Exhibit 3

Tongass National Forest Young-Growth Management Guidelines for Stands with a Wildlife Management Objective

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Suggested Citation: Bennetsen, Bonnie M. B. 2020. Tongass National Forest young-growth management guidelines for stands with a wildlife management objective. Exhibit 3 of the Tongass Young-Growth Management Strategy, USDA Forest Service, Tongass National Forest, Juneau, Alaska. 86 pages.

I. Overview, Goals and Objectives

A. Overview

Several decades of even-aged timber harvest have created about 451,000 acres of young-growth forest across the Tongass National Forest (Tongass). Over 140,000 of these young-growth acres are in land use designations (LUDs) and other buffers that are managed for old-growth objectives, including old-growth reserves, forested beach fringe, and riparian areas. Over 89,000 acres in these areas have had no prior young-growth treatments.

Though young-growth forests typically lack several key habitat characteristics integral to old-growth forest, thinning and other treatments can be done in ways that improve many of these characteristics for old-growth associated wildlife in short and long terms (i.e., years to decades and multiple decades to centuries, respectively). Short-term benefits may include improved understory vegetation and structural and plant species diversity, while long-term benefits include expedited development of old-growth conditions. Evidence suggests young-growth management may even be necessary in some stands to achieve important large-size characteristics of these conditions such as large trees, crowns, boles, branches, snags, and logs that are important to a variety of Tongass wildlife. Using strategically timed and placed silvicultural treatments to promote key habitat characteristics will benefit many Tongass wildlife in the long term as well as some in the short term. Actions can also be taken to minimize short-term impacts of precommercial thinning so that benefits are realized more quickly.

This document aids in integrating young-growth management for wildlife with other resource goals as introduced in the broader Tongass Young-Growth Management Strategy (USDA 2014). Broader complimentary themes include integrating common goals, managing the system to meet multiple objectives, developing a common language and mutual understanding, focusing on young growth to support the conservation of old growth, and using the young-growth strategy to set priorities.

This strategy provides guidance for young-growth management to benefit Tongass wildlife species, detailing how, where, and when work should be prioritized and implemented given limited resources. Synopses of management direction, the natural scale and distribution of disturbance, key habitat characteristics, and relevant effectiveness literature from the Tongass and Pacific Northwest rainforest ecosystems provide the basis. This exhibit offers value at multiple levels, including in programmatic, project, and collaborative planning, conducting effects analyses, and guiding implementation.

B. Goals and Objectives – Management Direction

The Tongass Land and Resource Management Plan (USDA 2016a; hereafter Forest Plan) provides goals and objectives and other direction for young-growth management aimed at wildlife habitat improvement on the Tongass. Verbatim from the Forest Plan for Wildlife (pages 4-86, 4-93 and 4-94):

- Identify habitat improvement projects to meet wildlife habitat and population objectives.
    - Consider the following factors to assess habitat improvement project opportunities and priorities:
        - To meet state wildlife population objectives
        - To meet subsistence use needs
        - Existing habitat in poor condition compared to its potential
        - Habitat with a history of receiving high levels of use
        - Treatments with a favorable benefit/cost ratio.
    - Use silvicultural practices, where applicable, to accomplish wildlife habitat objectives.
- Develop an aggressive young-growth management program to maintain, prolong, and/or improve understory forage production and to increase the development of old growth characteristics in young-growth timber stands for a variety of wildlife species (deer, moose, black bear, small mammals, birds, and other species of interest).
- Consider stands for young-growth treatments that meet the following conditions:
    - Historical deer winter range with high deer use.
    - Historical or potential moose winter range.
    - Areas with important and accessible consumptive and non-consumptive human uses of wildlife benefited by young-growth management.
    - High risk value comparison units (VCUs) and within beach fringe – these areas have significant young growth and are important habitat for a variety of wildlife species. Young-growth treatments may be used to accelerate development of old-growth characteristics and improve habitat conditions.
    - Young-growth timber sales that have a relatively high tree stocking density that would result in early loss of understory forage. Plant associations containing hemlock or spruce and *Vaccinium* or skunk cabbage on high site potential should be considered for treatment.
- Consider the following for precommercial thinning:
    - Time precommercial thinning before desirable forage species are shaded out by trees, although trees should fully occupy the site. Generally, highly productive sites will need to be thinned at younger age (15 to 20 years) than moderate or low productive sites (20 to 25 years). Use site-specific conditions to determine the timing of precommercial thinning.
    - Vary tree spacings according to site specific information and dependent on a desired condition. Consider spacings from 16 feet by 16 feet to 24 feet by 24 feet. Site-specific objectives should be developed in conjunction with silviculture staff, and should identify spacings to be used. Consider variable spacings and leaving some unthinned thickets and corridors to create future structural diversity.
    - Generally, slash disposal treatments will not be necessary. In some site-specific areas, slash treatments may be needed to facilitate animal movements or increase forage production and availability. Slash treatments may include girdling trees, falling trees away from high forage areas, piling trees, or lopping and scattering of slash.
- Consider the following for canopy gaps:

  - It is generally recommended that canopy gaps be created at the same time as precommercial thinning activity[1].
  - Generally, slash disposal treatments will not be necessary. In some site-specific areas, slash treatments may be needed to facilitate animal movements or increase forage production and availability. Slash treatments may include girdling trees, falling trees away from high forage areas, piling trees, or lopping and scattering of slash.
  - Site-specific objectives and analysis should identify the gap sizes.
- Coordinate the timing and location of habitat improvement projects with other resources so as to provide opportunities to decrease treatment costs and provide multi-resource benefit.

Though there is no acreage objective specific to areas managed for old-growth objectives and wildlife habitat restoration, the Forest Plan specifies an acreage objective for precommercial thinning that applies broadly to all areas (Forest Plan page 5-3):

- Annually, pre-commercially thin 4,000 to 7,000 acres of young-growth stands.

The Forest Plan also identifies and provides specific direction for LUDs and buffers that are particularly important for the Tongass Conservation Strategy reserves and connective corridors, wildlife habitat restoration needs, and management for old-growth objectives. These include the 1000-foot beach and estuary fringe of development/timber LUDs (hereafter 'beach fringe'), Old-Growth Habitat LUD, and Riparian Management Areas. Exhibit 2 of the Tongass Young-Growth Management Strategy (USDA 2014) addresses young-growth management direction within Riparian Management Areas. The remainder of this section therefore focuses on management direction applicable to young growth within the beach fringe and Old-Growth Habitat LUD, and touches on other LUDs.

1. Beach Fringe

Desired condition and management approaches for young growth in beach fringe that are most pertinent to wildlife include the following (Forest Plan page 5-5):

- These areas provide habitat and connectivity for wildlife and opportunities for accelerating old-growth characteristics while also providing commercial timber byproducts.
- The intent is that determinations of prescriptions and opening sizes in the beach fringe consider spatial and temporal conditions of adjacent landscapes.
- It is expected that treatment prescriptions facilitate a more rapid recovery of the late-seral (successional) forest characteristics, while also producing commercial timber byproducts.

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[1] Though this is language directly from the Forest Plan, silviculturists currently recommend precommercial thinning with variance at an early age to help accelerate development of old-growth characteristics and enhance stand stability and using dispersed, small gaps to address stands beyond the precommercial thinning window where treatment is needed before commercial treatment is feasible. Gaps can be effectively used to promote pockets of understory vegetation while minimizing slash impacts. Gaps seem to provide longer forage benefits for deer than single-entry thinning, but will not have the same benefits as thinning in promoting development of old-growth and large-tree characteristics.

The Forest Plan also more generally defines objectives for the beach fringe (Forest Plan page 4-4 and 4-5), which also apply to young-growth management when consistent with direction added under the 2016 amendment (Forest Plan page 5-5). Objectives pertinent to wildlife in beach fringe include the following (Forest Plan pages 4-4 and 4-5):

- To maintain the ecological integrity of beach and estuary fringe forest habitat to provide sustained natural habitat conditions and requirements for wildlife, plants, fish, recreation, heritage, scenery, wilderness, and other resources.
- To provide a relatively continuous forested corridor linking terrestrial landscapes.
- To maintain an approximate 1,000-foot-wide beach fringe of mostly unmodified forest to provide important habitats, corridors, and connectivity of habitat for eagles, goshawks, deer, marten, otter, bear, and other wildlife species associated with the maritime-influenced habitat. Old-growth forests are managed for near-natural habitat conditions (including natural disturbances) with little evidence of human-induced influence on the ecosystem.
- To maintain an approximate 1,000-foot-wide estuary fringe of mostly undisturbed forest that contributes to maintenance of the ecological integrity of the biologically rich tidal and intertidal estuary zone. Habitats for shorebirds, waterfowl, bald eagles, goshawks and other marine-associated species are emphasized. Old-growth conifer stands, grasslands, wetlands, and other natural habitat associated with estuary areas above the mean high tide line are managed for near-natural conditions with little evidence of human-induced disturbance.
- Wildlife habitat restoration of young-growth conifer stands is encouraged to accelerate development of advanced seral stand structure. Treatments may include thinning of young stands, release, pruning, and fertilization.

Commercial young-growth harvest in the beach fringe is limited to a one-time only entry and to the first 15 years after Forest Plan approval, unless best available scientific information shows that additional entries are both warranted and meet the LUD objectives (Forest Plan page 5-5). Commercial young-growth harvest may also only occur outside of a 200-foot forested no-commercial-harvest buffer beginning at mean high tide (Forest Plan page 5-5) or beginning at the limit of salt-tolerant vegetation for estuaries (Forest Plan page 4-4). There is also direction on the quantity and intensity: maximum size of any created opening must not exceed 10 acres; maximum removal of up to 35% of total stand area or 33% of the stand's basal area, or a combination of these with no more than 35% total stand removed in basal area and/or acres (Forest Plan page 5-5). Percent of area calculations are based on the original harvest unit excluding administratively withdrawn areas. Forest Plan requirements to accelerate development of late-seral characteristics within the beach fringe may further restrict tree-removal intensities.

2. Old-Growth Habitat LUD

The desired condition and management approaches for young growth in the Old-Growth Habitat LUD are similar to those given above for beach fringe (Forest Plan page 5-8):

- Young-growth stands within the Old-Growth Habitat LUD maintain habitat and connectivity for wildlife and are managed to accelerate development of old-growth characteristics while also providing commercial timber byproducts.
- In the Old-Growth Habitat LUD, treated young-growth emulates the natural scale and distribution of disturbance patterns (for example, wind-thrown timber that creates gaps and patches; landslides that create corridors and gaps; and mortality that naturally thins stands).

- The intent is that determinations of prescriptions and opening sizes consider spatial and temporal conditions of adjacent landscapes.
- The intent is that treatment prescriptions in the Old-Growth Habitat LUD would facilitate a more rapid recovery of the late successional forest characteristics, while creating commercial timber byproducts.

The Forest Plan also more generally defines goals, objectives, desired condition, and management prescriptions for the Old-Growth Habitat LUD, which also apply when consistent with young-growth direction added under the 2016 amendment (Forest Plan page 5-8).

Goals relevant to wildlife include the following (Forest Plan page 3-58):

- Maintain areas of old-growth forests and their associated natural ecological processes to provide habitat for old-growth associated resources.
- Manage early seral conifer stands to achieve old-growth forest characteristic structure and composition based upon site capability. Use old growth definitions as outlined in Ecological Definitions for Old-growth Forest Types in Southeast Alaska (R10-TP-28)[2].

Old-Growth Habitat LUD objectives are as follows (Forest Plan page 3-58):

- Provide old-growth forest habitats, in combination with other LUDs, to maintain viable populations of native and desired non-native fish and wildlife species and subspecies that may be closely associated with old-growth forests.
- Contribute to the habitat capability of fish and wildlife resources to support sustainable human subsistence and recreational uses.
- Maintain components of flora and fauna biodiversity and ecological processes associated with old-growth forests.
- Allow existing natural or previously harvested early seral conifer stands to evolve naturally to old-growth forest habitats, or apply silvicultural treatments to accelerate forest succession to achieve old-growth forest structural features. Consider practices such as thinning, release and weeding, pruning, and fertilization to promote accelerated development of old-growth characteristics.
- To the extent feasible, limit roads, facilities, and authorized uses to those compatible with old-growth forest habitat management objectives.

Direction related to desired condition and management prescriptions of the Old-Growth Habitat LUD includes the following:

- All forested areas within this LUD have attained old-growth forest characteristics. A diversity of old-growth habitat types and associated species and subspecies and ecological processes are represented (Forest Plan page 3-58).
- Allow previously harvested or natural early seral stands to develop into old-growth, or provide young-growth management to accelerate attainment of old-growth characteristics (see WILD2, below). (Forest Plan WILD1 C, page 3-63).

