more opportunities for economic timber sales.

Project design is affected by laws and national direction, primarily National Forest Management Act which limits the size of openings and Tongass Timber Reform Act which applied a buffer on fish-bearing streams.

Resource protections impact the intensity and acres available for timber harvest. Since the 1997 Forest Plan, standards and guidelines to achieve these protections have played a large part in affecting project design. Notably the Scenery Integrity Objectives often limit the size of openings for even-aged management, making equipment set-up costly and inefficient. Other standards and guidelines that affect project design are buffers for raptor, murrelet and heron nests and rookeries, timing protections for goshawks, avoidance of high-value karst, riparian management areas especially for alluvial fans, steep slope analysis requirements, buffers for sensitive plant locations, and beach buffers.

The above project design restrictions will become more apparent as the transition to young-growth management occurs. The majority of these were not in place during the initial harvest of the timber stands and, as such, adjustments will need to be made relative to the original harvest footprint. The 2016 Forest Plan imposed additional restrictions and limitations to address various resource concerns that made traditional even-age harvest more challenging.

Specific Young-Growth Direction from 2016 Forest Plan that influences project design includes the following:

- S-YG-BEACH-01: ...”the maximum size of any created opening for commercial timber harvest in the beach fringe must not exceed 10 acres and a maximum removal of up to 35 percent of the acres of the original harvested stand is allowed. Commercial thinning is limited to 33 percent of the stand’s basal area. A combination of the two treatments may be used, with no more than 35 percent of the total stand removed in either basal area and/or acres”...
- S-YG-BEACH-03: Commercial harvest within the beach and estuary fringe is not allowed within a minimum 200-foot forested buffer beginning at the mean high tide.
- S-YG-RIP-01... “The maximum size of any created opening for commercial timber harvest in the RMA must not exceed 10 acres and a maximum removal of up to 35 percent of the acres of the original harvested stand is allowed. Commercial thinning is limited to 33 percent of the stand’s basal area. A combination of the two treatments may be used, with no more than 35 percent of the total stand removed in either basal area and/or acres.”...
- S-YG-WILD-01: ... The maximum size of any created opening for commercial timber harvest in the Old-growth Habitat LUD must not exceed 10 acres and a maximum removal of up to 35 percent of the acres of the original harvested stand is allowed. Commercial thinning is limited to 33 percent of the stand’s original basal area. A combination of the two treatments

¹⁸ As described in FSH 2409.18 - Timber Sale Preparation Handbook, financial efficiency analysis is used compare treatment alternatives to determine their relative efficiency with each other. It also provides a comparison of anticipated costs and revenues that are part of Forest Service monetary transactions. Forest Supervisors and District Rangers must have information about projected costs, revenues, and benefits prior to making substantial resource and capital investments in timber sale or stewardship projects. Financial efficiency analysis is used to ensure financial efficiency measures are considered as decision criteria when evaluating timber sale proposals, and when selecting a project alternative in accordance with the plan components of the land management plan.

¹⁹ Costs associated with any road construction and maintenance for logging operations would be more appropriately addressed at the project level and not as part of forest plan assessments.

may be used, with no more than 35 percent of the total stand removed in either basal area and/or acres.”...

These restrictions and avoidance measures present operational challenges to reaching harvestable timber based on existing access and road locations. In particular, areas managed with co-intent, such as the beach buffers and riparian management areas, have been noted as challenging regarding plan implementation given the difficulty with developing economically feasible timber projects and the complexity of direction in the plan standards listed above.

Service Contracting Difficulties

Service contracts are awarded to businesses to achieve specific tasks on behalf of the agency, with the amount and type of work and local business capacity determining the extent to which local communities benefit from these contracts. Challenges associated with contracting include existing contracts and acquisitions processes that are difficult to change and hard to navigate. In some cases, certain types of work may be more suited to local business capacity than others. For example, small sized contracts or contracts for mechanical work (e.g., road brushing) requiring just a few operators may be more feasible for small local contractors than manual work for large crews (e.g., tree thinning) or specialized or expensive equipment (e.g., helicopter logging). As such, matching the size of operations is limited by available contractor pool and type of work needed. The Tongass has also experienced recent challenges with the increasing cost of service work and finding contractors to complete pre-commercial thinning work.

Career Development and Educational Opportunities

Timber management and employment in the forestry and natural resources sector help support trade and degree programs and entry into the natural resources sector broadly. Forest Service professionals working in the field of forestry engage with prospective students or applicants through career fairs, environmental education, and outreach events in the community. The Tongass NF also partners with local universities to conduct research and host learning opportunities. These efforts generate research that further promote effective management strategies on the Forest.

Within the communities of Southeast Alaska, local high schools are using young growth in woodworking and shop classes, providing an opportunity to integrate the shift towards young-growth forest management into training and education at multiple scales (Meridian Institute 2023).

The Tongass timber management program has offered several recent workforce development and skills enhancement opportunities in the local communities. One notable example is the Forest Academy, held periodically on Prince of Wales Island. The first two Forestry Academies in 2016 and 2017 were the result of a Challenge Cost Share Agreement between the Tongass National Forest and State of Alaska. These initial academies were designed to train locally recruited residents a variety of technical skills in natural resource management such as timber stand inventories and collection of aquatic, wildlife, and cultural resource information. Twenty residents participated in the 2016 and 2017 academies with the majority applying their learned skills in seasonal or permanent jobs with the State of Alaska, USFS, Sealaska, or local forestry contractors. Following the successes of the 2016 and 2017 academies, the Tongass hosted a follow up multi-week Forest Academy in 2019 that included a week of forestry skills, a week of aquatic organism passage survey methods, and a week of learning aquatic habitat mapping techniques. The 2019 academy had sixteen participants and was partially led by four previous academy participants now serving as teachers and field assistants to USFS staff. These Forest Academies have led to additional trainings and workshops with an increasing range of partners, including local community

forest partnerships and conservation based non-profit organizations, to continue providing forestry and natural resource management training and workforce development opportunities for residents.

The Alaska Youth Stewards (AYS) is an employment program for rural and Indigenous youth of Southeast Alaska. AYS offers place-based on-the-job experiential education and training to care for our lands, waters and communities, with varied projects focused on stream restoration, community harvest efforts, forest inventorying, and a suite of other forestry projects.

Risks, Areas of Uncertainty, Assumptions

Climate Change

Climate change is anticipated to affect the composition, distribution, and performance of vegetation communities throughout the Tongass National Forest, although it is difficult to predict the extent and direction of these effects. A climate change vulnerability assessment (CCVA) for the Tongass NF (Halofsky et al. DRAFT) is in development and is drawn on and summarized in the [Drivers, Stressors, and Climate Change](#) assessment section. Elements of climate change that may affect the timber resource include changes in temperature, precipitation, wind, landslides, drought, fire, insects, and disease.

Forest Health

Insect and disease outbreaks have the potential to impact the diverse ecoregions and ecological integrity of forested land in Southeast Alaska. Tree mortality and decline can impact tree growth, stand health, commercial availability of timber, species distribution and occurrence across the landscape, and wildlife habitat. Concern for tree damage and tree mortality, and management interventions to address tree disease impacts to forest ecosystems, reflects the values and cultures forest users hold. In addition to the ecological and economic impact, tree diseases, like other disturbances, can alter practical and psychological attachments humans hold to healthy trees and forests, degrading the social values that forested ecosystems support (Roy et al 2024).

Alaska Yellow-Cedar Decline

Alaska yellow-cedar (AYC) has cultural, economic, and ecological values. The chemistry of the heartwood of AYC allows the tree to live for longer than 1,000 years and persist long after death as sequestered carbon and durable wood products (Hennon et al 2016). The wood has many favorable characteristics that make it highly valued including durability, structural integrity, and resistance to rot. The chemical composition of the wood makes the trees highly resistant to fungal decay and attack by marine borers, termites, and other insects (Hennon et al 2016). Alaska yellow-cedar wood is used for a variety of products such as carpentry and decorative paneling, wood furniture, molding, cabinetwork, shingles, posts, poles, marine pilings, small boat hulls, oars and paddles, exterior door and window boxes. It is also used in exterior applications such as bridges, decking and stairs as well as specialty construction projects such as temples and shrines.

Climate exerts long-term influence over vegetation patterns, hydrology, and soil development, and relatively shorter-term influence over seasonal precipitation, temperature, and acute weather events (Hennon et al 2016). The widespread AYC decline is associated with freezing injury to fine roots that occurs where snowpack in early spring is insufficient to protect roots from late-season cold events (Hennon et al 2016). Yellow-cedar trees appear to be protected from spring freezing injury where snow is present in spring and able to insulate tree roots and prevent premature dehardening and freezing (Hennon et al 2016).

Alaska yellow-cedar has experienced extensive mortality and forest decline in Southeast Alaska during the past century (Hennon et al 2016) and causes patches of dead trees across the landscape. Mapping of AYC decline began around 1990 during annual U.S. Forest Service aerial surveys of forest health; more than 710,000 acres of AYC decline have been mapped across Southeast Alaska to date (Mulvey 2024).

Among stands with a component of healthy Alaska yellow-cedar in Southeast Alaska, there are also isolated patches of dying AYC associated with climate change (Johnson et al 2021). Affected stands are usually composed of long-dead, recently dead, dying, and surviving trees, which suggests that mortality has occurred for a long time and continuing. Yellow-cedar decline has elevational limits that vary by latitude in a manner that suggests that climate plays a key role in the mortality; in Alaska, elevational patterns of AYC decline have been documented over the 3° of latitude where it occurs (Hennon et al 2016).

In 2023, more than 20,000 acres of active yellow-cedar decline were mapped in Southeast Alaska during aerial detection survey, a two-fold increase from last year. Yellow-cedar decline has continued to impact young-growth stands managed for timber (Mulvey 2024) and has the potential to impact small sawmills and free use permittees that utilize the wood for niche commercial and non-commercial uses. Yellow-cedar decline, as perceived by Tlingit and Haida Alaska Natives, creates concerns when tree diseases damage cultural uses, provoking a loss of connection to nature, spiritual well-being, and cultural identity (Roy et al 2024). Under climate change, decline impacts are anticipated to continue based on models that incorporate the risk factors of yellow-cedar decline (hydrology and snowpack) (Mulvey 2024).

Recent Defoliator Outbreaks

The Tongass NF has experienced recent defoliator outbreaks across the landscape, including Western black headed budworm (*Acleris gloverana*) and hemlock sawfly (*Neodiprion tsugae*) causing mortality and decline of forested stands.

Western blackheaded budworm populations began to rise in 2020, resulting in a largescale outbreak in 2021 and 2022 primarily impacting western hemlocks and Sitka spruce to a lesser degree, dominated by top-killed trees with some trees showing needle regeneration that cast a subtle green shade to gray trees (FS-R10-FHP 2023). Outbreaks typically last two to three years and then crash due to parasitism, predation, disease and ultimately starvation; in 2023 the western blackheaded budworm outbreak subsided throughout Southeast Alaska with minimal damage and light defoliation found (FS-R10-FHP 2023).

An outbreak of hemlock sawfly started in 2018, peaked in 2019, and crashed in 2020 (FS-R10-FHP 2023). No hemlock sawfly damage was recorded in 2023 (FS-R10-FHP 2023). Hemlock mortality from past defoliation was minimal in most areas, but dense in some pockets on Admiralty and Chichagof Islands and along Excursion Inlet, totaling 28,700 acres (FS-R10-FHP 2023). Areas previously impacted were dominated by top-killed trees with some trees showing needle regeneration that cast a subtle green shade to gray trees. Hemlock sawfly larvae preferentially feed on the older foliage of western hemlock, often leaving part of the needle uneaten, resulting in thin inner tree crowns. Typically, outbreaks last a couple years and may result in growth loss and topkill (FS-R10-FHP 2023). Tree mortality is limited unless hemlock sawfly outbreaks co-occur with outbreaks of the western blackheaded budworm, which has been observed.

Ground surveys indicate that young-growth forest stands have rebounded and have shown stand-level resilience to hemlock sawfly and western blackheaded budworm outbreaks. Young-growth stands have recovered more quickly than old growth stands from these outbreaks.

Priority Work and Policy Development

The Tongass NF has a long history of debate between timber industry, state and local governments, and environmental and conservation groups. Decisions regarding work priorities and policy making that impact timber management on the Tongass NF are often made at the executive and departmental level. Litigation and court orders have also impacted the ability of the Tongass NF to offer a level of timber for sale that is analyzed and permitted under the Forest Plan.

Key Takeaways

The following list represents a summary of key findings contained within this report, with each item discussed in more detail within its corresponding section of the report.

- The timber industry is part of the diversity of industries for many of the communities of Southeast Alaska.
- Timber harvest has declined substantially on the Tongass NF and across Southeast Alaska since 1997, the date of the last Forest Plan revision.
- Free use and special forest product use has been ongoing and remains an important aspect of Southeast Alaska way of life.
- The Forest Plan includes calculations for a sustained yield limit, lands suitable for timber production, projected wood sale quantity, and projected timber sale quantity, which will be recalculated as part of the revision effort. Timber offered, sold, and harvested on the Tongass NF has been well below this limit and projected amounts.
- Even-aged regeneration harvest, using clearcutting, has been the primary silvicultural system used for commercial timber harvest. Even-aged harvest is effective for meeting several management objectives, including regeneration of Western redcedar, Alaska yellow-cedar, and Sitka spruce; minimizing windthrow impacts; removing disease pathogens like dwarf hemlock mistletoe; minimizing the need for roadbuilding across the landscape; and providing harvest efficiency and economically viable timber sales.
- The Tongass NF has been transitioning from primarily old growth timber harvest to primarily young-growth timber harvest. The 2016 Forest Plan outlines a 15-year transition, with old growth harvest amounts at an average of 5 MMBF in 2031. Five MMBF or less of old growth has been offered and sold on the Tongass NF since 2020.
- As more young growth stands become available for commercial harvest to support investment and development of a young growth industry, operators have expressed that continued availability of old growth as a component of the timber program is important to remain viable through production of high value specialized products for domestic markets.
- At this time, the only established large-scale market for young-growth Tongass timber is export destinations; export percentages are expected to remain high unless processors establish new domestic markets for young-growth products in Southeast Alaska.
- Flexibility in management is needed for management options to address emergent forest health issues such as insect and disease outbreaks and to address changing conditions due to climate.

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Glossary

Sustainability

The capability to meet the needs of the present generation without compromising the ability of future generations to meet their needs. For the purposes of this Handbook “ecological sustainability” refers to the capability of ecosystems to maintain ecological integrity; “economic sustainability” refers to the capability of society to produce and consume or otherwise benefit from goods and services including contributions to jobs and market and nonmarket benefits; and “social sustainability” refers to the capability of society to support the network of relationships, traditions, culture, and activities that connect people to the land and to one another, and support vibrant communities (36 CFR 219.19).

Mean annual increment of growth and culmination of mean annual increment of growth

The mean annual increment of growth is the total increment of increase of volume of a stand (standing crop plus thinnings) up to a given age divided by that age. The culmination of mean annual increment of growth is the age in the growth cycle of an even-aged stand at which the average annual rate of increase of volume is at a maximum. In land management plans, the mean annual increment of growth is expressed in cubic measure and is based on the expected growth of stands according to intensities and utilization guidelines in the plan (36 CFR 219.19).

Regeneration harvest

Any removal of trees intended to assist in the regeneration of a new age class or to make regeneration of a new age class possible. Regeneration harvest may be through even-aged or uneven-aged methods.

Restoration

The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. Ecological restoration focuses on reestablishing the composition, structure, pattern, and ecological processes necessary to facilitate terrestrial and aquatic ecosystems sustainability, resilience, and health under current and future conditions. (36 CFR 219.19).

Salvage harvest

The removal of dead trees or trees damaged or dying because of injurious agents, other than competition, that recovers economic value that would otherwise be lost, or because the removal of the dead or damaged trees contributes to achieving plan desired conditions or objectives.

Timber harvest

The removal of trees for wood fiber use and other multiple use purposes (36 CFR 219.19).

Timber production

The purposeful growing, tending, harvesting, and regeneration of regulated crops of trees to be cut into logs, bolts, or other round sections for industrial or consumer use (36 CFR 219.19).



United States Department of Agriculture

Species of Conservation Concern Assessment

Tongass National Forest Plan Revision



Forest
Service

Alaska
Region

Tongass
National Forest

June 2025

Cover Photo: Alaska Ricasolia lichen, a species under review as a Species of Conservation Concern for the Tongass National Forest. Photograph by Karen Dillman

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Species of Conservation Concern Assessment

Tongass National Forest Plan Revision

Forest Service, Alaska Region

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Introduction

The 2012 Planning Rule requires the identification of Species of Conservation Concern (SCC), which are at-risk species “other than federally recognized threatened, endangered, proposed, or candidate species, that are native and known to occur in the plan area and for which the Regional Forester has determined that the best available scientific information indicates substantial concern about the species’ capability to persist over the long- term in the plan area” (36 CFR 219.9 (c)). Forest Service planning directives (FSH 1909.12_12.52) state that the responsible official (forest supervisor) will coordinate with the regional forester to identify potential SCC “relevant to the plan area and the planning process.” In identifying SCC, the regional forester must consider information provided by the public, Tribes and cooperating agencies. The Forest Service is required to provide opportunities for public participation and feedback. The SCC list is developed for forest planning purposes; it does not confer special regulatory status on any species beyond existing state and federal statutes.

Scope and Scale of Assessment

The identification of Species of Conservation Concern is a multi-step process that may occur concurrently with the Land Management Plan Revision process. As such, the SCC identification process runs independently from, and informs and relates to, the Land Management Plan Revision process. This assessment provides information on the SCC policy, and an overview of the general steps taken for including SCC in the plan revision and the SCC identification process. More detailed information on the [process of identifying SCC](#) can be found on the Tongass National Forest Plan Revision webpage. Included in this assessment is the ***Species Under Review List*** (see Glossary), which includes at-risk species that are known to occur on- and are native to- the Tongass National Forest (Tongass) and are not listed under the Endangered Species Act (ESA). For these species, we show our preliminary findings if they have been evaluated, but note that not all species have yet been evaluated. Further analysis is underway to determine whether there is substantial concern for the long-term persistence of these species on the Tongass. We also present the ***List of Species to Consider***, which is the list of species that were considered but were not brought forward for further evaluation because they were either not native or not known to occur on the Tongass, were ESA-listed, did not meet the initial criteria for inclusion (e.g., NatureServe ranking; see below) or local concern was not substantiated.

Because we are still in the evaluation period for the ***Species Under Review List***, and our findings are preliminary (i.e., evaluations are still being reviewed), we are not yet sharing the supporting documentation for the determinations. Once we complete the evaluation process, the ***Proposed SCC List*** will be shared with all the supporting documentation (including species-specific evaluations) for all the species that were in the ***Species Under Review List***. The public, cooperating agencies and the Tribes will have the opportunity to review and comment on the ***Proposed SCC List*** and supporting documents.

Resource Importance

The purpose of identifying SCC is to aid in developing land management plan components that maintain the diversity of plant and animal communities and provide for the persistence of native species in the plan area (36 CFR 219.9). Most species will be maintained by plan components in the revised plan (through desired conditions, objectives, standards, guidelines, and suitability of lands) that maintain broad level ecosystem integrity and diversity. Some species may require additional species-specific plan components to maintain or recover populations, or where the species requires unique and specific ecological conditions that are best addressed with more focused plan components (FSH 1909.12_23.11). Plan

components will be developed that meet the needs of each SCC, whether they are ecosystem-level or species specific, during the plan development stage.

The 2012 Planning Rule provides direction to maintain biodiversity and the persistence of native species through an emphasis on ecological integrity. The 2012 Planning Rule recognizes that it may not be possible to maintain a viable population of some at-risk species within the plan area due to circumstances beyond the authority of the Forest Service or due to limitations in the inherent capability of the land. Examples might be migratory species where viability is primarily affected in other locations, temperature-sensitive species affected by warming temperatures, or where the plan area has limited ecological capacity to provide sufficient habitat to sustain the species.

Managing ecosystems to sustain biodiversity relies on maintaining the appropriate mix of habitat quantity, quality, and distribution across the landscape. Landscapes are diverse, highly complex systems influenced by many factors, including the interaction of soils, aspect, elevation, climate, disturbance events, and humans. Together, these influences have shaped vegetative composition and distribution that have, in turn, influenced the biodiversity in the region. All plant and animal species contribute to the biological diversity and ecosystem integrity of an ecosystem.

The Tongass National Forest is the largest national forest administered by the USDA Forest Service, covering almost 17 million acres. The Forest is primarily temperate rainforest which encompasses islands of the Alexander Archipelago, together with continental lands with coastal mountains, fjords, and glaciers. Along with Canada's Great Bear Rainforest, the Tongass is considered the largest intact temperate rainforest on the planet and provides many ecosystem services, including carbon storage and provision of habitat for diverse species (DellaSala et al. 2022). The Tongass is considered a biologically rich area, with generally high productivity essential to maintaining its ecosystem services (Oliver et al. 2015). It is home to many species of flora, fauna, and fungi, some of which are unique to Southeast Alaska.

Biodiversity, which includes both variation within the same species and the diversity of species across landscapes, is crucial for the longer-term resilience of ecosystems' function and the services they provide (Oliver et al. 2015). The mission of the USDA Forest Service is to "sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations" (<https://www.fs.usda.gov/about-agency/meet-forest-service>). In the face of anthropogenic disturbances and changes in global climate, sustainability requires maintenance of resilient ecosystems and their function; that is, ecosystems that can resist or recover rapidly from environmental perturbations (Oliver et al. 2015).

Biodiversity can substantially influence local communities' social and economic sustainability. For example, Alaska resident and migratory bird species generated approximately \$378 million in overall economic output through bird watching in 2016 alone and were enjoyed by more than 300,000 people, supporting approximately 4,000 jobs (Schwoerer and Dawson 2022). Hunting and fishing are traditional recreational, subsistence, and customary and traditional uses within the Tongass. Species being evaluated for identification as SCC include huntable big game such as mountain goats (*Oreamnos americanus*), fish such as Eulachon (*Thaleichthys pacificus*), which is used for subsistence, and watchable wildlife (e.g., bird watching). Moreover, some potential botanical SCCs (vascular plants, bryophytes, lichen, and fungi) may be used as food, medicine, and weaving material. In addition, potential SCC may provide vital ecosystem services such as pollination, water filtration, insect pest control, host plants for other species, indicators of air quality, nutrient cycling, and ecosystem engineering to provide habitat for different species, thus contributing to overall biodiversity.

Current Management Direction

The National Forest Management Act (NFMA) of 1976 requires the Forest Service to “provide for the diversity of plant and animal communities.” The 1982 planning rule implemented this aspect of NFMA by requiring the Agency to manage habitat for viable populations of native and select non-native species and through the development of management indicator species. The Forest Sensitive Species (FSS) policy embodies part of the Agency’s commitment to managing habitat for viable populations as directed in the 1982 planning rule. The current 1997 Tongass National Forest Land Management Plan, as amended, operates uses Forest Sensitive Species, which are “those plant and animal species identified by a Regional Forester for which population viability is of concern” (FSM 2670.22). There are currently 23 Forest Sensitive Species for the Tongass National Forest, with 18 plant and 5 terrestrial wildlife species.

The 2012 planning rule implements the NFMA requirement to “provide for the diversity of plant and animal communities” using a different approach. Under the new Forest Plan, the Forest Sensitive Species policy will be replaced by the Species of Conservation Concern (SCC) policy. Both SCC and Regional Forester FSS were established to maintain *viable populations* of species on National Forest System lands. As defined in the 2012 Planning Rule, Species of Conservation Concern must be native to and known to occur in the plan area, whereas for sensitive species, if suitable habitat is present, habitat is managed for the species regardless of whether the occurrence is confirmed, and the species does not have to be native (i.e., it can be a desirable introduced species, such as a sport fish).

Moreover, scientific uncertainty is evaluated differently for determining SCC than for sensitive species. Insufficient scientific information does not exclude species from consideration as Forest Sensitive Species (i.e., some species are included with little information by following the precautionary principle). However, “If there is insufficient scientific information available to conclude there is a substantial concern about a species’ capability to persist in the plan area over the long-term that species cannot be identified as a species of conservation concern,” (FSH 1902.12.52c).

In addition, the SCC process acknowledges the limitations and gaps in data, which are documented and considered in decision-making. For example, the 2012 Planning Rule incorporates adaptive management principles, where plans include monitoring strategies to track changes in species populations, habitats and threats. As such, documented gaps in data can inform monitoring strategies and priorities, and as new information becomes available, plans can be updated to reflect improved understanding or changing conditions. Another way in which the SCC process addresses uncertainty is by engaging in collaboration and obtaining expert input. Subject matter experts assess the risks of species and stakeholders, and the public may provide additional data or highlight uncertainties not previously considered. Further, the list of SCC is not static and can be changed outside of the Plan Revision process as new information becomes available or species’ status changes.

Although there are similarities in the goals for identifying Forest Sensitive Species and Species of Conservation Concern, the processes and purpose for identifying the species lists differ. The Forest Sensitive Species is designed to proactively manage species to prevent them from becoming federally listed whereas the SCC list focuses on maintaining the ecological integrity of forest plan area by identifying species that require specific management considerations during forest planning. Both these categories were established with the goal for species to remain viable on National Forest System lands. However, when a final decision is signed, and the revised plan is in effect, the Regional Forester’s Sensitive Species list will no longer apply.

General SCC Steps for Plan Revision

The planning process can be divided into the following phases to describe the SCC identification process: pre-assessment, assessment, plan content development, and NEPA analysis (Figure 1).

The pre-assessment phase included the organization and preparation for revising the land management plan before the first official step, the assessment process. The list of species to consider was developed during this phase using an information-gathering and screening process. The initial search for the best available scientific information (BASI), application of BASI during screening, and preliminary assessments of the species occurred during this pre-assessment because of the significant amount of time needed to gather the information.

Currently, we are in the assessment phase. Assessments are developed to “rapidly evaluate existing information about relevant ecological, economic, and social conditions, trends, and sustainability and their relationship to the land management plan within the context of the broader landscape” (36 CFR 219.5(a)(1)). The ***Species to Consider List*** and the ***Species Under Review List*** were provided during the assessment process (in the draft assessment), and the public had an opportunity to give feedback on the initial lists. It should be noted that the lists provided are not static and contain the set of species considered or under review up to the release of this assessment.

After the assessment phase, a ‘need to change’ is developed based on the assessment and the ***Potential SCC List***. The need to change generally involves comparing the needs of species and any groups identified on the ***Proposed SCC List*** to existing plan content to determine if the existing plan content provides those needs (i.e., using a crosswalk between the species needs and draft plan contents). Any gaps identified are the basis for developing new draft plan components, including species-specific ones, that will provide for the ecological conditions the SCC needs to persist.

Next, draft plan content is developed while engaging with tribes, other governments, and the public. The draft plan will address identified needs to change. These draft Plan Components will serve as the ‘proposed action’ for the following environmental analysis phase.

Once the plan content is developed, environmental analysis of the draft plan will be conducted, including an evaluation of the long-term persistence of SCC, which may vary by plan alternatives. It is important to note that the potential SCC list does not vary by alternative; however, the plan components may vary by alternative. The long-term persistence of SCC is evaluated based on the predicted effects of the draft plan components and documented in the EIS.

Two objection processes apply to SCC identification: The ***Regional Forester’s SCC List*** goes through a separate objection process which generally occurs concurrently with the objection process for the FEIS and the forest plan. Finally, after resolving any issues raised during the objection periods, the Regional Forester identifies the SCC for the Tongass concurrent with the Forest Supervisor’s signing of the final forest plan decision. This concludes the plan revision process.

Phases of SCC Identification

(Species of Conservation Concern)

SPECIES CONSIDERED

FSH 1909.12, chap. 10 sec. 12.52d – Nature Serve Ranks G(T)1,2, or 3, or S1 or 2; current RFSS; ESA de-listed or 90-day findings; State or Tribal T&E or Tier 1 SWAP; current SCC or RFSS or BLM sensitive on adjoining lands

SPECIES UNDER REVIEW

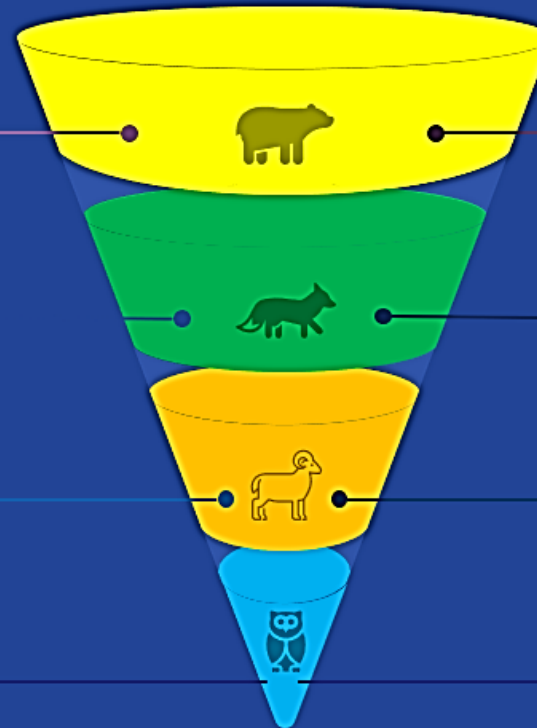
FSH 1909.12, chap. 10, sec. 12.52c.1 – Species considered (above) and confirmed to be native and known to occur from list above.

PROPOSED SCC

FSH 1909.12, chap. 10, sec. 12.52c.2 – BASI about the species indicates substantial concern about the species' capability to persist over the long term in the plan area.

REGIONAL FORESTER SCC

36 CFR 219.9(c) & FSH 1909.12, chap. 20, sec. 21.22a – Regional Forester (RF) reviews rationale and documentation provided by the Responsible Official (MPSG and Unit) and applies further assessment as deemed necessary by RF.



PRE-ASSESSMENT

Internal processing by PSG with Unit check-ins to review results and provide additional data and information. Species overviews with BASI drafted for species determined to be native and known to occur.

ASSESSMENT

Unit and Regional Office review of the Potential SCC list for release with the Draft Assessment. Tribal, partner and public engagement. Species overviews and BASI references provided with Assessment.

PROPOSED ACTION

Substantial Concern determinations finalized by Regional Forester incorporating Assessment inputs and other RF considerations. Species Overviews and Rationales finalized for Proposed Action and Draft Plan.

DRAFT & FINAL PLAN

Plan component crosswalk for SCC viability. Draft Plan includes the Proposed SCC list for the second and final public engagement. Final Plan includes finalized SCC

Figure 1. Multiple planning phases for Species of Conservation Concern.

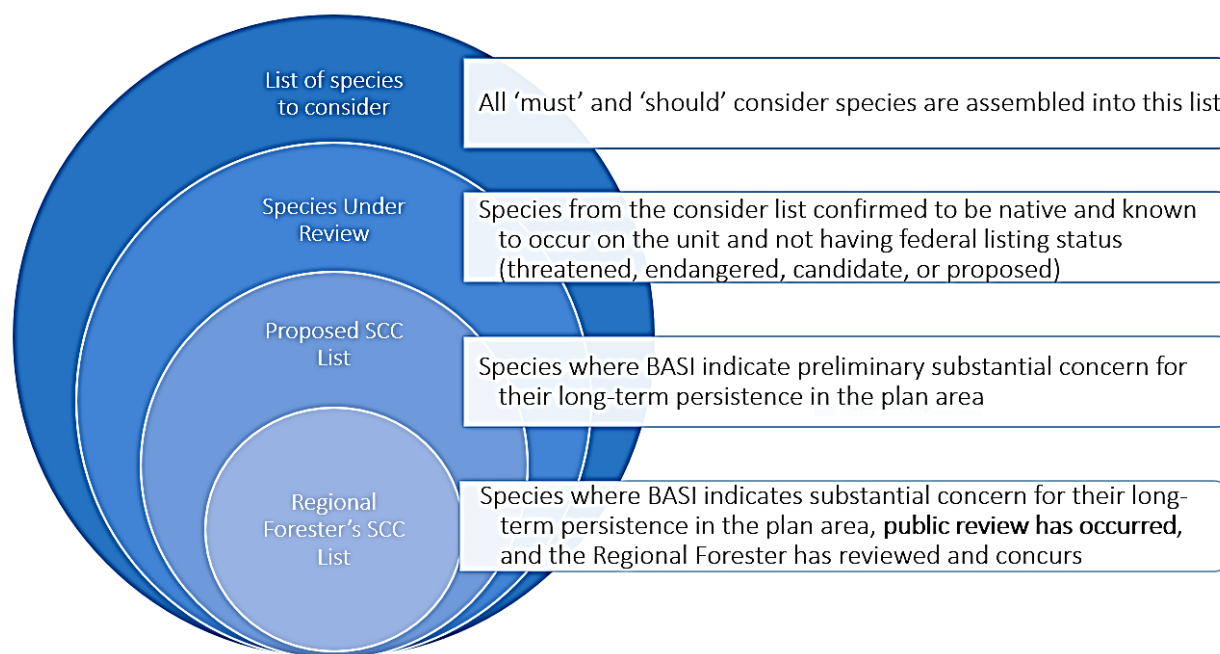


Figure 2. Major steps undertaken to establish a list of proposed Species of Conservation Concern.

Methods for Identifying SCC

To fulfill the requirements of the 2012 Planning Rule and transition from the Forest Sensitive Species policy to SCC, Forest Service personnel developed a [process paper](#) that describes the identification of SCC for the Tongass Forest Plan Revision (USDA 2025). The process paper details the general steps to identify SCC by phase of plan revision and the methods that are being used, which are based on the Forest Service Land Management Planning Manual and Handbook and the Practitioner's Reference for Applying the 2012 Planning Rule to Conserve Species (Hayward et al. 2016). Figure 2 summarizes the process from assembling the **List of Species to Consider** to the identification of the **Regional Forester's SCC List**.

The initial **List of Species to Consider** as potential SCC includes both 'must' and 'should' consider categories as described in Forest Service Handbook direction (FSH 1909.12 Ch. 10 §12.52d), including:

- Current Regional Forester Sensitive Species identified for Region 10,
- SCC for the Chugach National Forest in Alaska,
- Species with NatureServe global ranks of G/T1 through G/T3 or state ranks of S1 or S2.
- Other species considered include species with NatureServe state rank S3 as well as species identified as 'rare' by the Alaska Natural Heritage Program and for which the best available scientific information (BASI) indicates there is local conservation concern about the species' capability to persist over the long-term in the plan area. We also considered species confirmed to be endemic to the Tongass. In addition, we considered species brought to our attention as having local conservation concerns in the plan area through public comments.

Following the process outlined in our process paper for the identification of SCC (USDA 2025; summarized In Figure 3), we are currently applying the evaluation criteria to the species in the **Species**

Under Review List in order to identify species for which BASI indicates substantial concern about the species' capability to persist over the long-term in the plan area. These evaluations are done at the appropriate scale, based on the biology and ecology of the species (e.g. island scale for island endemics). Once the evaluation process is complete, and the **Proposed SCC List** has been assembled, we will release the list and the supporting information for each species for public review and comments.

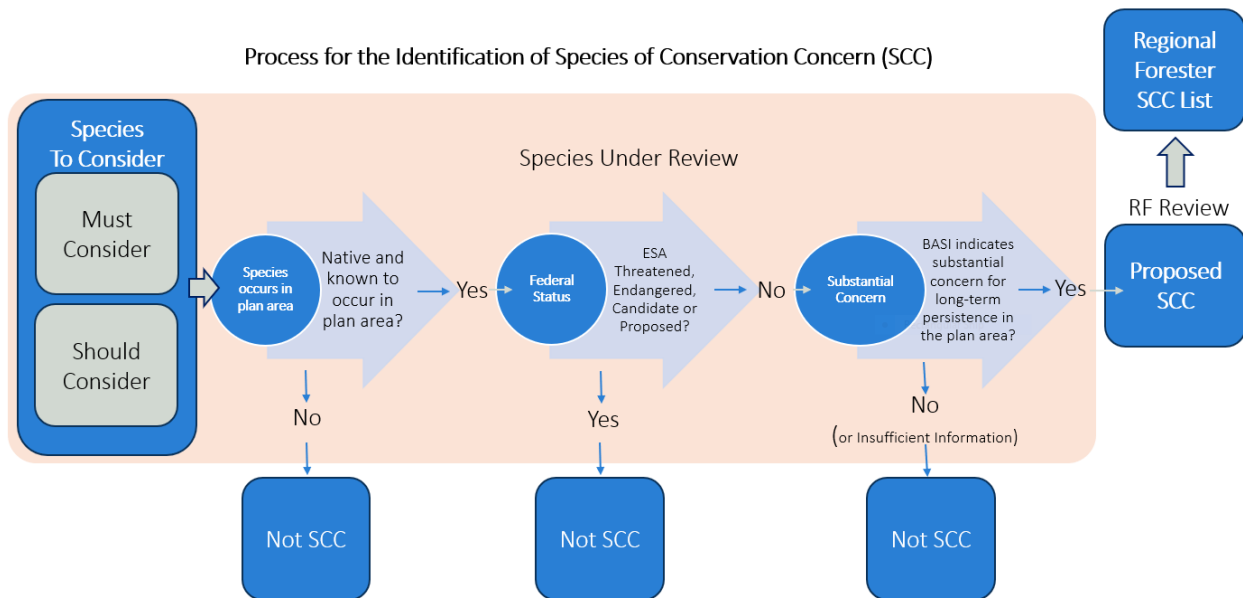


Figure 3. Simplified graphic summary of the process used to identify species of conservation concern (SCC). RF Review indicates review of the Proposed SCC List by the Regional Forester for approval.

It should be noted that species ranked as vulnerable, imperiled or critically imperiled in NatureServe throughout their range (or part of their range) are not necessarily so in the planning unit. For example, threats and stressors found elsewhere might be absent in the planning unit and all the necessary conditions for the species' persistence might be available so that there is no concern over the long-term persistence of the species in the planning area. This is addressed in the species evaluation.

Public Engagement

The primary input requested during the draft assessment stage was knowledge of any species that should have been added or removed from consideration, along with supporting scientific information or traditional ecological knowledge (e.g., date of last observation, threats observed, condition and size of the occurrence, habitat parameters associated with the species). We received approximately 42 comments from different individuals or organizations on the SCC draft assessment and the SCC lists. Through the information provided in the comments, we identified additional species for consideration, some of which were added to the lists, and also identified species that needed to be removed from the lists because they are candidates under the Endangered Species Act. We also received and are in the process of reviewing species-specific literature, which may be added to the species evaluations, if appropriate.

The updated list of **Species Under Review** and preliminary findings are included in Tables 1-3. Species that were in the updated **Species to Consider List** and that were not brought forward for review are listed in Appendix A with the preliminary findings for the determination.

The agency will publicly release the ***Proposed SCC List*** when it is completed, and at that time will solicit any additional best available scientific information and traditional ecological knowledge that would be valuable for evaluating a species for identification as an SCC. Public input and information received at that stage will be reviewed and will be incorporated into species evaluations and the lists as appropriate.

Potential Species of Conservation Concern

Following the procedures described above for the pre-assessment and assessment phases, and as part of the screening efforts to identify SCC, the Forest compiled a total of 502 species into the ***List of Species to Consider***. Of these, 389 are botanical species (including vascular and non-vascular plants, lichen, and fungi), 79 are terrestrial wildlife species (animals and invertebrates), and 34 are aquatic species (fish and invertebrates).

Through a screening process, the list of ***Species Under Review***, species that are native and known to occur on the Tongass and that are not listed (threatened, endangered) or considered (proposed or candidate) under the Endangered Species Act (ESA), was developed. The list of ***Species Under Review*** includes 227 species, of which 169 are botanical species, 49 are terrestrial wildlife species, and 9 are aquatic species. Tables 1 through 3 present the species that belong to the ***Species Under Review List*** divided by taxa. Currently, we have produced preliminary Evaluations for 41% of the species in the ***Species Under Review List***. The remaining 59% are currently being assessed or evaluated.