[2] (USDA 1992; also summarized in Table 1).

- Manage early seral forest stands for purposes of wildlife habitat development. Allow techniques such as thinning, pruning, and planting to accelerate development of advanced seral stand structure, including maintenance of shrub and forb understory (Forest Plan WILD2, page 3-63).

Commercial young-growth harvest in the Old-Growth Habitat LUD is limited to a one-time only entry and to the first 15 years after Forest Plan approval, unless best available scientific information shows that additional entries are both warranted and meet the LUD objectives (Forest Plan page 5-8). There is also direction on the quantity and intensity: maximum size of any created opening must not exceed 10 acres; maximum removal of up to 35% of total stand area or 33% of the stand's basal area, or a combination of these with no more than 35% total stand removed in basal area and/or acres (Forest Plan page 5-8). Percent of area calculations are based on the original harvested stand excluding administratively withdrawn areas. Forest Plan requirements to accelerate development of late-seral characteristics within the Old Growth Habitat LUD may further restrict tree-removal intensities.

The added direction for young-growth management in the Old-Growth Habitat LUD and beach fringe provided in the 2016 Forest Plan (Forest Plan pages 5-8 and 5-5, respectively) did not change the general goals, objectives, and desired condition described for these areas in the Forest Plan (pages 3-58 and 4-4 to 405, respectively). The intentions of commercial young-growth harvest in the Old-Growth Habitat LUD and beach fringe were further clarified in a letter by the Forest Supervisor (2016 Tongass Land and Resource Management Plan Amendment Clarification, March 26, 2018, pages 7-8 and 13):

- My approach to harvesting young growth in the [Beach and Estuary Fringe: pages 7-8; Old-growth Habitat LUD: page 13] is that any such harvest must "facilitate a more rapid recovery of late-seral (successional) forest characteristics". If the harvest does not facilitate a more rapid recovery, then no commercial young growth harvest can occur.

Recommendations by the Tongass Advisory Committee (2015) that were used in developing the 2016 Forest Plan Amendment also reflect these priorities (Forest Plan Appendix B page 11):

- "Examine young growth within those Old Growth Reserves, Riparian Management Areas, and beach buffers that are now in young growth (early seral stage) and are of sufficient maturity to advance the transition to determine the opportunities for habitat improvement. If active adaptive management would likely facilitate a more rapid recovery of late successional forest characteristics than would leaving it alone, the Tongass Advisory Committee recommends co-intent management activities that advance the seral stages toward Tongass old growth conditions, while creating commercial timber by-products."

3. Other LUDs, Landscape Connectivity, and Remnant Retention

Other LUDs also help meet wildlife habitat needs. Exhibit 1 (USDA 2014) covers young growth management direction within LUDs that include a timber yield objective (development LUDs). For young growth and wildlife, the most important management direction in development LUDs pertains to maintaining habitat connectivity:

- Design projects to maintain landscape connectivity. (Forest Plan page 4-87)

- The objective is to maintain corridors of old-growth forest among large and medium old-growth reserves (Appendix K) and other forested Non-development LUDs at the landscape scale. (Forest Plan page 4-87; [applies to old growth but provides objective for young-growth applications in next bullet])
- During the environmental analysis for projects proposing to harvest timber, construct roads, or otherwise significantly alter vegetative cover, conduct an analysis at the landscape scale to identify blocks of contiguous old-growth forest habitat within large and medium reserves and other Non-development LUDs to determine whether forest connectivity exists among old-growth blocks in large and medium reserves and natural setting LUDs. Consider existing features of the old-growth strategy such as the beach fringe, small old-growth reserves, riparian buffers, or other lands not suitable for timber production as contributing to maintaining connectivity among large and medium Old-growth Habitat reserves and Non-development LUDs. Use the following parameters to determine if a large or medium reserve is connected: a) only one connection is needed; b) the beach fringe serves as a connector; and c) the connection does not have to be the shortest distance between reserves. Where these features do not provide sufficient productive old-growth forest connectivity to meet the objective [in 1] above, provide stands, where they exist, of productive old-growth forest or other forest that provides adequate wildlife habitat values (i.e., older young growth that provides adequate snow interception for deer). Designed corridors should be of sufficient width to minimize edge effect and provide interior forest conditions. Consider elevation, natural movement corridors, length of corridor, tree heights, adjacent landscapes, and windthrow susceptibility in corridor design. (Forest Plan page 4-87)
- Ensure interdisciplinary involvement and consideration of deer habitat in project planning and in the environmental analysis process (Forest Plan page 4-88).
- Travel corridors used by mountain goats between important seasonal sites should be identified and maintained, especially when they occur in forested areas (Forest Plan page 4-92).

These landscape-scale habitat connectivity measures are especially important in young-growth management when considering slash and snow impediments from precommercial thinning and loss of snow interception from harvest of older young-growth stands.

The Forest Plan also addresses retention of patches or residual trees in development LUDs harvested under two-age silvicultural systems (Verbatim from Forest Plan pages 4-69 and 4-70):

- Two-aged silvicultural systems are designed to maintain and regenerate a stand with two-age classes. The resulting stand may be two-aged or trend towards the uneven-aged condition as a consequence of both and extended period of regeneration establishment and the retention of reserve trees that may represent one or more age classes. The reserve trees provide structural diversity and a biological legacy. Two-aged management regimes can produce stands of greater structural diversity than even-aged management. This method may be used where windthrow or dwarf mistletoe are not major threats or can be tolerated.
    - Emphasize green-tree and snag retention in landscape management. The actual number and attributes of the trees retained is dependent on Forest Plan and site-specific silvicultural objectives. To the extent feasible, residual patches and single trees should include large, old trees and snags.

- Retained patches or residual trees should not be scheduled for removal. The retained patches and residual trees will provide support for those organisms that require old forests.

Continued retention of these features is important for wildlife in subsequent young-growth management.

Several other natural-setting LUDs, such as LUD II, Remote Recreation, Semi-Remote Recreation, Municipal Watershed, and others also provide wildlife habitat values that may benefit from young-growth management. These areas are not suitable to timber production, but wildlife habitat improvements may generally be done non-commercially to meet the specific objectives of these LUDs, while emulating natural conditions. These lands also offer value in maintaining and improving habitat connectivity for wildlife:

- Forest-wide, within the beach fringe, riparian buffers, and other lands not suitable for timber production, consider designing young-growth treatments to accelerate old-growth characteristics in order to increase connectivity for wildlife (Forest Plan page 4-87).

4. Interagency Wolf Habitat Management Program Recommendations

In 2017, the Tongass worked with the Alaska Department of Fish and Game (ADF&G) and the U.S. Fish and Wildlife Service (USFWS) to develop interagency management recommendations for wolves on Prince of Wales and nearby islands (Wolf Technical Committee 2017). This document included several recommendations pertinent to young growth management for deer within the Old Growth Habitat LUD and beach fringe. Though the focus was on the Prince of Wales area, recommended measures were intended to be considered in other areas when applicable. Relevant recommendations verbatim from that document (except for footnotes) include:

Young-Age Young Growth[3] *in All Areas:*

- Aim to treat all young-aged young growth, prioritizing as needed based on factors such as stand readiness, slash impacts, deer winter range, and landscapes dominated by untreated young growth or devoid of understory forage.
- Emphasize multiple smaller treatments spread across even-age landscapes and staggered in time, to provide a variety of stand and patch ages.
- Incorporate leave strips that provide elevational movement corridors for deer. Maintain or enhance connectivity between higher and lower elevations, aiming to connect the full elevational span of alpine to beach habitat.

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[3] The Wolf Technical Committee (2017) defined young-age young growth as early seral stands in which tree canopies have started to connect, but that are not yet exhibiting stem exclusion. Older non-commercial young growth referred to stand ages that have reached stem exclusion but are not yet commercially viable for timber harvest. Older commercial young growth referred to stands that have reached sizes that are commercially viable but have not yet pushed through to developing shrubs and forbs again. Though highly dependent on site productivity and timber markets for commercial viability, the approximate age ranges for each of these stages in more productive sites were identified as 16-25 years, 26-60 years, and >60 years, respectively.

- Evaluate current and historic migration and movement routes and identify terrain features and habitat connectivity, possibly with interagency involvement, that are most likely to allow elevational movements by deer during severe winters and prioritize leave strips in these areas. In absence of more definitive information, establish leave strips at about 400 foot spacing[4].
- Consider a variety of treatment combinations including variable-spaced thinning, girdling, pruning, small-gap creation, and slash treatments, with the goal of creating deer forage and movement corridors in close proximity, increasing heterogeneity of habitat to address needs of deer across young-growth landscapes, and avoiding the creation of a secondary conifer-recruitment flush.
- Encourage additional monitoring and research in conjunction with examination of currently available information to evaluate effectiveness of young-growth treatments on deer response.
- Strongly consider investigating population-level effects of stand treatments on deer using an experimental framework.
- Favor yellow cedar and red cedar for retention over hemlock and spruce that have no winter forage value for deer. Retain, and consider planting, red alder to allow longer retention of understory forage.

Older Non-Commercial Young Growth in All Areas:

- To avoid effects of heavy slash accumulations on deer mobility, generally avoid treating older young growth non-commercially except where older young-growth forests are exhibiting stem exclusion across large portions of the landscape. In these areas, consider thinning, creating small gaps, pruning, girdling, and a combination of these treatments to provide forage for deer on a sustainable basis through time and elevational movement corridors across the landscape.
- Thinning treatments should favor dominant trees to maintain snow interception capacity of the overstory and incorporate unthinned travel corridors to facilitate elevational movements by deer.
- For gap treatments, encourage understory recruitment and growth by considering a) pruning along the edges of gaps to maximize side-lighting into adjacent forest, b) siting gaps on remnant understory vegetation, c) mixing (mulching or tilling) the duff and topsoil layers to stimulate microbial activity and help release nutrients, d) planting target understory forage plants, and e) designing gap sizes to about 70 feet diameter, with slight variation from this depending on tree sizes, to avoid creating a secondary recruitment flush of conifers that would shade out understory forage and to help the openings function as gaps.
- Older stands thinned or gapped non-commercially should include treatments to reduce or abate effects of slash on deer mobility. Slash treatment options could include bucking,

[4] Refers to widths between unthinned leave corridors within thinned landscapes. Using existing or perhaps GPS modelled movement corridors is best. Field reconnaissance to determine locations of existing movement corridors is recommended. Empirical data on applicable home range sizes and movement patterns should also be incorporated into corridor planning for deer as should the potential for future windthrow.

chipping, trail cutting, windrowing, smashing with heavy equipment, moving/piling (e.g., out of gaps), and looking for creative ways to use the logs elsewhere.

Commercial Young Growth in Areas where Succession towards Old-Growth Conditions is Identified as a Dual Objective (i.e., Old-Growth Habitat LUDs, and Beach and Estuary Fringe and Riparian Management Areas outside of Tongass Timber Reform Act Buffers that are within Development and Old-Growth Habitat LUDs):

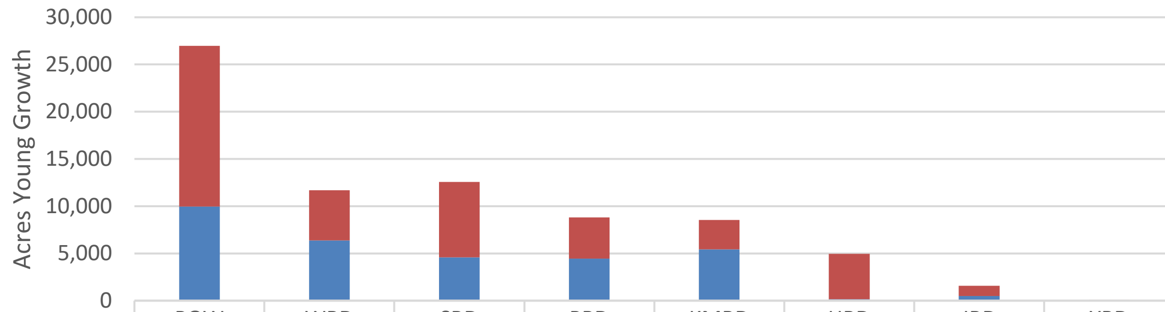
- Design treatments that progress stands towards old-growth conditions to benefit deer in the long term. The long-term habitat objective for deer includes a rich understory of forb, shrub, and lichen forage species combined with snow interception, from a heterogeneously-structured canopy mosaic with occasional small gaps and side-lighting.
- Design treatments that provide understory deer forage and reduce effects of stem exclusion and slash to foster short-term habitat for deer, when such treatments can be done without compromising continued succession towards old-growth conditions that support long-term habitat for deer. Treatments could include variable-density thinning, thinning to favor dominant trees, creating small gaps and narrow openings, and pruning in areas with prior young-age thinning or adjacent to gaps.
- Avoid creating gaps and opening widths that are likely to result in a subsequent flush of conifer recruits and lose gap function that promotes understory forage; design gaps to be about 70 feet wide, adjusting as appropriate based on canopy height.
- Incorporate leave strips of intact canopy, especially along ridgelines, to promote elevational movements during severe winters and minimize distance between deer movement and foraging opportunities across the landscape.