In the following sections, details on the species encompassing the ***Species Under Review List*** are discussed by taxa, their status, and preliminary findings if applicable. The list of species that were screened out because they were either not native or not known to occur on the Tongass or they are listed or considered under the ESA can be found in Appendix A.

Botanical Species

Of the 389 botanical species on the ***List of Species to Consider***, a total of 169 botanical species (43%) met the initial criteria for consideration as SCC. The rest of the species (57%) were not known to occur or were determined not to be native to the Tongass. Therefore, 169 botanical species were carried forward as part of the list of ***Species Under Review*** (Table 1). Twenty-two percent of the botanical species have been evaluated, and the remaining 78% are under initial review. For the species evaluated (38), preliminary findings indicate that there is lack of basic scientific information to make a determination for 55% of the species, for 8%, threats do not appear substantial, and 37% have threats that may be substantial, and thus, may be recommended as SCC after further evaluation.

Terrestrial wildlife species

A total of 79 terrestrial wildlife species have been assessed on the ***List of Species to Consider***, of which 37% were not carried forward into the ***Species Under Review List*** because they either did not meet the NatureServe ranking or local concern criteria, were not native and were not known to occur in the plan area, or were ESA-listed (Appendix A). The remaining 49 species made it into the ***Species Under Review List*** (Table 2). Of these, 27% are under initial review, and 73% (36) have preliminary evaluations. Preliminary determinations of the species evaluated to date indicate that 67% lack basic information, threats do not appear to be substantial for 17% of the species, and 16% appear to have threats that are substantial which could affect their long-term persistence in the forest. Therefore, the latter may be recommended as SCC after further evaluation.

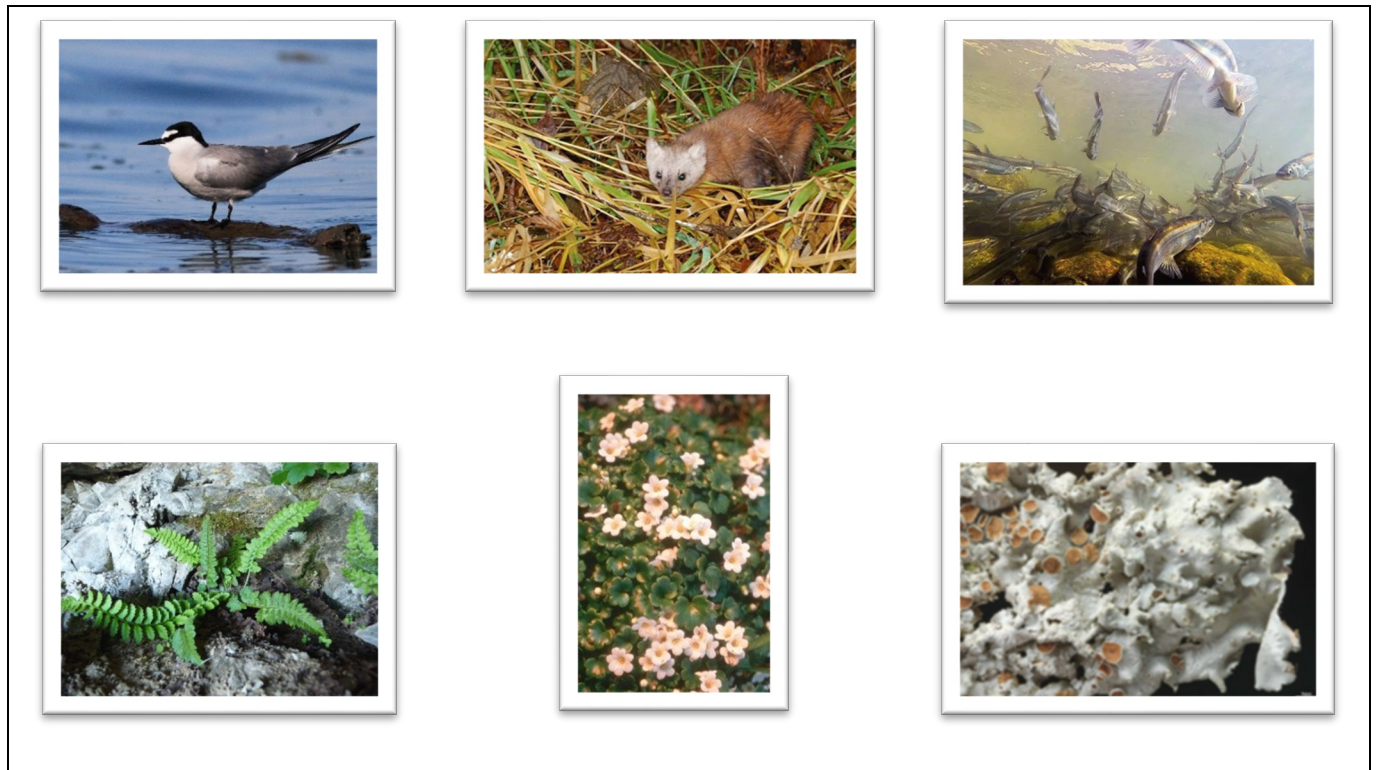


Figure 4. Selection of species under review as Species of Conservation Concern (SCC) on the Tongass National Forest. Top row left to right: Aleutian Tern (*Onychoprion aleuticus*; photo by Jay McGowan), Pacific marten (*Martes caurina*; photo by the Alaska Department of Fish and Game), Eulachon (*Thaleichthys pacificus*; photo by NOAA Fisheries). Bottom row left to right: Kruckeberg's holly fern (*Polystichum kruckebergii*; photo by Dana York), Unalaska mist-maid (*Romanzoffia unalaschensis*; photo by USDA), and Alaska Ricasolia lichen (*Ricasolia amplissima*; photo by T. Wheeler).

Aquatic wildlife species

Nine of the 34 aquatic species on the **List of Species to Consider** have been included in the list of **Species Under Review** (Table 3). Most of the aquatic species (72%) that were screened out did not meet the vulnerability criteria (NatureServe ranks) to be evaluated as SCC and local concern was not raised; some (24%) were determined not to occur or be native to the Tongass National Forest, and one was found to be ESA-listed as a candidate species (Chinook salmon, *Onchorhynchus tshawytscha*; see Appendix A). We have preliminary evaluated eight of the nine species that were brought forward. Of these, 75% lack basic scientific information, threats do not appear substantial for 25%, and, so far, no aquatic species has been found that may have substantial threats which can compromise its long-term persistence on the Tongass.

Status and Trends

Southeast Alaska extends approximately 500 miles northwest from south of Metlakatla to Yakutat Bay. Of the 23 million acres it covers, almost 17 million acres are within the Tongass National Forest (Smith 2016). The Alexander Archipelago, made up of over 5,000 islands, dominates the region, and the shoreline is >18,000 miles long, accounting for about 20% of the entire United States coastline (Smith 2016). The Tongass, and Southeast Alaska in general, is naturally fragmented by islands and steep glacial terrain with glacial fjords and major river systems dissecting the mountainous mainland region (Smith 2016). Moreover, 10,000 years ago, many regions in North America were covered with massive continental glaciers, but some areas near the coast of southeast Alaska remained ice-free, acting as refugia

for the organisms that survived the glacial period (Smith 2016). These factors, together with island biogeography and mainland influences (e.g., icefields and steep topography), have resulted in the biological variation we observe today, with many islands having distinct climatic, botanical, and faunal differences (Schoen and Dovichin 2007; see the [Terrestrial Ecosystems](#) assessment). This means the Tongass also has unique wildlife diversity, which is characterized by many endemic subspecies and genetic lineages.

Human activities have influenced some Tongass ecosystems, primarily through logging and road construction. These activities have led to habitat fragmentation across portions of roughly 4% of the Tongass where logging has occurred (see the [Timber Resources](#) assessment). These impacts include increased human access and subsequent impacts on species in some areas. From the 1950s through the 1990s, logging on the Tongass targeted old-growth forests, which are crucial for maintaining biodiversity with many dependent species. However, logging on the Tongass has been greatly reduced since the late 1990s (see the [Timber Resources](#) assessment), partially due to the need to balance logging practices and the expectation of a conservation framework.

The mode and intensity of human activities on the Tongass are mainly driven by land management policy and activities. Throughout the years, there have been policy changes in how the Tongass is managed which have had different effects on biodiversity. The current Forest Plan emphasizes a transition from primarily old-growth to primarily young-growth timber harvest. The information gathered in the species evaluations of the species in the *Proposed SCC List* will inform future policies and resource management under the revised Forest Plan, particularly for non-ESA listed at-risk species and their habitats.

Drivers and Stressors

[The Drivers, Stressors, and Climate Change](#) assessment discusses the dominant ecological processes and disturbance regimes (drivers) and the factors that may directly or indirectly degrade or impair ecological integrity (stressors), including increasing temperatures and changing precipitation on the Tongass. Moreover, the Climate Change Vulnerability Assessment for the Tongass National Forest (Baer et al. DRAFT) provides valuable information about the effect on wildlife species' habitats, wildlife species, biological processes, and species distribution. These sections, together with the scientific literature assessed during species evaluations, will provide insights into the common drivers and stressors for species identified as SCC.

Based on literature reviewed thus far, threats faced by many of these species include changes in weather and climate, which can lead to habitat loss or encroachment (BAER et al. DRAFT), physiological challenges (e.g., thermoregulation), and altered phenology (which can affect pollination, seed dispersal and resource availability) (Bennetsen et al. DRAFT). In addition, some of the species being considered as SCC have low population numbers and abundances or have shown a declining trend, which makes them vulnerable to inbreeding depression and stochastic events. Moreover, direct anthropogenic disturbances that include current and past logging, harvesting (e.g., hunting, gathering), and ground disturbances, may affect many of these species. Restricted habitats, which can result from the species being a specialist in a particular habitat or due to low abundances or patch sizes of certain habitats, can negatively affect population connectivity and population growth and further the species' vulnerability to stochastic events. Also, species interactions such as symbiotic relationships (i.e., absence of an interacting partner, e.g., mycorrhizal fungi associations with plants) or antagonistic relationships (e.g., pathogens or competition and displacement by invasive species) may also negatively affect the species identified as potential SCC. Finally, management by the Tongass National Forest may not be sufficient to maintain viable population for some species on the Tongass, highlighting the need for a more comprehensive approach to conservation planning (Smith and Flaherty 2023).

Evaluations of the species in the *Species Under Review List* identify and document the drivers and stressors that may raise concern over the long-term persistence of species in the plan area. This, in turn, may support the grouping of species by common drivers and stressors, which would aid in designing plan components that promote effective management.

Information Needs

One of the Forest Service directives is to “document information gaps relevant to at-risk species that may be filled in through inventories, plan monitoring program or research” in the assessment report (FSH 1909.12_10, 12.53). Overall, a high proportion (61%) of the species in the list of *Species Under Review* reviewed thus far (84 spp. in total) lack basic scientific information to determine if there is substantial concern over their long-term persistence in the plan area, or if the species are secure. For example, Droghini et al. (2022), found we lack basic information on the demographics, abundances, and population trends for most small mammals within the Tongass. We also lack information on their habitat or ecological requirements, habitat trends, and species' response to increased temperatures and changing precipitation (Droghini et al. 2022). By documenting information gaps in our species evaluations, we will help inform and prioritize targeted inventories, plan monitoring, or research needs.

Current Management Practices

ADF&G manages fish and wildlife populations throughout Alaska including on the federal public lands of the Tongass National Forest, whereas the Federal Subsistence Board administers the subsistence taking and uses of fish and wildlife on public lands. Under ANILCA, the taking of fish and wildlife on federal public lands, such as the Tongass National Forest, for non-subsistence uses is generally governed by state law unless such state law is preempted by federal law (see [Subsistence and Other Non-Commercial Harvest](#) assessment for more detail). As such, in cooperation with ADF&G and the Federal Subsistence Board, the Forest Service manages fish and wildlife and their habitats on the Tongass National Forest.

Species and habitats are covered by many different parts of the existing Forest Plan. Plan components include protections for all types of ecosystems, general wildlife, and some specific species such as marine mammals, waterfowl and raptors, wolf, deer, and mountain goats. The Tongass Old Growth Conservation Strategy is the cornerstone for wildlife management on the Tongass, because many species depend either directly or indirectly on old growth habitat. The Conservation Strategy was developed in the 1990s and adopted as a part of the 1997 Forest Plan, to ensure continued existence of viable populations of old-growth dependent and old-growth associated wildlife, well-distributed across the Tongass. The Strategy includes a system of large, medium, and small old-growth reserves, a network of old-growth corridors connecting the reserves, and a series of standards and guidelines providing additional protection for species and species groups with conservation needs not fully addressed by the reserve system alone. Recently, the Tongass Old-Growth Conservation Strategy was re-assessed and determined to be consistent with the 2012 Planning Rule. The review also suggested that it is still relevant and necessary, albeit with modifications, to provide a solid basis for the conservation of old-growth dependent species (USDA 2023).

Key Takeaways

- The Forest Service must maintain ecological conditions to support viable populations of native animal and botanical species and implement practices to ensure that species do not become threatened or endangered because of agency actions. Potential SCCs include species providing important ecological services, thus influencing the region's ecological, social, and economic sustainability.
- Maintenance of biodiversity and the persistence of native species on the Tongass National Forest are essential to maintaining the ecosystem services it provides.
- All species are contributors to biological diversity and ecosystem integrity as components of “the diversity of plant and animal communities,” and the revised plan must address the “persistence of most native species in the planning area” (36 CFR 219.9).
- Potential Species of Conservation Concern may provide vital ecosystem services such as pollination, water filtration, insect pest control, host plants for other species, and ecosystem engineering to provide habitat for other species, thus contributing to overall biodiversity.
- A total of 502 species were screened as part of the Species to Consider List, including 389 botanical species (inclusive of vascular plants, bryophytes, fungi, and lichen), 79 terrestrial wildlife species, and 34 aquatic species.
- A total of 227 species were identified as part of the Species Under Review List, composed of species that are native and known to occur on the Tongass and that are not ESA-listed. Of those, 169 are botanical species, 49 are terrestrial wildlife species, and 9 are aquatic species.
- A large proportion of species reviewed so far (61%) lack sufficient information to determine whether there is substantial concern over their long-term persistence on the Tongass or if they are secure.
- Preliminary findings indicate that common stressors and threats include change in climate trends, habitat loss and degradation, harvesting, and air pollution.

Species Under Review by Taxa Groups

Table 1. Species under review: Botanical species of the Tongass National Forest. Botanical species include bryophytes, fungi, lichens, and vascular plants. The list is organized by taxa and species in alphabetical order. Species that have been evaluated, and for which threats may be substantial and raise potential concern about their long-term persistence in the plan area, are in bold. These species will be evaluated further.

Sub-taxa	Species	Common name	Preliminary findings
Bryophytes	<i>Acrobolbus ciliatus</i>	A liverwort	Under initial review.
Bryophytes	<i>Andreaea sinuosa</i>	A rock moss	Under initial review.
Bryophytes	<i>Apotreubia nana</i>	A liverwort	Under initial review.
Bryophytes	<i>Atrichum flavisetum</i>	A smoothcap moss	Under initial review.
Bryophytes	<i>Blepharostoma arachnoideum</i>	A liverwort	Under initial review.
Bryophytes	<i>Campylopus gracilis</i>	Schwarz's Swan-neck Moss	Under initial review.
Bryophytes	<i>Cololejeunea macounii</i>	A liverwort	Under initial review.
Bryophytes	<i>Crossocalyx hellerianus</i>	Heller's Notchwort	Under initial review.
Bryophytes	<i>Didymodon maschalogenae</i>	Michigan Beard Moss	Under initial review.
Bryophytes	<i>Didymodon maximus</i>	Big Beard Moss	Under initial review.
Bryophytes	<i>Gymnomitrium commutatum</i>	A liverwort	Under initial review.
Bryophytes	<i>Hookeria acutifolia</i>	Sharpleaf HookeriA moss	Under initial review.
Bryophytes	<i>Hypopterygium flavolimbatum</i>	A moss	Under initial review.
Bryophytes	<i>Lepidozia sandwicensis</i>	A fingerwort	Under initial review.
Bryophytes	<i>Mastigophora woodsii</i>	A liverwort	Under initial review.
Bryophytes	<i>Mielichhoferia elongata</i>	Mielichhofer's Copper Moss	Under initial review.
Bryophytes	<i>Riccia fluitans</i>	Floating Crystalwort	Under initial review.
Bryophytes	<i>Scapania carinthiaca</i>	Carinthian Earwort	Under initial review.
Bryophytes	<i>Sphenolobopsis pearsonii</i>	Horsehair Threadwort	Under initial review.
Bryophytes	<i>Tetralophozia filiformis</i>	A pawwort	Under initial review.
Bryophytes	<i>Tetradontium repandum</i>	Small Four-toothed Moss	Under initial review.
Fungi	<i>Ascocoryne turficola</i>	A fungus	Under initial review.
Fungi	<i>Boletopsis grisea</i>	A fungus	Under initial review.
Fungi	<i>Fomitopsis officinalis</i>	Quinine Conk	Under initial review.
Fungi	<i>Hydnellum cyanopodium</i>	Bleeding Blue Tooth	Under initial review.

Sub-taxa	Species	Common name	Preliminary findings
Fungi	<i>Hydnellum geogenium</i>	A fungus	Under initial review.
Fungi	<i>Hydnellum mirabile</i>	A fungus	Under initial review.
Fungi	<i>Neolbatrellus subcaeruleoporus</i>	A fungus	Under initial review.
Fungi	<i>Polyozellus atrolazulinus</i>	A fungus	Under initial review.
Fungi	<i>Polyozellus multiplex</i>	A fungus	Under initial review.
Fungi	<i>Polyozellus purpureoniger</i>	A fungus	Under initial review.
Fungi	<i>Ramaria gelatiniaurantia</i>	A fungus	Under initial review.
Fungi	<i>Stereopsis humphreyi</i>	A fungus	Under initial review.
Lichens	<i>Acroscyphus sphaerophoroides</i>	Mountain Crab Eye Lichens	Evaluated. Threats may be substantial.
Lichens	<i>Bunodophoron melanocarpum</i>	Northern Fan-coral Lichens	Under initial review.
Lichens	<i>Cladonia alaskana</i>	Alaska Cup Lichens	Under initial review.
Lichens	<i>Dendroscosticta gelida</i>	Greater Green Moon Lichens	Under initial review.
Lichens	<i>Erioderma soledatum</i>	Mouse Ears	Under initial review.
Lichens	<i>Leioderma soledatum</i>	Mouse Ears	Under initial review.
Lichens	<i>Lobaria retigera</i>	Smoker's Lung Lichens	Under initial review.
Lichens	<i>Nephroma occultum</i>	Cryptic Paw Lichens	Under initial review.
Lichens	<i>Niebla cephalota</i>	Powdery Fog Lichens	Evaluated. Threats may be substantial.
Lichens	<i>Parmotrema arnoldii</i>	Powdered Ruffle Lichens	Under initial review.
Lichens	<i>Parmotrema crinitum</i>	Salted Ruffle Lichens	Under initial review.
Lichens	<i>Peltigera gowardii</i>	Western Waterfan Lichens	Evaluated. Threats may be substantial.
Lichens	<i>Physciella chloantha</i>	Cryptic Rosette Lichens	Under initial review.
Lichens	<i>Pilophorus cereolus</i>	Powdered Matchstick Lichens	Under initial review.
Lichens	<i>Pseudocyphellaria perpetua</i>	Gilded Specklebelly Lichens	Under initial review.
Lichens	<i>Pseudocyphellaria rainierensis</i>	Oldgrowth Specklebelly Lichens	Under initial review.
Lichens	<i>Ramalina obtusata</i>	Hooded Ribbon Lichens	Under initial review.
Lichens	<i>Ramalina subleptocarpa</i>	Slit-rimmed RamalinA lichen	Under initial review.
Lichens	<i>Ricasolia amplissima sheiyi</i>	A lichen	Evaluated. Threats may be substantial.
Lichens	<i>Xanthoria alaskana</i>	A lichen	Under initial review.
Vascular Plants	<i>Abies amabilis</i>	Pacific Silver Fir	Under initial review.
Vascular Plants	<i>Agoseris aurantiaca</i> var. <i>aurantiaca</i>	Orange Agoseris	Under initial review.
Vascular Plants	<i>Agoseris glauca</i>	Prairie Agoseris	Under initial review.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Ambrosia chamissonis</i>	Silver Bursage	Under initial review.
Vascular Plants	<i>Androsace chamaejasme lehmanniana</i>	Lehmann's Fairy-candelabra	Under initial review.
Vascular Plants	<i>Anemone patens</i> var. <i>multifida</i>	American Pasqueflower	Under initial review.
Vascular Plants	<i>Aquilegia flavescens</i>	Yellow Columbine	Under initial review.
Vascular Plants	<i>Arctophila fulva</i>	Pendantgrass	Under initial review.
Vascular Plants	<i>Arnica mollis</i>	Hairy Arnica	Under initial review.
Vascular Plants	<i>Asplenium trichomanes quadrivalens</i>	Limestone Maidenhair Spleenwort	Under initial review.
Vascular Plants	<i>Astragalus robbinsii</i> var. <i>harringtonii</i>	Robbins' Milkvetch	Under initial review.
Vascular Plants	<i>Betula glandulosa</i>	Tundra Dwarf Birch	Under initial review.
Vascular Plants	<i>Boechera stricta</i>	Drummond's rockcress	Under initial review.
Vascular Plants	<i>Botrychium alaskense</i>	Alaska Moonwort	Under initial review.
Vascular Plants	<i>Botrychium pinnatum</i>	Northern Moonwort	Under initial review.
Vascular Plants	<i>Botrychium spathulatum</i>	Spoon-leaf Moonwort	Evaluated. Threats may be substantial.
Vascular Plants	<i>Botrychium tunux</i>	Moosewort	Evaluated. Threats may be substantial.
Vascular Plants	<i>Botrychium yaaxudakeit</i>	Yakutat Moonwort	Evaluated. Threats may be substantial.
Vascular Plants	<i>Brasenia schreberi</i>	Watershield	Under initial review.
Vascular Plants	<i>Callitropsis nootkaensis</i>	Alaska-cedar	Evaluated. Threats do not appear substantial.
Vascular Plants	<i>Cardamine angulata</i>	Seaside Bittercress	Evaluated. Threats do not appear substantial.
Vascular Plants	<i>Cardamine pensylvanica</i>	Pennsylvania Bittercress	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Carex bebbii</i>	Bebb's Sedge	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Carex bicolor</i>	Two-color Sedge	Under initial review.
Vascular Plants	<i>Carex crawfordii</i>	Crawford's Sedge	Under initial review.
Vascular Plants	<i>Carex echinata echinata</i>	Little Prickly Sedge	Under initial review.
Vascular Plants	<i>Carex interior</i>	Inland Sedge	Under initial review.
Vascular Plants	<i>Carex lasiocarpa</i>	Slender Sedge	Under initial review.
Vascular Plants	<i>Carex leptalea</i>	Bristly-stalked Sedge	Under initial review.
Vascular Plants	<i>Carex phaeocephala</i>	Mountain Hare Sedge	Under initial review.
Vascular Plants	<i>Carex preslii</i>	Presl's Sedge	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Chimaphila umbellata umbellata</i>	Pipsissewa	Under initial review.
Vascular Plants	<i>Cirsium edule</i> var. <i>macounii</i>	Macoun's Thistle	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Crassula aquatica</i>	Water Pygmyweed	Evaluated. Threats may be substantial.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Cryptogramma stelleri</i>	Fragile Rockbrake	Under initial review.
Vascular Plants	<i>Cypripedium montanum</i>	Mountain Lady's-slipper	Evaluated. Threats may be substantial.
Vascular Plants	<i>Cypripedium parviflorum var. pubescens</i>	Large Yellow Lady's-slipper	Evaluated. Threats may be substantial.
Vascular Plants	<i>Cystopteris montana</i>	Mountain Bladderfern	Under initial review.
Vascular Plants	<i>Danthonia intermedia</i>	Vasey's Oatgrass	Under initial review.
Vascular Plants	<i>Danthonia spicata</i>	Poverty Oatgrass	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Diapensia lapponica</i>	Lapland Diapensia	Under initial review.
Vascular Plants	<i>Draba incerta</i>	Yellowstone Whitlow-grass	Under initial review.
Vascular Plants	<i>Elymus violaceus</i>	Alaska Wild Rye	Under initial review.
Vascular Plants	<i>Epilobium lactiflorum</i>	White-flower Willowherb	Under initial review.
Vascular Plants	<i>Eriophorum viridicarinatum</i>	Green Keeled Cotton-grass	Under initial review.
Vascular Plants	<i>Erythranthe lewisii</i>	Lewis' Monkeyflower	Under initial review.
Vascular Plants	<i>Festuca saximontana</i>	Rocky Mountain Fescue	Under initial review.
Vascular Plants	<i>Gentiana prostrata</i>	Pygmy Gentian	Under initial review.
Vascular Plants	<i>Gentianella propinqua aleutica</i>	Aleutian Four-parted Gentian	Under initial review.
Vascular Plants	<i>Geum rossii</i>	Ross' Avens	Under initial review.
Vascular Plants	<i>Glehnia littoralis leiocarpa</i>	American Silvertop	Under initial review.
Vascular Plants	<i>Glyceria leptostachya</i>	Slim-head Mannagrass	Under initial review.
Vascular Plants	<i>Isolepis cernua</i>	Low Bulrush	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Juncus articulatus</i>	Jointed Rush	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Juncus covillei var. obtusatus</i>	Coville's Rush	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Juncus nodosus</i>	Knotted Rush	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Lactuca biennis</i>	Tall Blue Lettuce	Under initial review.
Vascular Plants	<i>Lagotis glauca</i>	Glaucous Weaselsnout	Under initial review.
Vascular Plants	<i>Ligusticum calderi</i>	Calder's Lovage	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Lobelia dortmanna</i>	Water Lobelia	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Lonicera involucrata</i>	Four-line Honeysuckle	Under initial review.
Vascular Plants	<i>Luzula comosa</i>	Pacific Woodrush	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Lysimachia thyrsiflora</i>	Water Loosestrife	Under initial review.
Vascular Plants	<i>Maianthemum racemosum amplexicaule</i>	Solomon's-plume	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Maianthemum stellatum</i>	Starflower Solomon's-plume	Under initial review.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Melica subulata</i>	Alaska Oniongrass	Under initial review.
Vascular Plants	<i>Micranthes nelsoniana</i> var. <i>carlottae</i>	Haida Gwaii Saxifrage	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Micranthes tolmiei</i>	Tolmie's Saxifrage	Under initial review.
Vascular Plants	<i>Monotropa uniflora</i>	Ghost Pipe	Under initial review.
Vascular Plants	<i>Montia chamissoi</i>	Chamisso's Miner's-lettuce	Under initial review.
Vascular Plants	<i>Myriophyllum farwellii</i>	Farwell's Water-milfoil	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Nymphaea tetragona</i>	Pygmy Water-lily	Under initial review.
Vascular Plants	<i>Oxytropis campestris</i>	Yellow Locoweed	Under initial review.
Vascular Plants	<i>Packera ogotorukensis</i>	Ogotoruk Creek Groundsel	Under initial review.
Vascular Plants	<i>Packera pauciflora</i>	Few-flower Ragwort	Under initial review.
Vascular Plants	<i>Packera paupercula</i>	Balsam Ragwort	Under initial review.
Vascular Plants	<i>Packera subnuda</i> var. <i>moresbiensis</i>	Queen Charlotte Groundsel	Under initial review.
Vascular Plants	<i>Papaver mcconnellii</i>	McConnell's Poppy	Under initial review.
Vascular Plants	<i>Papaver radiculatum alaskanum</i>	Arctic Poppy	Under initial review.
Vascular Plants	<i>Parnassia kotzebuei</i>	Kotzebue's Grass-of-Parnassus	Under initial review.
Vascular Plants	<i>Phyllodoce empetriformis</i>	Pink Mountain-heath	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Physocarpus capitatus</i>	Pacific Ninebark	Under initial review.
Vascular Plants	<i>Platanthera ephemerantha</i>	White Piperia	Evaluated. Threats do not appear substantial.
Vascular Plants	<i>Platanthera orbiculata</i>	Lesser Roundleaf Orchid	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Platanthera unalasensis</i>	Alaska Rein Orchid	Evaluated. Threats may be substantial.
Vascular Plants	<i>Polygonum minimum</i>	Leafy Dwarf Knotweed	Under initial review.
Vascular Plants	<i>Polystichum kruckebergii</i>	Kruckeberg's Swordfern	Evaluated. Threats may be substantial.
Vascular Plants	<i>Polystichum setigerum</i>	Alaska Holly Fern	Under initial review.
Vascular Plants	<i>Primula pumila</i>	Arctic Primrose	Under initial review.
Vascular Plants	<i>Ranunculus orthorhynchus</i> var. <i>orthorhynchus</i>	Straight-beak Buttercup	Under initial review.
Vascular Plants	<i>Ranunculus pacificus</i>	Pacific Buttercup	Under initial review.
Vascular Plants	<i>Ranunculus pallasii</i>	Pallas' Buttercup	Under initial review.
Vascular Plants	<i>Romanzoffia unalaschensis</i>	Alaska Mistmaiden	Evaluated. Threats may be substantial.
Vascular Plants	<i>Rorippa curvisiliqua</i>	Curve-pod Yellowcress	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Salix hookeriana</i>	Hooker's Willow	Under initial review.
Vascular Plants	<i>Salix prolixa</i>	Mackenzie's Willow	Evaluated. Lack of basic scientific information.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Saussurea americana</i>	American Saw-wort	Under initial review.
Vascular Plants	<i>Saxifraga adscendens</i>	Ascending Saxifrage	Under initial review.
Vascular Plants	<i>Saxifraga eschscholtzii</i>	Cushion Saxifrage	Under initial review.
Vascular Plants	<i>Saxifraga hyperborea</i>	Pygmy Saxifrage	Under initial review.
Vascular Plants	<i>Schoenoplectus subterminalis</i>	Water Bulrush	Under initial review.
Vascular Plants	<i>Scolochloa festucacea</i>	Sprangletop	Under initial review.
Vascular Plants	<i>Sedum oreganum</i> var. <i>oreganum</i>	Oregon Stonecrop	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Silene uralensis</i>	Apetalous Catchfly	Under initial review.
Vascular Plants	<i>Stachys mexicana</i>	Mexican Hedge-nettle	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Suaeda calceoliformis</i>	American Sea-blite	Evaluated. Lack of basic scientific information.
Vascular Plants	<i>Tanacetum bipinnatum</i>	Dwarf Tansy	Evaluated. Threats may be substantial.
Vascular Plants	<i>Thalictrum occidentale</i>	Western Meadowrue	Under initial review.
Vascular Plants	<i>Therorhodon camtschaticum</i>	Kamchatka Rhododendron	Under initial review.
Vascular Plants	<i>Tiarella trifoliata</i> var. <i>laciniata</i>	Cutleaf Foamflower	Under initial review.
Vascular Plants	<i>Vicia americana</i>	American Purple Vetch	Under initial review.
Vascular Plants	<i>Viola sempervirens</i>	Redwood Violet	Under initial review.
Vascular Plants	<i>Woodsia alpina</i>	Northern Woodsia	Under initial review.
Vascular Plants	<i>Woodsia glabella</i>	Smooth Woodsia	Under initial review.
Vascular Plants	<i>Woodsia ilvensis</i>	Rusty Woodsia	Under initial review.
Vascular Plants	<i>Zigadenus elegans</i>	White Camas	Under initial review.

Table 2: Species under review: Terrestrial wildlife species of the Tongass National Forest. The list is organized by taxa and species in alphabetical order. Species that have been evaluated, and for which threats may be substantial and raise potential concern about their long-term persistence in the plan area, are in bold. These species will be evaluated further.

Sub-taxa	Species	Common name	Preliminary findings
Amphibians	<i>Ambystoma gracile</i>	Northwestern Salamander	Under initial review.
Amphibians	<i>Ambystoma macrodactylum</i>	Long-toed Salamander	Under initial review.
Amphibians	<i>Anaxyrus boreas</i>	Western Toad	Under initial review.
Amphibians	<i>Rana luteiventris</i>	Columbia spotted frog	Evaluated. Lack of basic scientific information.
Birds	<i>Accipiter gentilis laingi</i>	Queen Charlotte goshawk	Evaluated. Threats may be substantial.
Birds	<i>Aythya collaris</i>	Ring-necked duck	Evaluated. Lack of basic scientific information.

Sub-taxa	Species	Common name	Preliminary findings
Birds	<i>Brachyramphus brevirostris</i>	Kittlitz's murrelet	Evaluated. Lack of basic scientific information.
Birds	<i>Brachyramphus marmoratus</i>	Marbled Murrelet	Evaluated. Threats may be substantial.
Birds	<i>Calidris [Aprhiza] virgata</i>	Surfbird	Evaluated. Threats do not appear substantial.
Birds	<i>Calidris canutus</i>	Red Knot	Under initial review.
Birds	<i>Empidonax flaviventris</i>	Yellow-bellied flycatcher	Evaluated. Lack of basic scientific information.
Birds	<i>Euphagus carolinus</i>	Rusty Blackbird	Under initial review.
Birds	<i>Falcipennis canadensis isleibi</i>	Prince of Wales Spruce Grouse	Under initial review.
Birds	<i>Falco peregrinus pealei</i>	Peale's peregrine falcon	Evaluated. Lack of basic scientific information.
Birds	<i>Fulica americana</i>	American coot	Evaluated. Lack of basic scientific information.
Birds	<i>Gavia adamsii</i>	Yellow-billed Loon	Under initial review.
Birds	<i>Haematopus bachmani</i>	Black oystercatcher	Evaluated. Threats do not appear substantial.
Birds	<i>Hydroprogne caspia</i>	Caspian tern	Evaluated. Lack of basic scientific information.
Birds	<i>Megascops kennicottii</i>	Western screech owl	Evaluated. Lack of basic scientific information.
Birds	<i>Onychoprion aleuticus</i>	Aleutian tern	Evaluated. Threats may be substantial.
Birds	<i>Phalacrocorax penicillatus</i>	Brandt's cormorant	Evaluated. Threats do not appear substantial.
Invertebrates	<i>Bombus mckayi</i>	McKay's bumblebee	Under initial review.
Mammals	<i>Canis lupus ligoni</i>	Alexander archipelago wolf	Evaluated. Threats do not appear substantial.
Mammals	<i>Clethrionomys [Myodes] gapperi wrangeli</i>	Wrangell Red-backed Vole	Evaluated. Threats do not appear substantial.
Mammals	<i>Clethrionomys gapperi soleus</i>	Revillagigedo Island red-backed vole	Evaluated. Lack of basic scientific information.
Mammals	<i>Clethrionomys rutilus glacialis</i>	Glacier Bay red-backed vole	Evaluated. Lack of basic scientific information.
Mammals	<i>Eumetopias jubatus</i>	Steller sea lion (eastern DPS)	Evaluated. Threats do not appear substantial.
Mammals	<i>Glaucomys sabrinus griseifrons</i>	Prince of Wales flying squirrel	Evaluated. Threats may be substantial.
Mammals	<i>Lasionycteris noctivagans</i>	Silver-haired bat	Evaluated. Lack of basic scientific information.
Mammals	<i>Lontra canadensis mira</i>	Prince of Wales river otter	Evaluated. Lack of basic scientific information.
Mammals	<i>Marmota caligata vigilis</i>	Glacier Bay hoary marmot	Evaluated. Lack of basic scientific information.
Mammals	<i>Martes caurina</i>	Pacific marten	Evaluated. Threats may be substantial.
Mammals	<i>Microtus longicaudus coronarius</i>	Coronation Island vole	Evaluated. Lack of basic scientific information.
Mammals	<i>Microtus oeconomus sitkensis</i>	Sitka tundra vole	Evaluated. Lack of basic scientific information.
Mammals	<i>Microtus oeconomus yakutatensis</i>	Yakutat root vole	Evaluated. Lack of basic scientific information.

Sub-taxa	Species	Common name	Preliminary findings
Mammals	<i>Microtus pennsylvanicus admiraltiae</i>	Admiralty Island vole	Evaluated. Lack of basic scientific information.
Mammals	<i>Mictomys borealis</i>	Northern bog lemming	Under initial review.
Mammals	<i>Mustela erminea initis</i>	Baranof Island ermine	Evaluated. Lack of basic scientific information.
Mammals	<i>Mustela erminea salva</i>	Admiralty Island ermine	Evaluated. Lack of basic scientific information.
Mammals	<i>Mustela erminea seclusa</i>	Suemez Island ermine	Evaluated. Lack of basic scientific information.
Mammals	<i>Myotis evotis</i>	Long-eared myotis	Evaluated. Lack of basic scientific information.
Mammals	<i>Myotis keenii</i>	Keen's myotis	Under initial review.
Mammals	<i>Myotis lucifugus</i>	Little brown myotis	Under initial review.
Mammals	<i>Myotis volans</i>	Long-legged myotis	Under initial review.
Mammals	<i>Ochotona collaris</i>	Collared Pika	Evaluated. Lack of basic scientific information.
Mammals	<i>Oreamnos americanus</i>	Mountain goat	Evaluated. Threats may be substantial.
Mammals	<i>Sorex pacificus malitiosus</i>	Warren Island dusky shrew	Evaluated. Lack of basic scientific information.
Mammals	<i>Tamiasciurus hudsonicus picatus</i>	Kupreanof red squirrel	Evaluated. Lack of basic scientific information.

Table 3. Species under review: Aquatic species of the Tongass National Forest. The list is organized by taxa and species in alphabetical order. Species that have been evaluated, and for which threats may be substantial and raise potential concern about their long-term persistence in the plan area, are in bold. These species will be evaluated further.

Sub-taxa	Species	Common name	Preliminary findings
Fish	<i>Esox lucius (pop. 1)</i>	Northern pike- Pike Lake	Evaluated. Threats do not appear substantial.
Fish	<i>Lampetra richardsoni</i>	Western brook lamprey	Evaluated. Lack of basic scientific information.
Fish	<i>Lampetra ayresi</i>	River lamprey	Evaluated. Lack of basic scientific information.
Fish	<i>Oncorhynchus keta (pop.1)</i>	Chum Salmon - Fish Creek	Evaluated. Threats do not appear substantial.
Fish	<i>Thaleichthys pacificus</i>	Eulachon/Hooligan smelt	Under initial review.
Invertebrates	<i>Caudatella jacobi</i>	Jacob's spiny crawler mayfly	Assessed. Lack of basic scientific information.
Invertebrates	<i>Limnephilus atercus</i>	Fort Dick limnephilus caddisfly	Assessed. Lack of basic scientific information.
Invertebrates	<i>Rhyacophila rickeri</i>	Ricker's free-living caddisfly	Assessed. Lack of basic scientific information.
Invertebrates	<i>Stygobromus quatsinensis</i>	Cave obligate amphipod	Evaluated. Lack of basic scientific information.

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Glossary

At-risk species: Species that are endangered, threatened, proposed, or candidate, as determined by the Endangered Species Act (ESA); and species of conservation concern (see below), as determined by the 2012 Planning Rule and Directives FSH 1909.12, Chapter 10, Section 12.5.

Best available scientific information (BASI): the most accurate, reliable, and relevant scientific information to the issues being considered. FSH 1909.12 zero code, section 07.

Ecological integrity is defined as the quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence.

Known to occur in the plan area: A species is known to occur in a plan area if, at the time of plan development, the best available scientific information indicates that a species is established or is becoming established in the plan area. A species with individual occurrences in a plan area that are merely “accidental” or “transient,” or are well outside the species’ existing range at the time of plan development, is not established or becoming established in the plan area. If the range of a species is changing so that what is becoming its “normal” range includes the plan area, an individual occurrence should not be considered transient or accidental. FSH 1909.12, Chapter 10, Section 12.52c

Native species: An organism that was historically or is present in a particular ecosystem as a result of natural migratory or evolutionary processes; and not as a result of an accidental or deliberate introduction into that ecosystem. An organism's presence and evolution (adaptation) in an area are determined by climate, soil, and other biotic and abiotic factors. 36 CFR 219.19

NatureServe Global (G) and State (S) ranks: These ranks apply at the global or state rank. Sometimes the state rank and the global rank are different from one another depending on more local factors.

G1 or S1	Critically imperiled – at very high risk of extinction or elimination due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors.
G2 or S2	Imperiled – At high risk of extinction or elimination due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
G3 or S3	Vulnerable — At moderate risk of extinction or elimination due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
G4 or S4	Apparently Secure — At fairly low risk of extinction or elimination due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
G5 or S5	Secure — At very low risk of extinction or elimination due to a very extensive range, abundant populations or occurrences, and little to no concern from declines or threats.

Need to change: In the context of at-risk species, the need to change the plan is identified where current plan content is found to be insufficient to maintain a viable population of each species of conservation concern within the plan area, except where the responsible official determines that it is beyond the authority of the Forest Service or not within the inherent capability of the plan area to maintain or restore the ecological conditions to maintain a viable population. 36 CFR 219.9(b)

Persistence: Continued existence. 36 CFR 219.19

Potential SCC List: Species for which preliminary analysis shows that they are native and known to occur, and evaluations show that there *may be* substantial concern regarding the species ability to persist in the long term in the planning area. is the identified potential SCC lista list that includes species that have been screened for inclusion in , but have not yet been reviewed by the Regional Forester,

Regional Forester’s SCC list: Species identified by the Regional Forester that are found to have substantial concern for long-term persistence in the plan area (see definition of SCC below).

Species Evaluations: Detailed synthesis of BASI and analysis of the 8 evaluation criteria as well including substantial concern rationales and recommendation determinations.

Species groups: This term is meant to indicate a group of species that have common ecological conditions or habitat requirements (e.g., guilds), and/or have common threats. The intent is to develop these groups to inform the need to change process, and plan content development.

Species of Conservation Concern (SCC): Species, other than federally recognized threatened, endangered, proposed, or candidate species, that is known to occur in the plan area and for which the Regional Forester has determined that the best available scientific information indicates substantial concern about the species’ capability to persist over the long-term in the plan area.” (2012 Planning Rule, 36 CFR 219.9(c) and Directives, FSH 1909.12, Chapter 10, Section 12.5).

Species to Consider as Potential SCC: All species that meet the “must” and “should” consider categories in FSH 1909.12, 12.52d. Species in the following categories must be considered:

*Species in the following categories **must** be considered:*

a. Species with status ranks of G/T1 or G/T2 on the NatureServe ranking system. See exhibit 01 for description of NatureServe Conservation Status Ranks.

Note: Species with NatureServe G/T1 or G/T2 status ranks are expected to be included unless it can be demonstrated and documented that known threats for these species, such as those threats listed for the species by NatureServe, are not currently present or relevant in the plan area.

b. Species that were removed within the past 5 years from the Federal list of threatened or endangered species, and other delisted species that the regulatory agency still monitors.

*Species in the following categories **should** be considered:*

a. Species with status ranks of G/T3 or S1 or S2 on the NatureServe ranking system. See exhibit 01 for description of NatureServe Conservation Status Ranks.

b. Species listed as threatened or endangered by relevant States, federally recognized Tribes, or Alaska Native Corporations.

c. Species identified by Federal, State, federally recognized Tribes, or Alaska Native Corporations as a high priority for conservation.

d. Species identified as species of conservation concern in adjoining National Forest System plan areas (including plan areas across regional boundaries).

e. Species that have been petitioned for Federal listing and for which a positive “90-day finding” has been made.

f. Species for which the best available scientific information indicates there is local conservation concern about the species' capability to persist over the long-term in the plan area due to:

- (1) Significant threats, caused by stressors on and off the plan area, to populations or the ecological conditions they depend upon (habitat). These threats include climate change.*
- (2) Declining trends in populations or habitat in the plan area.*
- (3) Restricted ranges (with corresponding narrow endemics, disjunct populations, or species at the edge of their range).*
- (4) Low population numbers or restricted ecological conditions (habitat) within the plan area.*

Viable population: A population of a species that continues to persist over the long term with sufficient distribution to be resilient and adaptable to stressors and likely future environments. 36 CFR 219.19

Appendix A

List of species that were considered as SCC (*List of Species to Consider*), but that were screened out from further consideration. Species were screened out because they were either not native or not known to occur on the Tongass National Forest, were listed or proposed to be listed under the Endangered Species Act or were deemed too common in the planning area by local experts (the latter only applies to botanical species) or if local conservation concern was not substantiated. The list is organized by taxa group, sub-taxa and species in alphabetical order.

Sub-taxa	Species	Common name	Preliminary findings
Fish	<i>Catostomus catostomus</i>	Longnose sucker	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Coregonus clupeaformis</i>	Lake whitefish	Assessed. Not known to occur on the planning area.
Fish	<i>Cottus aleuticus</i>	Coastrange sculpin	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Cottus asper</i>	Prickly sculpin	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Cottus cognatus</i>	Slimy sculpin	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Entosphenus tridentatus</i>	Pacific lamprey	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Gasterosteus aculeatus</i>	Three-spine stickleback	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Onchorhynchus tshawytscha</i>	Chinook Salmon	ESA-listed (Candidate). No further review recommended.
Fish	<i>Oncorhynchus clarkii clarkii</i>	Coastal cutthroat trout	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Oncorhynchus gorbuscha</i>	Pink salmon	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Oncorhynchus keta</i>	Chum salmon	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Oncorhynchus kisutch</i>	Coho salmon	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Oncorhynchus mykiss</i>	Steelhead/Rainbow trout	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Oncorhynchus nerka</i>	Sockeye salmon	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Osmerus mordax</i>	Rainbow smelter	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Prosopium cylindraceum</i>	Round whitefish	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Salvelinus fontinalis</i>	Brook trout	Assessed. Not known to occur on the planning area.
Fish	<i>Salvelinus malma</i>	Dolly varden	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Spirinchus thaleichthys</i>	longfin smelt	Assessed. Does not meet initial criteria for consideration.
Fish	<i>Thymallus arcticus</i>	Arctic grayling	Assessed. Not known to occur on the planning area.
Invertebrates	<i>Anodonta kennerlyi</i>	Western floater	Assessed. Does not meet initial criteria for consideration.
Invertebrates	<i>Beringiana beringiana</i>	Yukon Floater	Assessed. Not known to occur on the planning area.
Invertebrates	<i>Haliotis kamtschatkana</i>	Pinto abalone	Assessed. Not known to occur on the planning area.
Invertebrates	<i>Isocapnia agassizi</i>	Agasiz snowfly	Assessed. Does not meet initial criteria for consideration.

Sub-taxa	Species	Common name	Preliminary findings
Invertebrates	<i>Margaritifera falcata</i>	Western Pearlshell	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Andreaea megistospora</i>	Big-spored Rock Moss	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Bryoerythrophyllum wallichii</i>	a moss	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Buxbaumia piperi</i>	Piper's Shield Moss	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Buxbaumia viridis</i>	Green Shield Moss	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Cephaloziella massalongoi</i>	a liverwort	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Cephaloziella phyllacantha</i>	a liverwort	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Dicranella pacifica</i>	Pacific Forklet Moss	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Eremonotus myriocarpus</i>	a clubwort	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Gymnomitrion pacificum</i>	a liverwort	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Haplodontium macrocarpum</i>	Porsild's Bryum	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Lejeunea alaskana</i>	Alaska Pouncewort	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Peltolepis quadrata</i>	a liverwort	Assessed. Not known to occur on the planning area.
Bryophytes	<i>Tetradontium brownianum</i>	Brown's Four-toothed Moss	Assessed. Not known to occur on the planning area.
Fungi	<i>Amanita alaskensis</i>	Alaskan Alder Ringless Amanita	Assessed. Not known to occur on the planning area.
Fungi	<i>Hygrophorus saxatilis</i>	Waxgill of the Rockies	Assessed. Not known to occur on the planning area.
Fungi	<i>Lactarius cordovaensis</i>	A fungus	Assessed. Not known to occur on the planning area.
Lichens	<i>Ameliella andreaeicola</i>	A lichen	Assessed. Lack of basic information to evaluate.
Lichens	<i>Anaptychia bryorum</i>	Ascending Fringed Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Aspicilia caesiopruinosa</i>	A lichen	Assessed. Not known to occur on the planning area.
Lichens	<i>Bryoria friabilis</i>	Friable Horsehair Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Bryoria pikei</i>	Pike's Horsehair Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Bryoria subcana</i>	a horsehair Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Cavernularia lophyrea</i>	Fruiting Honeycomb Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Cladonia luteoalba</i>	Lemon Pixie Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Epigloea medioincrassata</i>	A lichen	Assessed. Not known to occur on the planning area.
Lichens	<i>Erioderma pedicellatum</i>	Boreal Felt Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Evernia prunastri</i>	Valley Oakmoss Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Fuscopannaria ahlneri</i>	Corrugated Shingles Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Fuscopannaria alaskana</i>	Alaska Shingle Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Fuscopannaria globigera</i>	A lichen	Assessed. Not known to occur on the planning area.

Sub-taxa	Species	Common name	Preliminary findings
Lichens	<i>Heterodermia sitchensis</i>	Seaside Centipede Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Hypogymnia inactiva</i>	Mottled Tube Lichens	Assessed. Deemed too common by local experts.
Lichens	<i>Hypogymnia oceanica</i>	Seaside Tube Lichens	Assessed. Deemed too common by local experts.
Lichens	<i>Hypogymnia pulverata</i>	Tube Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Leptogium parculum</i>	A lichen	Assessed. Not known to occur on the planning area.
Lichens	<i>Pannaria rubiginella</i>	Shingle Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Parmeliella parvula</i>	Poor-man's Shingle Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Peltigera cinnamomea</i>	Cinnamon Pelt Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Phaeophyscia kairamoi</i>	Least Shadow Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Pilophorus clavatus</i>	Tapered Matchstick Lichens	Assessed. Deemed too common by local experts.
Lichens	<i>Placynthium stenophyllum</i>	Pale-bellied Ink Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Pseudocyphellaria mallota</i>	Disjunct Lung Lichens	Assessed. Deemed too common by local experts.
Lichens	<i>Pycnothelia papillaria</i>	Nipple Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Pyrrhospora quernei</i>	Sulphured Crimson Dot Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Rhizocarpon cumulatum</i>	A lichen	Assessed. Not known to occur on the planning area.
Lichens	<i>Stereocaulon nanodes</i>	Pixie-scale Foam Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Stereocaulon octomerum</i>	a foam Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Stereocaulon pileatum</i>	Pixie Foam Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Stereocaulon saviczii</i>	a foam Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Stereocaulon spathuliferum</i>	Chalk Foam Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Sticta oroborealis</i>	Half Moon Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Umbilicaria angulata</i>	Starred Rocktripe Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Umbilicaria aprina</i>	Tentacled Rocktripe Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Umbilicaria decussata</i>	Netted Rocktripe Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Umbilicaria havaasii</i>	Havaas' Rocktripe Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Umbilicaria hirsuta</i>	Granulating Rocktripe Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Umbilicaria krascheninnikovii</i>	Lesser Salted Rocktripe Lichens	Assessed. Lack of basic information to evaluate.
Lichens	<i>Umbilicaria lyngei</i>	Puckered Rocktripe Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Umbilicaria rigida</i>	Roughened Rocktripe Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Umbilicaria scholanderi</i>	Scholander's Rocktripe Lichens	Assessed. Not known to occur on the planning area.
Lichens	<i>Vestergrenopsis elaeina</i>	Eyed Brownette Lichens	Assessed. Deemed too common by local experts.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Abies lasiocarpa</i>	Subalpine Fir	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Adiantum aleuticum</i>	Aleutian Maidenhair Fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Androsace alaskana</i>	Alaska Dwarf-primrose	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Antennaria alpina</i>	Alpine Pussytoes	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Antennaria monocephala</i>	Single-head Pussytoes	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Antennaria pulcherrima</i>	Handsome Pussytoes	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Antennaria rosea</i>	Rosy Pussytoes	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Aphragmus eschscholtzianus</i>	Aleutian-cress	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Arctagrostis latifolia</i>	Broadleaf Arctagrostis	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Arnica ovata</i>	Rayless Arnica	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Artemisia tilesii</i>	Tilesius Wormwood	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Aspidotis densa</i>	Dense Lace Fern	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Asplenium viride</i>	Green Spleenwort	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Bolboschoenus maritimus paludosus</i>	Alkali Bulrush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Botrychium ascendens</i>	Upward-lobed Moonwort	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Botrychium campestre</i>	Prairie Dunewort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Botrychium lanceolatum</i>	Triangle Grapefern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Botrychium lunaria</i>	Common Moonwort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Botrychium minganense</i>	Mingan Moonwort	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Botrychium montanum</i>	Mountain Moonwort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Botrypus virginianus</i>	Rattlesnake Fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Bromus pacificus</i>	Pacific Brome	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Calamagrostis deschampsoides</i>	Circumpolar Small-reedgrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Calamagrostis stricta</i>	Slim-stem Small-reedgrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Carex arctiformis</i>	Polar Sedge	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Carex athrostachya</i>	Jointed-spike Sedge	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Carex gynocrates</i>	Northern Bog Sedge	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Carex hoodii</i>	Hood's Sedge	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Carex membranacea</i>	Fragile-seed Sedge	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Carex ramenskii</i>	Ramensk's Sedge	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Carex stipata</i>	Awl-fruit Sedge	Assessed. Probably introduced (not native).

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Cassiope mertensiana</i>	Western Bell-heather	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Cassiope tetragona</i>	Arctic Bell-heather	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Castilleja chrymactis</i>	Panhandle Indian-paintbrush	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Castilleja miniata</i>	Greater Red Indian-paintbrush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Castilleja parviflora</i>	Small-flower Indian-paintbrush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Catabrosa aquatica</i>	Brook Grass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Ceratophyllum demersum</i>	Common Hornwort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Chrysosplenium tetrandrum</i>	Northern Golden-carpet	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Cirsium brevistylum</i>	Short-style Thistle	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Clintonia uniflora</i>	Single-flowered Clintonia	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Cochlearia sessilifolia</i>	Sessile-leaf Scurvy-grass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Coptis asplenifolia</i>	Spleenwortleaf Goldthread	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Crataegus gaylussacia</i>	Suksdorf's Hawthorn	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Cypripedium guttatum</i>	Spotted Lady's-slipper	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Cypripedium passerinum</i>	Sparrow's-egg Lady's-slipper	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Dactylorhiza aristata</i>	Key Flower	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Delphinium brachycentrum</i>	Northern Larkspur	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Diphasiastrum complanatum</i>	Trailing Clubmoss	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Douglasia laevigata</i>	Cliff Dwarf-primrose	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Draba cinerea</i>	Grayleaf Whitlow-grass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Draba lonchocarpa</i>	Lance-pod Whitlow-grass	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Draba praealta</i>	Tall Whitlow-grass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Dryopteris fragrans</i>	Fragrant Cliff Woodfern	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Eleocharis acicularis</i>	Least Spikerush	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Eleocharis quinqueflora</i>	Few-flower Spikerush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Eleocharis uniglumis</i>	Creeping Spikerush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Elymus glaucus</i>	Smooth Wild Rye	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Elymus villosus</i>	Hairy Wild Rye	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Enemion savilei</i>	Haida Gwaii False Rue-anemone	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Equisetum scirpoides</i>	Dwarf Scouring-rush	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Equisetum sylvaticum</i>	Woodland Horsetail	Assessed. Lack of basic information to evaluate.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Erigeron glacialis</i> var. <i>glacialis</i>	Subalpine Fleabane	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Erythranthe tilingii</i>	Tiling's Monkeyflower	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Festuca occidentalis</i>	Western Fescue	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Festuca subulata</i>	Nodding Fescue	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Festuca viviparoidea viviparoidea</i>	Northern Fescue	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Galium kamtschaticum</i>	Boreal Bedstraw	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Gaultheria shallon</i>	Salal	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Geum aleppicum</i>	Yellow Avens	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Geum schofieldii</i>	Haida Gwaii Avens	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Glyceria striata</i>	Fowl Mannagrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Goodyera repens</i>	Dwarf Rattlesnake-plantain	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Hymenophyllum wrightii</i>	Wright's Filmy Fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Hypericum anagalloides</i>	Tinker's-penny	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Hypopitys monotropa</i>	American Pinesap	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Iris setosa</i>	Beachhead Iris	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Isoetes occidentalis</i>	Western Quillwort	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Juncus dudleyi</i>	Dudley's Rush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Juncus effusus</i>	Soft Rush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Juncus falcatus</i>	Sickleleaf Rush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Juncus tenuis</i>	Slender Rush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Juncus triglumis</i>	Three-flower Rush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Juniperus horizontalis</i>	Creeping Juniper	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Lathyrus ochroleucus</i>	Pale Vetchling	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Luzula groenlandica</i>	Greenland Woodrush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Luzula kjellmaniana</i>	Kjellman's Woodrush	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Luzula multiflora</i>	Common Woodrush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Luzula wahlenbergii</i>	Wahlenberg's Woodrush	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Lycopodiella inundata</i>	Bog Clubmoss	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Lycopodium dendroideum</i>	Treelike Clubmoss	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Lycopus uniflorus</i>	Northern Bugleweed	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Malaxis paludosa</i>	Bog Adder's-mouth Orchid	Assessed. Deemed too common by local experts.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Micranthes occidentalis</i>	Western Saxifrage	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Micranthes porsildiana</i>	Porsild's Saxifrage	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Mitella nuda</i>	Naked Mitrewort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Mitella pentandra</i>	Five-point Bishop's-cap	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Myriophyllum verticillatum</i>	Whorled Water-milfoil	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Neottia convallarioides</i>	Broad-lip Twayblade	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Oreopteris quelpaertensis</i>	Queen's-veil Maid fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Osmorhiza berteroi</i>	Chilean Sweet-cicely	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Osmorhiza depauperata</i>	Blunt-fruit Sweet-cicely	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Papaver alboroseum</i>	Pale Poppy	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Pedicularis macrodonta</i>	Muskeg Lousewort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Penstemon serrulatus</i>	Cascade Beardtongue	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Phyllospadix scouleri</i>	Scouler's Surf-grass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Phyllospadix serrulatus</i>	Serrulate Surf-grass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Pinus contorta</i> var. <i>latifolia</i>	Tall Lodgepole Pine	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Plagiobothrys orientalis</i>	Oriental Popcorn-flower	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Poa laxiflora</i>	Loose-flower Bluegrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Poa leptocoma</i>	Bog Bluegrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Poa macrantha</i>	Sand-dune Bluegrass	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Poa macrocalyx</i>	Large-glume Bluegrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Podagrostis humilis</i>	Alpine Bentgrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Podagrostis thurberiana</i>	Thurber's Bentgrass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Polygonum fowleri fowleri</i>	Fowler's Knotweed	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Polystichum andersonii</i>	Anderson's Holly Fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Polystichum kwakiutlii</i>	Kwakiutl's hollyfern	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Polystichum lonchitis</i>	Northern Holly Fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Polystichum munitum</i>	Western Swordfern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Potamogeton robbinsii</i>	Flatleaf Pondweed	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Potentilla drummondii</i>	Drummond's Cinquefoil	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Potentilla glaucophylla</i>	Blueleaf Cinquefoil	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Psilocarphus elatior</i>	Tall Woolly-heads	Assessed. Not known to occur on the planning area.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Pteridium aquilinum</i>	Bracken Fern	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Puccinellia phryganodes</i>	Creeping Alkali Grass	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Ranunculus cooleyae</i>	Cooley's Buttercup	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Ranunculus occidentalis</i> var. <i>nelsonii</i>	Western Buttercup	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Salix pulchra</i>	Tealeaf Willow	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Salix setchelliana</i>	Setchell's Willow	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Saxifraga bracteata</i>	Bract Saxifrage	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Saxifraga serpyllifolia</i>	Thymeleaf Saxifrage	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Saxifraga taylorii</i>	Taylor's Saxifrage	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Sceptridium robustum</i>	a moonwort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Scheuchzeria palustris</i>	Marsh Scheuchzeria	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Sedum divergens</i>	Spreading Stonecrop	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Sedum lanceolatum</i>	Lanceleaf Stonecrop	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Selaginella sibirica</i>	Northern Spikemoss	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Selaginella wallacei</i>	Wallace's Spikemoss	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Shepherdia canadensis</i>	Canada Buffaloberry	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Sidalcea hendersonii</i>	Henderson's Checker-mallow	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Sinosenecio newcombei</i>	Newcombe's Butterweed	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Sparganium natans</i>	Small Bur-reed	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Spiraea douglasii</i>	Douglas' Spiraea	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Spiraea stevenii</i>	Steven's Spiraea	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Stellaria ruscifolia</i> aleutica	Circumpolar Starwort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Stellaria umbellata</i>	Umbellate Stitchwort	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Symphoricarpos albus</i>	Snowberry	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Symphyotrichum boreale</i>	Boreal Aster	Assessed. Lack of basic information to evaluate.
Vascular Plants	<i>Taxus brevifolia</i>	Pacific Yew	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Tephrosia frigida</i>	Dark Purple Groundsel	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Thuja plicata</i>	Western Red-cedar	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Tofieldia coccinea</i>	Purple Featherling	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Veronica wormsjkoldii</i>	Alpine Speedwell	Assessed. Deemed too common by local experts.
Vascular Plants	<i>Viola biflora</i>	Northern Violet	Assessed. Lack of basic information to evaluate.

Sub-taxa	Species	Common name	Preliminary findings
Vascular Plants	<i>Viola selkirkii</i>	Great-spurred Violet	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Woodsia oregana</i>	Western Cliff Fern	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Woodsia scopulina</i>	Mountain Cliff Fern	Assessed. Not known to occur on the planning area.
Vascular Plants	<i>Zannichellia palustris</i>	Horned Pondweed	Assessed. Not known to occur on the planning area.
Birds	<i>Calidris ptilocnemis ptilocnemis</i>	Pribilof rock sandpiper	Assessed. Not known to occur on the planning area.
Birds	<i>Contopus cooperi</i>	Olive-sided Flycatcher	Assessed. Does not meet initial criteria for consideration.
Birds	<i>Cypseloides niger</i>	Black swift	Assessed. Not known to occur on the planning area.
Birds	<i>Dendragapus fuliginosus</i>	Sooty Grouse	Assessed. Does not meet initial criteria for consideration.
Birds	<i>Empidonax difficilis</i>	Pacific-slope Flycatcher	Assessed. Does not meet initial criteria for consideration.
Birds	<i>Gavia stellata</i>	Red-throated Loon	Assessed. Does not meet initial criteria for consideration.
Birds	<i>Limosa fedoa beringiae</i>	Beringian marbled godwit	Assessed. Not known to occur on the planning area.
Birds	<i>Selasphorus rufus</i>	Rufous Hummingbird	Assessed. Does not meet initial criteria for consideration.
Birds	<i>Sterna paradisaea</i>	Arctic Tern	Assessed. Does not meet initial criteria for consideration.
Invertebrates	<i>Bombus occidentalis</i>	Western bumblebee	Assessed. Not known to occur on the planning area.
Invertebrates	<i>Bombus suckleyi</i>	Suckley's bumblebee	Assessed. Not known to occur on the planning area.
Invertebrates	<i>Speyeria zerene</i>	Zerene fritillary	Assessed. Not known to occur on the planning area.
Mammals	<i>Callorhinus ursinus</i>	Northern fur seal	Assessed. Not known to occur on the planning area.
Mammals	<i>Castor canadensis phaeus</i>	Admiralty beaver	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Clethrionomys rutilus insularis</i>	Island red-backed vole	Assessed. Not known to occur on the planning area.
Mammals	<i>Gulo gulo</i>	Wolverine	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Myotis californicus</i>	California myotis	Assessed. Not known to occur on the planning area.
Mammals	<i>Neogale vison nesolestes</i>	Island mink	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Neotoma cinerea</i>	Bushy-tailed woodrat	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Odocoileus hemionus sitkensis</i>	Sitka black-tailed deer	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Ondatra zibethicus</i>	Muskrat	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Pekania pennanti</i>	Fisher	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Peromyscus keeni</i>	Northwestern deer mouse	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Phenacomys intermedius</i>	Western Heather vole	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Phenacomys ungava</i>	Eastern Heather vole	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Sorex alaskanus</i>	Glacier Bay water shrew	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Ursus americanus pugnax</i>	Dall Island black bear	Assessed. Does not meet initial criteria for consideration.

Sub-taxa	Species	Common name	Preliminary findings
Mammals	<i>Ursus arctos sitkensis</i>	Sitka brown bear	Assessed. Does not meet initial criteria for consideration.
Mammals	<i>Zapus hudsonius alancensis</i>	Alaska jumping mouse	Assessed. Does not meet initial criteria for consideration.
Reptiles	<i>Dermochelys coriacea</i>	Leatherback	ESA-listed (Endangered). No further review recommended.

ANALYSIS OF STUDIES ON THE AVAILABILITY OF NORTHERN GOSHAWK FORAGING HABITAT IN KNOWN VERSUS RANDOMLY GENERATED HOME RANGES ON THE COAST OF BRITISH COLUMBIA

Ross G Vennesland

Parks Canada Agency

2018

Introduction

Studies have consistently found that Northern Goshawks prefer to forage in habitats that have the characteristics of mature/old forests (e.g., a closed canopy and low stem density). Eight of nine telemetry studies conducted during the breeding season in primarily forested habitats of North America found that goshawks foraged in forests with mature/old structural characteristics disproportionately more often than the availability of these forests on the landscape (Austin 1993, Bright-Smith and Mannan 1994, Beier and Drennan 1997, Bloxton 2002, Hargis et al. 1994, Iverson et al. 1996, Good 1998, Boal et al. 2006, Mahon 2009). Forest structure has typically been found to be more important than prey abundance to goshawk foraging, likely because forest structure is a key attribute for prey accessibility. For example, a closed canopy results in a relatively open understory and a low stem density increases sub-canopy flyways; both of which increase access to prey (reviewed by Greenwald et al. 2005 and McClaren et al. 2015). Given these results, it is not surprising that five of seven studies have shown a positive relationship between home range occupancy and the amount of forest with mature/old characteristics within home ranges (Crocker-Bedford 1990, Crocker-Bedford 1995, Ward et al. 1992, Patla 2005, Finn et al. 2002, McClaren and Pendergast 2003, Mahon 2009). These conclusions have led land managers in different regions of North America to suggest thresholds for availability of forests with mature/old characteristics, including on the coast of British Columbia where McClaren et al. (2015) recommended that 40% to 60% of the total landscape within home ranges be composed of forests with mature/old characteristics.

The importance of forest structure to goshawk foraging ecology appears to be relatively consistent across western North America (Greenwald et al. 2005), but little empirical study has addressed this issue on the coast of British Columbia. The question of how much forest with mature/old characteristics is required by Northern Goshawks at the home range scale is a difficult one, largely due to the expansive scale of home ranges (thousands of hectares),

increased variability in the habitat use of goshawks away from the nesting area, and challenges in collecting robust population data (reviewed by McClaren et al. 2015).

In comments on the proposed version of the federal Recovery Strategy for Northern Goshawk *laingi* subspecies in Canada (Parks Canada Agency 2017), a reviewer (Wilson 2018) provided an analysis of unpublished data (from McClaren 2009) that showed significantly more suitable foraging habitat¹ within known home ranges on Haida Gwaii compared to random locations; but not on Vancouver Island, where there was no significant difference between the amount of suitable foraging habitat within known home ranges compared to random. Wilson (2018) suggested that goshawks were selecting home ranges for the availability of suitable foraging habitat on Haida Gwaii but not on Vancouver Island, stating that reduced prey abundance was driving goshawks on Haida Gwaii to select for habitat structure, but not on Vancouver Island where high prey abundance presumably meant that forest structure was less important to successful foraging. Consequently, Wilson (2018) suggested that critical habitat for foraging was warranted on Haida Gwaii, but not on Vancouver Island.

Studies have suggested that prey abundance on Haida Gwaii may be compromised by introduced species (McClaren et al. 2015), but Wilson's (2018) conclusions in regard to Vancouver Island are not supported by the bulk of the available science for goshawks in North America. Forest structure has consistently been shown to be more important than prey abundance for goshawks in North America (reviewed by Greenwald et al. 2005 and McClaren et al. 2015). And studies on the north-west coast of North America have typically found lower prey diversity and abundance than elsewhere on the continent (reviewed by McClaren et al. 2015). Furthermore, determining habitat management for a high priority species at risk based on an analysis of an unpublished data set, with no peer review, that contradicts the broad global scientific literature (e.g., Greenwald et al. 1995), including local recommendations in British Columbia (McClaren et al. 2015), is decidedly not a precarious path.

To attempt to gain a deeper understanding of the available data on the availability of suitable foraging habitat for Northern Goshawks on the coast of British Columbia, Parks Canada analysed and compared three data sets from two data sources that have looked at the availability of suitable foraging habitat on Haida Gwaii and Vancouver Island within known home ranges compared to random locations.

Data Sources and Methods

The two available data sources that compared the availability of suitable foraging habitat in known versus random locations used the same spatial mapping data derived from a Habitat

¹ On the coast of British Columbia, 'suitable foraging habitat' has been defined using a Habitat Suitability Index model (Mahon et al. 2008, 2015) and typically has the general structural characteristics of mature/old forests.

Suitability Index (HSI) model (Mahon et al. 2008 spatial mapping output, based on British Columbia forest cover data circa 2003 to 2008). However, the two data sources used different approaches as follows:

1. Smith and Vennesland (2013) used a simulation model (Mahon et al. 2008, Smith and Sutherland 2008) to grow out predicted home ranges (to a target size of 11,310 ha on Haida Gwaii and 4,616 ha on Vancouver Island). Predicted home ranges were grown out only in capable areas, resulting in polygonal shaped home ranges that were essentially fit onto the landscape. Randomly generated home ranges were only seeded in patches of suitable habitat (> 50 ha). This study did not explicitly consider occupancy, using all available home range records. For Haida Gwaii, 18 known and 300 randomly generated home ranges were included, and on Vancouver Island 82 known and 300 randomly generated home ranges were included. The Smith and Vennesland (2013) data source is referred to as "S&V (2013) - All Home Ranges" in the tables and figures of this report.
2. McClaren (2009) used circular shaped home ranges (9,155 ha on Haida Gwaii and 3,745 ha on Vancouver Island) irrespective of the landscape within. Randomly generated home ranges were only seeded in patches of suitable habitat (>50 ha). This data source included two data sets, one that explicitly considered occupancy and one that did not. The data set that explicitly considered occupancy included 13 known home ranges on Haida Gwaii and 35 known home ranges on Vancouver Island (only those with recent and/or consistent occupancy from 1991 to 2004). McClaren (2009) also included a data set for a larger number of known home ranges that presumably included home ranges where occupancy was not known or not detected (but only for Vancouver Island; no data was available for Haida Gwaii). This additional Vancouver Island data set included 77 known home ranges. The two McClaren (2009) data sets of known home ranges were compared with 25 randomly generated home ranges on Haida Gwaii and 27 randomly generated home ranges on Vancouver Island. The two McClaren (2009) data sets are referred to as "McC (2009) – Occupied Home Ranges", and "McC (2009) – All Home Ranges" in the tables and figures of this report.

Both data sources (Smith and Vennesland 2013 and McClaren 2009) provided estimates of the amount of suitable foraging habitat (defined as an HSI rating of 0.5 or higher, as per Mahon et al. 2008) mapped within individual home ranges (known or randomly generated). To generate a proportion of suitable foraging habitat in each known or randomly generated home range, the amount of suitable habitat was divided by the full area of the modelled or circular home ranges. Means and standard errors for each grouping of known or randomly generated home ranges were calculated. Comparison of samples was accomplished using Statistica 10 (Statsoft 2011), using two-tailed t-tests for unpaired samples and one-way ANOVA. Non-parametric methods were not used because the data did not diverge greatly from a normal distribution. Due to large sample sizes in some of the data sets, t-test methodology was employed instead of z-test methodology for pair wise comparisons. Due to sharply divergent sample sizes in some

comparisons, a Levene's test was used to determine if the t-tests employed were to assume equal or unequal variance. ANOVA was used for a single comparison of three means (known home ranges on Vancouver Island; McClaren 2009). In addition, to compare the pattern of availability of suitable foraging habitat across data sets, the percent change between the sample of known and the sample of randomly generated home ranges within each data set was calculated [Percent change = $1 - (\text{Mean proportion of suitable habitat for random home ranges} / \text{Mean proportion of suitable habitat for known home ranges})$]. No statistics were produced for this view of the data.

Results

On Haida Gwaii (Figure 1), the Smith and Vennesland (2013) data source that did not explicitly consider occupancy showed a similar availability in suitable foraging habitat between known and randomly generated home ranges, but the McClaren (2009) data set that did consider occupancy showed significantly more suitable foraging habitat in known home ranges compared to randomly generated home ranges (Table 1). Comparing estimates across data sets for known home ranges only (Table 2) showed that there was nearly significantly more suitable foraging habitat in known home ranges in the McClaren (2009) data set that did consider occupancy compared to the larger data set that did not consider occupancy (Smith and Vennesland 2013). There was no significant difference in suitable foraging habitat availability across randomly generated home ranges. These results suggest that Northern Goshawks were selecting home ranges on Haida Gwaii for an increased amount of suitable foraging habitat, as concluded by Wilson (2018).

On Vancouver Island (Figure 2), both the Smith and Vennesland (2013) and McClaren (2009) data sets that did not explicitly consider occupancy had significantly less suitable foraging habitat in known home ranges versus randomly generated home ranges (Table 1). The fact that this counter intuitive effect is shown in both data sources suggests this is a real effect on Vancouver Island. In contrast, the McClaren (2009) data set that did consider occupancy showed no significant difference between the availability of suitable foraging habitat in known versus randomly generated home ranges (with known home ranges having slightly, but not significantly, more suitable foraging habitat than randomly generated home ranges; Table 1). Comparing estimates across data sets for known home ranges only (Table 2), showed that there was significantly more suitable foraging habitat in known home ranges in the McClaren (2009) data set that did consider occupancy compared to the larger samples where occupancy was not considered (Smith and Vennesland 2013, McClaren 2009). As on Haida Gwaii, there was no significant difference in suitable foraging habitat availability across randomly generated home ranges on Vancouver Island. These results suggest that Northern Goshawks were indeed selecting home ranges on Vancouver Island for an increased amount of suitable foraging habitat, contrary to the conclusions of Wilson (2018).

The percent change between known and randomly generated home ranges is shown in Figure 3. This depiction of the data shows that there was an increased bias towards higher amounts of suitable foraging habitat on both Haida Gwaii and Vancouver Island in the McClaren (2009) data set that did explicitly consider occupancy (McClaren 2009) compared to the two data sets where occupancy was not considered (Smith and Vennesland 2013, McClaren 2009). The pattern of increased suitable foraging habitat in home ranges known to be recently and/or consistently occupied was similar on both Haida Gwaii and Vancouver Island, suggesting a similar trend in both regions. This provides additional evidence for selection of home ranges based on the availability of suitable foraging habitat on both Haida Gwaii and Vancouver Island.

Discussion

The analysis used in this paper considered a wider comparison of the available data than Wilson (2018). The comparison between the three relevant data sets from the two available data sources that have looked at the availability of suitable foraging habitat for Northern Goshawks in known and randomly generated home ranges (Smith and Vennesland 2013 and McClaren 2009) showed that goshawks appear to have selected home ranges for the availability of suitable foraging habitat on both Haida Gwaii and Vancouver Island. The availability of suitable foraging habitat within consistently occupied home ranges on both Haida Gwaii and Vancouver Island was significantly (or nearly significantly) higher than for the larger samples of known home ranges that did not explicitly consider occupancy (Figures 1 and 2, Table 2). Although not all comparisons were significant at the $\alpha = 0.05$ level, these results suggest that Northern Goshawks were selecting home ranges for an increased amount of suitable foraging habitat on both Haida Gwaii and Vancouver Island. The Wilson (2018) analysis that showed a significant difference in foraging habitat between known and randomly generated home ranges on Haida Gwaii, but not on Vancouver Island, thus appears to distract from a fuller understanding of the landscape.

The conclusion that Northern Goshawks may be selecting home ranges for the amount of suitable foraging habitat on Vancouver Island may be surprising given that there was no significant difference between the amount of suitable foraging habitat in known home ranges that were consistently occupied versus randomly generated home ranges (Figure 2; Table 1). Northern Goshawks on Vancouver Island may not have selected home ranges for higher amounts of foraging habitat compared to the landscape as a whole, but comparing across data sets appears to show they were indeed selecting among known sites to increase the amount of suitable foraging habitat within currently occupied home ranges (perhaps through time abandoning home ranges with an unsuitable level of foraging habitat). The pattern across data sets in the availability of suitable foraging habitat on Vancouver Island and between known and randomly generated home ranges can perhaps be explained by an extensive survey effort for goshawks in the same areas where forestry has been concentrated. It is possible that known

Northern Goshawk home ranges and forestry operations have been co-located on accessible lands.

Other studies have also suggested that occupancy is linked to the amount of older forests at the home range scale (Crocker-Bedford 1990, Crocker-Bedford 1995, Ward et al. 1992, Patla 2005, Finn et al. 2002). So the results reported here, although counter intuitive given some of the statistics, should not be a total surprise. Nevertheless, one previous study on Vancouver Island (McClaren and Pendergast 2003) found that the amount of forest of any age class was not significantly related to nest occupancy. McClaren and Pendergast (2003) used similar data to McClaren (2009), so it is not clear why the results differ. Perhaps less occupancy data was available to McClaren and Pendergast (2003) and this affected the statistical power of their analyses. It is also possible that the lack of a comparison to random locations as a control in McClaren and Pendergast (2003) obscured the results that are reported here based on McClaren (2009).

Further work is clearly needed for several reasons: one statistic reported here showed only a marginally significant difference (perhaps due to small sample sizes or overall high variability in the data), the results appear to contradict a previous study on Vancouver Island (McClaren and Pendergast 2003), and there may be data quality issues from the underlying data in these analyses (HSI models that have not been validated and used sometimes questionable British Columbia Forest Cover data). Nevertheless, based on the available data, it is clear that it is premature to institute management decisions that disregard the value of forests with mature/old characteristics for Northern Goshawks anywhere on the coast of British Columbia.

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APPENDIX – TABLES AND FIGURES

Table 1. Summary of statistics comparing the availability of suitable foraging habitat in data sets considering known versus randomly generated home ranges. Data from Smith and Vennesland (2013) and McClaren (2009).

Region	Data Source	Home Range Variables		Tests of Significance				
		All / Occupied	Known / Random	Mean	St Error	n	T	P Value
Haida Gwaii								
	S&V (2013)	All	Known	0.54	0.029	18	0.46	0.65
	S&V (2013)	All	Random	0.53	0.010	300		
	McC (2009)	Occupied	Known	0.62	0.032	13	2.50	0.017
	McC (2009)	Occupied	Random	0.49	0.035	25		
Vancouver Island								
	S&V (2013)	All	Known	0.44	0.016	82	-4.57	<0.0001
	S&V (2013)	All	Random	0.51	0.0046	983		
	McC (2009)	All	Known	0.39	0.026	77	-2.39	0.020
	McC (2009)	All	Random	0.48	0.027	25		
	McC (2009)	Occupied	Known	0.51	0.023	35	0.70	0.49
	McC (2009)	Occupied	Random	0.48	0.027	25		

Table 2. Summary of statistics conducted comparing the availability of suitable foraging habitat in known home ranges across data sets and randomly generated home ranges across data sets. Data from Smith and Vennesland (2013) and McClaren (2009).