II. Existing Condition

Even-aged forest management (also known as clearcutting) was the most common timber harvest system used on the Tongass since the 1950s. As a result, large tracts of land were harvested using the clearcut method, resulting in over 451,000 acres of young growth on the Tongass, including about 31,562 acres within beach fringe and 43,576 acres within the Old-Growth Habitat LUD (data queried Dec 2020). About 19,761 and 29,879 acres of young growth within beach fringe and Old-Growth Habitat LUD, respectively have never been treated. About 1,220 and 7,344 of these untreated acres in these areas, respectively are within typical precommercial thinning windows of 15-30 years, many of these about to age out of this window within the next 5 years.

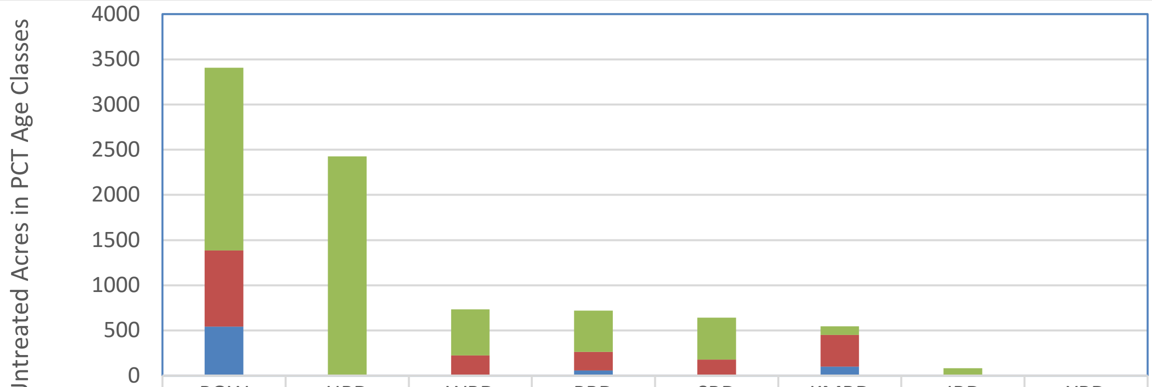
Historical timber harvest was disproportionate across the Tongass; 11.9% of productive old-growth forests, 28.1% of large-tree stands, and 66.5% of landscapes with the highest volume contiguous old growth were logged from 1954 through 2004 (Albert and Schoen 2013). The majority of existing young growth in Old-Growth Habitat LUD and beach fringe is located on Prince of Wales Island, with high proportions also on Wrangell, Sitka, Petersburg, and Ketchikan-Misty Fjords ranger districts, less on the Hoonah Ranger District and the smallest amounts on Juneau and Yakutat ranger districts (Figure 1).

Most stands were harvested between the mid-1950s and the late 1990s, so that most young growth on the Tongass was between 15 and 55 years of age post-harvest in 2014 (USDA 2014, Exhibits 7 and 10). Figure 2 shows the number of acres of untreated young growth in age classes typical of precommercial thinning that occur within Old-Growth Habitat LUD and beach fringe on each district. Prince of Wales (including Thorne Bay and Craig ranger districts) has the highest number of untreated young-growth acres in these age classes and areas, followed by Hoonah, Wrangell, Petersburg, Sitka, Ketchikan-Misty Fjords, Juneau, and Yakutat ranger districts.



	POW	WRD	SRD	PRD	KMRD	HRD	JRD	YRD
OGH	16,990	5,303	7,983	4,334	3,113	4,783	1,061	10
Beach	9,976	6,371	4,576	4,468	5,435	171	508	56

Figure 1. Number of acres of young growth within the Old Growth Habitat LUD (OGH) and beach fringe (Beach) on Tongass districts. POW = Prince of Wales, WRD = Wrangell Ranger District, SRD = Sitka Ranger District, PRD = Petersburg Ranger District, KMRD = Ketchikan-Misty Fjords Ranger District, HRD = Hoonah Ranger District, JRD = Juneau Ranger District, and YRD = Yakutat Ranger District. Data queried Dec 2020.



	POW	HRD	WRD	PRD	SRD	KMRD	JRD	YRD
25 to 30 Years	2024	2426	510	458	464	96	83	6
20 to 25 Years	842		220	204	177	350		
15 to 20 Years	542		4	57		99		2

Figure 2. Acres of untreated young growth in 15-20, 20-25, and 25-30 year age classes typical of precommercial thinning (PCT) within Old Growth Habitat LUD and beach fringe on Tongass districts. POW = Prince of Wales, HRD = Hoonah Ranger District, WRD = Wrangell Ranger District, PRD = Petersburg Ranger District, SRD = Sitka Ranger District, KMRD = Ketchikan-Misty Fjords Ranger District, JRD = Juneau Ranger District, and YRD = Yakutat Ranger District. Data queried Dec 2020.

A. Structural Stages and Site Types

Even-aged stands follow relatively predictable structural stages. These progressive stages of young growth development include stand-initiation, poletimber stem-exclusion, sawtimber stem-exclusion, and understory-reinitiation stages. The combinations of four developmental variables – tree diameter, trees per acre, basal area, and live crown ratios – that characterize these stages, as well as their generalized age ranges and management considerations under high, medium, and low site productivity, are detailed in the Overview to Exhibits 1-3 (USDA 2014). A brief synopsis of these stages is provided below.

In general, the stand-initiation stage lasts from 0-15, 0-30, and 0-40 years post-harvest in high, medium, and low productive sites, respectively. This stage is characterized by a single canopy of tree seedlings and saplings, with more even stocking in more productive sites. Understory shrub and herb cover go from dense to sparse depending on the stocking of the site and age. Crown closures range from 0% in the beginnings of this stage to almost complete canopy closure towards the end of this stage. It is not clear how the canopies of these small trees contribute to snow interception; snow interception may increase with canopy closure, but small branches are not likely to be able to support snow weights comparable to larger-branched trees. Traditionally, the first entry for precommercial thinning occurs or is planned towards the end of the stand-initiation stage.

The poletimber stem-exclusion stage begins when trees fully occupy the site and the canopy begins to close and block sunlight to the forest floor. Shade eliminates new recruitment of trees, shrubs, and herbs. Without treatment, most understory plants decline until they are nearly nonexistent. Snags and logs are comprised of mostly intermediate- and smaller-sized material from trees that have succumbed to suppression mortality or were previously felled during precommercial thinning. This stage generally has high tree densities (e.g., 1,600 trees/acre in medium productive sites). Canopy cover is high in this stage. Snow interception is likely moderate owning to high canopy cover with small branches. The canopy comprises a single story. Tall slender trees in unthinned stands of this stage are often unstable. In less productive sites, pockets of poorly drained areas in the stand may never enter full stem exclusion, thereby retaining higher plant species and structural diversity. On the Tongass, many of the more productive younger stands in this stage have previously been precommercially thinned.

The sawtimber stem-exclusion stage has similar habitat characteristics to the poletimber stem-exclusion stage with small and intermediate sized snags and logs from suppression mortality, moderately high tree densities (e.g., 365-385 trees/acre in medium productive sites), nearly complete single-story canopy cover, and instability in unthinned stands. The key difference between the poletimber and sawtimber stem-exclusion stages for timber is that trees in the latter stage, which generally begins at around 60-90 years post-harvest, are usually commercially viable. These older stands appear to provide some snow interception, and often contain patches of understory vegetation within blow-down gaps, patches of remnant late-seral trees that were retained in original cuts, road and stream openings, and possibly less productive pockets. As these stands approach the understory reinitiation stage, stratification of trees will begin to occur allowing dominant trees to begin emerging in the canopy and understory vegetation may start to reinitiate. Very few stands currently in this stage were previously thinned.

In the understory-reinitiation stage, understory shrubs and herb cover are present and expanding as the stand develops gaps in the canopy, allowing light to once again reach the forest floor.

Shrubs and herbs recolonize first, followed by conifer tree regeneration (Nowacki and Kramer 1998). Canopy structure starts to exhibit two stories due to competition mortality, windthrow, other natural disturbances and dominant-tree emergence. This stage begins at around 70-150 years post-harvest. This stage eventually develops into old growth characterized by a multi-aged, multi-layered canopy and continuous gap-phase replacement, where canopy gaps from individual tree or small-group mortality allow enduring light and space for tree establishment and growth (Oliver and Larson 1996, Nowacki and Kramer 1998). As with stands in the sawtimber stem-exclusion stage, the vast majority of stands in the understory-reinitiation stage on the Tongass have not been previously thinned.

Thirteen common site types include two alder types and eleven site types derived from the four structural stages described above, split out by high, medium, and low site quality (excludes one of the stem exclusion stages in the low site category because lower quality sites do not grow trees as densely and so have less stem exclusion). These thirteen site types have specific structure and growth characteristics that help guide young-growth management on the Tongass. Management considerations for each site type, many specific to wildlife, are detailed in USDA 2014 (Overview to Exhibits 1-3).

Contemporary views of forest succession recognize many successional pathways that can be influenced by a multitude of factors such as site history, seed source, recruitment and sprouting capabilities, and disturbance (Halpern 1988, D'Amato 2007). This perspective highlights both the complexity of young-growth management and opportunities to lead an even-aged stand along a different ecological pathway, perhaps one that better emulates natural disturbances and is more likely to develop key habitat characteristics.

B. Tongass Old-Growth Attributes

An interagency Regional Old-Growth Task Group met in 1990 to quantify old-growth attributes on the Tongass in a document titled *The Ecological Definitions for Old-growth Forest Types in Southeast Alaska* (USDA 1992). Old-growth characteristics in this document can be used to guide young-growth management for wildlife objectives. Attributes include tree canopy layers and diameter classes that indicate structural complexity, habitat indicators such as large trees, decadent trees, snags, and logs, and forb cover that indicates horizontal diversity. The group calculated average attributes from 10-119 plots per forest type and a total sample of 583 plots across all forest types. The combination of all attributes, considered as minimums, together define functional old growth. These characteristics are identified for each of the ten forest types on the Tongass and split out between well-drained (high-site potential) and poorly drained (low-site potential) sites. Table 1 shows these characteristics for eight forest types most applicable to young-growth management. Averages from well-drained and poorly-drained sites can be modeled with Forest Vegetation Simulator to aid in the development of young-growth silvicultural prescriptions designed to achieve wildlife objectives.

Old-growth mapping and assessments on the Tongass use a tree size and tree density model of forest structure that defines 7 types of old growth (USDA 2016b, pages 3-189 – 3-190). Two subgroupings, high volume and large tree, are considered the most important for biodiversity and wildlife habitat. The high-volume subgroup includes the highest volume size-density classes 5N, 5S, and 67 while the large-tree subgroup includes only size density class 67 that is characterized by low densities of large diameter trees (quadratic mean diameter >21 inches, trees greater than 40 inches common and uniformly distributed throughout the stand).

Table 1. Old-growth attributes in well-drained and poorly drained forest types. DBH = diameter at breast height. Large trees = trees ≥ the specified minimum DBH and tree age for each forest type. Decadent large trees = large trees with evidence of top, bole, or root decadence. Large snags = standing dead trees without support, ≥ the specified minimum DBH, and ≥ 10 feet in height. Large logs = logs and dead fallen trees receiving support, ≥ the specified minimum DBH, and ≥ 10 feet in length. Forbs include all forbs except grasses, sedges, ferns, skunk cabbage, and deer cabbage and express discontinuous canopy closure. Forb cover is not applicable (N/A) as an old-growth attribute in mixed conifer owing to the natural openness of this forest type. A minimum of 2 decay class groups for snags and logs also apply to all forest types. The combination of all of these attributes, considered as minimums, together define functional old growth. From USDA (1992).

Well-Drained Forest Types	**Specified min DBH (inches) / tree age (years)**	**# Tree canopy layers**	**# Tree diameter classes**	**Large trees/ac**	**Decadent large trees/ac**	**Large snags/ac**	**Large logs/ac**	**% forb cover**
Sitka Spruce (not alluvial)	23 / 160	2	3	7	2	1	4	5
Western Hemlock	19 / 150	3	4	21	7	2	6	5
Western Hemlock - Western Red Cedar	21 / 170	3	6	16	6	5	6	5
Western Hemlock - Alaska Yellow Cedar	15 / 150	3	4	28	7	3	8	10
Average	**20 / 158**	**3**	**4**	**18**	**6**	**3**	**6**	**6**
Poorly Drained Forest Types	**Specified min DBH (inches) / tree age (years)**	**# Tree canopy layers**	**# Tree diameter classes**	**Large trees/ac**	**Decadent large trees/ac**	**Large snags/ac**	**Large logs/ac**	**% forb cover**
Sitka Spruce (alluvial)	27 / 260	2	2	6	4	2	2	5
Western Hemlock	15 / 180	2	4	17	6	3	6	5
Western Hemlock - Western Red Cedar	19 / 150	3	6	15	7	3	6	3
Mixed Conifer	11 / 170	3	3	12	7	4	4	N/A
Average	**18 / 190**	**3**	**4**	**13**	**6**	**3**	**5**	**4**

C. Natural Scale and Distribution of Disturbance

As mentioned in the Goals and Objectives – Management Direction section, young-growth management in the Old-Growth Habitat LUD and beach fringe should emulate the projected natural scale and distribution of disturbance patterns and the spatial and temporal conditions of nearby old-growth stands in accelerating development of late-seral characteristics. Therefore, it is important to understand scale and distribution patterns of natural disturbance on the Tongass.

Both large and small-scale disturbance mechanisms structure Tongass forests (Kramer et al. 2001). Wind is the primary natural agent of large-scale disturbance on the Tongass (Harris 1989, Nowacki and Kramer 1998). Blow-down areas averaged 10, 35, 39, and 18 acres from studies on southeast Chichagof, northeast Chichagof, Kuiu, and Prince of Wales and nearby islands, respectively, and ranged from 1-1,000 acres in these studies (summarized in Nowacki and Kramer 1998). Blow downs concentrate in certain topographic locations, especially on south-facing slopes exposed to prevailing winds and in exposed areas such as hilltops and ridge noses (Nowacki and Kramer 1998). Blow downs also only occur during certain conditions, based on a number of influences, including stand composition, canopy structure, size, age, and vigor, as well as wind severity and direction, soil and site properties, and topography (Harris 1989, Stathers et al. 1994, Ott 1997, Nowacki and Kramer 1998, Mitchell and Rodney 2001). These factors interact in complex ways, making them difficult to predict (Fosberg et al. 1976, Attiwill 1994). Despite these difficulties, Kramer et al. (2001) developed a model of wind-throw based on exposure, slope, soil stability, and elevation from Kuiu Island data that resulted in fairly close predictions (72% correct) for Zarembo Island. Late-seral forests and associated larger, older trees are more abundant in wind-protected landscapes (DeGayner et al. 2005) and past timber harvest (now young growth) largely occurred outside of areas prone to large-scale wind disturbance (Kramer et al. 2001).

The cool, maritime climate of Tongass temperate rainforests do not currently support fire as a significant disturbance mechanism (Noste 1969). Climate change may influence this relationship in the future. For comparison to slightly warmer, dryer climates, fire acts upon coastal British Columbia forests to the south (Pearson 2010), mostly by small burns restricted to steep south-facing hill slopes (Gavin et al. 2003). Fire frequencies have been reported in coastal British Columbia forests to average about every 300-350 years (Gavin 2000: average 350 years, range 64-12,220 years before present, Hoffman et al. 2016: median 327 years, range 100-12,670 years before present), though short frequencies in wetter forests have been questioned (Daniels and Gray 2006). A significant proportion of low-elevation British Columbia coastal forest has not burned for the last 6,000 years (Gavin et al. 2003). Similar to the Tongass, canopy gaps from mortality of dominant trees is currently the dominant disturbance mechanism in coastal British Columbia forests (Lertzman et al. 1996, Daniels and Gray 2006).

The scale of tree disease and insect-related disturbance may also be increasing. No known reports of large-scale tree mortality from fungal or insect attack existed on the Tongass prior to 2001 (Kramer et al. 2001 citing P. Hennon, personal communication). More recently, hemlock canker disease caused western hemlock mortality along over 70 miles of roadside forest on Prince of Wales Island (USDA 2017) and repeated years of hemlock sawfly infestation along with recent drought conditions likely resulted in about 80,000 acres of mortality attributed to hemlock sawfly defoliation in 2020 (Elizabeth Graham, personal communication, USDA In Press).

Other large-scale agents, such as landslides and avalanches cause natural disturbance on the Tongass, though typically on specific sites under specific conditions. For example, natural landslides on the Tongass develop on exceptionally steep slopes that average 40 degrees or 84%, have gullies or linear depressions from previous landslides, exhibit presence of glacial till and debris, and occur under conditions of high rainfall intensity and duration (Swanston and Marion 1991). Though prior tree harvest affects landslide characteristics (Swanston and Marion 1991), harvest is generally not allowed on slopes greater than 72% except on a case-by-case basis (Forest Plan page 4-62), and only 5% of Tongass young growth is on slopes >67% (USDA 2016b, page 3-40). Therefore, most young growth is outside of areas historically prone to landslide disturbance. Indeed, recent analysis suggests landslides impact only about 19 acres of young growth per year across the Tongass (D. Landwehr, personal communication). Snow avalanches are similarly site-specific, releasing at slopes averaging about 38 degrees or 78% (Peitzsch et al. 2014).

Emulating large-scale disturbances in young-growth management may be problematic for a few reasons. First, though a wind-throw model exists (Kramer et al. 2001), model assumptions and the complexity of factors contributing to large-scale wind disturbance, subsequent wind-expansion of disturbed areas, and whether greater wind exposure results in higher mortality rates through time rather than large-scale events (see Hennon and McClellan 2003) continue to challenge informed management. Second, most timber harvest, and therefore current young growth, occurred in storm-protected areas that were not subject to historic large-scale disturbances by wind (Kramer et al. 2001) or other mechanisms (see preceding paragraphs). Lastly, within Old-Growth Habitat LUDs and beach fringe there are fundamental inconsistencies with using large gap harvests to accelerate late-seral characteristics, especially in areas where large-scale disturbances did not historically occur.

While large-scale disturbance by wind, landslides, avalanches, and disease and insect shapes some areas on the landscape, the dominant form of natural disturbance in the region occurs at smaller scales stemming from canopy-gap formation. Individual or small-group tree mortality from processes such as disease, heart rot, insects, wind snap, and root freezing drive gap patterns and dynamics in Tongass forests. This scale of disturbance offers guidance for young-growth management intent on accelerating late-seral conditions and emulating natural disturbance regimes (Lertzman et al. 1996). Ott and Juday (2002), and others where noted, describe old-growth gap patterns on the Tongass to include the following:

- A majority of canopy gaps are <540 square feet (0.01 acre) in area.
- A majority of canopy gaps have a diameter to height ratio <0.3.
- A majority of canopy gaps were created from the death of one or two trees (range one to seven trees).
- A slight majority of canopy gaps have experienced gap expansion, on average doubling (109%) in area after gap expansion events.
- Forest area in canopy gaps, defined as the land surface area directly under a canopy opening, averages 8.7% (range 5.8 to 12.6%) in western hemlock-dominated forests. Canopy gap coverage from studies in western hemlock-Sitka spruce forests in southeast Alaska is similar, at 3.8-7.4% (Hocker 1990 cited in Ott and Juday 2002, Ott 1997). Yellow cedar on northwest Baranof Island associates with higher canopy gap coverage; 23.1 and 33.7% of

forest area was comprised of canopy gaps in western hemlock-yellow cedar and western hemlock-Sitka spruce-yellow cedar forests, respectively (Ott 1997).

- Canopy gaps are dispersed across the landscape (Ott 1997), distributed broadly and evenly over a range of decay classes (Lertzman et al. 1996, Hennon and McClellan 2003).
- Gaps or portions of gaps can persist for >80 years.
- Forest area in 'expanded gaps', defined as the canopy gap plus the adjacent area extending to the bases of canopy trees surrounding the canopy gap and reflecting area directly and indirectly influenced by the canopy-gap opening, averaged 27.4%. Note that another method of calculating effective gap area using tree shadow length (Zhu et al. 2015) may be overly conservative at higher-latitude sites on the Tongass (Schneider and Larson 2017).

Examples of a small gap disturbance from the death of a large tree and a large-scale disturbance from a landslide are shown in Figure 3. Photos of large-scale wind disturbance can be viewed in Harris (1989). Abundant understory vegetation is apparent in and around the small gap, along with larger trees and canopy cover nearby that will help intercept snow especially around the bases of the larger trees. The landslide is characteristic of large-scale disturbances on the Tongass that are closely tied to specific topographic characteristics such as steep slopes.

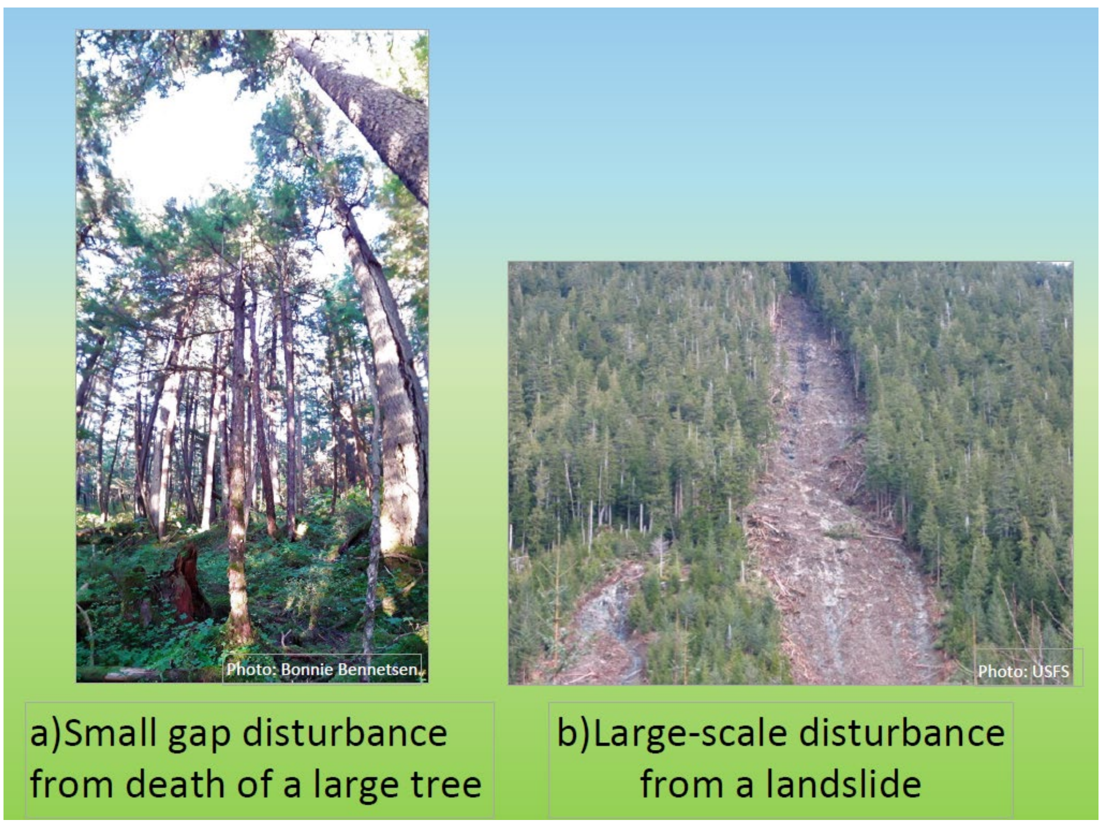


Figure 3. Photos of a) small gap disturbance created by the death of a large tree, with the remnant natural stump in the lower left and b) large-scale disturbance created by a landslide on a steep slope. Notice the abundant understory vegetation in and around the small gap, along with larger trees and canopy cover nearby that will help intercept snow especially around the bases of the larger trees. The landslide is characteristic of large-scale disturbances on the Tongass that are closely tied to specific topographic characteristics, in this case steep slopes.

III. Desired Condition and Key Habitat Characteristics

Many wildlife species inhabit temperate rainforest on the Tongass. These species belong to diverse taxa such as mammals, birds, amphibians, and arthropods. In general, key habitat characteristics for these species tend to include some combination of the following old-growth characteristics:

at landscape scales:

- sufficient area of complex forest and
- habitat connectivity

and at stand scales:

- structurally complex canopies that provide vertical and horizontal heterogeneity and tree-species diversity,
- rich understory vegetation, and
- abundant large trees, snags, and logs.