Region	Data Source	Home Range Variables		Tests of Significance				
		All / Occupied	Known / Random	Mean	St Error	n	T or F	P Value
Haida Gwaii								
	S&V (2013)	All	Known	0.54	0.029	18	-1.86	.074
	McC (2009)	Occupied	Known	0.62	0.032	13		
	S&V (2013)	n/a	Random	0.53	0.010	300	1.02	.31
	McC (2009)	n/a	Random	0.49	0.035	25		
Vancouver Island								
	S&V (2013)	All	Known	0.44	0.016	82	4.89	0.0085
	McC (2009)	All	Known	0.39	0.026	77		
	McC (2009)	Occupied	Known	0.51	0.023	35		
	S&V (2013)	n/a	Random	0.51	0.0046	983	1.16	0.25
	McC (2009)	n/a	Random	0.48	0.027	25		

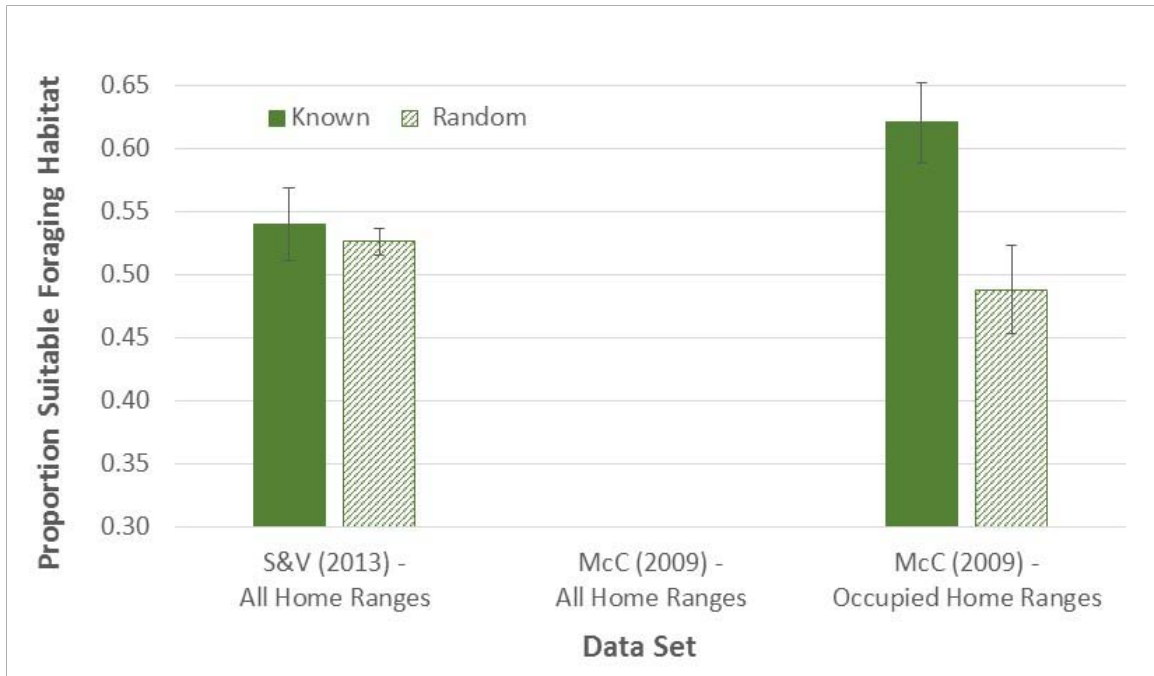


Figure 1. Comparison of the Smith and Vennesland (2013) and McClaren (2009) data sources/sets for Haida Gwaii. Statistics relating to the above comparisons are included in Tables 1 and 2. Error bars represent standard error of the mean.

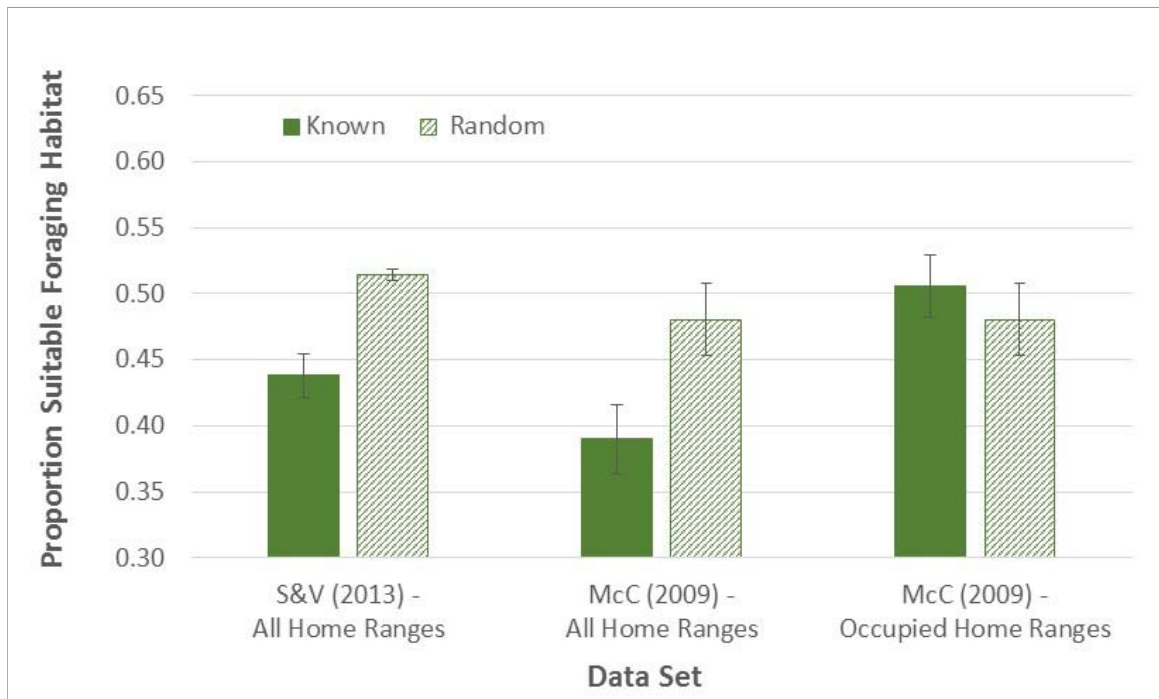


Figure 2. Comparison of the Smith and Vennesland (2013) and McClaren (2009) data sources/sets for Vancouver Island. Statistics relating to the above comparisons are included in Tables 1 and 2. Error bars represent standard error of the mean.



Figure 3. Comparison across data sources/sets of the percent change in the proportion of suitable foraging habitat from known to randomly generated home ranges on both Haida Gwaii and Vancouver Island. Points above the x axis represent a higher mean proportion of suitable foraging habitat in known versus randomly generated home ranges, and points below the x axis a lower mean proportion in known versus randomly generated home ranges. For both Haida Gwaii and Vancouver island, the relative amount of suitable foraging habitat in known versus randomly generated home ranges increased when comparing the one data set that considered occupancy (McClaren 2009 – Occupied Home Ranges) to the two data sets that did not consider occupancy (Smith and Vennesland 2013 – All Home Ranges and McClaren 2009 – All Home Ranges).



The Importance of Alaska for Climate Stabilization, Resilience, and Biodiversity Conservation

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Alaska is globally significant for its large tracts of intact habitats, which support complete wildlife assemblages and many of the world's healthiest wild fisheries, while also storing significant amounts of carbon. Alaska has 1/3 of United States federal lands, the bulk of the United States' intact and wild lands, and over half of the country's total terrestrial ecosystem carbon on federal lands. Managing Alaska's public lands for climate and biodiversity conservation purposes over the next 30–50 years would provide meaningful and irreplaceable climate benefits for the United States and globe. Doing so *via* a co-management approach with Alaska's 229 federally recognized tribes is likely not only to be more effective but also more socially just. This paper lays out the scientific case for managing Alaska's public lands for climate stabilization and resilience and addresses three primary questions: Why is Alaska globally meaningful for biodiversity and climate stabilization? Why should Alaska be considered as a key element of a climate stabilization and biodiversity conservation strategy for the United States? What do we need to know to better understand the role of Alaska given future scenarios? We summarize evidence for the role Alaska's lands play in climate stabilization, as well as what is known about the role of land management in influencing carbon storage and sequestration. Finally, we summarize priority research that is needed to improve understanding of how policy and management prescriptions are likely to influence the role Alaska plays in global climate stabilization and adaptation.

Keywords: Alaska, climate change mitigation, adaptation, biodiversity, carbon storage

INTRODUCTION

Alaska is globally significant for its large tracts of intact habitats and their role in conserving biodiversity and storing carbon while supporting traditional and cultural uses (Kofinas et al., 2010; Reynolds et al., 2018; Dinerstein et al., 2020). Alaska holds one third of United States federal lands, the bulk of the United States' intact and wild lands, and 62 percent of the country's

terrestrial ecosystem carbon stocks on federal lands (Merrill et al., 2018). The Alaska Native Claims Settlement Act of 1971 (ANCSA) established twelve (later thirteen) Alaska Native regional corporations and over 200 local village corporations, representing a total of 44 million acres (17,806 km²) of land (Figure 1). Alaska is home to 229 federally recognized tribes and it is the United States state with the highest proportion of American Indian and Alaska Native people¹. Alaska has >30% of the United States coastline² and 63% of the nation's wetlands (Hall et al., 1994). Most of Alaska far exceeds landscape condition values of even the most protected places in the contiguous United States (Reynolds et al., 2018; Figure 2). The intactness of Alaska's systems as part of a national climate change mitigation strategy has been underexplored in both science and public policy.

In discussing the role of Alaska's intact systems in fostering biodiversity and storing carbon, it is important to recognize that the region is already experiencing and will continue to experience climatic changes that will influence carbon sequestration and storage capacity across landscapes. While physically Alaska's landscapes are largely undeveloped (Figure 3), the region is changing quickly. Presently, climate change is the biggest driver of change for Alaska's ecosystems, species, and people, and this has been well documented (Stone et al., 2002; Chapin et al., 2004; Hinzman et al., 2005; Brubaker et al., 2011). Likewise, cultural and economic climate change impacts across Alaska have been reviewed elsewhere (e.g., Hinzman et al., 2005; Wolken et al., 2011; Cochran et al., 2013; Berman and Schmidt, 2019). With reference to these previous reviews, this analysis focuses on carbon dynamics and ecosystem integrity.

Due to the geographic size and spatial extent of Alaska's landscapes, along with the relative intactness of many of its ecological systems, recent reviews suggest that Alaska could contribute over 50% of total carbon storage for the entire United States (Zhu and McGuire, 2016). Northern permafrost soils contain almost two times the amount of stored carbon as that found within the atmosphere. However, soil carbon concentrations will change with the melting of permafrost (Hugelius et al., 2014; Jones et al., 2017). The decomposition of permafrost carbon could accelerate climate warming through the loss of stored carbon, and methane releases have been widely documented from warming lakes (Jorgenson et al., 2001). The interaction of marine and terrestrial systems across seasonal variations makes predicting changes to total carbon storage challenging (Parmentier et al., 2017). Likewise, as will be discussed, the effects of climate change on the frequency and intensity of wildfires add complexity to issues of carbon balance. Here we focus on the role that Alaska's intact systems and species might play in maintaining biodiversity, storing carbon, and mitigating climate change – even as climate change continues to affect those systems.

Global climate targets have been established in order to prevent the worst effects of climate change, including disruption to weather patterns, extreme heat and flood events, water and

food shortages, and loss of biodiversity and essential ecosystem services (IPCC, 2018). Naturally functioning ecosystems are critical for mitigating greenhouse gas emissions and meeting global climate targets *via* both protecting existing carbon stocks and new sequestration (Griscom et al., 2017; Teske, 2019). These natural-climate solutions (NCS) include proforestation (allowing forests to continue to grow), which is the most rapid means to accumulate additional carbon in forests and out of the atmosphere (Law et al., 2018; Moomaw et al., 2019). Other strategies—including conservation and restoration that increase carbon storage and/or reduce greenhouse gas emissions—are increasingly recognized as essential to meeting global climate targets (Griscom et al., 2017; Seddon et al., 2020). Nearly all pathways to staying below 2°C rise in average global temperature require preventing conversion of the vast majority of Earth's remaining, terrestrial habitats (Teske, 2019). Significantly, much of the land essential to achieving carbon storage objectives is also essential for protecting biodiversity (Dinerstein et al., 2019, 2020; Buotte et al., 2020).

Protection of intact and low human-impact forests is one of the most cost-effective ways to mitigate climate change. Globally, forests store 662 Gt C, or 75% of the amount currently in the atmosphere (Food and Agricultural Organization, 2020), and terrestrial ecosystems (primarily forests) annually remove 30% of excess carbon emitted by human activities. A large portion of this carbon is found in the globally important forest and wetland areas of the tropics and boreal region (Bradshaw and Warkentin, 2015). Protection of intact ecosystems from industrial land uses is particularly important since carbon storage values are diminished as natural areas are degraded or converted (Grünzweig et al., 2004; Martin and Watson, 2016).

Though the impacts to Alaska systems from climate change are well established, there has been little focus on the potential contribution of Alaska land and water management to climate stabilization (Zhu and McGuire, 2016). Though Alaska's marine areas are also extremely significant for global biodiversity and carbon budgets, we focus here on terrestrial ecosystems. We synthesize existing literature and provide expert input to answer three primary questions: Why is Alaska globally meaningful (for biodiversity and climate)? Why should Alaska be a key element of a climate stabilization and biodiversity conservation strategy for the United States? What do we need to know to better understand the role Alaska will play in climate stabilization and resilience given projected changes?

THE GLOBAL SIGNIFICANCE OF ALASKA FOR BIODIVERSITY, CLIMATE STABILIZATION, AND RESILIENCE: INTACT HABITATS AND BIODIVERSITY

Alaska is recognized for its naturally functioning ecosystems, undammed rivers, complete wildlife assemblages, and healthy populations of fish and wildlife. Much of this is attributed to its large tracts of intact or undeveloped habitat, which are important for sustaining ecological and evolutionary processes central to

¹ <https://www.bia.gov/regional-offices/alaska>

² www.coast.noaa.gov

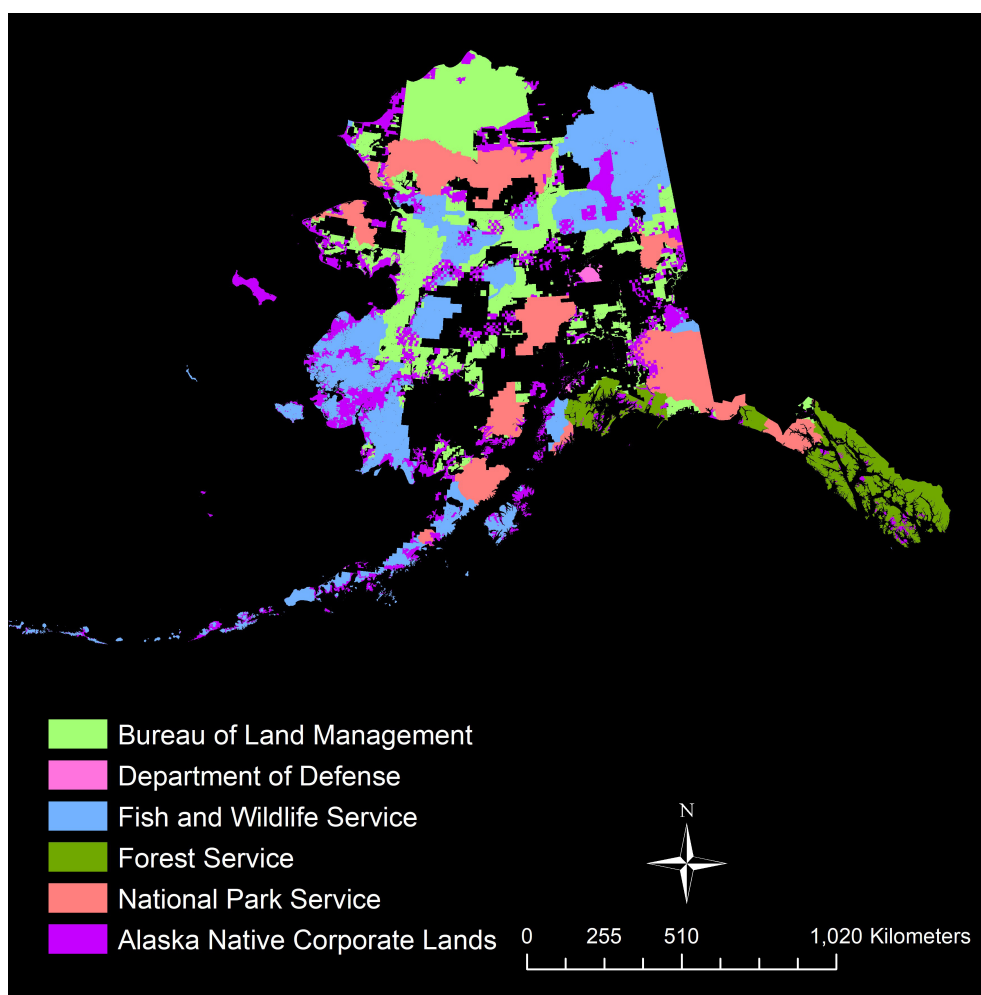


FIGURE 1 | Federal and Alaska Native corporate lands in Alaska.

the long-term persistence of biodiversity (**Figure 2**; Locke et al., 2019). The majority of the world's most significant congregations of species, remaining migrations, and sheer numbers of individuals of many species occur in the world's most intact landscapes (Betts et al., 2017). Ecologically intact ecosystems are becoming increasingly limited on the planet, making their identification and conservation an important priority (Plumptre et al., 2019). These remaining intact landscapes contain the last strongholds for many imperiled species (Watson et al., 2016). In Alaska, they also support Alaska Native peoples, who currently and historically maintain complex and vibrant traditions of subsistence hunting, fishing, and gathering. These traditions are key to not only the cultures and people themselves, but also to public policy (Wheeler and Thornton, 2005).

Large tracts of undeveloped areas also support a majority of the world's remaining intact mega-fauna assemblages, as well as species sensitive to exploitation or conflicts with humans (Morrison et al., 2007; Ripple et al., 2014, 2015). Alaska is the only location in the United States outside of the Yellowstone Ecosystem that has landscapes with their full roster of historically

present (AD1500) large mammals (Morrison et al., 2007). The state as a whole is a global priority for conserving or restoring large mammal assemblages, as all of Alaska's ecoregions contain either complete or near-complete rosters of their historically present large mammals (Dinerstein et al., 2020). Alaska is also a priority for conserving the increasingly rare phenomenon of mass migration of large terrestrial mammals, with a number of significant caribou migrations occurring throughout the region (Harris et al., 2009).

Alaska hosts a number of globally significant sites for large aggregations of breeding shorebirds. The state provides breeding habitat for more shorebirds than any other state in the United States and hosts between 7 and 12 million shorebirds, or as much as 50% of all the shorebirds that occur in North America³. Most of the world's population of three shorebird species, entire populations of five subspecies, and large portions of North America's populations of six other species or subspecies depend on Alaska's habitats². The Copper River Delta supports

³www.fws.gov/alaska/pages/migratory-birds/shorebirds; accessed 1 October 2020

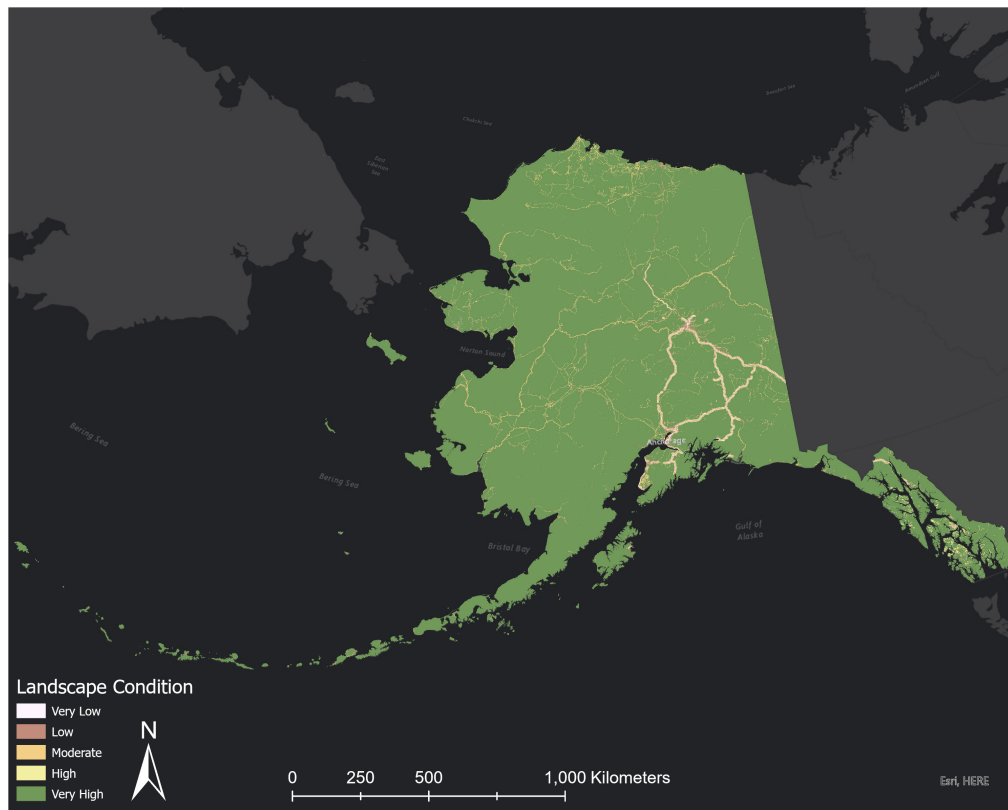


FIGURE 2 | Landscape condition of Alaska; data from Trammell and Aisu (2015). Landscape condition uses a method developed by Hak and Comer (2017) but was modified to better represent the effect of human development on systems in Alaska. Each type of human footprint (e.g., major highways or logging) is assigned a site impact score, which are a relative and scaled measure of the overall impact of a human activity on the landscape, and a decay score to represent the gradual decreasing impact as you move away from the activity (Trammell and Aisu, 2015). This is meant to represent the physical impact of human activities to the landscape, not necessarily all the ecological impacts.

what is thought to be the world's largest concentration of shorebirds, with between 5 and 8 million shorebirds visiting each spring. Concentrations of over one million birds each occur at ten key migration or stopover sites in Alaska³. 155 Key Biodiversity Areas, globally significant sites for species conservation, occur in the state (Birdlife International, 2019). According to the National land cover database, 24% of Alaska is forested, and 74% is vegetated (i.e., not all ice and barren land (Figure 3).

Salmon-producing regions of Alaska are highly diverse, ranging from rainforest, to boreal forest, to Arctic tundra lowlands.⁴ Alaska's contribution to global salmon catch is profound; roughly half of the world's sockeye salmon spawn in the Bristol Bay watershed and rivers along the Gulf of Alaska alone produce one-third of the world's wild salmon (Schoen et al., 2017). Salmon are known to use approximately 36,000 km of streams in the state, which equates to nearly three trips around the globe; and cataloging of salmon occurrence in Alaska is incomplete and ongoing due, in part, to insufficient funding. No other place on Earth has as many healthy and diverse populations of wild salmon.

⁴www.alaskasalmonandpeople.org

In Alaska, large tracts of intact habitat support multiple runs of salmon. Maintaining multiple populations with diverse responses to environmental fluctuations within a landscape provides greater ecological resilience to threats and stochastic events (Schindler et al., 2010). The Tongass and Chugach National Forests in southeastern and southcentral Alaska represent some of the largest tracts of intact rainforest in the world (Orians and Schoen, 2017) and these forests support diverse and productive Pacific salmon fisheries (Johnson et al., 2019). Intact landscapes support habitat diversity allowing, for instance, the peak migration timing of the same species in nearby streams to vary by 3 weeks or more due in part to temperature differences. This variability allows trout, bears, and various birds (e.g., gulls) to eat salmon and salmon eggs for months rather than weeks by moving progressively from colder to warmer streams (Ruff et al., 2011; Schoen et al., 2017). Diversity in the timing of migration can also extend fishing seasons and improve food security for Indigenous and other people (Nesbitt and Moore, 2016). Further, salmon provide a bridge between marine, freshwater, and terrestrial ecosystems, enriching adjacent forests through nutrient transfer that enhances tree growth (Quinn et al., 2018), and carbon sequestration.



FIGURE 3 | Land Cover for Alaska according to the National Land Cover Database maintained by the United States Geological Service. * Alaska only.

The coastal temperate rainforests of coastal British Columbia and southeast Alaska exhibit a distinct aspect of “intactness” that is rarely replicated globally: river systems and their surrounding watersheds with no history of industrial exploitation or modern urban development (Lertzman and MacKinnon, 2013). These watershed ecosystems represent not just ecological communities, seral stage distributions, and carbon stores in their historic proportions and configurations on the landscape, but also are more likely to maintain the hydrological, geomorphic, and other physical processes that sustain the ecosystems over time. These undeveloped watersheds represent a globally rare and significant, process-based conservation opportunity.

INTACT ECOSYSTEMS AND CARBON STORAGE

The temperate rainforests of the Pacific Northwest, including those in the southeast of Alaska, contain the most extensive

examples of undeveloped and semi-natural temperate rainforest remaining globally, and are recognized for their significance in storing large amounts of carbon (Hudiburg et al., 2009; Law et al., 2018). Trees in the Pacific Northwest often live for 800 years or more, storing carbon in boles and roots for that length of time, and they continue to accumulate carbon annually (Hudiburg et al., 2009; Stephenson et al., 2014; Lutz et al., 2018). In Oregon and Washington, forests east of the Cascade crest, large trees (greater than 21 inches in diameter) are only 3% of the trees but account for almost half of the total tree biomass (Mildrexler et al., 2020). Protecting more forest carbon on public lands, lengthening harvest cycles, and reforestation contribute the most to increase forest carbon storage and sequestration (Law et al., 2018). These findings led to the promotion of proforestation, or letting forests grow, as a high priority climate mitigation strategy globally (Moomaw et al., 2019, 2020).

The rainforests of southeast Alaska are notable for supporting large tracts of old growth forest, where tree size and biomass are higher than in younger forests. There is more old-growth

than young forest area in Alaska (Pan et al., 2011), and the most effective measure to protect existing carbon stocks is to protect and maintain existing old growth stands. The total carbon stock in the forest and soils of the Tongass National Forest in southeast Alaska alone is 8% of that of the forests in the conterminous United States (Leighty et al., 2006). Protecting forests with old trees will also confer co-benefits to wildlife, biodiversity, and other ecosystem services including the provision of microclimate buffering under future extreme climate conditions and various cultural ecosystem services (Sutherland et al., 2016).

The boreal forest biome, which covers much of interior Alaska, is increasingly recognized for the important role it plays in carbon storage (Dinerstein et al., 2020; Wells et al., 2020). The forests in Alaska have relatively low carbon density in living vegetation compared with coastal forests (Domke et al., 2018), but when maps of total biomass (including soil) are included, these areas stand out as globally significant (Dinerstein et al., 2020; Soto-Navarro et al., 2020; **Figures 4, 5**). Half the carbon in Alaska and Canada's boreal zone is stored in coniferous forests (Schuur et al., 2018). The boreal forests of Alaska show growth increases in productivity at the boreal-tundra ecotones where it is colder and sparsely forested, and drought-induced declines in productivity throughout interior Alaska, indicating a biome shift is underway (Beck et al., 2011). These forests also lose a substantial amount of carbon in wildfires, primarily from the burning of soils and duff (Goetz et al., 2012; Kasischke and Hoy, 2012).

Disturbances reduce the net carbon sink, yet have been challenging to quantify in this region. Satellite and field

observations showed that the Alaska Boreal Interior ecoregion's above ground biomass carbon averaged 29.3 MgC ha^{-1} from 1984 to 2014, and 36.8 MgC ha^{-1} in the Boreal Cordillera ecoregion (Wang et al., 2021). The total biomass stocks in the Alaska Boreal Interior averaged 1,410 TgC for the same period. The net change in above ground biomass carbon was +60 and +143 TgC for the ecoregions, respectively, though most of the Boreal Cordillera ecoregion is in Canada. This indicates that the above ground carbon of these forests was still a net carbon sink after accounting for disturbance losses from primarily wildfires and harvest. On an area basis, harvest impacts on above ground carbon were nearly two times larger than from wildfire (Wang et al., 2021).

While the forests of Alaska are globally significant carbon storehouses, the vast majority of carbon in Alaska is stored in undisturbed soils. Globally, peatlands-wetlands whose soils consist almost entirely of organic matter-cover just 3% of the Earth's surface but store more carbon than any other types of ecosystems and for longer periods of time. Due to rising temperatures, permafrost is thawing rapidly and is thus altering carbon storage dynamics with potentially dire consequences. But as new unfrozen peatlands form, more carbon may be taken from the atmosphere due to increased plant growth. The carbon balance of these peatlands is changing rapidly with as yet unknown consequences for carbon storage and hence the global climate (McGuire et al., 2012; Graven et al., 2013; Commene et al., 2017). While long-term warming will likely restructure Arctic tundra, there are multiple lines of evidence of Arctic greening and increasing productivity (Berner et al., 2020).

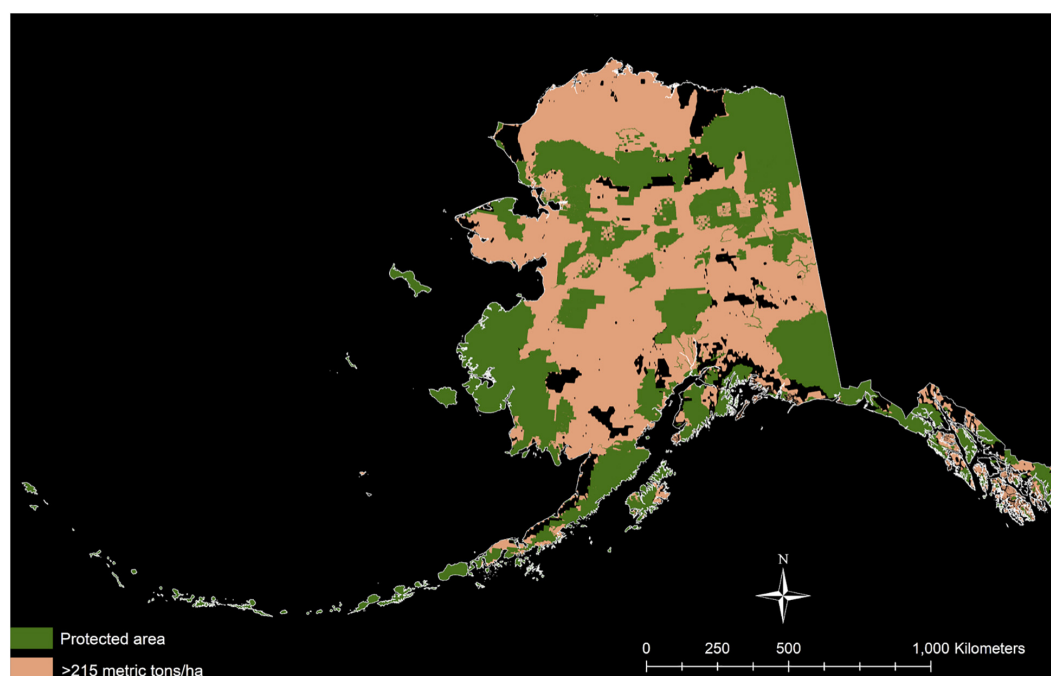


FIGURE 4 | IUCN I-VI Protected Areas in Alaska, according to the Protected Areas Database of the United States, maintained by the United States Geological Survey, and areas outside of the protected areas system where total carbon biomass is above the global median.

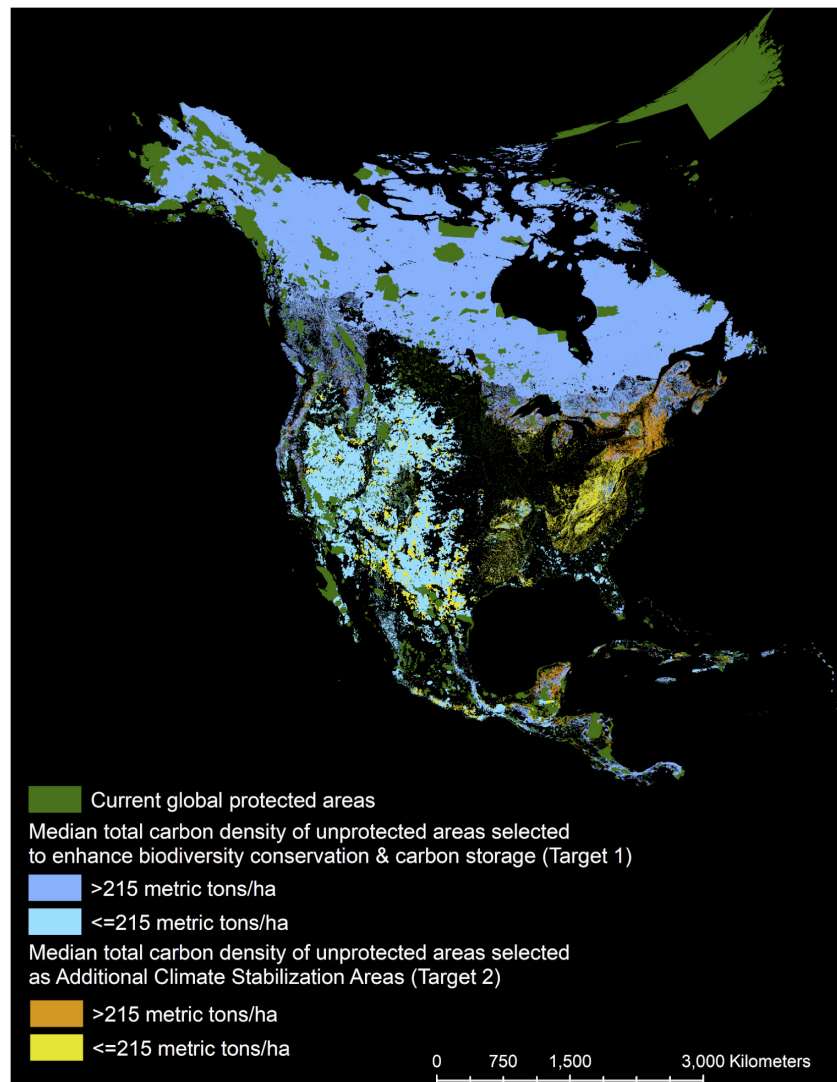


FIGURE 5 | Median total carbon distribution in the Nearctic realm [from Dinerstein et al. (2020)].

The amount of carbon stored on federal lands in Alaska is approximately 62% of the total carbon stored on all United States federal lands (Merrill et al., 2018). Average carbon storage in live vegetation and soils (2005–2014) was 131,675 MMT CO₂ Eq. on Alaska's federal lands, with 92 percent stored in soils and eight percent stored in live vegetation (Merrill et al., 2018). In the Tongass National Forest, 26 percent is stored in live vegetation (Leighty et al., 2006). Maps of total biomass carbon, which integrate above and below ground sources, indicate that nearly all of Alaska is above the global median (Figures 4, 5). Protecting these carbon-storing intact systems in Alaska is important because the ability of these ecosystems to recover carbon once lost is very slow (Goldstein et al., 2020). It takes hundreds to thousands of years to accumulate carbon in trees and soils to their ecological potential, respectively, and it takes that long to regain that amount of carbon once removed, if ever (Sun et al., 2004; Luyssaert et al., 2008; Hudiburg et al., 2009).

Ecosystem types that host large amounts of this “irrecoverable” carbon dominate much of Alaska, and include boreal forest, boreal peatlands, and seagrasses (Goldstein et al., 2020). Even partial “carbon recovery-ability” in the boreal and temperate peatlands could take millennia (Leifeld and Menichetti, 2018).

In a recent global analysis of remaining intact habitats and essential places to conserve to stabilize climate and avoid species extinctions, 93.6% of Alaska's lands were identified as essential (Dinerstein et al., 2020). Besides the existing protected areas (IUCN Category I–VI designations), the role of intact areas and high carbon storage areas were central to Alaska featuring prominently in this analysis (Dinerstein et al., 2020). Intact large mammal assemblages—places where rosters of the historically present (as of AD 1500) large mammals still remain—occur across much of Alaska (Morrison et al., 2007; Dinerstein et al., 2020). Presence of healthy populations of large mammals contributes to healthy ecosystem functioning and carbon storage

(Ripple et al., 2014; Cromsigt et al., 2018). Conserving and restoring robust populations of large mammals that occur in Alaska is an opportunity to maximize carbon storage, as well as to confer other benefits that the presence of large mammals brings for Indigenous, local, and visiting human communities (Colt, 2001; Colt et al., 2002; Chapin et al., 2004; Wolfe, 2004; Balley et al., 2006).

Though this paper primarily focuses on synthesizing information on terrestrial systems, coastal systems are also a key component of Alaska's globally significant carbon storage capacity. Blue carbon refers to the carbon stored in coastal wetlands and estuaries. Seagrass and salt marshes can store up to 2.5 times the buried carbon as terrestrial boreal and temperate forests (McLeod et al., 2011). Salt marshes and seagrass estuaries are losing up to 7% of their global distribution on an annual basis, however, most of the coastal seagrass estuaries in Alaska remain intact (Short et al., 2007). Alaska has among the largest eelgrass beds in the world (Ward et al., 1997). Though the blue carbon potential of peatlands, wetlands, and coastal estuaries has been studied in the Pacific coast region of Washington State (Kauffman et al., 2020), no such studies have been completed for Alaska.

CARBON EMISSION RISKS IN ALASKA

Wildfire is the dominant driver of ecosystem change in much of Alaska, particularly the boreal region, and is strongly linked to climate. The area that burns in Alaska has increased significantly in recent decades (Kasischke et al., 2010), and points to the importance of accounting for the potential changes in the Alaska fire regime with respect to carbon storage and fluxes. Recent large burns put Alaska as contributing to approximately half of United States fire carbon emissions in certain years (Veraverbeke et al., 2015, 2017). As the changes in future climate will affect the landscape configuration of vegetation types throughout fire-initiated secondary succession, there are potential feedbacks to the fire regime and hence differences in modeled projections (Wolken et al., 2011; Zhu and McGuire, 2016). In some cases, such as in white spruce forests of south-central and interior Alaska, old forests are better able to withstand fire than young forests due to their higher water content, taller canopies and thicker bark. However, in black spruce forests, old stands are highly fire prone. The extent to which mature forest stands can escape or withstand fire and other disturbances will therefore be a key factor in determining their near-term climate-change resilience. Hotter and more intense fires are also likely to burn more of the organic layer, further increasing emissions.

Despite short-term releases of carbon due to more intense and more frequent fires, shifts in dominant plant species catalyzed by severe fire could mitigate feedback to climate warming if future deciduous-dominated boreal forests are managed to reduce fire activity. Fast-growing deciduous trees that replace slow-growing black spruce following severe boreal forest burns has been shown to result in a net increase in carbon storage by a factor of five over the disturbance cycle (Mack et al., 2021).

A thorough review of baseline and projected future carbon storage and greenhouse-gas fluxes in Alaska was done by Zhu and McGuire (2016). They found that across upland and wetland ecosystems, Alaska will likely see substantial increases in carbon sequestration potential between now and 2099. This is due primarily to increases in net primary productivity and is predicted despite likely and substantial increases in carbon emissions due to wildfire. The temperate forests in south-central and southeast coastal Alaska, which store significant carbon in live and dead tree biomass, are also projected to increase storage potential. Susceptibility to climate change in lowland shrub tundra ecotypes is significant due to large amounts of soil organic carbon becoming available for loss by decomposition. It should be noted, however, that systems that are more intact and less disturbed are expected to maintain higher carbon storage levels (Martin and Watson, 2016).