The old-growth habitat conservation strategy of the Forest Plan addresses the need for large areas of complex forest and landscape-scale habitat connectivity through establishment of a reserve network with connective corridors and associated management standards. Many of the reserves are part of the Old Growth Habitat LUD as well as other areas (e.g., LUD II and protected goshawk nest buffers in development LUDs), while the connective corridors include Riparian Management Areas and beach fringe. As discussed in the Goals and Objectives – Management Direction section, young growth in these areas is to be managed to accelerate development of late-seral characteristics. Tongass old-growth attributes that were detailed in the Existing Condition section and summarized in Table 1 are therefore the desired condition of these areas.

Managing for and restoring biocomplexity in even-aged temperate coniferous forests is paramount to maintaining the biodiversity of these forest ecosystems (Carey 2003). Forest stand attributes that denote biocomplexity of temperate rainforests constitute a mosaic. This structural and plant species mosaic offers an intermixing of a number of attributes important to Tongass wildlife including: good understory development for food and cover, snow interception that facilitates movement and food accessibility, canopy cover from predators, subcanopy heterogeneity to facilitate flying and gliding and protective cover for prey, and abundance of large logs, snags, and trees used for shelter and reproduction.

Studies show that young-growth management can be effective in promoting accelerated development of many late-seral characteristics of the temperate rainforest mosaic (see synopsis in Table 2, starts on page 67). Figure 4 visually demonstrates the structural and diversity benefits that can be attained a few decades after precommercial thinning medium productivity young growth on the Tongass. Variable-density precommercial and commercial thinning in combination with unthinned patches and small gaps promotes vertical and horizontal structural diversity and associated habitat breadth (Carey 2000, 2003). Retaining red alder (Deal et al. 2004, Deal 2007, Deal et al. 2017) and other deciduous and conifer species as well as deformed trees can also help further species diversity and development of future microhabitat sites (e.g., cavities, bark features; Michel and Winter 2009, Sheridan et al. 2013).

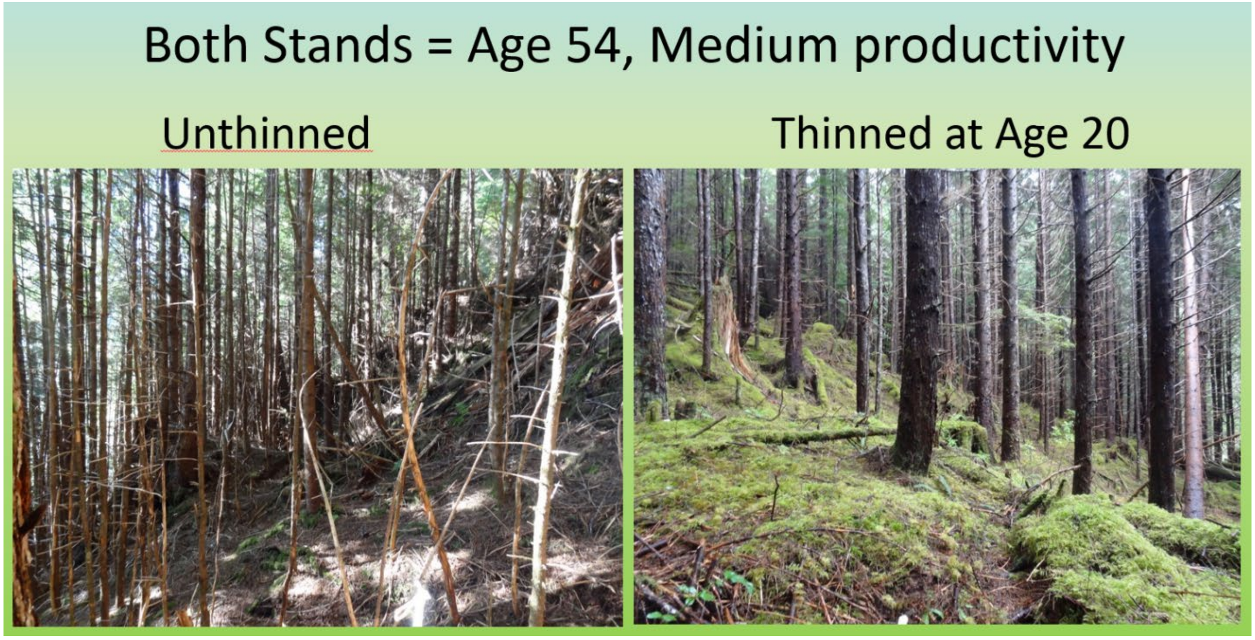


Figure 4. Habitat characteristics of 54-year old young-growth stands of medium productivity that were left unthinned (on the left) or precommercially thinned at age 20 (on the right) on the Tongass National Forest.

Treatments also improve understory vegetation in thinned areas until forests close in again or they are subsequently treated (Cole et al. 2010, Doerr and Sandburg 1986, DellaSala et al. 1996, Zaborske et al. 2002, Farmer and Kirchhoff 2007, Hanley et al. 2013, Eckrich 2016, Crotteau et al. 2020a, b), and longer-term in small gaps (Alaback 2010, Harris and Barnard 2017). The intensity of thinning positively influences the understory vegetation response (Bauhus et al. 2009, Hanley 2005), though differential effects from thinning intensities may disappear with greater time since thinning (Crotteau et al. 2020b). Understory vegetation biomass decreases as the canopy closes in again, but significant and stable proportional differences between thinned and unthinned stands exist several years post treatment (e.g., Doerr and Sandburg 1986: at least 18 years post treatment, Crotteau et al. 2020b: at least 16 years post treatment).

Benefits also arise in producing larger trees, crowns, and branches sooner (Harris and Farr 1974, Maguire et al. 1991, Marshall et al. 1992, Hayes et al. 1997, DeMars 2000, McClellan 2005, Newton and Cole 2012) and growth rates more typical of historical rates for old-growth trees (Hayes et al. 1997, Tappeiner et al. 1997). Given strong associations between the size of large, old-growth trees and their growth rate and size at 50 years of age and that over 70% of height growth and crown development of most conifers in the Pacific Northwest occurs before the trees are 60 years old, early growth rates induced by thinning may have implications for the eventual size potential of old-growth trees (Poage and Tappeiner 2002, Tappeiner et al. 2002, Altman and Hagar 2007, Sensenig et al. 2013). However, greater inherent stand variability and microsite heterogeneity that is thought to be more prevalent on the Tongass compared to other Pacific Northwest forests due to differences in precipitation and drainage may alleviate this issue some on the Tongass (Mike Sheets and Damien Zona, personal communication). Precommercial thinning also promotes stand stability towards wind, snow, and ice and increases subsequent treatment opportunities to mold the stand towards desired conditions that might not be otherwise feasible in unthinned stands (Harris 1989, USDA 2014). Lastly, there is some evidence that young-growth treatments may be able to improve the adaptive capacity and ecosystem resilience of Pacific Northwest young-growth forests (Ares et al. 2010, Neill and Puettmann 2013).

The ability for young-growth management to improve large snag and log features is complicated and further long-term data are needed (Garman et al. 2003, Dodson et al. 2012). Accelerating the development of large trees to promote long-term recruitment of large snags and logs makes sense. But because fewer trees die in thinned stands due to less competition for resources, associated short-term snag and log recruitment decreases with thinning and with higher-intensity compared to lower-intensity thinning (Dodson et al. 2012, Pollock and Beechie 2014). However, the relatively small size of trees that would die from competition in young-growth stands with lower-intensity thinning, or if left unthinned, likely do not provide the same ecosystem benefits as future larger snags and logs. Regardless, maintaining dense patches of trees as short-term sources of competition mortality and smaller-diameter coarse woody debris for some wildlife species is recommended (Wessell 2005, Altman and Hagar 2007). Different young-growth management strategies may be taken depending on the age and size of the trees, and given uncertainties, multiple strategies are likely best, especially at landscape scales (Garman et al. 2003).

Other strategies also exist to promote snag and log features for wildlife. Snags, logs, and cavities can be created artificially using a variety of techniques (Lewis 1998, Carey 1995, Carey and Curtis 1996, Carey et al. 1999a) and heart rot can be introduced into young-growth trees via injury or targeted artificial inoculation to enhance wildlife habitat (Hennon and Mulvey 2014). These methods depend on availability of trees large enough to meet snag, log, and cavity diameter needs, and they may be best focused on specific management needs, sites, and vulnerable wildlife species due to their time-intensive nature. Additionally, large legacy trees (including deformed or diseased trees), snags, logs, and stumps from the preceding forest and retained as uncut or left during the original clearcut can be critical features for wildlife (Carey and Curtis 1996, Curtis et al. 1998, Carey 2000, Michel and Winter 2009, Sheridan et al. 2013, Porter et al. 2020). Alone without thinning, stands with legacy retentions are less ecologically productive than young-growth forests managed with variable-density thinning (Wilson and Carey 2000), so combining these two strategies is best.

Several studies document influences of young-growth management on wildlife species on the Tongass and in broader Pacific Northwest rainforests (see synopsis in Table 3, starts on page 76). Effects on diversity and abundance of forest-dwelling species are typically positive or neutral across most taxa, with exceptions in a few groups such as mycophagists (species that eat mycorrhizal fungi) due to short-term impacts on fungi (Colgan et al. 1999, Carey 2003, Pilz et al. 2006) and amphibians, which warrant further study (Verschuyl et al. 2011). These and other species would benefit from leaving unthinned patches and corridors. The remainder of this section details key habitat characteristics and young-growth management effectiveness for wildlife species that occupy Tongass forests. While the intent is not to cover every species, a variety of Tongass forest species among multiple taxa are considered to build a broad ecological and biodiversity perspective.

A. Sitka Black-Tailed Deer

The Sitka black-tailed deer is an important resource for the Tongass. This subspecies is endemic to the region, meaning it is native and only occurs within this area. Deer are a key food source for humans and predators in southeast Alaska. They also strongly influence region-wide cultural, social, economic, and ecological systems. Most past and ongoing young-growth restoration for Tongass wildlife has aimed at improving short- and long-term habitat for the Sitka black-tailed deer.

1. Goals for Deer

Tongass deer rely on the temperate rainforest ecosystem. Stand-level key habitat characteristics include structurally complex canopies that both intercept snow and provide accessible understory vegetation for forage during heavy snow accumulation (Wallmo and Schoen 1980, Schoen et al. 1984, Hanley et al. 1986, Kirchhoff and Schoen 1987). Key landscape characteristics include habitat connectivity especially for seasonal movements between alpine and low-elevation forests (Schoen and Kirchhoff 1985) and enough old-growth configured on the landscape to ensure winter survival (Kirchoff 1994).

Young-growth management for deer should aim to:

- accelerate development of late-seral characteristics to promote long-term habitat needs,
- promote heterogeneity within young-growth landscapes and stands to ensure short-term accessible winter forage with minimized slash and deep snow impacts, and
- facilitate habitat connectivity by incorporating slash minimization measures and unthinned elevational corridors.

To meet young-growth management goals for deer, three factors should be considered for success: accessible winter forage, slash impacts, and snow interception.

2. Accessible Winter Forage

Deer have sensitive nutritional needs and become malnourished in snowy and prolonged winters when forbs and browse are not accessible. Evergreen forbs such as bunchberry dogwood (*Cornus canadensis*), trailing bramble (*Rubus pedatus*), and goldthread (*Coptis aspleniifolia*), as well as blueberry shrubs (*Vaccinium* spp.) and arboreal beard lichens (*Alectoria sarmentosa* and *Usnea* spp.) are particularly important as winter forage (Hanley et al. 1989). While quality summer forage is important for deer health especially leading into winter (Klein and Olson 1960, Hanley et al. 1989, Parker et al. 1999), high-quality forage on the Tongass is generally most limited in winter when plant nutritional qualities decline, succulent herbs die back, deciduous shrubs lose their leaves, and forage becomes buried by snow (Schoen and Kirchhoff 2007). Winter range and accessible winter forage is therefore critical and believed to be population limiting at Tongass latitudes (Klein and Olson 1960, Suring et al. 1992a).

Effectiveness of young-growth treatments in promoting accessible winter forage may be influenced by a number of factors, including the following:

- initial density, composition, and vigor of understory plants (Hanley et al. 1989, Hayes et al. 1997),
- time since treatment (Cole et al. 2010, Crotteau et al. 2020a, b),
- thinning intensities (DeMars 2000),
- understory sunlight (Hale 2003, Lochhead and Comeau 2012, Hanley et al. 2014),

- type of treatment (e.g., thinning vs gap creation; Alaback 2010, Harris and Barnard 2017),
- thinning prescriptions (e.g. even-spaced vs. variable density, Carey 2003, Bauhus et al. 2009; thinning from below vs. proportional thinning, Maguire et al. 1991; or spatial distribution of thinning, Lowell et al. 2014),
- inclusion of other treatments (e.g., pruning, girdling, fertilization, alder planting; Sullivan et al. 2006, Briggs et al. 2008, Hanley et al. 2013),
- subsequent treatments (Alaback and Herman 1988, Hanley et al. 1989, Berger et al. 2012),
- site drainage (Casey 1997),
- soil disturbance (Hayes et al. 1997), and
- regional differences in forest, climate, or biotic communities (Bauhus et al. 2009).

3. Slash Impacts

Slash is caused by the felling of trees during precommercial thinning and affects both the accessibility of forage and deer mobility within a stand and landscape. Results of young-growth treatment effectiveness for deer have had mixed results, largely due to differences in slash impacts among studies (Table 3, starts on page 76). For example, on Big Level Island, Doerr and Sandburg (1986) found benefits to deer use and browse in stands thinned precommercially at 16 years of age and sampled 18 years post-treatment when most slash was decomposed. Similarly, Martin et al. (2019, unpublished data) also found highest deer densities on Chichagof Island 6-9 years after precommercial thinning when no significant slash barriers to movement remained, but not at 2 years post thinning when slash had not yet decomposed and was often >10 feet in height. Further, slash volumes were significantly lower, and deer use of thinned stands was sooner when trees were thinned at <5 inches DBH compared to thinning implemented at >8 inches DBH (Martin et al. 2019, unpublished data).

In contrast, when large amounts of woody slash covered the forest floor often 3-6½ feet high, precommercial thinning on Heceta Island resulted in increased fawn malnutrition and mortality, likely because slash made forage inaccessible to young deer (Farmer et al. 2006). Additionally, in a study of wolves on Prince of Wales Island (deer inference as their primary prey in this system), stands that were generally thinned at older ages (average 24 years, ranging to 52 years) were avoided by wolves during winter with no selection patterns exhibited during other seasons (Roffler et al. 2018). Slash levels were not reported in this study, but were likely high, owing to older thinning ages.

Slash impacts will depend largely on the diameter of the material when cut (Martin et al. 2019, unpublished data), as well as the number of years since treatment (McClellan et al. 2014, Todd Brinkman unpublished data, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop) and perhaps on snow levels that influence how much weight is pushing the slash down to the ground. Decay of side branches that allow the boles to lay on the ground, rather than bole decay, are thought to be enough to promote deer permeability (McClellan et al. 2014). Slash height has been estimated to decrease by about 17% per year under Chichagof Island snow levels (Todd Brinkman unpublished data, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop), though rates may be slower in areas with less snow. Slash break-down can also be faster with bucking or limbing and may also be influenced by site productivity and associated stocking and slash volumes.

The option of not doing precommercial thinning to avoid slash impacts leads to two potential ecological issues: 1) feasibility of later treatments to support development of old-growth conditions diminishes due to the instability of unthinned stands and 2) growth rates required to develop large-tree and associated old-growth characteristics from the current young-growth cohort may not be met in some stands without treatment (Hayes et al. 1997, Tappeiner et al. 1997, 2002, Poage and Tappeiner 2002, Altman and Hagar 2007, Sensenig et al. 2013). The Siuslaw National Forest in coastal Oregon, which had earlier large-scale logging than the Tongass, is discovering that some untreated young-growth stands will not develop desired old-growth characteristics, especially large diameter trees and branches, and will need to be reset with heavier basal area cuts to achieve desired trajectories (Deanna Williams, unpublished data, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop). Tongass young growth is believed to be prone to higher levels of natural variability than elsewhere in the Pacific Northwest due to higher precipitation and poorer drainage on the Tongass, so this issue is less likely of broad-scale concern for the Tongass (Mike Sheets, personal communication), though this may affect some stands and further understanding is warranted. The Siuslaw also now does first-entry commercial timber thinning earlier (e.g., around age 40) resulting in economic benefits from the smaller product and avoidance of slash impacts. Smaller-product commercial thinning is not currently implemented or feasible on the Tongass.

4. Snow Interception

Snow limits deer in a few key ways: by decreasing access to winter forage and changing diet composition, by decreasing mobility, and to a lesser extent by increasing energy expended to thermoregulate (Hanley et al. 1989, Parker et al. 1984, 1999). To avoid heavy snow accumulations, deer tend to move to old-growth forests on low elevation, south-facing steep slopes and sometimes near beach fringe within their home ranges (Schoen and Kirchhoff 1985, Doerr et al. 2005, Person et al. 2009, Gilbert et al. 2017). The importance of old-growth forest interception of snow strengthens at higher latitudes (Nelson et al. 2008) and elevations and in areas closer to the mainland that have greater snowfall. This relationship is most relevant during more severe winters, which have been drivers for past population declines (Klein and Olson 1960) and especially raise the importance of habitat connectivity for deer (Gilbert et al. 2017). Increased snow depths also intensify deer preference for older young-growth forests, likely due to facilitated movement from snow interception from the closed canopy despite low forage (Gilbert et al. 2017).

Snow interception increases with tree and branch wood volume and canopy closure (Hanley and Rose 1987), so that snow depths are greatest to least in this order: stand initiation/clearcut > recently thinned > less recently thinned > unthinned > high volume old growth (Todd Brinkman, unpublished data, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop). Snow depths greater than 10 inches have been shown to increase energetic costs of locomotion (Parker et al. 1984). Snow burial of blueberry plants, an important winter browse for deer, is a complex function of snow depth, plant height, plant architecture, and twig height, but in general, the probability of burial increases substantially even at low snow depths and all blueberry plants are buried at snow depths greater than 24 inches (White et al. 2009). Based on preliminary data with small sample sizes, snow depths greater than 28 inches may lead to deer exclusion (Todd

Brinkman, unpublished data, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop).

Young-growth management that accelerates long-term development of larger tree and branch sizes is likely to have short-term reductions in snow interception due to reduced canopy closure, but long-term benefits of snow interception as trees grow faster and larger. For long-term goals, stands with overstory canopy coverage of at least 95% and net timber volumes of at least 20,000 board feet per acre offer best snow interception for deer winter range (Hanley and Rose 1987). Promoting heterogeneous young-growth management that incorporates unthinned patches and corridors at stand and landscape scales will alleviate short-term impacts from deep snow on deer.

5. Forage, Slash, and Snow Interception Visualized

Given complex relationships between forage, slash, and snow interception on deer habitat, infographics portraying their importance are depicted in Figures 5 and 6 (both developed by Megan Perra and Todd Brinkman in 2019). Figure 5 shows the influences of snow and canopy cover on summer and winter forage availability as young-growth stands develop. Key features include high summer forage availability in the youngest <12 years and 12-28 year-old stands but low levels in winter due to snow covering existing forage, little forage existing in summer and winter in stem exclusion stages, and moderate to high levels of forage in winter and summer in old growth. Figure 6 shows the influences of precommercial thinning on summer forage availability via changes in canopy cover and slash height. Features include high summer forage availability in the youngest stands before thinning, low summer forage availability about 0-2 years post thinning due to slash impediments, moderately high summer forage availability about 3-20 years after thinning due to diminishing slash heights allowing deer access to the increased forage from thinning, and a later trajectory back towards stem exclusion as thinned canopies close in again. Age ranges for slash impacts will depend on slash diameters and the amount of snow pushing the slash down to the ground; age ranges presented in these Figures are derived from Chichagof Island observations (Martin et al. 2019, unpublished data). While forage levels within thinned stands tend back towards pre-treatment levels and stem exclusion, proportional differences between thinned and unthinned stands may persist (e.g., Doerr and Sandburg 1986, Crotteau et al. 2020b). Both figures also tie in hunting quality, based on hunter preferences for more open, accessible habitats with deer (clearcuts > old growth > unthinned stem exclusion > thinned with slash; Brinkman et al. 2009).

6. Techniques for Deer

A variety of techniques promote short- and long-term habitat needs for deer (see synopsis in Table 2, starts on page 67). Variable-density precommercial and subsequent commercial thinning promotes development of late-seral forest characteristics important for deer in winter. Leaving unthinned patches and corridors helps minimize short-term snow and slash impacts. Thinning by girdling, creating small gaps, and pruning limbs also promotes understory forage with diminished slash impacts as does red alder retention and planting.

Timing precommercial thinning when trees are small (e.g., <5 inches DBH as per Martin et al. 2019, unpublished data) is critical to promoting quick slash break-down, minimizing slash impediment, and maintaining habitat connectivity for deer. Deer habitat connectivity can also be promoted by retaining uncut, slash-free and snow-intercepting elevational leave corridors that

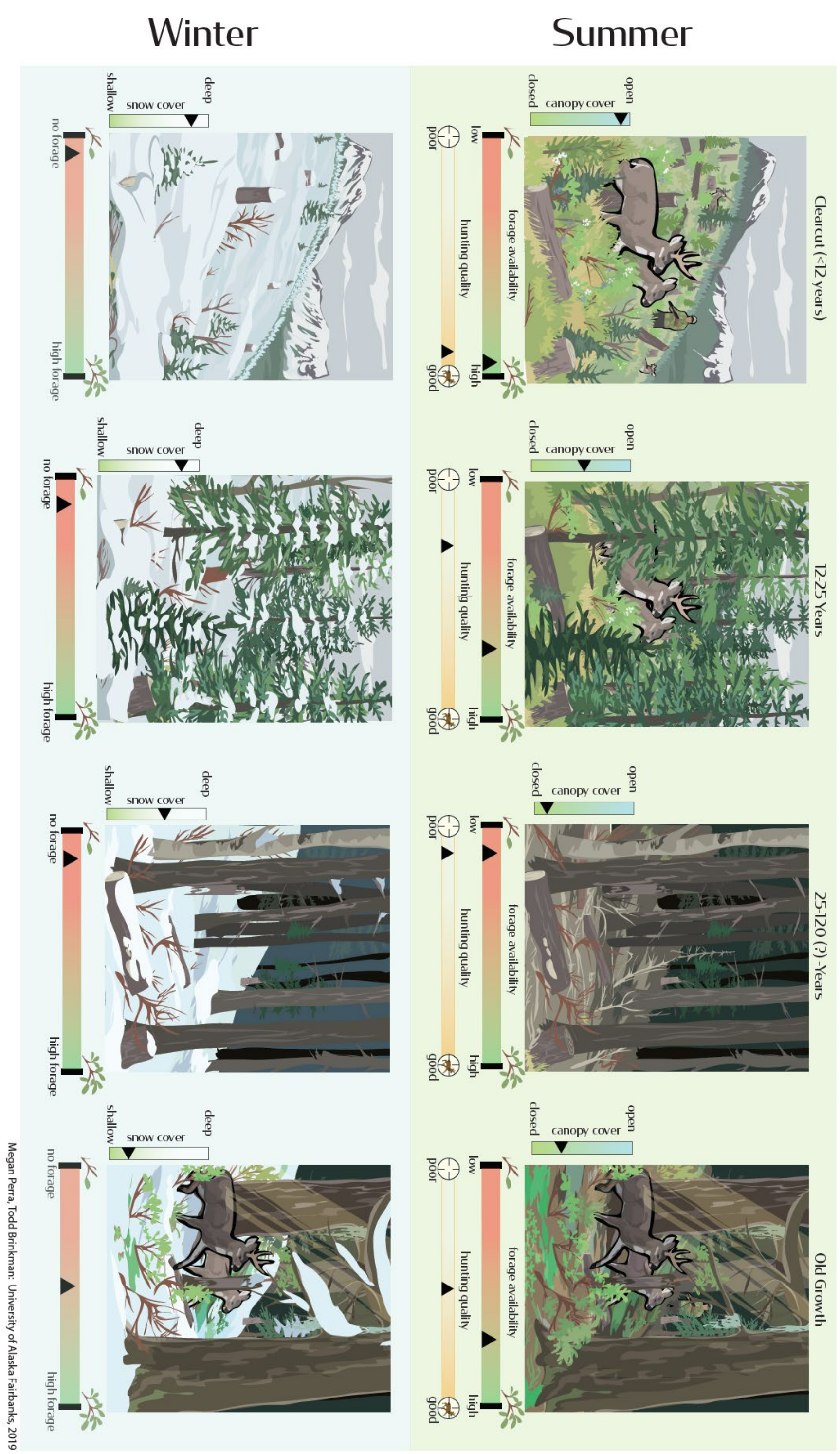


Figure 5. Infographic depicting deer summer and winter habitat response as stands develop from young to old. Features forage availability and hunting quality during summer (no snow) and winter (with snow) in clearcuts <12 years old, young stands 12-25 years old, stem exclusion stands 25-120(?) years old, and old growth. Developed by Megan Perra and Todd Brinkman, University of Alaska Fairbanks, 2019.