ALASKA'S IMPORTANCE IN CLIMATE ADAPTATION AND RESILIENCE

Beyond biodiversity and carbon storage sequestration, Alaska's intact ecosystems provide other essential ecosystem functions such as regulating hydrological regimes or buffering against major storm events. These systems provide services directly essential to human health, including provisioning of clean air and water. Globally, intact ecosystems are especially important for many Indigenous communities (Watson et al., 2018; Plumptre et al., 2019). In Alaska, dependence on wild resources is cultural, social, and economic across communities. Rural residents harvest about 18,000 tons of wild foods each year, with fish making up about 56 percent of this harvest⁵. Rural communities in Alaska are geographically isolated by waterways, varied and steep terrain, and lack of road infrastructure, and hence are particularly reliant on wild foods.

For Indigenous peoples in particular, wild foods such as salmon are a central facet of culture and social relationships as well as subsistence⁶. Because of the conjunction of widespread intact ecosystems with Indigenous communities retaining their strong connections to place-based culture, Alaska provides opportunities for supporting healthy relationships between cultures, communities, and ecosystems that are rare in a global context (Fernández-Llamazares et al., 2021; Thornton and Moss, 2021). Even elsewhere in the temperate rainforests of the Pacific Northwest, many critical resources for these communities have become dramatically reduced in abundance, negatively impacting the resilience of human communities (e.g., Benner et al., 2021). Salmon, herring, and other marine foods are iconic in this regard (Thornton and Moss, 2021), but access to a diverse array of terrestrial and marine plant and animal foods contribute to nutritional health, cultural continuity, and resilience to modern crises (Moss, 1993; Hunn et al., 2003; Fernández-Llamazares et al., 2021).

⁵<https://www.doi.gov/subsistence>; accessed 19 November 2020

⁶<https://alaskasalmonandpeople.org>; accessed 4 February 2021

Ecologically, Alaska could provide key refugia for species whose distributions will shift northward under climate change. Southeast Alaska will, for example, provide key refugia for temperate rainforest communities of the Pacific Coast (DellaSala et al., 2015), and future habitat for boreal species that presently occur further south and east (Stralberg et al., 2015). Land management decisions will affect how species, ecosystems and their services, and the people of Alaska and the nation as a whole, will adapt to climate-related changes. Conservation and informed management of areas of high refugia potential may help species and ecosystems persist, facilitate adaptation to new conditions, and allow for proactive management. This is consequential as many land managers are struggling to keep up with the accelerating consequences of climate change (Stralberg et al., 2020). Intact systems and the robust populations of species that occur in them can be viewed as an insurance policy against having to address the problems and associated costs that occur in trying to manage at-risk species in altered habitat in the future.

Leveraging the relatively intact nature of the Kenai peninsula in Alaska, the Kenai National Wildlife Refuge (KNWR) has been actively promoting proactive management to protect future anticipated ecosystem function (Magness and Morton, 2017). Leveraging climate envelope models developed for the region, managers at the KNWR have developed a portfolio approach that works with climate change trajectories to promote species more suited to future anticipated climates (Magness and Morton, 2018). Directing ecosystem change, in conjunction with resisting or accepting ecosystem change, is more attainable in intact ecosystems (Thompson et al., 2021).

Alaska is home to many of the last remaining intact and largely unaltered Pacific salmon (genus *Oncorhynchus*) producing ecosystems. The persistence of salmon and their supporting habitats has sustained the connection between Alaskans and salmon for over 10,000 years (Halfman et al., 2015). In contemporary times, salmon support multi-billion industries in Alaska through harvest by commercial fishermen and recreational anglers (Johnson et al., 2019). Salmon are harbingers of climate change and are increasingly observed in Arctic regions where Indigenous Peoples have little or no experience interacting with salmon (Dunmall et al., 2013) and where community reception to the newcomers is mixed (Carothers et al., 2019). Although Alaska is in a prolonged period of low abundance of the large-bodied and iconic Chinook salmon (*O. tshawytscha*), the numbers and biomass of wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean are as high as they have been since the 1920s (Ruggerone and Irvine, 2018).

Evidence points to major ocean changes as the primary drivers of these shifts in abundance (e.g., Cunningham et al., 2018), though changes in streamflow and freshwater discharge also play a role. Restoring and maintaining intact landscapes and flexible options for salmon to adapt in the future will determine where and how salmon are distributed across the state moving forward. In the rainforest region of Southeast Alaska, it is a priority to understand the efficacy of forest restoration from historical logging and if and how this can improve. For example, restoration and management to buffer against higher frequency

flooding events, drought, and variability has been prioritized by disciplinary experts (Shanley et al., 2015). Maintaining flexible options for salmon—by maintaining a diversity of habitats and keeping these as intact as possible—will increase the likelihood that salmon productivity can be maintained despite large-scale shifts that will occur (Cline et al., 2017; Schoen et al., 2017).

Mitigating climate change and maintaining flexible options into the future will be essential to minimize forced migration of human populations as climate refugees, loss of access to food resources, and other uncertain risks (Hamilton et al., 2016). This is particularly important in Alaska as communities deriving significant elements of their daily needs from subsistence economies and ecologies are particularly at risk from climate change (Savo et al., 2016). In Alaska, climate change could add \$5–6 billion to future costs for public infrastructure from now to 2080 (Larsen et al., 2008; Melvin et al., 2016). A recent report estimates that some of the most certain consequences of climate change in Alaska will cost between \$340 million and \$700 million per year over the next three to five decades (Berman and Schmidt, 2019), and this estimate included only a limited set of costs. Such costs may be borne by United States taxpayers more generally as well as Alaskans. Rural Alaskans will be disproportionately affected by changes to subsistence harvest cycles and reduced barge service as rivers become too shallow. Implementing plausible adaptation strategies could offset impacts by up to 45% over the long-run (Larsen et al., 2008).

THE IMPORTANCE OF ALASKA TO A UNITED STATES STRATEGY FOR CLIMATE STABILIZATION AND BIODIVERSITY CONSERVATION

The sheer size of Alaska and proportion of intact systems, much of which is public land, makes Alaska a singularly important and opportune place for the United States to consider natural climate solutions within its own borders. Approximately 60% (900,000 km² of 1.5 M km²) of Alaska's terrestrial surface area is federal land (Figure 1). Nearly 2/3 of this is within an IUCN protected category I–VI, with management ranging from protections for wildlife and recreational values [e.g., Fish and Wildlife Service (FWS) Refuges, National Park Service (NPS)], to managing lands for some oil and gas, mineral, and timber development [e.g., United States Forest Service (USFS), Bureau of Land Management (BLM)]. The State of Alaska manages another 100 million acres (404,685 km²), an area the size of the State of California, for an equally wide range of purposes. Together, 88% of Alaska is managed either by the federal or state government. No United States state has a larger amount of public lands nor the combined intactness, carbon storage, and native biodiversity importance of Alaska.

As noted, ANCSA, enacted in 1971, transferred 44 million acres (178,062 km²) of land (nearly 12% of the State) to newly created Alaska Native regional and village corporations. These lands are managed for the benefit of the corporations' Alaska Native shareholders. In addition, the Alaska National

Interest Lands Conservation Act (ANILCA), passed in 1980, provided varying protections to 157 million acres of land set aside as National Parks, National Forests, and other conservation areas. It also established subsistence priority in hunting, fishing, and gathering activities for rural residents, Alaska Native or otherwise, stating that, “the continuation of the opportunity for subsistence is essential to Native physical, economic, traditional, and cultural existence.” Roughly 80% of the population of remote rural Alaska residents are Indigenous People⁷, and federal and state public lands comprise much of the traditional territory of Alaska’s 229 federally recognized tribes—creating an unusual opportunity for a small number of landowners and sovereign tribes to work together on coordinated land management strategies across large regions of the state. Only about 1% of Alaska is in general private land ownership.

Many intact systems in Alaska face a variety of proposed industrial land uses that either increase carbon emissions through the extraction and production of fossil fuels or diminish carbon storage values and system intactness through degradation or conversion of natural areas. Among these are expanded fossil fuel development in the Brooks Foothills and Beaufort Coastal Plain (Figure 6), clear-cut old-growth logging in forest systems in southeast Alaska, and large-scale, fossil-fuel based mining operations and associated infrastructure in otherwise intact regions such as the Bristol Bay watershed. Land conversion from forest to agriculture in Alaska’s boreal region would be likely to result in net carbon release (Grünzweig et al., 2004). In Canada, agricultural conversion is the greatest source of historical loss of boreal forests, and remains an important driver of deforestation in some boreal zones (Hobson et al., 2002). Such conversion is not however, occurring at anything approaching large scales in Alaska (Figure 3).

RECOMMENDATIONS

While the tundra, forests, and other ecosystems of Alaska all face some degree of risk, there is potential for these to be managed through local land-use decisions and actions (Grünzweig et al., 2004; Goldstein et al., 2020). Managing for climate stabilization and adaptation benefits in Alaska may provide an opportunity to scale land conservation and augment management on the rapid timescale that is necessary to meet global climate and biodiversity objectives (Dinerstein et al., 2019). Land management has a significant role to play in how Alaska’s systems, species, and people contribute to climate stabilization and adapt to climate change. For example, forest carbon storage potentially could triple with management focused on limiting harvest in the high biomass forests of Southeast Alaska (Zhu and McGuire, 2016). Further, processes internal to an ecosystem can lead to a decoupling from regional temperature and moisture regimes, and relatively undisturbed systems can confer resistance to climate change (Stralberg et al., 2020). Management of fire in Alaska has also been suggested as a potentially important climate mitigation

strategy, as well as being important to directly protect human communities (Phillips et al., 2019). New evidence that shifting species dominance following severe burns in boreal forests is important as this has the potential to reduce likelihood of future fires, increase the tenure of this carbon on the landscape, and provide negative or stabilizing feedback to climate warming (Mack et al., 2021).

The singular opportunity that Alaska’s relatively intact systems present, particularly the irreplaceability of its accumulated carbon stores, merits consideration of an approach to the management of Alaska’s public lands that prioritizes climate stabilization, adaptation, and resilience. Such an approach might include a wide range of management actions. The identification and designation of areas important for climate stabilization and resilience could provide an opportunity to increase the use of nature-based approaches to mitigating climate change. These designations could include large intact areas and areas that are essential carbon storehouses, particularly vital in climate mitigation, and which could be managed to maintain and enhance conditions (e.g., vegetative cover, soil condition) for carbon storage and sequestration. Co-developing ideas and means to manage these areas with local people, particularly federally recognized tribes, could also increase stewardship and the efficacy of these areas in meeting not only conservation and climate objectives but also local economic, social, and cultural concerns.

Though additional IUCN-defined protected areas (categories I–VI) may be warranted in specific places, climate stabilization designations may simply shape management plans in a way that maximizes carbon storage and biodiversity conservation. Achieving expanded conservation objectives may also be achieved through other effective area-based conservation measures (OECMs) and Indigenous and Community Conserved Areas (ICCAs; Wells et al., 2020). Long-term or indefinite-term withdrawal of areas of public land and waters from specific activities that directly contribute to emissions (e.g., expanded fossil fuel development) or that diminish carbon storage, intact systems, and biodiversity values through significant degradation or conversion of natural areas (e.g., clear-cut old growth logging and large-scale hard rock mining) could be considered (Wells et al., 2020). Such targeted withdrawals provide near-term biodiversity and climate stabilization benefits while still meeting other human needs and retaining the option to adjust management in the future.

Targeted withdrawals or designations may be area-based or they may be ownership-based, such as withdrawals of categories of federally-owned or managed lands and waters from fossil fuel extraction, for example. The Northern Bering Sea Climate Resilience Area⁸ (NBSCRA) is an example of an area-based, targeted withdrawal of oil extraction activities. This designation, created in partnership between regional Indigenous entities, including over 70 federally recognized tribes, and the federal government, was also an example of a collaboratively-developed designation that increases authority, recognition, flexibility,

⁷https://iseralaska.org/static/legacy_publication_links/researchsumm/UA_RS10.pdf; accessed 4 February 2021

⁸<https://obamawhitehouse.archives.gov/the-press-office/2016/12/09/executive-order-northern-bering-sea-climate-resilience>; accessed November 20, 2020

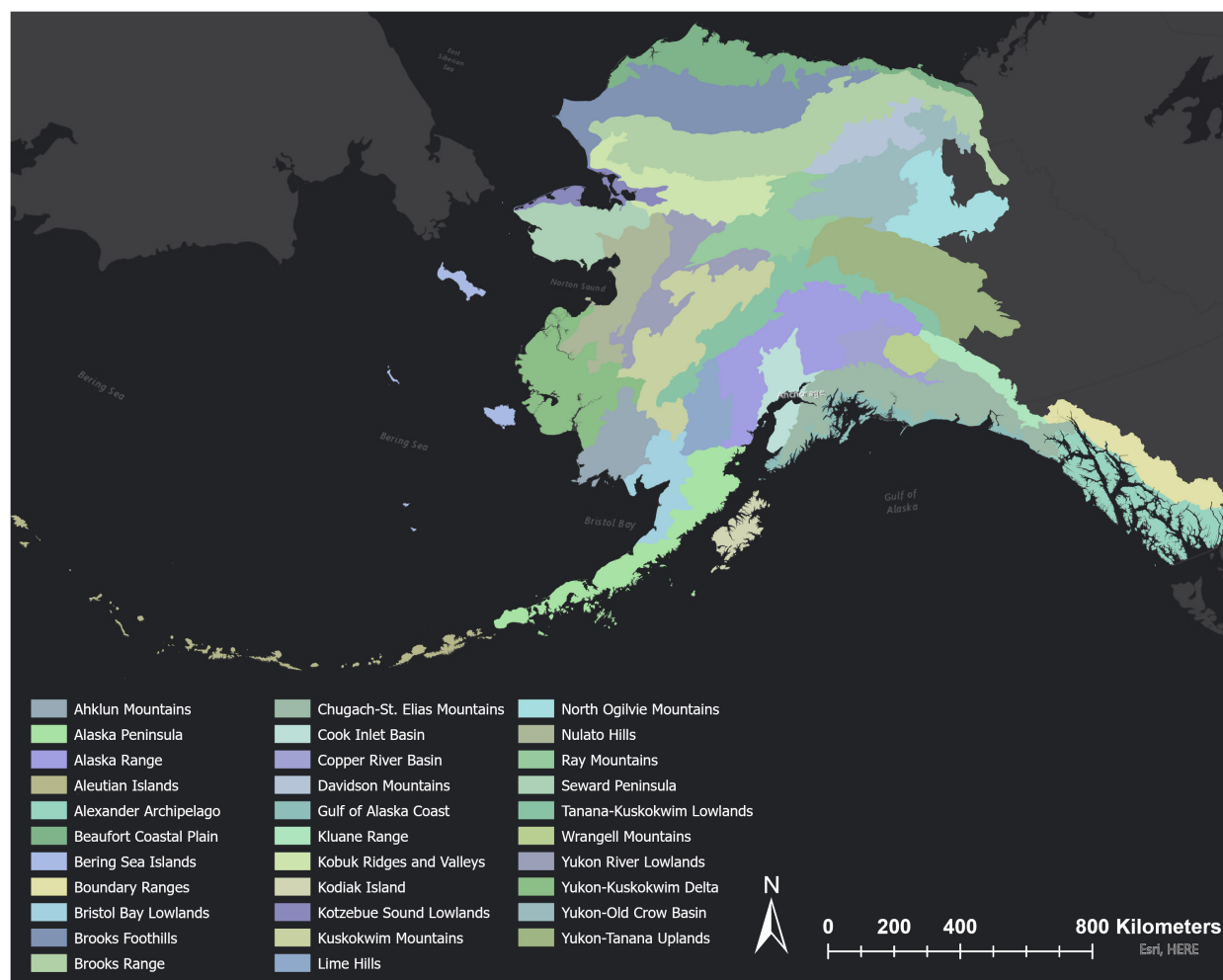


FIGURE 6 | Ecoregions of Alaska [from Nowacki et al. (2003)].

and benefits to local stakeholders, particularly Indigenous peoples. Notably, the NBSCRA required for the first time that Indigenous knowledge be included in federal decision-making. Co-development of climate stabilization and resilience designations and approaches with federally-recognized tribes could provide a means of recognizing tribal sovereignty, tapping Indigenous knowledge and governance, addressing the needs of Indigenous communities, and achieving climate and biodiversity objectives in an effective and socially just manner (Artelle et al., 2019). Designations might also include or be complemented by programs designed to be expanded to ensure multiple resource management benefits—such as water and food security and economic and educational opportunities—for resource users.

Prioritization of a climate stabilization, adaptation, and resilience approach may also be attractive to Alaska Native corporate landowners if the benefits to shareholders were to outweigh the benefits of resource extraction that diminishes carbon storage and biodiversity conservation but currently provides needed economic activity. Sealaska, the regional Alaska Native corporation for Southeast Alaska, established a carbon bank of 165,000 acres (667.7 km²) of its lands in Southeast

Alaska. No commercial timber harvest will occur on those lands for 100 years. Federal programs could be designed in partnership with Alaska Native corporate landowners, federally-recognized tribes, and Alaskan communities that complement market-based actions and further incentivize climate stabilization and resilience investments on Alaska Native corporate lands and federal lands. These programs could also provide economic opportunities related to stewardship of carbon, food security, and other ecosystem services. Similarly, federal, state, and private partnerships may incentivize state climate stabilization investments and enable coordinated climate stabilization strategies over intact systems with fragmented land ownership.

Based on the information synthesized above, such an approach in Alaska should consider:

1. **Maintaining intactness values: evaluate costs and benefits of developing industrial projects in intact areas as maintaining intact landscapes helps mitigate climate change as well as buffer its impacts.**

2. Promoting proforestation—letting forests grow—as a forest management strategy and a component of ecosystem-based management.
3. Conserving forests with old trees.
4. Together with local communities, addressing and developing wildfire response strategies and stewardship and restoration strategies that promote carbon storage.
5. Prioritizing conservation and restoration of intact large mammal faunas and healthy salmon streams; presence of viable populations of these species confer systems-level carbon storage, and a myriad of other benefits for people and nature.

A climate stabilization and resilience approach could also involve greater focus of public resources and funding for a research agenda to better inform land managers in stewarding Alaska's systems. Such an approach should also facilitate greater support and funding for Indigenous-led research and co-production of knowledge with Indigenous Peoples. According to a recent report assessing natural climate solutions across the United States, priority areas to maintain in Alaska comprise 29% of total carbon storage across all ecosystems, and are extremely important in terms of the United States commitment to draw down greenhouse gas emissions⁹. Filling key research gaps, particularly related to how the role of wildfire and ecosystem shifts may affect the carbon balance in Alaska, is particularly important. We elaborate on this and other research priorities in the next section.

RESEARCH PRIORITIES

Indigenous-led research and research needs prioritized by Indigenous Peoples in Alaska should be a central component of research priorities. Collaboration with Indigenous knowledge-holders is consistent with internationally recognized Indigenous rights and generates more impactful research outcomes (Ban et al., 2018). Such cooperation among scientific and Indigenous perspectives will both improve understanding of system dynamics and better inform both scenario planning and the design of any climate stabilization and resilience approach to Alaska's lands and waters.

Fire is a key ecosystem driver across the boreal region of Alaska. In this century, it has increased in range, with more frequent fires occurring further north, west, and south, as compared to historical records. Fire has also increased in frequency (leading to shorter average fire return intervals), intensity and severity, leading to more complete burning of biomass in trees and in soils, associated greater losses in carbon, and slower post-fire recouping and regenerating (Turetsky et al., 2011). Model results suggest that the boreal forest is particular at risk of carbon losses *via* fire, and that changes in fire regime will cause net carbon loss from deep organic soils and near-surface permafrost (O'Donnell et al., 2011; Genet et al., 2013). Carbon is lost to the atmosphere not only during fire events, but for years

afterward, as well—but this effect is poorly understood. Postfire changes in absorption of solar radiation and organic decay in soils alter rates of carbon turnover in boreal forests. These post-fire releases may have been vastly underestimated, in part due to poor understanding of “mass wasting” and carbon decomposition in the mineral soil layer in the 2 years post-fire (O'Neill et al., 2003; Potter, 2018). The magnitude of these changes, their overall impact on carbon balance, and the practical ability of human management strategies to alter their trajectory all merit additional research and modeling.

While it has already been noted that the increased temperatures and permafrost thaw associated with past and ongoing climate change have already accelerated carbon loss from soils *via* decomposition, the magnitude of past and future carbon losses are far from clear—as are potential management strategies that might limit or mitigate such losses. Decay rates and rates of carbon loss are temperature sensitive and occur differently at different depths and locations. More data are needed on the effects of climate change on soil organic carbon in boreal permafrost soils, especially from depths greater than one meter (Kane et al., 2005; Johnson et al., 2011). A meta-analysis of existing literature on the anticipated response of Alaska's ecosystems to climate change is a research priority. Synthesizing scientific conclusions and quantifying how projected changes are likely to influence boreal forest and tundra ecosystems, in particular, would benefit the research community and land managers. This meta-analysis could help inform a quantitative assessment of the potential for Alaska's natural climate solutions to help the United States meet national and global climate commitments, as was recently assessed for Canada (Drever et al., 2021).

Ecological shifts have seen some recent research, but much remains to be examined with regard to the impacts of shrub encroachment in tundra systems and increases in forest biomass in areas previously sparsely forested, particularly on land areas where permafrost has recently thawed (Lorant et al., 2018). Complex patterns of soil drainage, currently unmapped for the state, add to the difficulties of predicting these land cover changes. Of particular importance is to understand and monitor how shrub species in tundra ecosystems will vary in response to climate and environmental change, and how herbivores and their shifting distributions may limit this change (Myers-Smith et al., 2011). Filling data gaps so that analyses such as that of Fargione et al. (2018) on natural climate solutions for the United States may be completed for Alaska is a priority. Similarly, filling gaps and completing mapping and inventorying of blue carbon networks is also a pressing research priority so that Alaska's blue carbon potential can be adequately assessed.

The ecoregions of Alaska have many close parallels in the ecoregions of Canada, particularly with regard to permafrost tundra, vast boreal forests underlain with discontinuous permafrost southern boreal forests (aspen parkland), and temperate coastal rainforests (Figure 6). While in some cases the management of these lands has been similar in Alaska and in Canada, in many cases there have been key differences. For example, in Canada, there has been a policy of active clear-cutting and regeneration (large-scale forestry) in much of the

⁹<https://www.audubon.org/conservation/climate/naturalsolutions>; accessed 9 July 2021

boreal zone, while the same has not been true in Alaska. Research focused on the differing outcomes of these differing strategies, with regard to carbon storage and uptake, is a little-explored avenue. Another parallel is a shift from large-scale clearcutting in coastal rainforests of British Columbia to ecosystem-based management. Most of the coastal rainforest of British Columbia's central and north coast—which are ecologically similar to the rainforests of southeast Alaska—are now managed under an ecosystem-based regime.

Besides basic research, there is a need to conduct more work on scenario planning to inform policy-making and management. Scenario planning can identify opportunities to shift land management and to meet desired states, or to avoid, mitigate, or enhance certain outcomes. Geodesign is one potential approach to move this type of integrated carbon futures assessment forward. Based upon deep stakeholder engagement (Steinitz, 2012), geospatial science, and scenarios that are socially and environmentally plausible (Trammell et al., 2018), geodesign futures can identify priority landscapes for a range of carbon storage solutions. Currently, the International Geodesign Collaborative is exploring the feasibility of the Trillion Trees Initiative using the geodesign principles of stakeholder-informed landscape planning. Regardless of the tool, the early involvement of local communities and stakeholders in identifying options for developing a climate stabilization and adaptation approach is likely to result in stronger, more durable outcomes for both biodiversity conservation and community wellbeing (Salomon et al., 2018). Additionally, and as information becomes available, quantitative assessments of how nature-based solutions can contribute to sequestration targets will be helpful to help guide investments and decision-making.

DISCUSSION

Avoiding the worst effects of climate change requires rapid decarbonization and improved ecosystem stewardship. Alaska, with its intact ecosystems and ecoregions with full rosters of native species—many with relatively healthy populations—provides a globally exceptional opportunity for protecting biodiversity in a context linked to natural climate solutions. As climate warms, intact systems will become more valuable as they have greater potential to provide superior resilience to climate change and will help buffer against frequent droughts and other disturbance events. Analysis of vegetation cover data for Alaska shows that significant changes are occurring, with implications for both the biodiversity and carbon storage potential of the nation. Natural climate solutions offer win-win solutions to the linked crises of biodiversity loss, accompanying cultural and traditional losses, and climate change. Managing lands for climate stabilization, adaptation, and resilience provides an opportunity to prevent degradation of ecosystems and to increase the ability of ecosystems to remove CO₂ from the atmosphere. Because Alaska is also globally significant for its large contribution to carbon storage, incentivizing land management to conserve and enhance this storage presents a significant opportunity for the United States to lead in natural climate solutions.

Quantification of the near-term contribution of various land management scenarios to climate emissions reduction and to long-term climate stabilization in Alaska is difficult due to significant data gaps. In 2018, researchers identified and analyzed 21 natural climate solutions in the contiguous United States and found that combined they could reduce global warming emissions by an amount equivalent to nearly 21% of United States net emissions in 2016 (Fargione et al., 2018). No such study has been performed for Alaska, which accounts for 19.3% of the United States land mass (US Census Bureau, 2012). Given the size and importance of Alaska's lands and waters and the magnitude of its accumulated carbon stores and potential climate stabilization services over time, however, it is clear that Alaska must play a prominent role in any knowledge-based, United States climate stabilization strategy.

Design of a natural climate solutions approach for Alaska should consider both western-scientific and Indigenous perspectives and be developed within a framework that acknowledges the value of human-environment relationships in fostering ecosystem integrity and human well-being. The early involvement of local communities and stakeholders in identifying options is likely to result in stronger, more durable outcomes. In particular, collaboration with Alaska's Indigenous communities, tribes, and landowners is necessary to develop an effective and socially just approach. Worldwide, there is a growing recognition that ecological knowledge and stewardship practices of Indigenous peoples can offer pathways for conservation and resources management that is not only effective but also socially just (Atlas et al., 2020). A stewardship approach that acknowledges the value of human-environment relationships in fostering ecosystem integrity and human well-being provides a framework for such collaboration (Chapin et al., 2015).

New research from the World Economic Forum ties half the world's GDP—\$44 trillion dollars—directly to nature and its services¹⁰. The recent COVID-19 crisis has demonstrated the ability of the world's governments to mobilize trillions of dollars and there are a number of proposals emerging to tie environmental restoration and climate response to economic recovery. A climate stabilization and adaptation approach offers one framework to move beyond the incrementalism of protected area designation over the past couple of decades and to incentivize protection of intact lands that are already providing a myriad of benefits for biodiversity and humanity. Alaska, with its largely intact landscapes, wildlife values, and high carbon storage potential, is an opportunity for the United States to lead both in global climate and biodiversity conservation efforts.

AUTHOR CONTRIBUTIONS

CV and ED conceived of and drafted the manuscript. NF, ND, AJ, BL, KL, SR, FS, and ET contributed to ideas, writing, and editing of the manuscript. AJ and ET produced the figures. All authors contributed to the article and approved the submitted version.

¹⁰<https://www.weforum.org/press/2020/01/half-of-world-s-gdp-moderately-or-highly-dependent-on-nature-says-new-report/>

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Projecting the future of an alpine ungulate under climate change scenarios

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Abstract

Climate change represents a primary threat to species persistence and biodiversity at a global scale. Cold adapted alpine species are especially sensitive to climate change and can offer key “early warning signs” about deleterious effects of predicted change. Among mountain ungulates, survival, a key determinant of demographic performance, may be influenced by future climate in complex, and possibly opposing ways. Demographic data collected from 447 mountain goats in 10 coastal Alaska, USA, populations over a 37-year time span indicated that survival is highest during low snowfall winters and cool summers. However, general circulation models (GCMs) predict future increase in summer temperature and decline in winter snowfall. To disentangle how these opposing climate-driven effects influence mountain goat populations, we developed an age-structured population model to project mountain goat population trajectories for 10 different GCM/emissions scenarios relevant for coastal Alaska. Projected increases in summer temperature had stronger negative effects on population trajectories than the positive demographic effects of reduced winter snowfall. In 5 of the 10 GCM/representative concentration pathway (RCP) scenarios, the net effect of projected climate change was extinction over a 70-year time window (2015–2085); smaller initial populations were more likely to go extinct faster than larger populations. Using a resource selection modeling approach, we determined that distributional shifts to higher elevation (i.e., “thermoneutral”) summer range was unlikely to be a viable behavioral adaptation strategy; due to the conical shape of mountains, summer range was expected to decline by 17%–86% for 7 of the 10 GCM/RCP scenarios. Projected declines of mountain goat populations are driven by climate-linked bottom-up mechanisms and may have wide ranging implications for alpine ecosystems. These analyses elucidate how projected climate change can negatively alter population dynamics of a sentinel alpine species and provide insight into how demographic modeling can be used to assess risk to species persistence.

KEYWORDS

Alaska, alpine ecosystems, climate change, conservation, general circulation models, habitat change, mountain goat, *Oreamnos americanus*, population modeling, resource selection function

1 | INTRODUCTION

Climate change represents a primary threat to species persistence and biodiversity at a global scale; 7.9% of species are predicted to become extinct due to climate change (Urban, 2015). Thus, a mechanistic understanding of how climate influences population dynamics and viability is critical for forecasting, and potentially mitigating, deleterious effects of climate change. Identification of species and ecosystems that are particularly sensitive to climatic variability, along with the development of associated quantitative tools, can help expedite knowledge that is urgently needed to stem this conservation threat. In this regard, study of cold adapted alpine species that are especially sensitive to climate change (Dullinger et al., 2012; Gentili, Hemant, & Birks, 2015) and experiencing disproportionately rapid changes in climate (Christensen et al., 2013; Shanley et al., 2015), offer key opportunities to gain critical insights into broad-scale, forthcoming effects.

Alpine herbivores exhibit specialized strategies in order to survive and persist in highly seasonal and climatically extreme environments (Hoffman, 1974). Such species are sensitive to variation in climate during both summer and winter (Beever, Ray, Mote, & Wilkening, 2010; Bonardi, Corlatti, Bragalanti, & Pedrotti, 2017; Jacobson, Provenza, von Hardenberg, Bassano, & Festa-Bianchet, 2004; Pettolelli, Pelletier, von Hardenberg, Festa-Bianchet, & Côté, 2007; Willisch et al., 2013). Recent studies determined that survival of mountain goats (*Oreamnos americanus*) in coastal Alaska, USA was negatively related to both higher summer temperature and higher winter snowfall (White et al., 2011). This occurs because summer temperature can influence the energy balance of mountain ungulates directly, via behavioral responses to thermoregulatory stress, and indirectly, through effects on plant nutritional characteristics and availability (Aublet, Festa-Bianchet, Bergero, & Bassano, 2009; Fox, 1991; Lenart, Bowyer, Ver Hoef, & Ruess, 2002). For example, warm summer temperatures resulting in heat stress lead to reduced foraging rates and altitudinal shifts to suboptimal foraging habitats in alpine ungulates, such as ibex (*Capra ibex*) (Aublet et al., 2009). Warm summer conditions also influence the nutritional quality of food resources by accelerating growth and lignification of plant cell walls, which reduce digestible protein concentration of forage resources (Doiron, Gauthier, & Levesque, 2014; Lenart et al., 2002). At a landscape scale, such dynamics are further amplified by rapid melting of snow fields and subsequent protraction of green-up, a period when high-quality, early-phenological stage forages are most readily available (Fox, 1991). Variation in summer forage quality, even when small, can have a strong influence on herbivore nutritional condition and productivity due to multiplier effects (McArt et al., 2009; White, 1983). Such effects can be particularly pronounced in highly seasonal environments when nutritional reserves that animals accumulate during the summer growing season influence their subsequent vulnerability to malnutrition during the following winter (Mautz, 1978). During winter, deep snow significantly elevates energetic costs of locomotion and restricts availability of important winter forages through burial (Dailey & Hobbs, 1989; Fox,

1983; White, Pendleton, & Hood, 2009). The interactive effects of summer and winter climate on mountain goat survival are expected to have strong demographic consequences (Parker, Barboza, & Gillingham, 2009) and thus provide mechanistic insight into how climate influences alpine herbivores.

Assessing the “winners” and “losers” of climate change is a profound and critical conservation objective that has been addressed in a variety of different ecosystems (Bateman et al., 2015; Brodie et al., 2017; LaRue et al., 2013; Thompson, Handel, Richardson, & McNew, 2016). Yet, the effect of projected future changes in climate on most alpine vertebrates is unclear. General circulation models (GCMs) predict that coastal Alaska will experience warmer summer temperatures but less snowy winter conditions (Shanley et al., 2015). Since predicted summer and winter changes result in opposite effects on mountain goat survival, the net change in survival is likely to be related to the strength, range, and directionality of the respective summer (i.e., negative) and winter (i.e., positive) effects (White et al., 2011). For example, change in summer climate may be more influential than winter because the increase in summer temperature spans a larger continuum of the effect curve, as compared to winter snowfall (Shanley et al., 2015; White et al., 2011). However, since the winter effect on survival is stronger than the summer effect (i.e., the slope of the response curve), decreased winter snowfall may partially or completely compensate for predicted summer warming (Shanley et al., 2015; White et al., 2011). This example illuminates the potential complexity of climate change effects, and highlights the challenges associated with identifying the “winners” and “losers” of climate change. Derivations of realistic and actionable prognoses require detailed quantitative analyses based on a strong mechanistic understanding of species’ and climate relationships.

Demographic models are a powerful tool for integrating multiple sources of population data, including survival and reproductive data and associated ecological relationships. In the context of climate change, implementation of mechanistic modeling approaches offers the potential to provide realistic demographic outcomes that can be directly acted upon in conservation policy arenas (Pacifi et al., 2015). For example, the ability to project population sizes and trajectories for a given area at key points in time enables direct evaluation of conservation objectives (i.e., population status) and subsequent development of proactive conservation policy. For species with high human value, such as alpine ungulates, population status information represents the basic currency through which management decisions are made and conservation policy implemented.

In this study, we develop a sex- and age-structured population modeling approach designed to examine how climate affects population dynamics. We parameterize the model using data from a well-studied alpine ungulate system (mountain goats in coastal Alaska; White et al., 2011) and climate change model (i.e., GCMs) predictions to examine scenarios about how populations are expected to change in the future. Specifically, we examine the net result of reduced winter snowfall, which improves mountain goat survival, and increased summer temperature, which reduces survival, across a range of regionally relevant climate change and emissions scenarios

(sensu Shanley et al., 2015) on mountain goat population dynamics. Finally, we implemented a resource selection function (RSF) modeling approach to assess the degree to which increasing summer temperature would constrict available summer habitat. This provided a means to gauge whether behavioral adaptation (i.e., distributional shifts to higher elevation) could mediate effects of increased warming in extant summer ranges.

2 | MATERIALS AND METHODS

2.1 | Study system

Mountain goats are an iconic alpine ungulate species distributed throughout coastal and interior regions of western North America. Due to the extreme environments in which they inhabit, mountain goats have a conservative life-history strategy, relative to other temperate ungulates (Festa-Bianchet & Côté, 2008). Mountain goats are typically not physically and sexually mature until 4–6 years of age, rarely exhibit twinning, and have an average life span of 8 years (maximum age 15–18 years; Festa-Bianchet & Côté, 2008). A majority of mountain goats in North America live in northern temperate coastal areas in environments characterized by cool, wet summers, and snowy winters. In coastal areas, mountain goats typically exhibit seasonal migrations from high-elevation alpine summer habitat to lower elevation forested environments (Fox, Smith, & Schoen, 1989; Shafer et al., 2012; White & Gregovich, 2017). Seasonal migration to low-elevation, forested habitats during winter benefits mountain goats due to the reduced snow depths in such areas (Fox, 1983). Mountain goats are highly adapted for life in steep, rugged terrain, and exhibit strong selection for such terrain during both summer and winter (Fox et al., 1989; Shafer et al., 2012; White & Gregovich, 2017).

We modeled mountain goat population dynamics using climate data and projections for Juneau, Alaska, an area located near the geographic center of coastal mountain goat distribution and considered to be representative of North American coastal populations (Figure 1). Mountain goats in this region have been extensively studied (Fox, 1983, 1991; Fox et al., 1989; Shafer et al., 2012; White & Gregovich, 2017; White et al., 2011), and our previous research in this region has linked climate to mountain goat survival (White et al., 2011; Figure 1). Additionally, the Juneau International Airport (JIA) has a relatively long (1943–2014) time series of National Weather Service climate data, and served as the geographic reference for our climate data analyses and projections.

2.2 | Modeling approach

We developed a dual-sex, postbreeding, age-structured population model with 20 age classes (kids to 19+) to explore the impact of projected climate change from five GCMs and two emissions scenarios (details below; Figures 2 and 3). The population model is parameterized using published vital rates estimates and density-dependent relationships that vary at each annual time step in response to population density and summer/winter climate inputs (Houston & Stevens, 1988; Houston, Stevens, & Moorhead, 1994; Rice & Gay, 2010; White et al., 2011). Because temporal variation in adult survival can have a disproportionate influence on demographic outcomes (Gaillard, Festa-Bianchet, Yoccoz, Loison, & Toigo, 2000), the goal of our modeling efforts was to assess how change in projected climate influences adult survival and resultant demographic outcomes. To assess climate effects on long-term demography, we conducted a population viability analysis to determine the probability of quasi-extinction for mountain goats using three initial population sizes (at equal population density) for each GCM and emissions scenario.