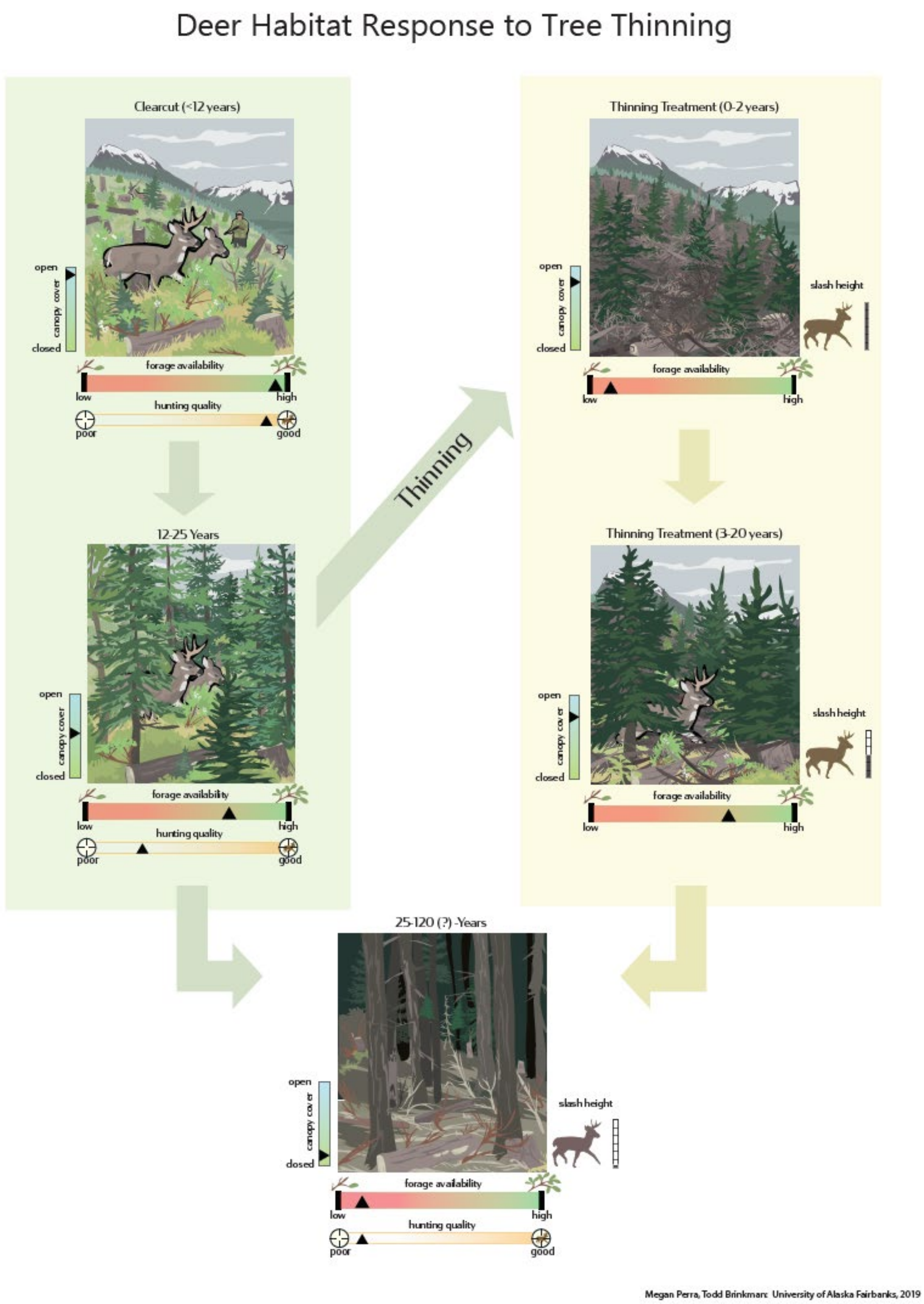


Figure 6. Infographic depicting deer habitat response to precommercial thinning. Features forage availability and hunting quality during no snow conditions as a relationship of canopy cover and slash height with and without precommercial thinning as well as before and 0-2 and 3-20 years after precommercial thinning. Developed by Megan Perra and Todd Brinkman, University of Alaska Fairbanks, 2019.

facilitate deer movement between summer alpine habitat and critical winter range. These corridors should be strategically planned and efforts should be made to locate existing movement routes on the ground or perhaps from GPS records. Retention of existing movement corridors is best, but if these cannot be identified then leave corridors along ridgelines or other topographic features or regularly spaced in thinned landscapes (Wolf Technical Committee 2017) may be needed.

Empirical data on applicable home range sizes and movement patterns of deer should also be used to inform corridor planning for deer. On Chichagof Island, 75% of the collared deer population migrated between low and high elevations at mean distances of 4.8 miles with the remaining low-elevation residents traveling only 0.5 miles on average (Schoen and Kirchhoff 1985). Another study on Chichagof Island reported variable deer movement patterns and that deer can cross watersheds and distances of about 9 miles, but typically stay within the same watershed and span on average 2.4 miles between summer and winter home ranges (McCoy et al. 2015). Yet another study, this one on Prince of Wales Island found very little seasonal migration; only 1 of 41 individuals seasonally migrated (Farmer et al. 2006). Deer home range sizes on Chichagof Island may be as large as 1,171 and 460 acres in summer and winter, respectively (McCoy et al. 2015) smaller than that at about 195 acres and similar between summer and winter (Schoen and Kirchhoff 1985). A study on Prince of Wales Island found total annual home ranges of 489 acres, and 111 and 79 acre within summer and winter core areas, respectively (Yeo and Peek 1992), while Farmer and others (2006) reported female and male home ranges on Prince of Wales Island as 193 and 272 acres, respectively and that these home ranges were used year-round without seasonal migration. These empirical data, with the help of GIS mapping and perhaps GPS- and LiDAR-based wildlife habitat use models, can help inform appropriate spatial scale for young-growth management to minimize impacts and benefit habitat connectivity for deer on the landscape. LiDAR models combined with GPS tracking data can help inform deer habitat use at levels of accuracy previously unavailable (Colin Shanley and others, unpublished data in Prep, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop). LiDAR could also be used to model slash loads in potential treatment stands.

Leave unthinned elevational corridors (at least one per deer home range, ideally a few to several) that are free of slash, do not follow a drainage as these tend to be cluttered and difficult to move through, have canopy structure likely to intercept snow, and are ideally follow pathways already being used by deer. The number of corridors needed will likely depend on home range sizes applicable to the area, size of the treatment stand, nearby treatments and associated impediments to habitat connectivity, and additional information on deer movement needs. Leave corridors should be wide enough to reduce any projected vulnerabilities from windthrow. In landscapes dominated by young growth, deer habitat connectivity should be addressed at landscape and stand scales.

Small gap creation is another strategy that can help improve deer forage, while limiting slash and snow interception impacts. Small gap creation may be effective in promoting forage for longer periods of time than with single-entry thinning (Alaback 2010, Harris and Barnard 2017), while also providing nearby canopies that help intercept snow. However, gaps without prior precommercial thinning will not have the benefits that thinning does in promoting development of old-growth characteristics, large-tree potential, or stand stability for subsequent treatments. Because of this, gaps are typically recommended as secondary treatments for precommercially thinned stands that are returning to stem exclusion or for initial entry into older stands in which treatment cannot wait for commercial windows. Directional felling of logs can minimize slash within the gaps as well as siting gaps where slash treatments will not be necessary. Therefore, more expensive slash treatments should generally not be needed for gap treatments. Gaps should be sited on remnant patches of understory vegetation to best promote retaining this feature. Gaps should be dispersed across the stand and landscape and create about 4-13% of the forest area as gaps, depending on the forest dominance type (Hocker 1990 cited in Ott and Juday 2002, Ott 1997, Alaback 2010, also see Natural Scale and Distribution of Disturbance section).

A variety of gap sizes have been implemented in the past with highly variable responses (Alaback 2010, Harris and Barnard 2017). The long-term, old-growth goal is small gaps that exhibit natural canopy gap sizes after windfall expansion (e.g., majority <540 square feet in mature western hemlock-Sitka spruce dominated forests – see Natural Scale and Distribution of Disturbance section), though in practice we cannot simply apply old-growth gap conditions to a young-growth stand. Gap sizes less than 70 feet in diameter (i.e., <0.1 acre) have been recommended for young growth for deer (Wolf Technical Committee 2017). Larger openings could hinder late-seral development by leading to subsequent even-aged stand initiation within the gap (Deal and Farr 1994) and by understocking stands (i.e., leaving too few trees for late-seral trajectories; Carey 2003). Alternatively, openings that are too small may have little effect, with rapid crown re-closure and resumption of tree competition (DeMars 2000, Carey 2003) caused by quick lateral branch expansion and vertical growth (Bauhus et al. 2009).

Gap prescriptions within Old-Growth Habitat LUD and beach fringe should be based in stand projections that accelerate development of old-growth characteristics. In considering the natural range of variation specific to a treatment area, recognize that most old growth and subsequent young growth does not occur in areas subjected to large-scale disturbance and that disturbance mechanisms are often highly localized to specific topographic and other characteristics (see Natural Scale and Distribution of Disturbance section).

Girdling, pruning and red alder retention are other useful young-growth strategies for deer. Precommercial thinning by girdling promotes deer forage (Hanley et al. 2006, Hanley et al. 2013) while potentially decreasing slash loads through time, though benefits could be diminished if girdled trees come down quickly with strong winds. Pruning of limbs from trees left during precommercial thinning provides increased side-lighting that helps sustain positive understory responses and benefit wildlife (Curtis et al. 1998, Altman and Hagar 2007, Hanley et al. 2006, Hanley et al. 2013). Pruning can also be applied to increase side lighting around gaps. Pruning attains more understory forage with less canopy loss and diminished impacts from loss of snow interception and slash, making it a possible winning strategy. Red alder promotes a more structurally diverse forest canopy, retains understory forage longer, improves nitrogen fixation, and enhances growth of understory plants (Tarrant and Trappe 1971, Hanley and Barnard 1998, Hanley 2005, Deal 2007, Nelson et al. 2008, Deal et al. 2017). However, deer may avoid alder-dominated habitats during winter months due to heavy snow accumulation (Miller 1968, Hines and Land 1974).

B. Mountain Goats

The mountain goat also relies on a combination of snow interception and accessible forage within forested winter sites (Fox et al. 1989). Mountain goat needs differ from deer in that their winter sites occur close to steep terrain, such as cliffs that help them escape predators. Mountain goats also readily survive on conifers, lichens, and mosses when deep snows cover other forbs and ferns (Fox and Smith 1988, Fox et al. 1989) so are less nutritionally sensitive. Key forest habitat characteristics for mountain goats include structurally complex canopies of high volume forest near steep terrain as well as travel corridors between seasonal sites. Within the Tongass, the mountain goat only naturally occurs on the mainland and Baranof Island, though the latter population was augmented with transplants in 1923. An introduced population also established on Revillagigedo Island. Heat stress effects on summer foraging behavior as well as declines in nutritional quality of forage during warm summers reduce Tongass mountain goat survival during the following winter (White et al. 2011). The predicted loss of summer alpine habitat along with impacts of these demographic changes on Tongass mountain goat population projections under likely climate change scenarios (White et al. 2018) raise the importance of management considerations for this species. Young-growth management strategies are similar to those for deer but focus in areas important for mountain goat winter habitat and vertical as well as horizontal seasonal movements.

C. Wolves

The Alexander Archipelago wolf is a subspecies of grey wolf endemic to this region. Though the subspecies generally does well across the islands and mainland of the region, sustainability concerns have been noted for the population on Prince of Wales and surrounding islands (USFWS 2015, Wolf Technical Committee 2017). Young-growth management that benefits wolf prey, such as deer, is expected to also benefit wolves (Wolf Technical Committee 2017). However, precommercial thinning of older stands that results in long-term slash impediments to deer and wolves would not be expected to benefit wolves. Indeed, wolves avoided stands precommercially thinned between 6 and 52 years of age (average 24 years) during winter and exhibited no patterns of selection for thinned stands during other seasons on Prince of Wales Island (Roffler et al. 2018).

Wolves most often select den sites for breeding in old-growth habitat (Person and Russell 2009). Den sites were preferentially located in root wads of large living or dead trees within old-growth forest stands <500 feet from freshwater at lower elevations and flatter slopes (Person and Russell 2009). Therefore, continued retention of remnants in older young growth, and young-growth management that accelerates restoration of late-seral conditions in these areas, should help wolf denning habitat in the long term.