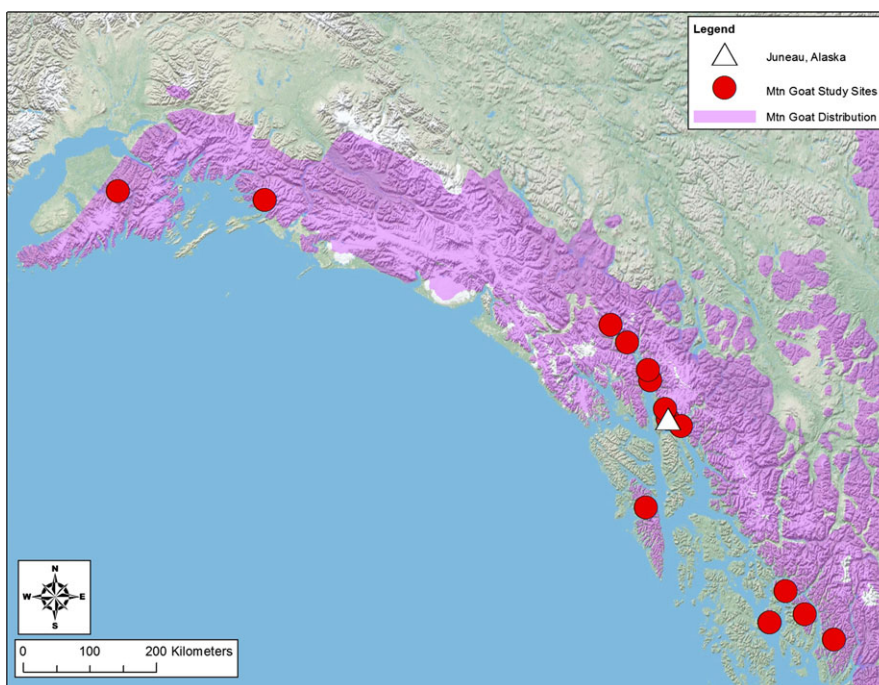


FIGURE 1 Map depicting mountain goat distribution in Alaska, USA and northwestern Canada. Study sites where field data were collected to parameterize mountain goat survival models are depicted by red circles (White et al., 2011, K. S. White, unpublished data). Juneau, Alaska is depicted by the white triangle and was used as the reference area for population simulations. Juneau, Alaska roughly coincides with the geographic center of mountain goat distribution in Alaska

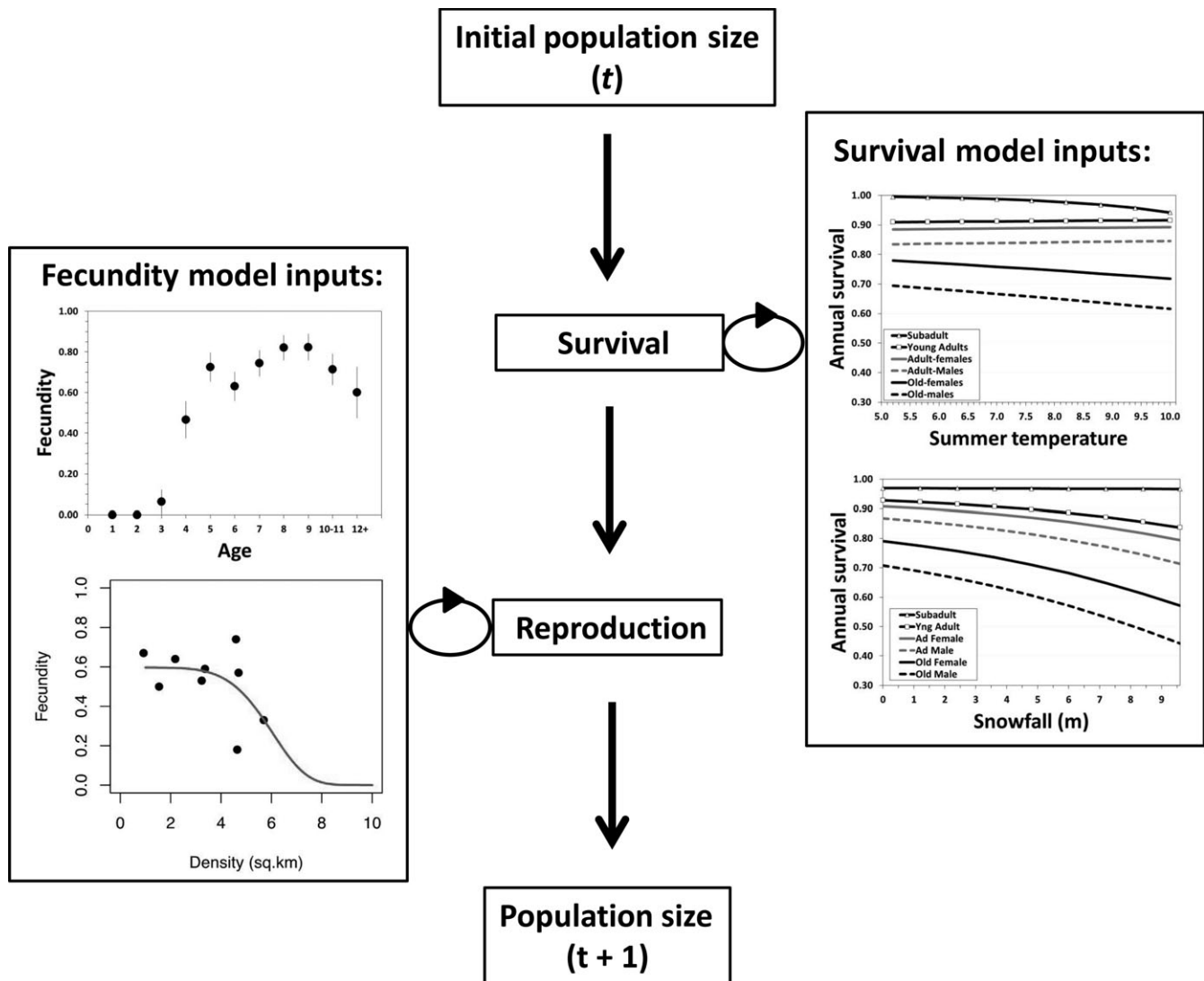


FIGURE 2 Conceptual diagram describing the dual-sex, postbreeding, age-structured population model used to examine demographic responses to GCM/RCP-based climate change scenarios. The model adjusts mountain goat survival for each sex and age class based on GCM predicted winter snowfall and summer temperature inputs for each annual time step. Mountain goat survival vs. climate relationships are based on White et al. (2011) and simulated based on the beta coefficient error distributions. Environmental stochasticity is simulated based on the statistical distributions of actual snowfall and summer temperature measurements recorded at the Juneau International Airport, Juneau, AK, USA, 1943–2014. Age-specific fecundity is modified based on density-dependent relationships. GCM, general circulation models; RCP, representative concentration pathway

Since we hypothesized that mountain goat populations would decline due to negative effects of increasing summer temperatures, we further examined a scenario involving the implications of behavioral adaptation to increasing temperature. Given that mountain goats are capable of shifting to higher elevations in order to mediate thermal stress, we used a habitat modeling approach to calculate how shifts to demographically thermoneutral elevations (i.e., the elevation that coincided with temperatures values required for $\lambda = 1.0$) reduced summer range carrying capacity. In this manner we were able to assess the implications of mountain goat adaptation to climate change.

To summarize, we first examine demographic outcomes for mountain goats in their current range. We then allow mountain goats to adapt to increasing summer temperatures and shift to

higher elevations, which we use to quantify the extent to which adaptation reduces summer range carrying capacity. Our adaptation results are conservative because of the expected temporal mismatch, or delay, between increasing temperature and growing season length and the subsequent soil development and plant colonization following high-elevation glacial recession (i.e., the highest elevation predicted habitats are unlikely to be immediately utilized by mountain goats, even if temperatures are suitable; sensu Jumpponen, Brown, Trappe, Cázares, & Strömmer, 2012).

2.3 | Sex- and age-structured population model

We used field data, literature values, and a statistical survival model based on 1,179 mountain goat-years to parameterize a sex- and

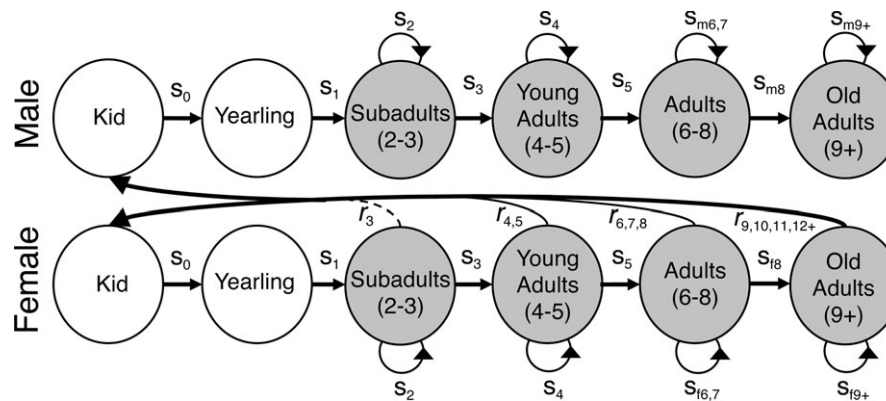


FIGURE 3 Mountain goat life cycle graph describing the dual-sex, postbreeding, age-structured population model used to examine demographic responses to GCM/RCP-based climate change scenarios. The model was implemented with 20 age classes (kids to 19+) for each sex but is simplified as a stage-structured model in the life cycle diagram for display purposes. Model description: S_0 = kid survival (no sex or climate effect; based on values from Rice & Gay, 2010), S_1 = yearling survival (no sex or climate effect; White et al., 2011), $S_{2,3}$ = 2- and 3-year-old survival (no sex effect, climate effects apply; White et al., 2011), $S_{4,5}$ = 4- and 5-year-old survival (no sex effect, climate effects apply; White et al., 2011), $S_{6,7,8}/S_{6,7,8}$ = 6-, 7-, and 8-year-old survival (sex and climate effects apply; White et al., 2011), S_{9+}/S_{9+} = 9+-year-old survival (sex and climate effects apply; White et al., 2011); r_{3-12+} = age-specific fecundity (Table S3) (no climate effect; density-dependent effects apply [Houston & Stevens, 1988; Houston et al., 1994, Fig. S4]). GCM, general circulation models; RCP, representative concentration pathway

age-structured stochastic population model (Figures 2 and 3, Appendix S1). To derive survival estimates we used the known-fates model in program MARK and RMARK (Cooch & White, 2016, Appendix S1). Specifically, we used the top model (determined via AIC model selection procedures; sensu Burnham & Anderson, 2002) published by White et al. (2011) in order to parameterize the effects of climate on sex- and age-specific mountain goat survival for all age classes, except kids. Estimates of kid survival were based on the average survival across studies reported by Rice and Gay (2010). Nonkid survival estimates were derived based on field data collected between 1977 and 2014 (1,179 goat-years, 447 radio-marked goats) in 10 different study areas located in coastal Alaska (White et al., 2011, K. S. White, unpublished data; Table S2a–b). White et al. (2011) estimated survival based on summer temperature and winter snowfall for all nonkid age classes. Overall, these models indicated that survival varied with respect to sex and age class. Furthermore, winter survival was negatively affected by the previous summer temperature (during July–August) and total winter snowfall (White et al., 2011). Fecundity was based on age-specific estimates derived from field data collected in coastal Alaska (K. S. White, unpublished data; Table S4) and modified based on previously described density-dependent relationships (Houston & Stevens, 1988; Houston et al., 1994; see below).

To account for uncertainty, we sampled from within the error distribution surrounding the beta coefficients (i.e., the effect of summer temperature and winter snowfall on survival) accounting for covariance structure among coefficients using the RMark package in R (Laake, 2013). We ran 1,000 iterations of our population model for each GCM and emissions scenario using stochastic annual survival estimates for each sex and age to propagate uncertainty in the relationship between climate variables and survival. Each GCM and

emissions scenario provided the expected change in temperature and precipitation as snow for the years 2025, 2055, and 2085; values for intervening years were interpolated. To implement environmental stochasticity around these expected values, we modeled temperature as a normally distributed random variable and precipitation as snow as a lognormally distributed random variable. The standard deviation of both distributions was parameterized using the observed variance in the residuals around a trend fit to summer temperature and $\ln(\text{winter precipitation as snow})$ using the JIA temperature record from 1943 to 2014. To reduce initial transient effects, we initialized each model based at the stable age distribution from a density-independent model run with the mean survival estimates.

We implemented density-dependent fecundity to more accurately project the mountain goat population through time and assess the probability of quasi-extinction by 2085 (quasi-extinction threshold of $N < 2$ individuals). Density-dependent effects reduced fecundity according to a statistical relationship fit to data from Houston and Stevens (1988) and Houston et al. (1994) following the S-shaped function from the per-capita formulation of the Ricker discretization of the theta-logistic model. This model has the desirable properties of a wide shoulder maintaining high fecundity at low population densities followed by a decline in fecundity toward zero at high densities, given by

$$F(D) = F_0 e^{-\left(\frac{D}{K}\right)^\theta} \quad (1)$$

$F(D)$ is the fecundity of females at population density (population size/km²) D , F_0 is the maximum fecundity, which occurs as density approaches 0, and K and θ are parameters that determine the shape of density-dependent declines in fecundity. Maximum likelihood estimates for F_0 , K , and θ were fit with simulated annealing using the *likelihood* package in program R with data from Houston and Stevens

(1988) and Houston et al. (1994) (Fig. S4). We then used field data from mountain goat populations in southeast Alaska to incorporate age-specific maximum fecundity (Appendix S3, Table S3) using the equation:

$$F_a(D) = F_a(0)e^{-\left(\frac{D}{K}\right)^\theta}, \quad (2)$$

where $F_a(0)$ is a field-derived estimate of maximum fecundity for female mountain goats with age a , $F_a(D)$ is the density- and age-dependent fecundity, and K and θ remain unchanged.

For each GCM and emissions scenario, we used the proportion of 1,000 model runs that fell below $N = 2$ to estimate the probability of quasi-extinction by 2085. Because the probability of extinction depends on the initial population size, we ran each model with initial small, average, and large mountain goat populations ($N = 50, 300, 1,000$; defined based on field surveys from coastal Alaska, K. S. White, unpublished data). All models began with a population density of one mountain goat per km^2 , well below the onset of significant density-dependent reductions in fecundity, so that we could understand the effect of climate change rather than site-specific effects due to densities that approach carrying capacity. Initial climate values (total winter snowfall [m] and mean daily temperature [$^{\circ}\text{C}$]—July/August) were based on the average values for the JIA during the 20 years preceding our start time (1994–2014).

2.4 | General circulation models

To examine the effects of climate change on mountain goat population demography, we considered five different GCMs determined to perform well for coastal Alaska (Radic & Clarke, 2011; Walsh, Chapman, Romanovsky, Christensen, & Stendel, 2008) and previously used to assesses ecological implications of climate change in the North Pacific (Shanley et al., 2015). These models (CCSM4, GFDL-CM3, GISS-E2-H, IPSL-CM5B-LR, and MRI-CGCM3) were each parameterized based on two different (“worst case” and “best case”) representative concentration pathway (RCP) scenarios: (1) RCP4.5 which assumes low–medium emissions and (2) RCP8.5 which assumes a “business-as-usual” high emissions scenario. Models were run using the CLIMATEWNA software (version 4.85; Wang, Hamann, Spittlehouse, & Murdock, 2012) to derive annual estimates (2015–2085) of precipitation as snow (PAS; mm) and mean temperature ($^{\circ}\text{C}$) during July/August for the JIA. Since our mountain goat survival models required estimates of total annual snowfall and July/August temperature at 914 m (i.e., average mountain goat elevation during summer), we used historic data from the JIA (1943–2014) to calculate total annual snowfall based on PAS (Fig. S5), and adjusted JIA summer temperature estimates using the standard environmental lapse rate ($-6.5^{\circ}\text{C}/1,000 \text{ m}$; Barry & Van Wie, 1974), following White et al. (2011). The resulting summer and winter climate estimates were then input into the population model at annual time steps to derive sex- and age-specific survival estimates and model mountain goat demographic performance for each GCM and emission scenario.

2.5 | Habitat modeling simulations

Resource selection function models (*sensu* Boyce, Vernier, Nielsen, & Schmiegelow, 2002; Fieberg, Matthiopoulos, Hebblewhite, Boyce, & Frair, 2010) were developed for a 300- km^2 study area in the Kakuhan Range, AK (60–100 km north of the JIA) by White and Gregovich (2017), and used to estimate the amount of summer range habitat. RSF models predicted the relative probability of use of mountain goats for given 5-m pixels across the landscape and were based on empirically derived mechanistic relationships between mountain goat use and availability for multiple covariates such as elevation, distance to cliffs, slope, terrain ruggedness, and solar exposure (an index of plant productivity in wet, coastal environments). These variables represent biologically relevant correlates of ecophysiologic niche requirements of mountain goats as they relate to foraging conditions, predation risk, thermal constraints, and winter snow conditions. Specifically, RSF modeling indicated that mountain goats selected areas with high elevation, close proximity to cliffs, moderate-steep slopes, high terrain ruggedness, and high solar exposure during summer (White & Gregovich, 2017). Models had high predictive performance based on k -fold cross-validation analysis criteria (Boyce et al., 2002; White & Gregovich, 2017). Rasterized RSF surfaces were postprocessed to determine the amount of important summer habitat using methods described by Fedy et al. (2014).

We coupled this habitat modeling framework with GCM/RCP population modeling outputs to determine the extent to which mountain goat summer habitat is reduced if mountain goats adapt to climate warming by shifting to higher, “thermoneutral” elevations. Thermoneutral elevations were defined as the mean elevation that mountain goats currently inhabit in the Kakuhan Range case study area (mean elevation = $896 \pm 163 \text{ m}$, $n = 104$ GPS collared mountain goats between 2005 and 2015); due to the current existence of mountain goats in this distribution we consider such areas to be demographically stable, or thermoneutral. First, we determined the predicted change in summer temperature for each GCM between 2015 and 2085. We then multiplied that quantity by the standard environmental lapse rate ($-6.5^{\circ}\text{C}/1,000 \text{ m}$; Barry & Van Wie, 1974) to determine how many meters a mountain goat would need to shift upslope to occupy an environment thermally identical to the mean summer elevation that mountain goats use during the current (2005–2015) time period (i.e., the current thermoneutral elevation). The estimated upslope altitudinal shift for each GCM/RCP scenario was added to the digital elevation model raster input layer for each customized GCM/RCP model run. The resulting RSF model output assumed that future mountain goat resource selection patterns for all model covariates would be identical to the current time period with the exception of elevation, which was shifted upslope to a degree dictated by the GCM/RCP under consideration. Finally, we compared how the amount of summer range differed between each GCM/RCP scenario—that is, how the amount of summer range available for mountain goats would be reduced in order for mountain goats to occupy a thermoneutral environment in the future.

3 | RESULTS

3.1 | General circulation models

All GCMs predicted similar trends in climate change between 2015 and 2085, however the degree of change differed between each GCM/RCP scenario (Table 1). Specifically, GCMs predicted that winter snowfall will decrease between 0.4 and 1.6 m (mean = 1.1 m) and summer temperature will increase between 1.3 and 6.0°C (mean = 3.5°C) between 2015 and 2085. As expected, the RCP8.5 emissions scenarios resulted in greater change than the RCP4.5 scenarios. Among the GCMs, the CCS, GFDL, and IPSL models predicted greater changes (i.e., “worst case scenarios”) than the MRI and GISS models (i.e., “best case scenarios”).

3.2 | Population projections

Mountain goat demographic performance was negatively influenced by predicted changes in future climate for all GCMs considered (Table 2, Figure 4). The CCS, GFDL, and IPSL climate modeling scenarios all resulted in simulated populations with a mean trajectory reaching extinction by 2085; the GISS and MRI models resulted in greatly reduced densities by 2085 relative to the baseline (i.e., the “no climate change” scenario), but the mean mountain goat

population trajectory did not yet fall to extirpation (Table 2, Figure 4). As expected, higher emissions scenarios (RCP8.5) resulted in higher likelihood and faster rates of extinction than the low emission scenarios (RCP4.5; Table 2). In cases where populations went extinct for a given GCM for both RCP emission scenarios, populations went extinct 17 years sooner, on average, for the RCP8.5 scenario, as compared to the RCP4.5 scenario (Table 2). Given that GCMs predicted a decline in total annual snowfall and increase in average daily summer temperature between 2015 and 2085, our population simulations indicate the negative effects of increasing summer temperature exert a stronger effect on mountain goat population demography than the positive effects of decreasing winter snowfall.

3.3 | Initial population size

A larger initial population size reduced the likelihood that a population fell to quasi-extinction (Table 2, Figure 4). A higher proportion of model simulations resulted in extinction for small (0.50; 5/10 scenarios), relative to medium (0.30; 3/10), and large population sizes (0.30; 3/10; Table 2, Figure 4). However, in the CCS-RCP4.5 and GFDL-RCP4.5 scenarios, 92.5%–99.9% of simulated populations went extinct for medium- and large-sized populations suggesting that extinction would likely occur over slightly longer time frames than considered in our analyses (Table 2, Figure 4). Small populations also tended to go extinct sooner than larger populations (Table 2, Figure 4). In the three scenarios where all-sized populations went extinct, small populations went extinct 6–8 years sooner than medium-sized populations and 9–12 years sooner than large-sized populations (Table 2, Figure 4).

3.4 | Habitat modeling simulations

At current conditions, RSF modeling indicated that 179 km² of important summer habitat existed in the 300 km² Kakuhan Range reference study area. Summer temperature lapse rate/elevation shift simulations indicated that the relationship between summer temperature and summer habitat was nonlinear due to the variable, but generally conical, shape of the mountain landscape (Figures 5 and 6). Specifically, the amount of summer habitat slightly increased as summer temperature increased up to 0.9°C above the baseline temperature (7.39°C), but then decreased rapidly; a temperature increase of 8.45°C resulted in complete elimination of existing summer range habitat conditions (Figure 5). Depending on the GCM/RCP scenario considered, the simulated change in summer habitat varied between a net loss of 153 km² (86% decline) and a net gain of 3 km² (1% increase) between 2015 and 2085 (Figure 5). Overall, 9 of 10 scenarios resulted in a net loss of summer habitat and 7 of 10 scenarios resulted in a net loss of 17%–86% of summer habitat (Figure 5).

4 | DISCUSSION

General circulation models predict that mountain goat populations in our coastal Alaska study area will experience increases in summer

TABLE 1 Observed and predicted mean daily summer temperature (July–August) and total annual snowfall for Juneau, AK, USA. Observed baseline values (i.e., 2015) represent the mean values for the preceding 20-year period (1995–2015). Predicted values (i.e., 2085) were derived based on 10 general circulation model (GCM) and representative concentration pathway (RCP) scenarios (Wang et al., 2012); GCM/RCP emission scenarios span a continuum of “best case” to “worst case” scenarios. Temperature values were adjusted using the standard environmental lapse rate and represent predicted temperature at 912 m (i.e., mean elevation of mountain goat summer range). These climate values were used as inputs to mechanistically model the effects of climate on mountain goat survival (via White et al., 2011) and population demography

GCM scenario	Temperature (°C)			Snowfall (m)		
	2015	2085	Change	2015	2085	Change
RCP 4.5						
CCS	7.4	11.2	3.8	2.3	1.3	−1.0
GFDL	7.4	10.9	3.5	2.3	1.2	−1.1
IPSL	7.4	10.2	2.9	2.3	1.3	−1.1
MRI	7.4	8.9	1.5	2.3	1.5	−0.8
GISS	7.4	8.7	1.3	2.3	2.0	−0.4
RCP 8.5						
CCS	7.4	13.4	6.0	2.3	0.8	−1.5
GFDL	7.4	12.5	5.2	2.3	0.9	−1.4
IPSL	7.4	13.2	5.8	2.3	0.7	−1.6
MRI	7.4	10.3	3.0	2.3	1.1	−1.2
GISS	7.4	9.7	2.3	2.3	1.4	−1.0
Average	7.4	10.9	3.5	2.3	1.2	−1.1

TABLE 2 Projected mountain goat demographic responses to climate change scenarios over a 70-year time period (2015–2085), referenced on Juneau, AK, USA. Populations were simulated for three different initial population sizes (i.e., small, medium, and large) across 10 different GCM/emission scenario combinations. Initial population sizes coincide with observed naturally occurring populations sizes. Populations were simulated 1,000 times for each combination and varied based on model-based and climatic stochasticity. GCM/RCP emission scenarios span a continuum of “best case” to “worst case” scenarios

GCM	% Extinct by 2085 ^a			Years to extinction ^b			Years to 50% extinction ^c		
	Initial pop size			Initial pop size			Initial pop size		
	50	300	1,000	50	300	1,000	50	300	1,000
RCP 4.5									
CCS	100.0	99.9	98.5	63	>70	>70	43	53	59
GFDL	100.0	99.3	92.5	68	>70	>70	45	56	63
IPSL	65.8	7.8	0.4	>70	>70	>70	68	>70	>70
MRI	0.0	0.0	0.0	>70	>70	>70	>70	>70	>70
GISS	0.0	0.0	0.0	>70	>70	>70	>70	>70	>70
RCP 8.5									
CCS	100.0	100.0	100.0	45	53	56	35	41	46
GFDL	100.0	100.0	100.0	53	60	65	40	48	52
IPSL	100.0	100.0	100.0	55	61	64	43	50	53
MRI	2.9	0.1	0.0	>70	>70	>70	>70	>70	>70
GISS	0.0	0.0	0.0	>70	>70	>70	>70	>70	>70
Baseline	0.0	0.0	0.0	>70	>70	>70	>70	>70	>70

GCM, general circulation model; RCP, representative concentration pathway.

^a% of population simulations going extinct by 2085.

^bNumber of years until 100% of population simulations go extinct.

^cNumber of years until 50% of population simulations go extinct.

temperature, which should negatively influence survival, and decreases in winter snowfall, which should improve survival. Our mountain goat population models predict that climate change will exert negative demographic effects on mountain goat populations in all scenarios. Specifically, population modeling predicted that climate change would result in lower mountain goat population densities in all scenarios compared to the baseline (i.e., no climate change) scenario. In addition, analyses predicted a net decline in mountain goat populations by 2085 in 9 of 10 scenarios, and a mean trajectory indicating extirpation in 5 of 10 scenarios. Overall, these findings indicate that negative changes linked to increasing summer temperature are more important in influencing mountain goat population demography than positive changes associated with decreasing winter snowfall.

4.1 | Importance of summer vs. winter effects

The predicted negative demographic outcomes of climate change result from the magnitude and directionality of change in summer vs. winter climate. For example, in the “worst case” scenario (CCS/RCP8.5) survival of old female mountain goats (9+year-old, the female age class most sensitive to climate effects) was predicted to decline 9% due to the predicted 6°C increase in summer temperature (2015 = 7.4°C, 2085 = 13.4°C), but only increase 2% due to the predicted 1.5 m decrease in winter snowfall (2015 = 2.3 m, 2085 = 0.8 m). Quantitatively, this outcome occurs because the

change in summer temperature spans a range of values where the slope of the effect curve is steeper, relative to winter snowfall. Consequently, future changes in snowfall are expected to have small, declining effects, whereas summer temperature is expected to exert increasingly stronger and negative effects on mountain goat survival and ultimately population dynamics.

Herbivore survival in highly seasonal alpine environments requires substantial accumulation of endogenous energetic reserves during the summer growing season (up to 25%–30% of total body mass in mountain goats; K. S. White, unpublished data) in order to survive winter seasons characterized by severe nutritional deprivation (Mautz, 1978; Parker et al., 2009). Consequently, summer growing season conditions have important implications for survival during the following winter (White et al., 2011). Warm summer temperatures can negatively influence herbivore nutrient assimilation via direct and indirect ecological mechanisms. For example, during cool summers slower plant growth and reduced lignification of cell walls lead to production of more digestible forages and higher quality animal diets (Bo & Hjeljord, 1991; Doiron et al., 2014; Lenart et al., 2002; Weladji, Klein, Holand, & Myrsetrud, 2002). Small changes in forage nutritional characteristics can lead to disproportionately large responses in animal nutritional condition and productivity via multiplier effects (McArt et al., 2009; White, 1983). Warm growing season temperature can also accelerate snow melt and lead to a more rapid green-up (Pettorelli et al., 2007), particularly if preceded by mild winter conditions. This results in an overall reduction in the

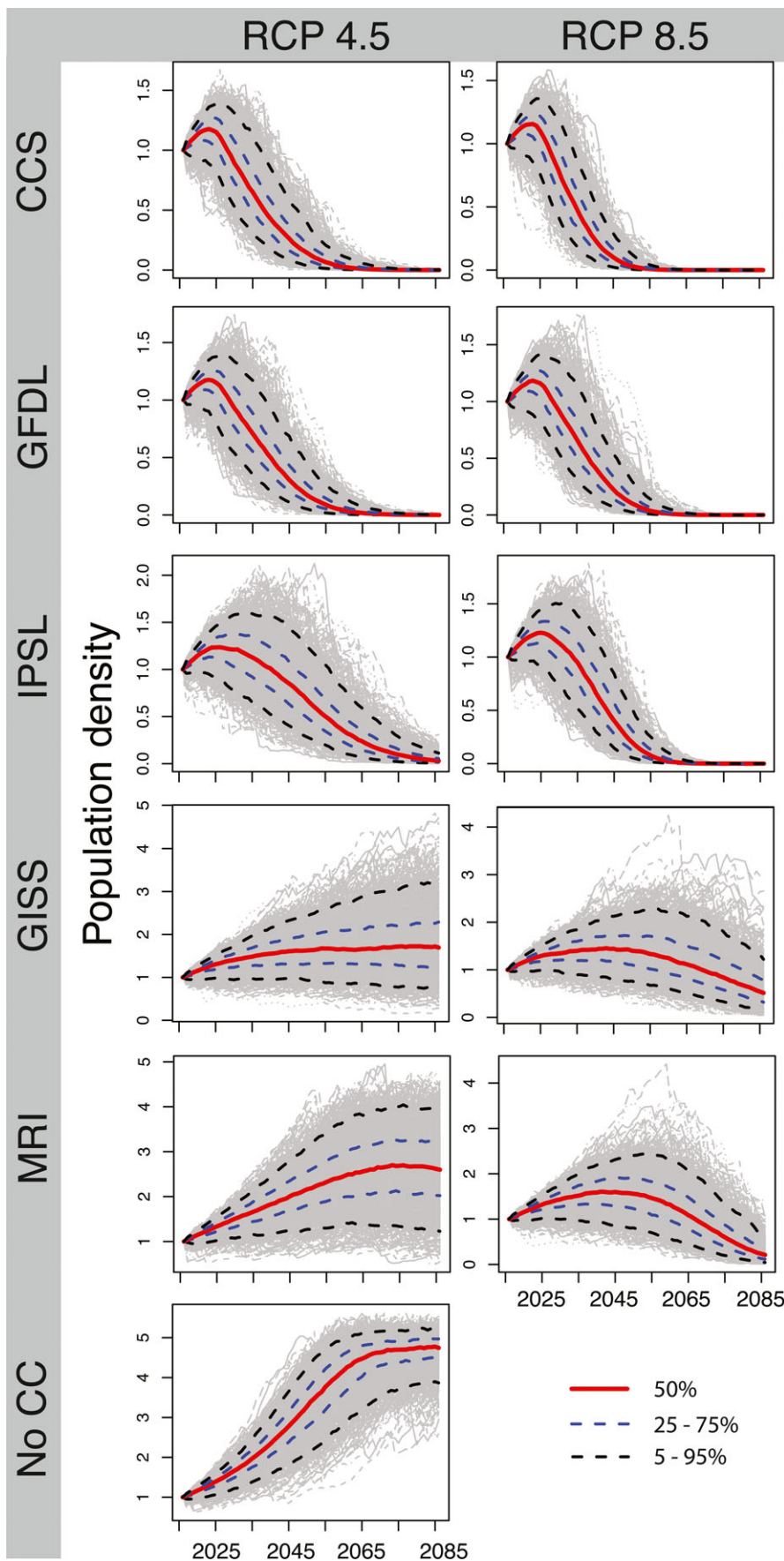


FIGURE 4 Projected mountain goat demographic responses to climate change scenarios over a 70-year time period (2015–2085); climate scenarios are referenced on Juneau, AK, USA. Populations were simulated for three different initial population sizes (i.e., small, medium and large) across 10 different GCM/emission scenario combinations. Initial population sizes coincide with observed naturally occurring populations sizes. In this example, relationships are described for medium-sized ($n = 300$) populations. GCM/emission scenarios span a continuum of “best case” to “worst case” scenarios. GCM, general circulation models

temporal availability of high-quality early-phenological stages forages across alpine landscapes which can negatively influence juvenile growth and survival in alpine ungulates (Pettorelli et al., 2007). Yet,

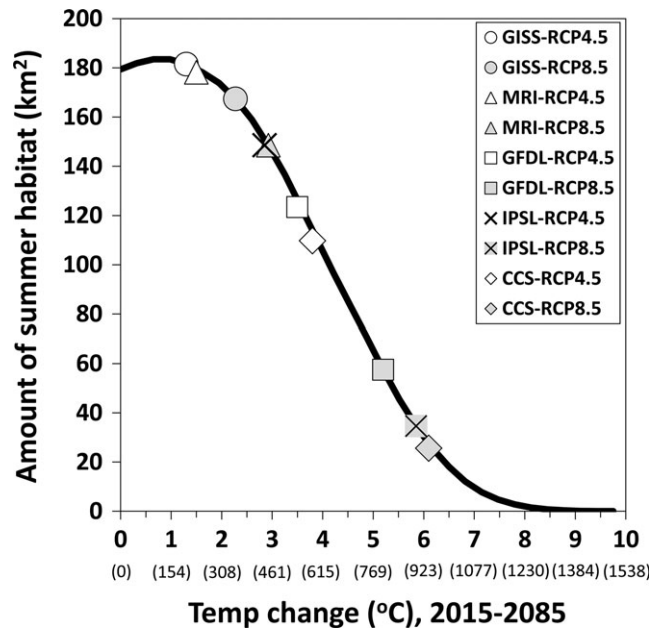


FIGURE 5 Relationship between predicted summer temperature change and the amount of summer habitat (based on RSF modeling) predicted for 10 different GCM/RCP scenarios in the Kakuan Range, AK, USA. Temperature change represents the difference between mean daily summer temperatures (July–August) observed in 2015 and predicted values for 2085 based on GCM/RCP models. Standard environmental lapse rates ($-6.5^{\circ}\text{C}/1,000\text{ m}$) were used to calculate altitudinal shifts (in parentheses on x-axis; meters) required by mountain goats to inhabit environments thermally equivalent to 2015 distributions. GCM, general circulation models; RCP, representative concentration pathway

summer temperature not only influences the availability of high-quality food resources across the landscape, but also the efficiency through which herbivores can procure them. Cold-adapted large mammalian herbivores are physiologically sensitive to heat stress (Renecker & Hudson, 1986) and during hot summer periods may reduce foraging rates and shift to suboptimal foraging habitats (Aublet et al., 2009). Overall, the net effect of warm summer temperatures on mountain goat survival is linked to environmental and behavioral processes that regulate assimilation of nutrient reserves needed to survive long winter periods. While extreme winter conditions (i.e., high snowfall) can exert strong negative effects on mountain goat survival, our modeling results indicate that the positive effects of mild winter conditions are relatively weak and not able to completely compensate for the deleterious effects of predicted future increases in summer temperature.

4.2 | Initial population size effects and environmental stochasticity

Population size can exert strong effects on population persistence and extinction (Lande, 1988) and such effects may be more pronounced in large bodied mammals with slow life-history strategies (Cardillo et al., 2005). In alpine ungulates, small populations exhibit greater vulnerability to extinction than large populations (Berger, 1990; Hamel, Côté, Smith, & Festa-Bianchet, 2006). This occurs because smaller populations exhibit heightened sensitivity to demographic and environmental stochasticity. Consistent with such expectations, our analyses documented increased extinction risk in small populations due to negative effects of climate change over a relatively short (70 years) time period. Mountain goats are capital breeders that exhibit slow life-history strategies (i.e., late age at first reproduction, small litter size, frequent reproductive pauses, long

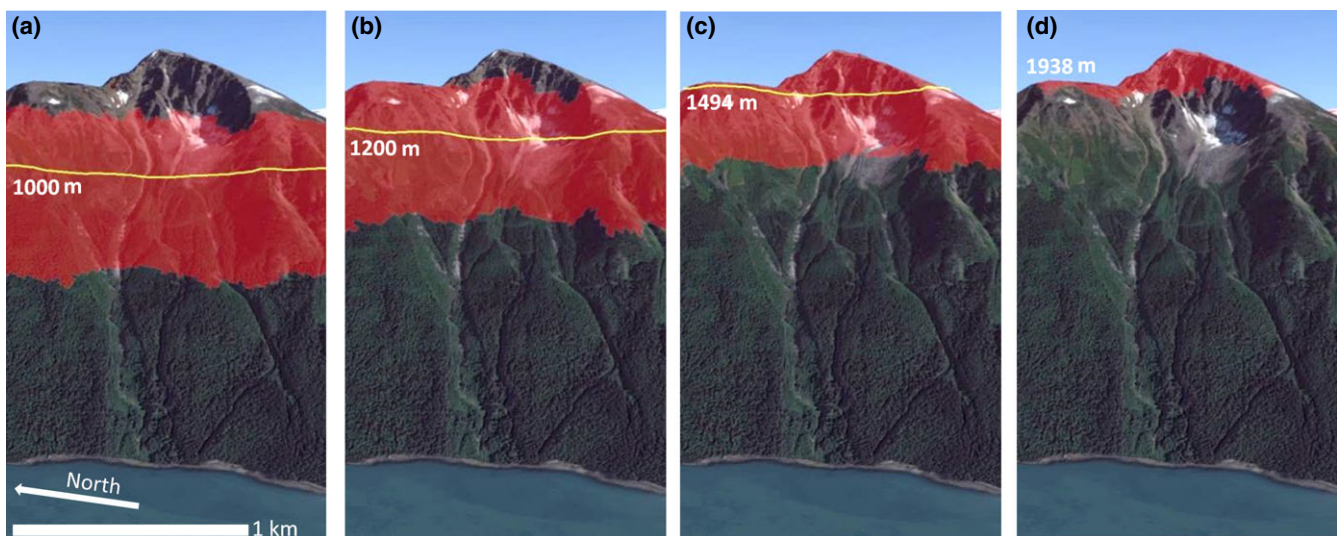


FIGURE 6 Resource selection function modeling output describing predicted changes in mountain goat summer habitat distribution for four scenarios: (a) current distribution (2005–2015 baseline conditions), (b) year 2085, GCM-GISS-RCP4.5 ("best case scenario"), (c) year 2085, GCM-MRI-RCP8.5/GCM-GFDL-RCP4.5 midpoint ("intermediate scenario"), and (d) year 2085, GCM-CCS-RCP-8.5 ("worst case scenario")

generation times), relative to other similar sized ungulates (Festa-Bianchet & Côté, 2008). These characteristics result in relatively low reproductive productivity and influence the capability of populations to rapidly recover from deleterious stochastic events. When populations are small, short interval recurrence of negative stochastic events can lead to rapid extinction due to the limited demographic capability to recover via reproduction. Climate change can thus have multidimensional effects on mountain goat demography. For example, our findings have emphasized the long-term negative effects of slow, incremental increases in mean summer temperature. However, extreme stochastic events in summer temperature and winter snowfall can both have short-term, but severe, negative demographic consequences that can require extended periods for population recovery. In contrast, extreme stochastic events that positively influence mountain goat demography are likely exert modest, or negligible population responses, due to the slow life-history strategy and low reproductive capability of the species which influence their ability to capitalize on favorable conditions. Consequently, these dynamics are likely to become increasingly relevant to the viability of mountain goats, and other similarly affected alpine species, if the likelihood of extreme stochastic events that negatively influence population demography increases over time—a prominent prediction of recent global climate change analyses (IPCC, 2012).

4.3 | Habitat change and behavioral adaptation

Large mammalian herbivores commonly track phenological or other beneficial environmental changes that occur spatially and temporally across seasonally dynamic landscapes (Armstrong, Takimoto, Schindler, Hayes, & Kauffman, 2016; Bischof et al., 2012; Hebblewhite, Merrill, & McDermid, 2008). In mountainous environments, species such as mountain goats exhibit seasonal migrations from low-elevation winter ranges to high-elevation alpine summer ranges in order to track the availability of high-quality, early-phenological stage forages as they emerge at the edge of melting snow patches (Fox, 1991; Pettoirelli et al., 2007). Such altitudinal migrations also enable animals to inhabit cooler summer environments, where heat stress events which negatively influence nutritional intake are less common (Aublet et al., 2009). Our population models suggest that under most climate change scenarios mountain goat populations are likely to decline, often to extinction, due to increases in summer range temperature (i.e., a proxy of nutritional and thermoregulatory constraints; White et al., 2011). Yet, our population models are based on population performance at average elevational distribution used by mountain goats during 1977–2014 and do not explicitly consider the consequences of mountain goats mitigating future summer warming by shifting to higher elevations where temperatures would more closely resemble current, thermoneutral conditions. We investigated the implications of this behavioral adaptation using a novel RSF modeling approach that enabled us to determine the amount of change in areal extent of summer range for each GCM/RCP scenario over a 70-year time horizon. These simulations predicted that under nearly all scenarios thermoneutral mountain goat summer range

would contract across our reference landscape. Consequently, we conclude that behavioral adaptation to summer warming by shifting to higher elevations could result in demographic stability, but would result in net reductions in summer range carrying capacity. Under the most extreme scenario, mountain goat summer range carrying capacity would decline by 86%. We consider our analyses to be conservative because a portion of the predicted “new” highest elevation habitat may not actually be suitable because of time lags between the occurrence of warmer temperatures (that facilitate plant primary productivity) and the development of soils and vegetation colonization of recently deglaciated or barren landscapes (Jumpponen et al., 2012). Furthermore, our analyses do not directly account for habitat shrinkage effects on fragmentation and connectivity—dynamics that would be expected to further reduce functional carrying capacity and utilization of future summer range (Bennett, 2003). Overall, behavioral adaptation can be considered a stopgap measure and is unlikely to fully mitigate summer range climate change effects on mountain goat demography, though dynamics are likely to be complex.

4.4 | Modeling considerations, constraints, and inference

Our modeling approach represents a powerful tool for quantifying explicit effects of climate change on population size—a universally meaningful currency required to assess conservation threats, successes, and failures. This approach is based on mechanistic field-derived relationships between species demographic rates and climate that rely on extensive, long-term data collection and explicitly account for parameter uncertainty at multiple stages of analyses. This framework allows for evaluation of consistent and strongly directional demographic responses across multiple climate modeling scenarios and thereby enable a robust determination of effects. The resulting population-level inference associated with this approach can significantly improve our capability to address conservation challenges relative to alternative methods such as correlative species distribution and bioclimate envelope modeling that may be better suited for complementary analyses (Pacifi et al., 2015; Pearson & Dawson, 2003). Furthermore, our mechanistic modeling approach is flexible and can be used for multiple applications involving conservation of mountain ungulates as well as other alpine or nonalpine species. While our analyses have highlighted relatively long time-horizon modeling outputs (i.e., 70 years), the modeling framework can be easily adapted to address “real-time” applications such as those required to make short-term population conservation and management decisions. Thus, possible modeling applications can range from the assessment of long-term effects of climate change on alpine ecosystems to the short-term effects of climate conditions in 1 year on resultant population performance the following year.

Parameterization of mechanistic population models is data intensive and can constrain model inference. In this study, our goal was to directly assess the effects of climate change on mountain goat survival and resultant demographic outcomes using previously

published mechanistic models from our study system derived from an extensive long-term data collection effort (White et al., 2011). Given that variation in adult survival typically exerts the strongest influence on ungulate demographic outcomes (Gaillard et al., 2000), we consider our modeling outcomes to be realistic yet certain constraints apply. Specifically, our models would be strengthened if data were available within our study system to model mechanistic relationships between climate and age-specific reproduction, kid survival, and density dependence. In addition, our models do not incorporate meta-population dynamics and thus the spatial-demographic context of our reference study site and surrounding landscape is not considered. Our models are also specific to mountain goat populations inhabiting coastal environments, and it is unclear whether populations living in drier, colder interior climates are influenced by climate in a comparable manner. Finally, we considered extinction to occur when a simulated population dropped below two individuals, yet genetic- or demographic-linked effects of small population size may begin to occur when populations are larger than our predefined extinction threshold. Overall, we expect our modeling approach to substantially improve the capability to address conservation challenges associated with climate change and species conservation yet future refinements will be beneficial and expand its utility and enable a broader range of conservation applications.

4.5 | Conservation implications

Global climate change is considered to be among the most profound conservation challenges of our generation (Intergovernmental Panel on Climate Change, 2012). To a significant degree, existing analyses suggest the prognosis for many species and ecosystems is negative (Urban, 2015). In alpine and arctic environments change is occurring at a particularly rapid rate, relative to other ecosystems, and may have far-reaching implications. Mountain ungulates are iconic species that have high ecological and human value. Due to their unique adaptations for living in mountain environments they occupy a specialized ecophysiological niche that tightly overlaps alpine ecosystems. In such environments, mountain goat population dynamics are linked to climate via direct effects on thermoregulation and energetics, and indirectly through climate effects on plant phenology, population dynamics, and community ecology. In this context, mountain ungulates are sentinel species of alpine environments and population status can be considered a barometer of ecosystem function, viability, and resilience. Yet based on our analyses, the future viability of mountain goat populations is uncertain due to the opposing demographic effects of projected reductions in winter snowfall and increasing summer temperature.

Consideration of multiple GCMs and emissions scenarios provided a comprehensive assessment of future demographic outcomes for mountain goats inhabiting North Pacific coastal environments. Overall, our simulations indicated that mountain goat quasi-extinction probabilities were more influenced by the GCM considered than associated RCP emissions scenario, suggesting that modest emissions reductions may not be sufficient to maintain viable mountain goat

populations within their current range. Mountain goat quasi-extinction probabilities were higher for the most pessimistic GCMs and associated emissions scenarios, but all climate change scenarios resulted in significant reductions in population size and growth rate, including complete extirpation for 3 of the 5 GCMs for the 70-year time frame investigated. For the two GCM scenarios not resulting in extinction (on average), population trajectories remained largely negative, indicating that extirpation from current range is likely, given a longer time frame. These effects may be partially ameliorated by mountain goat range expansion upslope, but upward migration leads to reductions in the areal extent of summer range and may not be possible on the time scale of climate warming due to the multi-decadal delay of soil development and plant colonization following glacial recession. While our projections were spatially constrained, and also subject to other considerations (see above), they are likely relevant to a broad array of populations given our analyses were centered near the geographic center of the coastal mountain goat distribution. Overall, our results suggest that change in atmospheric policy leading to reduced emissions will marginally benefit mountain goat populations, perhaps providing time for higher elevation habitats to develop; although alpine ungulates already occupy the highest available elevation in many areas. Nonetheless, long-term strategic and effective conservation efforts focused on emissions reductions are likely to be beneficial and should be encouraged in order to maximize alpine ungulate, and ultimately ecosystem, viability, and resilience. In the near-term, research initiatives and conservation planning efforts focused on advancing mechanistic understanding of climate impacts on alpine ecosystems will foster human awareness and aid in mitigating undesirable consequences of climate change.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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Supporting Information

Appendix S1. Running population simulations using survival model input via the ‘run.pop.simulations’ function in program R.

All files necessary to run the goat population model are located within ‘goat.sim.code.and.data.zip’. The inputs for the main function ‘run.pop.simulations’ come from both the ‘goat.simulation.runner.script.R’ and the ‘goat.simulation.data.R’ files. The arguments supplied within ‘goat.simulation.runner.script’ are meant to be those most likely to be changed by a new user initially, while further data inputs that are sourced from ‘goat.simulation.data.R’ can also be manipulated when the user becomes more familiar with the code.

There are a few inputs that originate from csv files and in one case an Rdata file (‘goat.mod’) that are all necessary to run the ‘run.pop.simulations’ function.

The run.pop.simulations function takes the following arguments:

Argument values input via the script ‘goat.simulation.runner.R’:

`year.begin`—beginning year of simulation.

`year.end`—end year of simulation.

`initial.N`—initial total population size.

`n.ages`—number of ages of animals in the simulated population.

`n.runs`—the number of simulations to run of each climate scenario specified.

`area`—The area inhabited by animals simulated, which affects fecundity by way of density dependence.

`climate.scenario.nos`—which climate scenarios to run (1 through 11):

1 — no environmental change

2 — CCS_RCP45

3 — CCS_RCP85

4 — GFDL_RCP45

5 — GFDL_RCP85

6 — GISS_RCP45

7 — GISS_RCP85

8 — IPSL_RCP45

9 — IPSL_RCP85

10 — MRI_RCP45

11 — MRI_RCP85

`output.folder`—the folder under the working directory (perhaps ‘goat.sim.code.and.data’) to which a summary of results (graphs and csv files) will be output.

`density.dependence`—is density dependence implemented (TRUE or FALSE).

`update.betas.yearly`—should the Beta coefficients of the survival model be drawn from within their uncertainty interval every year (TRUE) or just once at the beginning of a simulation (FALSE).

`environmental.stochasticity`—apply stochasticity in climate parameter projections based on past patterns of variability in temperature and snowfall from near the study area (Juneau airport).

`demographic.stochasticity`—if TRUE, apply random noise to fecundity values to represent natural variability and uncertainty in parameters.

Arguments created in or imported by the 'goat.simulation.data.R' file:

`env.data`—A list of two matrices, one specifying June temperatures for each year of simulation, the other snow deposition in winter.

`F0vec`—Fecundity intercepts for each female age class.

`F1`—K from MLE fit to Olympic Nat'l Park data.

`F2`—theta from MLE fit to Olympic Nat'l Park data.

`goat.mod`—an RMARK model from which monthly survivals were obtained and transformed to yearly survivals.

`harvest.matrix`—an optional `n.ages X n.sim.years` matrix specifying harvest of animals by age and year (not implemented in current publication).

`scenario.names`—vector of the names of all potential climate scenarios investigated in White et al 2017.

`agest`—a vector of initial N for each age and sex to begin the simulation with, which are scaled to the total N specified by 'initial.N' above. The current publication uses the age structure obtained from the mountain goat life history matrix in year 2015.

Appendix S2: Mountain goat survival modeling.

White *et al.*, (2011) modeled mountain goat survival in relation to age-, sex- and climate using data collected in 8 different coastal Alaska study areas during 1977–2008. This model was based on monthly monitoring data collected from 279 individual radio-marked mountain goats (643 “goat years”; Table S2a). Since the White *et al.*, (2011) analyses were completed, a significant amount of additional monitoring data ($n = 168$ individuals, 536 “goat years”) were collected in four coastal Alaska study areas during 2008–2014 (Table S2a). In order to optimize the accuracy and precision of the survival model, we combined both data sets and re-calculated the model parameter estimates (Table S2b). We did not completely re-analyze the new, larger data set because we considered the original data set to be sufficient for identifying key modeling variables and estimating effects; instead we were interested in refining and reducing variation in parameter estimates. Thus, the data set used (via RMark) to model climate effects on sex- and age-specific survival is based on data collected from 447 individual mountain goats (1179 “goat years”) located in 10 different study areas (two study areas overlapped original study areas) during 1977–2014.

Table S2a. Study area location, study period, and sample size of radio-marked mountain goats used to estimate sex, age, and climate effects on mountain goat survival in coastal Alaska, 1977–2014.

Study Area	Years	Mountain goats			“Goat years”		
		M	F	Total	M	F	Total
<u>Original Data</u>							
Echo Cove-Herbert Glacier	1977–1981	6	14	20	14	30	44
Kelsall River	1981–1984	6	6	12	11	13	24
North Kenai Mountains	1979–1983	16	25	41	49	82	131
Ketchikan	1980–1985	25	37	62	65	88	153
Prince William Sound	1989–1991	1	14	15	2	29	31
Lions Head	1990–1994	8	4	12	28	17	45
Sheep Creek	1991–1994	4	9	13	9	28	37
Lynn Canal	2005–2008	51	38	89	80	67	147
North Kenai Mountains	2006–2008	1	14	15	3	28	31
		118	161	279	261	382	643
<u>New Data</u>							
Lynn Canal ¹	2008–2014	37	39	76	156	144	300
Cleveland Peninsula ²	2009–2014	6	6	12	18	26	44
Haines-Skagway ³	2010–2014	32	17	49	69	43	112
Baranof Island ⁴	2010–2014	21	10	31	54	26	80
		96	72	168	297	239	536
Grand Total		214	233	447	558	621	1179

¹ White, K. S. 2016. Mountain goat population monitoring and movement patterns near the Kensington Mine, Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.

² White, K. S., B. Porter and S. Bethune. 2010. Cleveland Peninsula mountain goat population monitoring. Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.

³ White, K. S., A. Crupi, R. Scott and B. Seppi. 2014. Mountain goat movement patterns and population monitoring in the Haines-Skagway area, AK. Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.

⁴ White, K. S., P. Mooney and K. Bovee. 2013. Mountain goat movement patterns and population monitoring on Baranof Island. Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.

Table S2b. Parameter estimates (β) and standard errors used to predict mountain goat survival in coastal Alaska, 1977–2014. Estimates reference the model receiving the highest support in White *et al.*, (2011).

Parameter	Estimate	SE	LCI	UCI
Intercept	3.351	0.866	1.653	5.050
Yearling	4.645	3.648	-2.506	11.796
Subadult	6.120	3.500	-0.739	12.979
Young adult	0.923	0.459	0.024	1.822
Adult	0.294	0.420	-0.530	1.117
Sex (adult, old)	0.381	0.182	0.025	0.737
June	0.647	0.848	-1.016	2.310
July	0.949	0.931	-0.877	2.774
August	1.271	0.949	-0.589	3.132
September	1.076	0.503	0.090	2.063
October	-0.217	0.366	-0.935	0.501
November	0.511	0.432	-0.335	1.358
December	0.610	0.445	-0.262	1.482
January	0.297	0.412	-0.511	1.105
February	0.201	0.328	-0.441	0.843
March	0.339	0.342	-0.332	1.011
April	-0.083	0.313	-0.697	0.531
Snowfall	-0.120	0.040	-0.199	-0.041
Snowfall (sub)	0.485	0.351	-0.203	1.173
Temp	-0.052	0.101	-0.249	0.145
Temp (sub)	-0.458	0.414	-1.269	0.353
Temp (yng ad, ad)	0.114	0.057	0.003	0.225

Variable definitions: age (yearling/ylg = 1-yrs, subadult/sub = 2-3 years, young adult/yng ad = 4-5 years, adult/ad = 6-8 years, old = 9+ years), month (June = 1, May = 12), snowfall = total annual snowfall (m; elevation: 0 m), temp = average daily temperature during July-August (°C; elevation: 914 m/3000 ft).

Appendix S3. Age-specific fecundity

Mountain goat fecundity was estimated by monitoring known-age radio-marked females during monthly surveys using fixed-wing aircraft (usually a Piper PA-18 Super Cub) equipped for radio-telemetry tracking or via ground-based observations. During surveys, radio-marked adult female mountain goats were observed (typically using 14X image stabilizing binoculars) to determine whether they gave birth to offspring. Data were collected in three separate study areas in coastal Alaska during 2005-2014: Lynn Canal (n = 76, 223 “goat years”; White 2016), Haines-Skagway (n = 17, 56 “goat years”; White *et al.*, 2014) and Baranof Island (n = 10, 34 “goat years”; White *et al.*, 2013). Data were combined (n = 103, 313 “goat years”) to derive average age-specific fecundity estimates for coastal Alaska (Table S3). These data were used to parameterize mountain goat population models, and modified based on density dependent relationships (as described in Eq 2, “Methods” section; also see Appendix S4).

References:

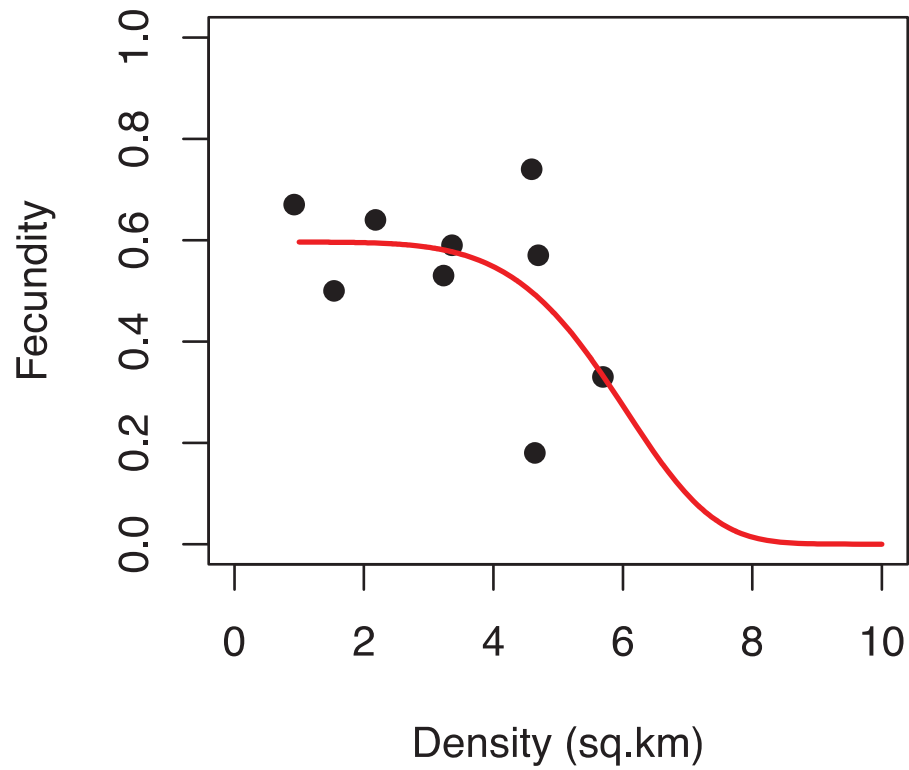
- White, K. S. 2016. Mountain goat population monitoring and movement patterns near the Kensington Mine, Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.
- White, K. S., A. Crupi, R. Scott and B. Seppi. 2014. Mountain goat movement patterns and population monitoring in the Haines-Skagway area, AK. Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.
- White, K. S., P. Mooney and K. Bovee. 2013. Mountain goat movement patterns and population monitoring on Baranof Island. Research Progress Report. Alaska Department of Fish and Game, Juneau, AK.

Table S3. Mountain goat age-specific fecundity estimates based on data from radio-marked females located in coastal Alaska, 2005-2014.

Age	n	Kid	No kid	Prop with kid	SE
1	3	0	3	0.00	0.00
2	8	0	8	0.00	0.00
3	16	1	15	0.06	0.06
4	30	14	16	0.47	0.09
5	40	29	11	0.73	0.07
6	46	29	17	0.63	0.07
7	47	35	12	0.74	0.06
8	39	32	7	0.82	0.06
9	34	28	6	0.82	0.07
10-11	35	25	10	0.71	0.08
12+	15	9	6	0.60	0.13
All ages	313	202	111	0.65	0.03

Appendix S4. Model describing density dependent effects on fecundity

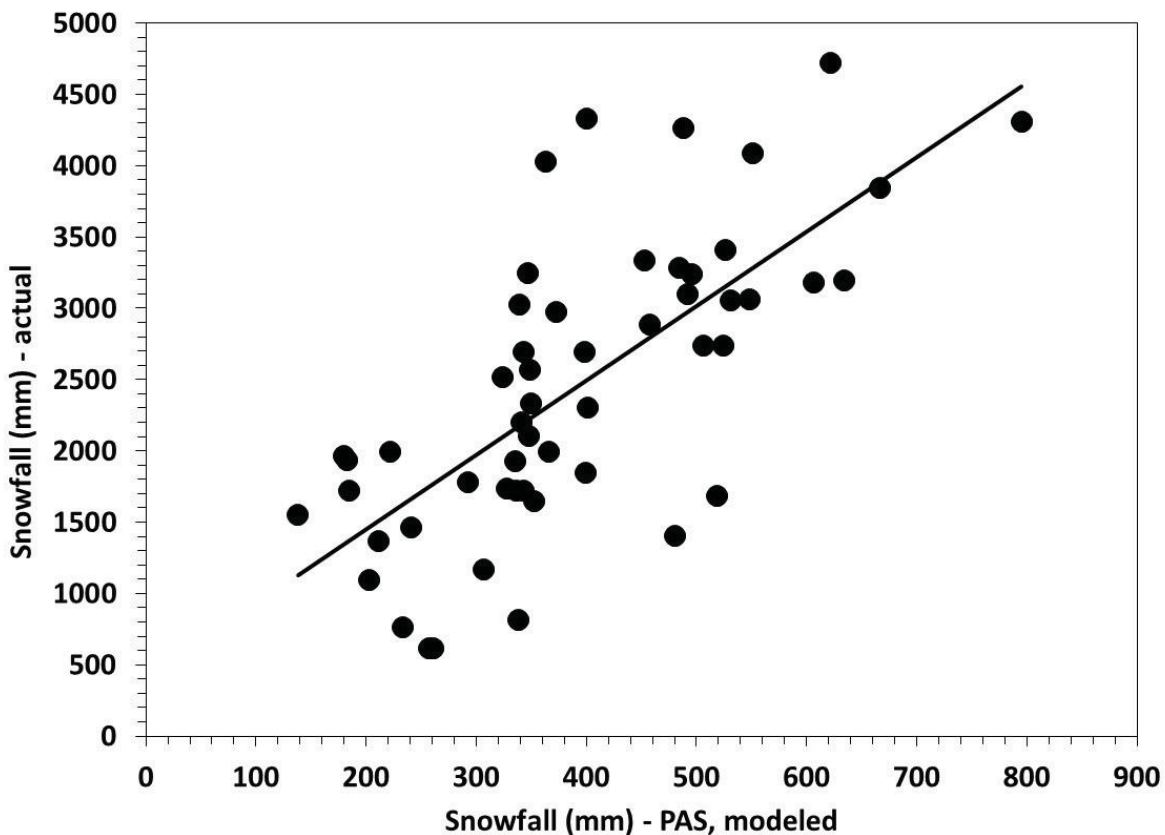
Figure S4. Fit of the discrete per-capita theta-logistic model (Eq. 1) to density-dependent mountain goat fecundity data collected by Houston and Stevens (1988) and Houston *et al.*, (2004).



Appendix S5. Estimating total annual snowfall based on precipitation as snow

Mountain goat survival is negatively influenced by total annual snowfall, as measured at sea-level (White *et al.*, 2011). Our simulations required derivation of total annual snowfall measurements at the Juneau International Airport (JIA), Juneau, AK in order to estimate survival and project population trajectories. GCM models for the JIA generate precipitation as snow (PAS, mm), a corollary of total annual snowfall. To derive total annual snowfall, we derived a linear regression equation using PAS estimates and actual snowfall observation collected at the JIA during 1960–2014. The resulting equation ($y = 5.2203x + 407.11$; $r^2 = 0.51$) predicts total annual snowfall (y) based on PAS (x) and enables projection of total annual snowfall estimates into the future for each GCM/RCP scenario.

Figure S5. Relationship between precipitation as snow (PAS, mm) and total annual snowfall (mm) at the Juneau International Airport, Juneau, AK, 1960-2014.



ORIGINAL ARTICLE OPEN ACCESS

Genomic Analysis Reveals Inbreeding in an Island Population of Alexander Archipelago Wolves

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ABSTRACT

Island populations are at heightened risk of inbreeding due to reduced mating opportunities with unrelated conspecifics. Extensive inbreeding can result in inbreeding depression (reduced fitness of individuals with related parents). Alexander Archipelago wolves (*Canis lupus ligoni*) are a geographically isolated subspecies that occur in the Southeast Alaskan panhandle, USA, and coastal British Columbia, Canada. Wolves on the Prince of Wales Island complex (POW) in Southeast Alaska are expected to have lower levels of resiliency because they are a small, insular population that has experienced habitat fragmentation and cycles of moderate to heavy harvest. To understand the extent of population structure and inbreeding in Alexander Archipelago wolves, we designed a DNA hybridization capture for wolves and sequenced captured DNA from 58 individuals sampled from across Southeast Alaska during 2002–2016. Estimates of the proportion of the genome in runs of homozygosity (F_{ROH}) regardless of run length, revealed that POW wolves were most inbred compared to wolves in other areas of Southeast Alaska. Wolves on POW also had more long (≥ 10 Mb) runs of homozygosity than the other populations we assessed, indicating more frequent mating between individuals with recent common ancestors (1–10 generations ago). This pattern indicates a smaller population size for POW wolves in the recent past compared to other Southeast Alaskan populations. Wolves on POW exhibit an extent of inbreeding similar to that observed in Isle Royale National Park wolves, a population that has exhibited severe inbreeding depression. Our work demonstrates the utility of using genomic capture data to infer individual inbreeding so that proactive management (e.g., setting population targets and harvest quotas, curtailing habitat alteration, etc.) can be considered to ensure the long-term sustainability of small, isolated populations.

1 | Introduction

Habitat loss, climate change, and other anthropogenic pressures are increasingly causing wildlife populations to become smaller, fragmented, and isolated, which can result in a cascade of negative outcomes (Shaffer 1987; Keller and Waller 2002;

Lobo et al. 2023). One such consequence is an increase in inbreeding (i.e., mating between relatives). Island populations are at a greater risk of inbreeding than their mainland counterparts because of low genetic diversity, small population size, and geographic isolation, which results in reduced mating opportunities with unrelated conspecifics (Frankham 1998;

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Colpitts et al. 2022). Inbreeding decreases heterozygosity and standing genetic variation, which reduces the resilience of populations and their potential to adapt to changes in the environment. Importantly, prolonged or extensive inbreeding can result in inbreeding depression (e.g., reduced fitness of individuals with closely related parents) and reduced population viability (Keller and Waller 2002; Charlesworth and Willis 2009). Therefore, the development of effective genomic tools can facilitate wildlife managers in monitoring the extent of inbreeding and implementing mitigation actions that may quell inbreeding depression before it results in a population decline and other deleterious effects (e.g., von Holdt et al. 2024).

Wolves are highly social carnivores living in packs typically comprised of a single breeding male and female and may also include non-breeding individuals (Mech and Boitani 2003). As territorial, cooperatively breeding canids, behavioral strategies such as dispersal outside of natal groups and avoiding breeding with close kin can alleviate the potential for inbreeding (von Holdt et al. 2008; Geffen et al. 2011; Ausband 2022a). One such documented strategy is for females to remain with their natal group to wait for a breeding opportunity with unrelated immigrant males (Ausband 2022b; Pacheco et al. 2024) although both sexes disperse from their natal packs (Morales-González et al. 2022). However, in circumstances where dispersal is impeded by geographic or anthropogenic barriers, co-occurrence and breeding with closely related individuals can occur more frequently and lead to inbreeding and potentially inbreeding depression (Liberg et al. 2005; Hedrick et al. 2014).

Alexander Archipelago wolves (*Canis lupus ligoni*) on the Prince of Wales Island complex (POW) in Southeast Alaska, USA (Figure 1) present a strong case study for detecting and characterizing inbreeding in a small, geographically isolated population of conservation concern. The Prince of Wales Island complex is designated as Game Management Unit 2 (GMU 2) and managed as a single population. Wolf dispersal among the islands of GMU 2 has been documented through radio and GPS-collared wolves (Person and Ingle 1995; Roffler et al. 2016) and from recapture and genetic data (Roffler et al. 2024). Wolf dispersal is common and may include long-distance movements (Mech 2020), even in archipelagic landscapes as wolves are capable of swimming and using smaller islands as stepping-stones (Darimont and Paquet 2002; Muñoz-Fuentes et al. 2010; Stronen et al. 2014; Collins et al. 2019). However, of the radio-collared wolves monitored on POW during 1993–1995, 1999–2004, and 2012–2018 ($n = 68$; Person and Russell 2008; Roffler et al. 2018), none have been documented traveling the three to seven kilometer distance between POW and adjacent islands or to mainland peninsulas in other GMUs (Figure 1). This geographic isolation is reflected by high levels of genetic differentiation of POW in relation to other geographical areas in Southeast Alaska documented in previous genetic analyses using microsatellites and single nucleotide polymorphisms (SNPs; Weckworth et al. 2005; Cronin et al. 2015).

In addition to the presence of geographic barriers to movement and dispersal, old-growth forests on POW have been heavily logged since the 1950s, resulting in decreased quantity and quality of habitat for both wolves and their main prey, Sitka black-tailed deer (*Odocoileus hemionus sitkensis*; Hanley 1984; Albert

and Schoen 2013). Wolves on POW have also experienced periods of moderate to heavy harvest, with annual harvest ranging from 7 to 164 wolves since 1985 (Roffler et al. 2024; Figure S1A). The population has been estimated annually, with the lowest recorded abundance in 2014 ($n = 89$, 95% CI = 50–159) and the highest in 2020 ($n = 386$, 95% CI = 321–472) (Dorendorf 2022; Figure S1B). Given the geographic isolation, habitat loss, and harvest pressure, we sought to understand whether wolves on POW were more inbred than wolves elsewhere in Southeast Alaska and whether inbreeding in POW is more strongly driven by recent or long-term demography.

To assess inbreeding in POW wolves, we required a method that was sensitive enough to detect and differentiate inbreeding that arose due to mating between individuals with more recent or more distant common ancestors. This would allow us to understand whether wolves on POW have experienced low levels of inbreeding over a long period of time or if they have experienced a recent increase in inbreeding, perhaps as the result of anthropogenic pressures on the population. High-throughput sequencing approaches have greatly improved the accuracy and precision of many approaches in population genomics, including estimates of individual inbreeding using runs of homozygosity (ROH; Kardos et al. 2015). Runs of homozygosity are stretches of the genome that are homozygous and identical-by-descent (IBD) due to parental common ancestors (Thompson 2013). Long ROH occur in offspring produced by inbreeding between parents with more recent common ancestors and are broken down into shorter segments over generations by recombination events during meiosis. The progressive shortening of ROH through generations by recombination means that ROH lengths can be used to estimate the coalescent time for the IBD haplotypes (Kardos et al. 2016).

Here we describe the development and application of a high-resolution targeted genomic sequencing method to infer the extent and timing of inbreeding in POW wolves. To accomplish this goal, we collected tissue samples from wolves ($n = 58$) harvested during 2002–2016 throughout Southeast Alaska, including POW and in adjacent Yukon, Canada. We used a custom hybridization-based capture to target tens of thousands of non-coding SNPs. Using the SNP genotypes, we assessed spatial genetic structure and identified populations within the sampled region. Finally, we conducted ROH analysis to assess levels of inbreeding and compare likely histories of inbreeding across these putative populations. We included previously sequenced genomic data from Isle Royale National Park (IRNP; Robinson et al. 2019) to make comparisons to a well-studied island population of wolves that experienced severe inbreeding depression.

Data to inform inbreeding depression are not currently available for Alexander Archipelago wolves in southeast Alaska. However, contextualizing the extent of genomic inbreeding in Southeast Alaskan wolves to the extent of genomic inbreeding observed in IRNP wolves provides an important platform to support future data collection and work to evaluate the potential for inbreeding depression in Southeast Alaskan wolves. It is possible that long-term isolation of wolves in Southeast Alaska has resulted in the purging of strongly deleterious recessive alleles, resulting in a small and isolated but stable population, as has been observed in other taxa (Robinson et al. 2023). In this

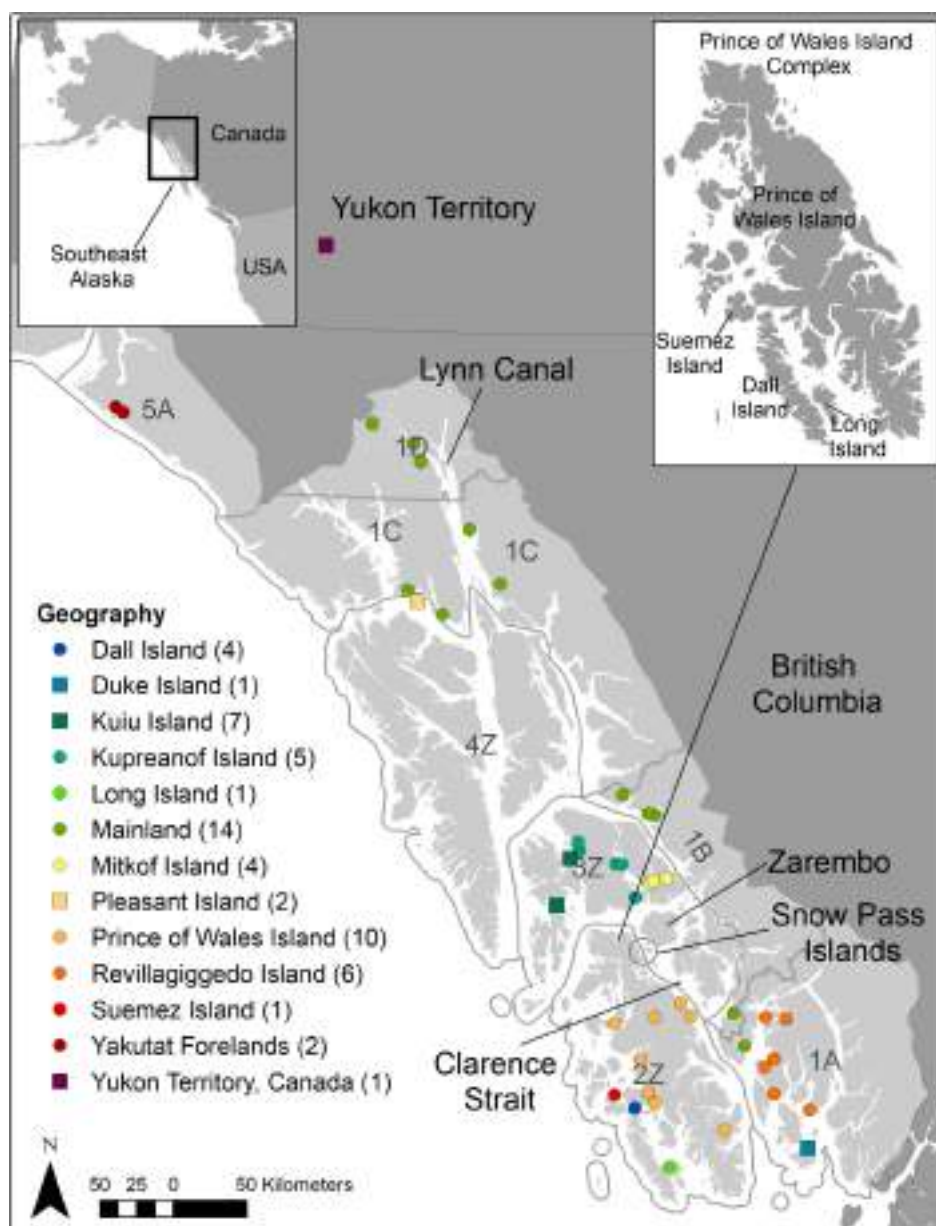


FIGURE 1 | Map of Southeast Alaska, USA and adjacent Canada showing locations and numbers of wolves included in this study ($n = 58$) by sampling location, Game Management Units and Subunits (dark gray text and outlines), and geographical features referenced in main text. Wolves do not inhabit islands in Game Management Unit (GMU) 4Z, with the exception of Pleasant Island which was administratively changed to GMU 1C in 2022.

scenario, the high extents of inbreeding reported here may not be indicative of inbreeding depression and a potential source of instability for long-term persistence of the population. Our results show a high extent of inbreeding in a geographically isolated population, providing critical information to support future studies on inbreeding depression and to facilitate management and conservation in this system.

2 | Materials and Methods

2.1 | Study System

Southeast Alaska is an expansive archipelagic landscape with over 2000 named islands and includes a narrow strip of mainland bordered to the east by the heavily glaciated Coast

Mountains (MacDonald and Cook 2007). These landscape features and geographic isolation have limited gene flow with neighboring continental wolf populations (Weckworth et al. 2005; Pacheco et al. 2022). Prince of Wales Island is located in the southern portion of Southeast Alaska (Figure 1) and is the fourth-largest island in the United States, covering 6670 km² with 1593 km of coastline characterized by numerous bays, inlets, and fjords. The Prince of Wales Island complex includes an additional 25 islands ranging from 5 to 661 km² and hundreds of smaller islands. The landscape of POW contains lakes, streams, river valleys, and mountainous terrain up to 1,160 m in elevation. The vegetative communities on POW include old-growth conifer forests, post-clear-cut forest stands of uniform ages at varying successional stages and, in less abundance, freshwater muskeg bogs and riparian and alpine areas. In addition to wolves, POW also supports populations of other mammals

such as Sitka black-tailed deer, North American beaver (*Castor canadensis*), North American river otter (*Lontra canadensis*), American marten (*Martes americana*), and black bear (*Ursus americanus*). Extensive old-growth logging has resulted in a 94% reduction of contiguous high-volume forests between 1954 and 2004 on northern POW (Albert and Schoen 2013) and old-growth timber sales and logging continue into the present day. Roads built for timber harvest also provide increased access for hunters and trappers, facilitating high wolf harvest (Person and Russell 2008).

2.2 | Sample Collection and Preparation

Samples for this study were obtained opportunistically from a larger sampling effort undertaken by the Alaska Department of Fish and Game (ADF&G) to survey population genetic structure and connectivity of wolves in Southeast Alaska. Tissue samples were collected during 2002–2016 (Table S1) from all GMUs in Southeast Alaska where wolves occur, including on Pleasant Island, which was formerly part of GMU 4Z until 2022 when it was changed to be a part of GMU 1C because of its closer geographical connection to the northern mainland. We also included 1 sample from the adjacent Yukon Territory, Canada, for comparison to interior wolves. Samples were collected in accordance with guidelines established by ADF&G Animal Care and Use Committee (ACUC #2012–028 and #2014–15) and the American Society of Mammologists (Sikes and Gannon 2011) or by voluntary tissue sample submission to ADF&G from trapper and hunter harvest. We extracted DNA from tissue samples using the DNeasy Blood and Tissue Kit (Qiagen) following the manufacturer's protocol, substituting buffer AE with TET buffer (10mM Tris–HCl, 1mM EDTA, 0.05% Tween-20, pH 8.0).

2.3 | Capture Design and Optimization

Wildlife conservation and management resources are limited, and we sought to develop a cost-effective genotyping method that would maximize sample size to assess genomic inbreeding and population genetic structure in a population of conservation concern. We also sought to develop a method that would induce less ascertainment bias than commercially available canine SNP genotyping methods. Commercially available SNP genotyping methods that are compatible with wolves are potentially cost-effective options, but are typically developed using a small number of domestic dogs to identify variable sites and with the intent to conduct breed association studies and/or evaluate genetic risk factors (e.g., Illumina CanineSNP20 Panel, Broad Institute Canine Array v1 and v2, etc.) The demographic history of dogs includes significant population bottlenecks, maintenance of small effective population sizes (breeds), and inbreeding, which has resulted in domestic dogs carrying relatively little genetic variation when compared to wild canids (Freedman et al. 2014; Marsden et al. 2016). Domestic dogs, particularly purebred dogs, also exhibit increased instances of recessive genetic disorders not commonly observed in wild canids (e.g., Pedersen et al. 2015; Leroy 2011; Farrell et al. 2015; Oberbauer et al. 2015; Marsden et al. 2016; Axelsson et al. 2021). SNP panels designed using a small number of dogs with the intent to perform breed

association and genetic disease studies are biased in favor of identifying variation specific to dog breeds and genetic disorders and could therefore carry significant ascertainment bias when applied to population genetic applications in wild wolves. We developed a cost-effective method that is less likely to incur ascertainment bias and more likely to reflect true population structure when applied to wild wolf populations.

We used the domestic dog reference genome (canFam3.1; Lindblad-Toh et al. 2005) to design a hybridization capture probe targeting 100,144,500-bp regions spaced $\geq 19,700$ nucleotides apart. Hybridization-based capture will enrich target DNA that is up to 40% divergent, and although enrichment efficiency begins to decline at 4%–10% divergence (Paijmans et al. 2016), genome-wide pairwise sequence divergence between dogs and wolves is $\sim 0.11\%$ on average (Freedman et al. 2014) so this approach is well-suited for targeted enrichment and genomic sequencing in wolves. To avoid challenges with mapping reads, we excluded repetitive sequence regions like microsatellites, nested repeats, short interspersed elements, long interspersed elements, and other repeating regions that we identified using RepeatMasker 4.0.7 (Smit et al. 2015), Tandem Repeats Finder (Benson 1999), and WindowMasker (Morgulis et al. 2006). These excluded regions were already masked in the sequence file for the domestic dog genome or available on UCSC's TableBrowser (<https://genome.ucsc.edu/cgi-bin/hgTables>). Our design also excluded exons (regions of the genome that code for proteins) and 100,000 base pairs (bp) flanking exons to avoid targeting SNPs under selection. We submitted our design to Roche (2024F. Hoffmann-La Roche Ltd) and after their proprietary screening and optimization to ensure efficient capture of target regions, the resulting probe set (SeqCap EZ Choice Probes) comprised 131,816 targets covering a total of 43,564,811 base pairs in the reference genome. The increased number of targets relative to the original capture design reflects the division of some targeted regions into one or more smaller fragments during Roche's proprietary screening and optimization process.

To further optimize the capture design, we prepared ten DNA samples for sequencing following the library preparation and capture protocol detailed below; then sequenced these samples on an Illumina MiSeq (v2 Nano 150 bp paired end reads) at the University of Montana Genomics Core (Missoula, MT, USA). Briefly, reads were processed through the removal of PCR duplicates step as detailed below in the section on Read Filtering, SNP Calling, and SNP Filtering. After removing PCR duplicates, we used Picard (v2.9.2, <http://broadinstitute.github.io/picard/>) CollectHsMetrics to assess fold-enrichment and mean on-target coverage. We then redesigned the capture, excluding all probes for which read coverage was three times or higher than the mean on-target coverage for all targets with above 0 $\times$ coverage. Many targets in the capture optimization sequencing returned 0 $\times$ coverage due to a relatively low sequencing effort. We excluded the 0 $\times$ coverage targets when calculating mean coverage to ensure that we did not remove more targets than necessary with the three times or higher mean coverage target filtering step. High coverage in the excluded regions is likely the result of reads from multiple paralogs mapping to a single region of the reference genome. These high coverage regions have lower mapping qualities and artificially inflated heterozygosity, so their removal from the

capture design facilitated improved mapping quality scores, more accurate SNP genotype calls, and more accurate identification of ROH in subsequent analyses. The final probe set comprised 136,542 targets covering a total of 45,985,696 bp in the reference genome (Figure S2).

2.4 | Library Preparation, Capture, and Sequencing

We prepared libraries according to Meyer and Kircher (2010) with the following modifications: we used a Covaris E220 to randomly fragment DNA to a mean size of 300 bp (125 μ L sample volume in a microTUBE Snap-Cap AFA Fiber, 140 W peak incident power, 10% duty factor, 200 cycles per burst, 55 s treatment time). For every post-reaction solid phase reversible immobilization clean-up step, we used Serapure beads (Faircloth and Glenn 2011). We used unique indexing oligos on both the P7 and P5 ends for each sample to avoid any cross-sample contamination from tag-switching during post-pool PCR amplification steps.

We pooled 10 sample libraries (125 ng each) for each capture. For hybridization preparation, hybridization, recovery, and post-capture amplification, we followed the protocol outlined in chapters five through seven in SeqCap EZ HyperCap Workflow User's Guide Version 2.1 (Roche), replacing the LM-PCR oligos with HPLC-purified primers IS5 and IS6 developed by Meyer and Kircher (2010). Thirty captured libraries were pooled in equimolar concentrations, and the pooled library was diluted to 10 nM total concentration and sent for sequencing on a single lane of a HiSeq 4000 (paired end 150 bp reads) at the University of Oregon Genomics and Cell Characterization Core Facility (GC3F, Eugene, OR, USA).

2.5 | Bioinformatics

We used Trimmomatic v0.33 (Bolger et al. 2014) to remove adapters and discard reads shorter than 100 bp from demultiplexed reads to improve mapping quality scores. Unpaired reads were discarded to ensure high mapping quality scores, and we used PEAR v0.9.6 (Zhang et al. 2014) to assemble overlapping reads. Assembled and unassembled paired reads were aligned to canFam3.1 using BWA mem v0.7.15-r1140 (Li 2013). We used Picard (<http://broadinstitute.github.io/picard/>) MergeSamFiles to merge SAM files for unassembled and assembled read pairs for each sample, MarkDuplicates to identify PCR duplicates, and SAMtools view (Li et al. 2009) to remove PCR duplicates. We then used Picard CollectHsMetrics to assess fold-enrichment and mean on-target coverage.

We used GATK v3.8 (McKenna et al. 2010) to identify SNPs. We used GATK to realign reads around indels and Picard (<http://broadinstitute.github.io/picard/>) to correct read mate information after realignment. We used GATK HaplotypeCaller to call raw SNPs for each individual within targeted regions and a 250 bp flanking region around each target. We used GATK GenotypeGVCFs to call SNPs using all samples, SelectVariants to filter out indels, and bcftools view (v1.16) to filter SNPs by allele frequency and u-based z-approximation

from the Rank Sum Test for mapping qualities (MQRankSum; 'INFO/AF > 0.01 and INFO/MQRankSum > -0.2') resulting in a reference dataset of known SNP sites. We used GATK BaseRecalibrator to recalibrate base quality scores using the aforementioned reference dataset and the realigned, mate-corrected BAM files. We called SNPs a final time using the recalibrated BAM files and GATK HaplotypeCaller and GenotypeGVCFs. Finally, we used VCFtools v0.1.16 (Danecek et al. 2011) to filter SNPs by minor allele frequency ($-maf$ 0.05), minimum genotype quality ($-minGQ$ 20), minimum mean coverage ($-min-meanDP$ 10), missingness ($-max-missing$ 0.85), Hardy-Weinberg proportions ($-hwe$ 0.001), and to only retain biallelic sites ($-min-alleles$ 2 $-max-alleles$ 2) on autosomes 1–38, which resulted in 31,526 SNPs. We used VCFtools $-relatedness$ 2 (Danecek et al. 2011) to screen for and remove duplicated samples.

2.6 | Admixture and Population Structure

To evaluate population genetic structure and identify populations within the sampled region, we used 31,526 SNPs resulting from the above variant calling and filtering methods with ADMIXTURE v1.3.0 (Alexander and Lange 2011) to estimate individual ancestry from one to ten potential ancestral populations. The best supported number of ancestral populations was indicated by the minimum cross-validation error (using 10-fold cross-validation) in our ADMIXTURE analysis. We used the highest proportion of individual ancestry to assign individuals to these putative populations. To evaluate genetic differentiation between the ADMIXTURE-identified populations, we estimated pairwise F_{ST} using VCFtools. We used a principal components analysis (PCA) plot in EIGENSOFT v6.1.4 (Price et al. 2006) to visualize genetic differentiation between individuals.

2.7 | Nucleotide Diversity and Inbreeding

To compare genetic variation and inbreeding of Southeast Alaskan wolves to another island wolf population of conservation concern, we included whole genome sequence data from a previous study of 11 wolves from Isle Royale National Park (IRNP) (Robinson et al. 2019). We obtained sequence reads from the 11 IRNP wolves (SRA Project PRJNA512209) and aligned them to canFam3.1 as described above. We converted the resulting SAM files to BAM format and then sorted BAM files using SAMTOOLS v1.15.1. We marked duplicate sequence reads using MarkDuplicates in GATK 4.2.0.0 and used BEDtools v2.29 (Quinlan and Hall 2010) to filter these BAM files so that only reads that overlap our sequence capture array targets remained. We then used Picard v2.23.9 to randomly remove sequence reads from each of the 11 IRNP wolves so that the genome-wide average read depth for each IRNP wolf approximately equaled the average SNP read depth of the Southeast Alaskan wolves (9.7, after removing individuals with mean read depth ≤ 5). We used the GATK v4.2.0.0 HaplotypeCaller and GenotypeGVCFs for variant calling on IRNP and Southeast Alaskan wolves jointly. We used VCFtools 0.1.16 to remove indels, retain only biallelic SNPs within sequence capture target regions, and to remove SNPs

that had average read depth >24 in order to exclude SNPs likely to be in duplicated genomic regions (Kardos et al. 2018). This yielded 327,049 SNPs across all four ADMIXTURE-identified populations (see Results Section 3.1). There were 157,306 SNPs in POW, 238,875 in the southern islands and mainland group (SE), 202,152 in the northwest group (NW), and 187,081 in IRNP.

We used estimated nucleotide diversity (π) in each ADMIXTURE-identified SE Alaska population and IRNP based on genotype likelihoods with the program *angsd* () to account for genotype uncertainty (Korneliussen et al. 2014). Using the aligned sequence data from each population trimmed to include only sites covered by our capture array as input, we (1) calculated the site allele frequency posteriors assuming the reference allele was ancestral (-doSaf 1 -GL 1), (2) used the posteriors from (1) to estimate the folded site-frequency spectrum (SFS) (realSFS-fold 1), (3) estimated site-specific pair-wise theta (realSFS saf2theta fold 1), (4) estimated pairwise theta (tP) across each chromosome (thetaStat do_stat), then (5) obtained the average genome-wide π by dividing the summed chromosome-specific estimates of tP by the total number of nucleotide sites in the genome with data.

We used SNP genotype likelihoods at all SNPs as input data for our analyses of inbreeding based on ROH (Khan et al. 2021; Kardos et al. 2023). The methods to detect ROH are described in detail in the Data S1. We identified ROH via analysis of genotype likelihoods as this approach uses information from all sequence reads at each SNP in every individual, including at loci with insufficient read depth for called genotypes to pass stringent filtering criteria (Nielsen et al. 2011; Kardos et al. 2023). However, we excluded individuals with average genome-wide read depth <5 , as such low coverage can result in high error rates in the identification of ROH (Duntsch et al. 2021). This resulted in sample sizes for the inbreeding analysis of 14 (POW), 29 (SE), 6 (NW), and 11 (IRNP). We calculated F_{ROH} as the proportion of 38 autosomes in ROH ≥ 1 Mb ($F_{\text{ROH} \geq 1\text{Mb}}$), and ≥ 10 Mb ($F_{\text{ROH} \geq 10\text{Mb}}$). We repeated this analysis after equalizing the number of SNPs in each population by randomly pruning down to 157,308 SNPs in SE, NW, and IRNP to test whether variation in SNP density across populations strongly affected the results. To ensure the absence of spurious results, we tested for a relationship between F_{ROH} and sequence read depth using linear regressions using the *lm* () function in R (R Core Team 2021). Neither $F_{\text{ROH} \geq 1\text{Mb}}$ nor $F_{\text{ROH} \geq 10\text{Mb}}$ had a significant relationship with sequence read depth ($p=0.34$ and $p=0.1$, respectively; Figure S3).

We generated bootstrap confidence intervals for average F_{ROH} in each population (Efron and Tibshirani 1994). For each of the four ADMIXTURE-identified populations, we resampled N F_{ROH} values with replacement (N =the number of sampled individuals) 5000 times; each time recording the average of the resampled F_{ROH} values. The 95% non-parametric bootstrap confidence interval was determined as the 0.025 and 0.975 quantiles of the 5000 means.

We analyzed the length distributions of ROH to evaluate inbreeding in each wolf population due to recent versus deep historical demographic history. The breaking up of haplotypes

by recombination during meiosis means that very long ROH are likely to arise from recent common ancestors of parents, whereas short ROH likely originate from common ancestors in deeper history. The number of generations (g) back to the ancestor where an ROH arises can be estimated by solving for g in $l = 100/2g\text{cM}$, where l = the genetic map length of an ROH in centiMorgans, under the assumption that the coalescent pattern is constant across an entire ROH (Thompson 2013). A high abundance of ROH with similar estimated g suggests a relatively small effective population size (N_e) during that time compared to populations with less frequent such ROH (Kirin et al. 2010). We estimated g for each ROH in every individual, assuming recombination rates from a domestic dog linkage map (Campbell et al. 2016). We then calculated the average Mb in ROH within each of six ranges of g (<10 , $10-20$, $20-30$, $30-40$, $40-50$, >50 generations) for each population as a metric of inbreeding arising from ancestors in different historical time periods.

3 | Results

3.1 | Admixture and Population Structure

In our ADMIXTURE analysis of one through 10 potential ancestral populations, we found that three ancestral populations were best supported (Figure 2A and Figure S4): (1) Prince of Wales Island and the adjacent GMU 2 islands Dall, Long, and Suemez (POW, $n=15$); (2) the southern inside islands (Kuiu, Kupreanof, Mitkof, Revilla, and Duke) and southern mainland (southeastern group [SE], $n=29$); and (3) the northern mainland west of Lynn Canal, Pleasant Island, and the Yukon Territory (northwest group [NW], $n=14$). One of the wolves sampled on POW had majority assignment to the SE group and therefore likely has a recent ancestor that immigrated from the SE population to POW, highlighting the possibility of natural migration across water bodies (Figure 2B,C). No wolves sampled outside of POW had majority ancestry assignment to the POW group, indicating that migration observed in this study was unidirectional. The mainland appeared to be a landscape corridor facilitating admixture, as one wolf sampled in the southern mainland had majority ancestry assignment to the NW group, and 2 wolves sampled in the northern mainland had majority or nearly majority assignment to the SE group (Figure 2A,C).

We used PCA to describe the first three principal components (PCs) in 31,526 SNPs (Figure 3) for all 58 individuals. Reflecting the results observed in the ADMIXTURE analysis, samples grouped into three clusters, with POW comprising one cluster (red circles in Figure 3A). The other two clusters were comprised of a mixture of samples from the remaining GMUs. The one sample collected in the Yukon Territory clustered with samples from northern Lynn Canal, Pleasant Island, and the Yakutat Forelands (GMUs 1C, 1D, and 5A). The POW wolves were not distinct from other wolves on PC1 or PC3, which explained 6.22% and 2.98% of the genetic variation observed in all samples, respectively (Figure 3B). Examination of the relationship between genetic divergence and individuals ($n=2$) with a high missingness profile (>0.85 proportion missing data) showed that they were not more divergent than

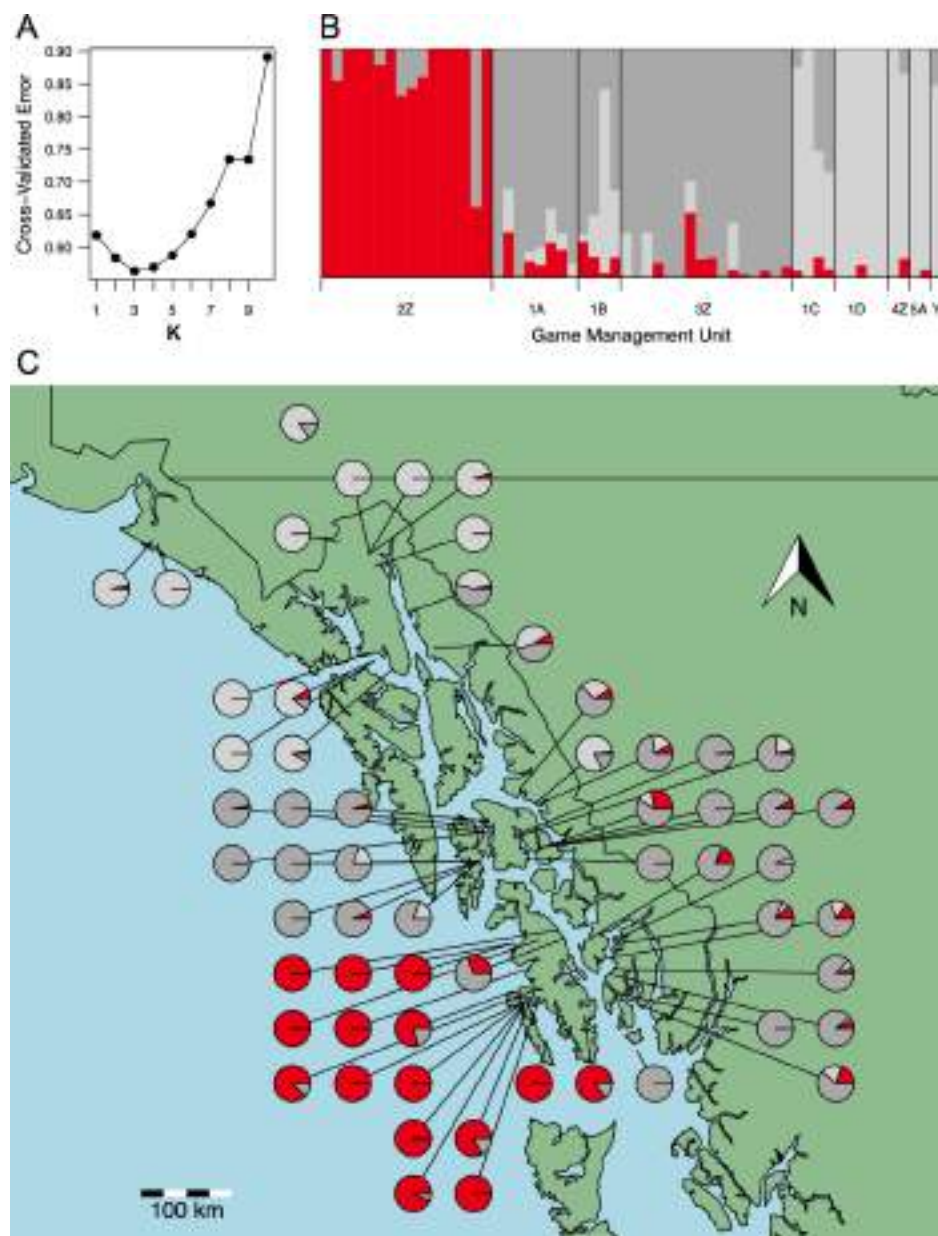


FIGURE 2 | Summary of ADMIXTURE analysis results to determine individual wolf population assignments for each Alexander Archipelago wolf sampled in Southeast Alaska and Yukon Territory. (A) Cross-validated errors for one through 10 putative populations. (B) Proportion of ancestry for wolves. (C) Spatial distribution of the estimates of individual ancestry proportions shown in (A). Ancestry proportions shown assume three ancestral populations as indicated by the lowest cross-validation error (B).

other individuals in the group to which they were assigned (Data S1). The POW wolves separated from other wolves on PC2, which explained 4.15% of the genetic variation observed across all samples (Figure 3A). Pairwise estimates of F_{ST} were 0.16 between POW and SE, 0.23 between POW and NW, and 0.20 between the SE and NW groups.

3.2 | Nucleotide Diversity and Inbreeding

The POW population had the lowest π and highest inbreeding among the four populations we evaluated. Estimated π for POW wolves (0.00109) was $\geq 20\%$ lower than in IRNP (0.00149), SE (0.00140), and NW (0.00150) wolves (Figure 4A).

The POW group had the highest inbreeding among the three ADMIXTURE-defined groups of Alaska wolves and wolves in IRNP. The highest mean $F_{ROH \geq 1Mb}$ was in the POW group (mean = 0.39, range = 0.22–0.49), followed by IRNP (mean = 0.30, range = 0.02–0.43), followed by SE (mean = 0.28, range = 0.07–0.66), then NW (mean = 0.18, range = 0.07–0.42; Figure 4B). Long ROH ($F_{ROH \geq 10Mb}$) indicative of inbreeding due to recent ancestors were more abundant in IRNP and POW wolves than in the SE and NW groups, but these differences were not substantial (Figure 4C). The highest mean $F_{ROH \geq 10Mb}$ was observed in the POW group (mean = 0.13, range = 0.01–0.25), followed by the IRNP (mean = 0.11, range = 0.00–0.20), followed by the SE group (mean = 0.09, range = 0.00–0.47), then the NW group (mean = 0.08,

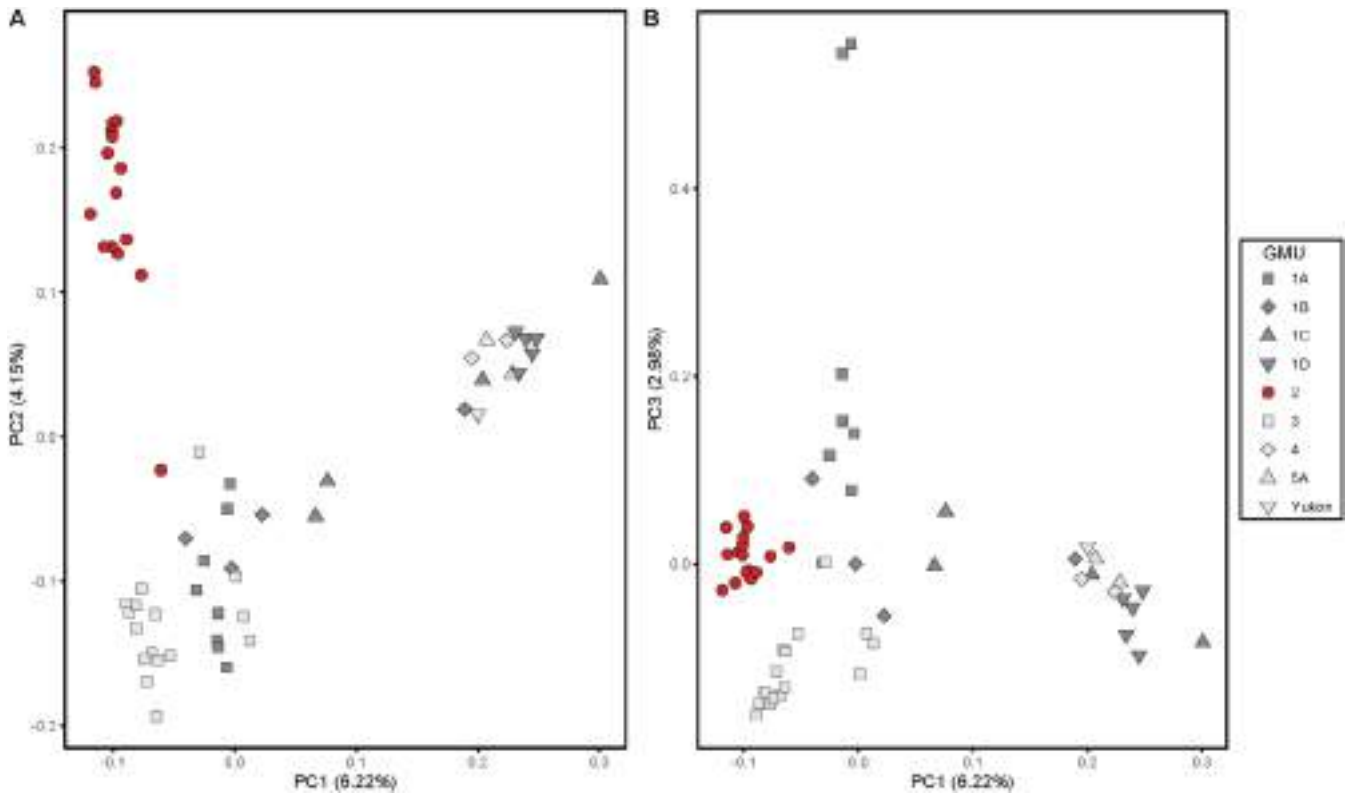


FIGURE 3 | Principal components analysis of 58 wolves sampled in Southeast Alaska, USA and the Yukon Territory, Canada. Color and symbol for each sample correspond to Game Management Units (GMUs, shown in Figure 1), and one sample from Yukon, as indicated in the legend. Wolves do not inhabit islands in Game Management Unit (GMU) 4Z, with the exception of Pleasant Island, which was administratively changed to GMU 1C in 2022. (A) PC2 versus PC1, (B) PC3 versus PC1.

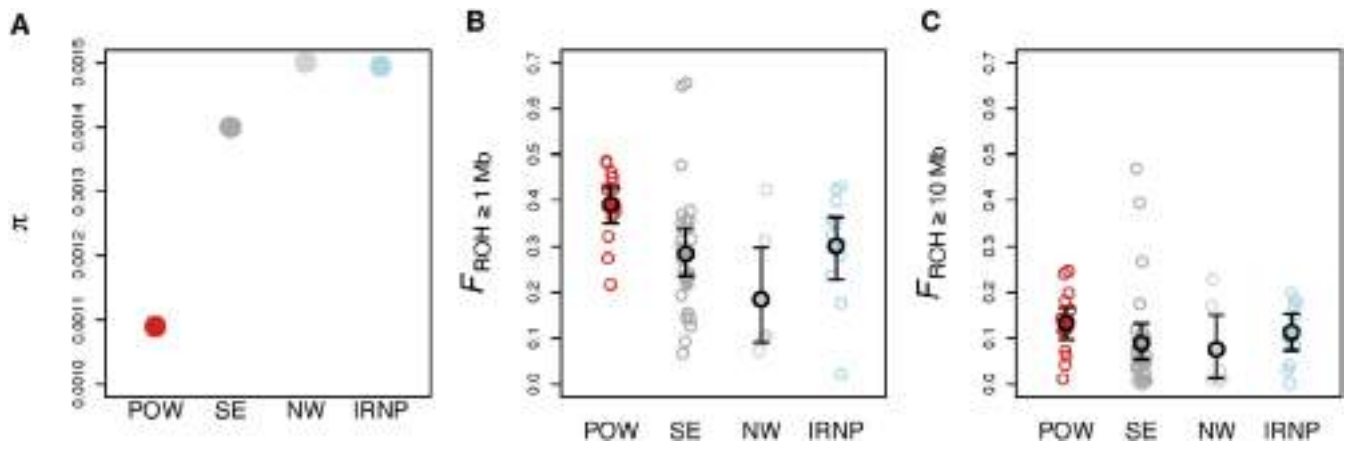


FIGURE 4 | Nucleotide diversity (π) and genomic inbreeding coefficients for wolves in Admixture-defined populations (Prince of Wales Island [POW; $n=14$], the southern mainland and inside islands [SE; $n=29$], and the northern mainland and the Yukon Territory, Canada [NW; $n=6$]) and Isle Royale National Park, USA (IRNP; $n=11$; Robinson et al. 2019) was included for comparison. (A) Nucleotide diversity was calculated considering all regions in the wolf genome covered by our custom sequence capture array. (B, C) F_{ROH} was measured using ROH ≥ 1 Mb (B), and ≥ 10 Mb (C). Filled points in B, C represent the average and bars represent 95% bootstrap confidence intervals.

range=0.01–0.23). Repeating the F_{ROH} analysis with equalized SNP numbers across populations did not substantively affect the results (Figure S5).

The distributions of estimated coalescent times for haplotypes comprising ROH suggest that POW wolves had the highest inbreeding due to small population size both recently and in deep

history (Figure 5). Specifically, POW wolves had the most ROH arising from ancestors in the last 10 generations, and in all of the deeper historical timeframe bins (Figure 5). Wolves in the IRNP group had an abundance of ROH with coalescent time < 10 generations that was only slightly lower than that of POW (Figure 5). However, IRNP had fewer average Mb in ROH with deep historical coalescent times compared to both SE and POW

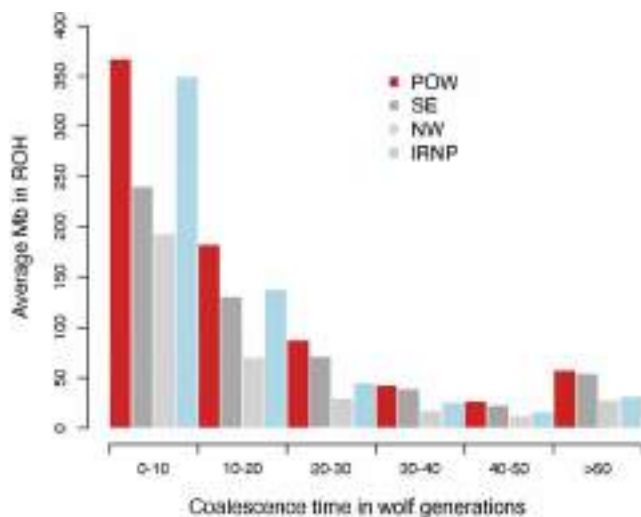


FIGURE 5 | Inbreeding of wolves arising from ancestors in different estimated historical time periods. The values on the y-axis are the average Mb covered in runs of homozygosity (ROH) with given estimated coalescent time (wolf generations) as indicated on the x-axis. The three populations in our Southeast Alaska, USA, study area identified with ADMIXTURE (Prince of Wales Island [POW; $n=14$], the southern mainland and inside islands [SE; $n=29$], and the northern mainland and the Yukon Territory, Canada [NW; $n=6$]) are shown, and Isle Royale National Park, USA (IRNP; $n=11$; Robinson et al. 2019) was included for comparison.

Alaska wolves, which may reflect the recent colonization of Isle Royale and large N_e of the mainland source population (Hedrick et al. 2014).

4 | Discussion

The objective of this work was to evaluate population structure and individual inbreeding in Alexander Archipelago wolves in Southeast Alaska, with a particular emphasis on the Prince of Wales Island complex (POW) because it is geographically isolated, has previously been identified as a population of conservation concern (U.S. Fish and Wildlife Service 2023), and the maintenance of the population is a management priority (Article 8, Section 4 of the Alaska Constitution; Wolf Technical Committee 2017). We developed a cost-effective and robust SNP genotyping method to evaluate population structure and individual inbreeding in wolves to address these questions. Relative to other populations in Southeast Alaska and wolves from Isle Royale National Park (IRNP), wolves on POW had low genetic variation and high inbreeding estimates, suggesting that future work to understand whether the population is exhibiting inbreeding depression is necessary to ensure appropriate management actions and long-term population persistence.

4.1 | Admixture and Population Structure

Our population genetic structure analyses revealed three distinct populations within the sampling area. This result is consistent with geographic features (e.g., islands, mountains, fjords)

contributing to habitat fragmentation and increased resistance to dispersal in some areas of the archipelago, and other features (e.g., the mainland, low elevation river corridors, shallow and narrow water channels) serving as regions of genetic connectivity. The POW group was most readily distinguished from wolves elsewhere in Southeast Alaska by PCA and ADMIXTURE analyses consistent with previous research (Weckworth et al. 2005; Cronin et al. 2015). The southeast group (SE) encompassed five major islands and the southern mainland. Unlike the POW island complex, which is separated from other island groups by wide expanses of water such as Clarence Strait (Figure 1), the islands in the SE group have several narrow water passages < 1 km that are shallower and have weaker current and therefore would present less of a barrier to wolves migrating between islands and the mainland. Water barriers of 2–7 km have been demonstrated to limit gene flow of brown bears between islands in Southeast Alaska (Paetkau et al. 1998) and similar patterns could be expected for wolves. The northwest group (NW) consisted entirely of northern mainland wolves and included the Yukon wolf, likely connected to the coastal Alaskan population by the several river valleys that extend into the interior of the Yukon Territory and British Columbia. The mainland of the southeast Alaskan panhandle appears to provide an area of geographic connectivity as admixture of the SE and NW populations was evident in the individual ancestry assignments (Figure 2B,C).

Although wolves have not been documented moving between POW and other GMUs, including islands and mainland units, genetic recapture data of wolves sampled on the islands of Snow Pass to the northeast of POW and on POW and other islands in the complex indicate dispersal has occurred (Roffler et al. 2024). The islands of Snow Pass and Zarembo could provide a potential pathway for wolves to migrate to or from the mainland or other southern island groups by swimming between the islands (longest straight-line swim = 2.7 km; Figure 1). This stepping-stone corridor was possibly the route taken by the one immigrant or offspring of an immigrant wolf from the SE group we identified on POW using genomic data in this study, which provides evidence that wolves can move between other GMUs (both island and mainland units) and POW. This immigrant wolf sired two litters on POW (Roffler et al. 2018) providing further evidence of gene flow. However, outside of this instance, the frequency of immigration events is unknown, as is the probability of these immigrants settling and reproducing with local POW wolves. Our results show that there are sufficient barriers to movement between POW and other parts of Southeast Alaska to inhibit all but infrequent migration of wolves among geographic regions, resulting in substantial genetic differentiation and genetic isolation of POW wolves.

The dispersal distances documented within the POW population through previous genetic recapture efforts were short in general (average 41.9 km, SD = 23.7 km) and occurred throughout Prince of Wales Island and other islands in the POW complex (Roffler et al. 2024). The straight-line dispersal distances were likely constrained by the geography of the relatively isolated island system and could result in a higher density of related wolves, making it more difficult to find an unrelated mate and rendering inbreeding avoidance strategies less effective (Viluma et al. 2022). Unlike other continental wolf populations that have substantial genetic connectivity to adjacent populations

facilitated by continuous habitat and long-distance dispersal capabilities, POW wolves remain restricted by their island geography, which is likely contributing to higher rates of breeding with close relatives.

4.2 | Nucleotide Diversity and Inbreeding

Wolves in the POW group exhibited the lowest π and highest $F_{\text{ROH}} \geq 1\text{Mb}$ and $F_{\text{ROH}} \geq 10\text{Mb}$ when compared to the two other Southeast Alaska populations (SE and NW) and wolves from IRNP. The most striking result in our F_{ROH} analyses was that despite the current relatively large annual population census sizes of POW wolves indicating a stable or growing population and consistent reproduction and juvenile survival (Dorendorf 2022; Figure S1B), they have experienced very high levels of inbreeding likely due to a small recent population size in the past 10 generations. Wolf generations are estimated at between 4.2 and 4.7 years (Mech et al. 2016), therefore this population bottleneck corresponds to approximately 1970. Although wolves in the POW population had the highest levels of inbreeding, wolves in the southeast (SE) group also demonstrated relatively high inbreeding measured by short $F_{\text{ROH}} (\geq 1\text{Mb})$, comparable to the extent of inbreeding observed in IRNP wolves. Wolves in the northwest (NW) group had the lowest F_{ROH} estimates, indicating that this population is relatively large and/or more genetically connected with nearby populations. Although POW and IRNP had the highest proportion of Mb in ROH, all three Southeast Alaska populations showed an increase during the last 0–10 generations indicating an overall genetic bottleneck (Figure 5).

It is important to note that POW wolf samples included in this current analysis were collected mostly during 2015 (Table S1), which is too soon after the lowest population estimate in 2014 ($n=89$; 95% CI=50–159) to capture any effect this decline in abundance may have had on individual genomic inbreeding. Therefore, the temporary low population size in 2014 could have resulted in increased mating events between related individuals in subsequent years; it is therefore possible that POW wolves currently have higher F_{ROH} inbreeding coefficients than estimated by the data and results presented here.

Our analysis of coalescence for haplotypes in ROH revealed additional similarities between POW wolves and IRNP wolves, with both populations demonstrating similar extents of genomic inbreeding as the result of mating events between close relatives within the last 10 generations. These results are notable because the IRNP population was founded by just two or three individuals in the late 1940s (Wayne et al. 1991); peaked at 50 individuals in 1980 (Peterson et al. 2014); and received only one immigrant in 1997 (Adams et al. 2011) before successful reproduction stopped in 2014 as the result of severe inbreeding depression (Peterson and Vucetich 2017), and the population went functionally extinct (Hedrick et al. 2019). The similarities in F_{ROH} and ROH coalescent time between POW and IRNP indicate that POW wolves have experienced substantial inbreeding in recent years; and due to limited immigration from other populations, are at heightened risk for exhibiting inbreeding depression.

Wolf populations with low genetic diversity and high individual inbreeding estimates have exhibited inbreeding depression,

including IRNP wolves (Räikkönen et al. 2009; Robinson et al. 2019), Mexican wolves (Fredrickson et al. 2007; Clement et al. 2024), and Scandinavian wolves (Liberg et al. 2005; Smeds and Ellegren 2023). Inbreeding depression in these populations has been documented via reduced litter size, reduced juvenile survival, and morphological anomalies (Salado et al. 2024 and citations therein). Between 2013 and 2017, at least three wolves on POW have been observed with shortened tails, but the causes of these deformities are unknown, and they could be either the result of inbreeding depression similar to the defects observed in IRNP and Scandinavian wolves (e.g., Räikkönen et al. 2009; Hedrick et al. 2016; Räikkönen et al. 2013) or from physical trauma. These anecdotal observations are not sufficient to either confirm or reject that wolves in Southeast Alaska are currently exhibiting inbreeding depression.

Inbreeding depression is expected to occur in all diploid populations due to the ubiquity of deleterious mutations and genetic drift (Lacy 1997; Kardos et al. 2021), including in populations that have been small and isolated for long periods (Stoffel et al. 2021; Kardos et al. 2023). Inbreeding increases homozygosity and results in the expression of deleterious, partially recessive alleles as well as reductions in the frequency of loci that are advantageous as heterozygotes. In some small populations that have been isolated over the long term, inbreeding may facilitate the purging of very highly deleterious alleles via natural selection as previously reported in island foxes and island dingoes (Robinson et al. 2018; Leon-Apodaca et al. 2024; but see Ralls et al. 2020 for a critique on this perspective). However, purging is not expected to eliminate all deleterious alleles (Hedrick and Garcia-Dorado 2016; Dussex et al. 2021; Khan et al. 2021), and consistently restricted population size means deleterious alleles are expected to reach a high frequency or fixation, resulting in decreased mean fitness in a population (Lynch et al. 1995). As demonstrated by the now extinct Sierra Morena wolves (the southernmost population of the Iberian wolf range), historical persistence of a small, isolated population should not be considered evidence of viability into the future (Gómez-Sánchez et al. 2018).

Wolves in Southeast Alaska diverged from nearby populations in interior Alaska and interior British Columbia approximately 12,000 to 16,000 years ago and have consistently demonstrated a low effective population size that has been declining for the past approximately 600 years (Nowak and Paradiso 1983; Nowak 1995; Pacheco et al. 2022). Low genetic diversity and high inbreeding coefficients reflect the declining effective population size, which has been particularly exacerbated during the past 280 years (Pacheco et al. 2022). This long-term isolation and geographic restriction of wolves in Southeast Alaska and in POW in particular have maintained low population sizes for thousands of years and may have facilitated the purging of deleterious recessive alleles. On the other hand, this historical pattern of a lack of gene flow leading to low genetic variation and very high individual inbreeding could result in inbreeding depression. It is important to note that despite the lack of evidence, no explicit investigations to detect inbreeding depression as a result of the genetic bottleneck and isolation have been conducted in POW wolves. Additional work is necessary to understand whether the observed low genetic variation and high individual inbreeding represent significant risks to the long-term persistence of

populations in this study and whether management actions like translocation of individuals would be beneficial.

Translocations or assisted migration, introducing captive animals, and providing foster offspring are among the tools that managers may consider to bolster genetic diversity in inbred wolf populations (Harding et al. 2016; Hervey et al. 2021; Clement et al. 2024). Gene flow from other populations can offset the negative effects of inbreeding in small, isolated populations; recommendations include maintaining gene flow of > 1 individual per generation (Laikre et al. 2016). However, as shown in the IRNP population, infrequent immigration of highly reproductively successful individuals into an extremely small population can result in much of an immigrant's genome rapidly sweeping to high frequency, ultimately exacerbating inbreeding and inbreeding depression (Hedrick et al. 2019). Scandinavian wolves also present a case where immigration temporarily mitigated inbreeding depression in a small and isolated population (Åkesson et al. 2016). The wolf population in Sweden was established by two individuals in 1983 and remained small and highly inbred until immigration in 1991 and 2007, which led to higher reproductive success in inbred wolves and population growth (Åkesson et al. 2016). However, those effects were short-lived as heterozygosity decreased after a couple of years, and the immigrants also delivered new deleterious alleles to the population (Smeds and Ellegren 2023). Therefore, translocation efforts must be well researched and designed to provide regular inputs of genetic diversity into the receiving population while avoiding the introduction of deleterious alleles or counterproductive genetic sweeps.

5 | Conclusions and Future Work

The low genetic variation and high individual inbreeding estimates in wolves on POW highlight the need to understand whether the population is exhibiting inbreeding depression before proposing and implementing management actions. Although we did not measure inbreeding depression in this study, this should be a priority for future research because the demographic consequences of inbreeding depression are difficult to predict without directly measuring these effects. However, measuring inbreeding depression is challenging in wild populations (Kardos et al. 2016), particularly those that are cryptic and rare. Additionally, estimating the reduction in fitness due to inbreeding depression is a formidable task in wildlife populations, as this requires significant sampling of difficult-to-acquire fitness measurements (e.g., litter size, pup survival) over long periods of time (Clement et al. 2024). Ideally, future research would assess the relationship of breeding success and survival to individual heterozygosity and especially differences in fitness among known immigrants, their offspring, and resident inbred wolves. Alternatively, future research could use whole genome sequencing to estimate the accumulation of deleterious genetic variants, which could lead to reductions in fitness (Bertorelle et al. 2022). Furthermore, simulation studies to predict the effects of potential wolf relocations, outbreeding, or fostering on increasing heterozygosity and reducing levels of inbreeding would be beneficial for managing viable populations of wolves in Southeast Alaska (Harding et al. 2016; Hervey et al. 2021).

This study presents a valuable use of genomic capture data to further our understanding of the status of Alexander Archipelago wolves on POW and in Southeast Alaska. Our results provide a solid foundation to promote and continue monitoring efforts to understand genetic structure and inbreeding in a population of conservation concern.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Raw DNA sequence reads generated in this study were submitted to the National Center for Biotechnology Information (NCBI) Sequence Read Archive (SRA) database under Accession Project no. PRJNA1194631. Wolf capture targets are available from Dryad <https://doi.org/10.5061/dryad.x3ffbg7wh>.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** eva70144-sup-0001-AppendixS1.docx.