Given strong positive associations between road densities and unsustainable wolf harvest (Person et al. 1996, Person and Logan 2012), road management and the benefits and impacts of decommissioning roads vs keeping roads open for subsequent young-growth management also need to be considered, especially where wolf populations have been identified as vulnerable. These impacts should be considered with the initial harvest and in subsequent young-growth planning.

D. Bears

The Tongass supports two species of bears, black and brown. Though black bears more regularly use forests, both black and brown bears use a variety of habitats, depending on seasonally available food (Schwartz et al. 1987, Miller 1990, Flynn et al. 2012a). Riparian forests with salmon streams are important foraging habitat for bears. Winter den sites are also critical habitat features for bears, used through the years by different individuals and generations (Schwartz et al. 1987, Davis 1996). Tree and woody dens occur in hollows of large live trees, snags, logs, or stumps and root wads, in both old- and young-growth forests (Erickson et al. 1982, Schoen et al. 1987, Davis 1996, Flynn et al. 2012a, Porter et al. 2020). Black bears typically den under the stem (76%) or less typically inside the trunk (24%) of woody structures requiring >300 years to develop, averaging 4.5 feet in diameter (Porter et al. 2020). On Prince of Wales Island, black bears strongly selected den sites in commercial forest over non-commercial or unforested habitat and older young growth over remaining old growth (Porter et al. 2020). The latter resulted because disproportionate logging of large trees (Albert and Schoen 2013) supplied stumps in older young growth that are large enough to be used as dens. Concerns exist about the longevity of denning stumps and the lack of near-term recruitment of suitable denning structures (Davis et al. 2012, Porter et al. 2020).

Young-growth management that accelerates the development of large trees in areas managed for old-growth objectives should help bear denning habitat in the long term. Retention of known den sites is important, while continued retention of large legacy trees, snags, logs, and stumps in harvested stands can also contribute to denning habitat (Erickson et al. 1982, Porter et al. 2020). Thinning enhancement of understory vegetation including berry bushes as well as trees rich in vascular sugars (Schmidt and Gourley 1992, Kimball et al. 1998, Perry et al. 2016) also improve short-term habitat value of young-growth forests for black bears. Habitat connectivity and slash planning in riparian forests by incorporating unthinned travel corridors and thinning when slash is small diameter so that it breaks down quickly will help both bear species.

E. Northern Flying Squirrels

The northern flying squirrel is another species with key habitat characteristics relevant to young-growth management on the Tongass. Two subspecies exist on the Tongass. *Glaucomys sabrinus zaphaeus* is endemic to Mitkof, Wrangell, Etolin, and Revillagigedo islands and the mainland within Southeast Alaska, while *G. s. griseifrons* occurs only on Prince of Wales and adjacent islands (Bidlack and Cook 2001, MacDonald and Cook 2007). Flying squirrels may act as sentinels of healthy coniferous forests due to associations with old-forest components, sensitivities to forest management, roles as prey for owls and other predators, and importance in dispersal of mycorrhizal fungi spores, nitrogen-fixing bacteria, and canopy lichens critical to forest processes (Li et al. 1986, Carey et al. 2002, Smith 2007, 2012).

Key habitat characteristics of flying squirrels tend to include large live trees, snags, and logs, canopy cover and structural complexity, understory shrubs, and fungal fruiting bodies (Carey 1995, Smith et al. 2004, Gomez et al. 2005, Smith 2007). Midstory tree cover and connectivity are important (Wilson and Forsman 2013). The Prince of Wales subspecies exhibits preference for individual microhabitat characteristics such as large trees and snags and blueberry shrubs rather than multifactor old-growth components typical of flying squirrels elsewhere, perhaps owing to the absence of red squirrel competitors and a more generalized diet (Smith et al. 2005a). Flying squirrel habitat characteristics aid in predator avoidance, food availability, denning cavities, and gliding locomotion (Colgan et al. 1999, Pyare et al. 2010, Wilson 2010, Holloway and Smith 2011, Smith 2007, 2012, Wilson and Forsman 2013). Flying squirrel densities within habitats are typically associated with availability of food, especially fungal fruiting bodies (Waters and Zabel 1995).

At larger scales, flying squirrels require 247 acre (1 km^2) habitat patches consisting of at least 73% old-growth forest cover and habitat connectivity (Smith and Person 2007, Shanley et al. 2013, Trapp et al. 2019). Flying squirrels avoid clearcuts and occur infrequently in young-growth forests (Mitsdarfer 2011, Shanley et al. 2013, Wilson and Forsman 2013). General avoidance of managed habitats may occur because of the following: decreased gliding capabilities in managed habitats and increased energy costs from quadrupedal locomotion (Scheibe et al. 2006, Flaherty et al. 2010a), poor food availability within managed habitats (Flaherty et al. 2010b, Hamill and Stone 2018), limited perceptual ranges so that flying squirrels have difficulty perceiving forest habitat across clearcuts (Flaherty et al. 2008), increased predation costs associated with crossing gaps (Wilson 2010, Smith et al. 2013, Wilson and Forsman 2013), and poor availability of denning sites (Pyare et al. 2010). Forest habitat connectivity facilitates movements for breeding, foraging, and dispersal by flying squirrels.

Studies indicate flying squirrel abundance is affected by thinning. Several authors have demonstrated at least short-term negative effects (Carey 1995, 2000, 2001, 2003, Garman 2001, Larson 2001, Manning et al. 2012, Wilson and Forsman 2013) possibly followed by recovery (Carey 2003), neutral (Gomez et al. 2005), and positive effects (Ransome et al. 2004, Sullivan et al. 2017; also see synopsis in Table 3, starts on page 76). Short-term impacts are thought to correlate with short-term impacts to fungal fruiting bodies from mechanical disturbance, loss of photosynthate due to removal of host trees, changes in microclimate, or loss of coarse woody debris (Colgan 1997, Colgan et al. 1999, Carey 2003, Gomez et al. 2003). Post-thinning fungi recovery has been documented (Pilz et al. 2006) as well as beneficial effects of low-intensity and variable density thinning on diversity and abundance of the most nutritional fungal species when they are needed the most by flying squirrels (winter; Colgan 1997, Colgan et al. 1999).

Retention of legacies (Carey 1995, 2000, 2001), including coarse woody debris (Gomez et al. 2003), use of variable density thinning and avoidance of wide-spread even-spaced thinning (Carey 2001), and associated retention of unthinned patches (Carey 2003) or unthinned stands (Larson 2001) are recommended for this species. Wilson and Forsman (2013) suggest precommercial thinning of young forests <25 years to stimulate midstory development and also recommend keeping some young, high-density forest on the landscape and exploring the use of skips and gaps for this species. Approaches that accelerate old-growth development, including variable density thinning, unthinned patches, and retention of remnant large trees, snags, and logs should benefit this species in the long term.

F. Red Squirrels

Red squirrels occur naturally in a wide variety of forest habitats throughout the coastal mainland of Southeast Alaska and on islands south of Frederick Sound and east of Clarence Strait (e.g., Betton, Deer, Douglas, Etolin, Gedney, Grant, Hassler, Horseshoe, Kuiu, Kupreanof, Mitkof, Read, Revillagigedo, Sullivan, Tatoosh, Tongass, Vank, Woronkofski, Wrangell, and Zarembo islands; MacDonald and Cook 2007). There are also presumed introduced populations on Gravina, Annette, Admiralty, Baranof, Chichagof, Hill, Inian, Kruzof, Moser, Partofshikof, and Yakobi islands, and on the smaller islands in the Sitka Sound (MacDonald and Cook 2007). Red squirrels are currently absent from Prince of Wales Island (MacDonald and Cook 2007).

Optimum habitat for red squirrels includes forest stands with 2 or more species of conifers of cone-bearing age for food, snags for den sites, and down logs to aid food caches (Suring 1983, USDA 2007). This species tends to be most often associated with high tree densities, canopy closure, and larger trees (Bakker 2003, Flaherty et al. 2012), likely owing to their dependence on conifer seed crops (Smith 1968, Gurnell 1983, Halvorson and Engeman 1983), along with predation risks and movement costs (Bakker 2003, USDA 2007). Large Sitka spruce trees are associated with high calling rates and midden use, while large conifers of any species predicted shorter home range movements (Bakker 2003). While red squirrels will cross clearcuts when forested detours are long, behaviors suggest higher perceived predation and/or energetic costs in clearcuts (Bakker 2003, Bakker and Van Vuren 2004).

Use of young forests is largely influenced by availability of cones (Ransome and Sullivan 1997; Gurnell et al. 2002) and movement feasibility through trees (Gurnell et al. 2002). Precommercial thinning of young lodgepole pine forests in south-central British Columbia had neutral effects on red squirrel abundance, mass, recruitment, movement, and survival 12-14 years afterwards (Ransome et al. 2004). However, radio tracking of red squirrels in pine forests in England documented use of young stands from the age they start bearing cones to when thinning gaps in the canopy became too large for the squirrels to easily move through trees (Gurnell et al. 2002). Mean red squirrel abundance in coastal and interior forests in British Columbia did not differ among variously thinned, unthinned, and mature stands, though some evidence suggests unthinned stands were used less than mature stands (Sullivan et al. 2017). Thinning has consistently been shown to stimulate cone production (Puritch 1977), which should benefit red squirrels as soon as young trees reach cone-bearing age. Cone production may not begin until age 40 in Sitka spruce (Ruth 1958) but can be heavy in 100-year-old stands indicating valuable habitat for red squirrels in Sitka spruce-western hemlock forests in Oregon (Ruth and Berntsen 1955). Variable density thinning with unthinned patches should help promote short- and long-term habitat characteristics for red squirrels, promoting large tree development and cone production while minimizing loss of interconnecting trees.

G. Small Ground-Dwelling Mammals

Small ground-dwelling mammals, such as mice, shrews, voles, and ermine also have habitat considerations for young-growth management. The Tongass supports at least 18 native species and 31 subspecies of small, ground-dwelling rodents and shrews as well as three distinct lineages and several subspecies of ermine, many of them endemic to the region, or to specific areas or islands within the region (MacDonald and Cook 2007). Many of the rodents inhabit meadow, marsh, riparian wetland, or alpine habitats (MacDonald 2009) so have less relevance to forest management. Many other small ground-dwelling mammals as well as the ermines are habitat generalists or open-habitat specialists (Van Horne 1982, MacDonald 2009, Smith et al. 2005b, Ben-David et al. 2014), making them less critical for young-growth management aimed at accelerating development of old-growth function, though they may be influenced by treatments.

Small mammals of Tongass forests generally prefer structurally rich and diverse understory vegetation and ground cover, especially of salmonberry and blueberry shrubs and herbaceous plants, which offer food (Smith et al. 2005b, MacDonald 2009, Eckrich 2016). Large logs are also important for food, serving as substrates for fungi and invertebrates, as well as for shelter and locomotion paths (Maser et al. 1979, Brown 1985, Butts and McComb 2000, Smith et al. 2005b). Moss, litter, and sites with moisture additionally promote invertebrate prey for Tongass shrews (MacDonald 2009). Small mammals serve as prey for raptors and mammalian carnivores and as dispersers of seeds and fungi spores and associated microorganisms (Li et al. 1986). Processes such as competition, predation, and habitat selection tend to structure populations of small ground-dwelling mammals at localized scales (e.g., within 100s of yards) possibly with less importance of larger landscape contexts (Bowman et al. 2001).

Southern red-backed voles closely associate with moist habitats with abundant litter, stumps, rotting logs, and exposed roots (Merrit 1981). These features are typical to old-growth forests and accordingly, red-backed voles occur most often in late-seral forests (Sullivan et al. 2000). Southern red-backed voles are also considered mycophagists because they regularly consume hypogeous fungi (Ure and Maser 1982, Maser and Maser 1988). Abundance and diversity of fungal fruiting bodies including underground truffles, and evidence of foraging on these by small mammals are all higher in old-growth stands than in paired, unthinned 45-70-year-old stands on the Tongass (Hamill and Stone 2018) and similar results have been observed elsewhere in the Pacific Northwest (Amaranthus et al. 1994). Four to five subspecies of the southern red-backed vole (*Myodes gapperi*) inhabit the Tongass, *M. g. phaeus* in the extreme south mainland, possibly *M. g. saturatus* in the upper reaches of the Portland Canal, *M. g. solus* endemic to Revillagigedo Island, *M. g. stikensis* from the Stikine River south to the Cleveland Peninsula, and *M. g. wrangeli* endemic to Wrangell and nearby Sergief islands (MacDonald and Cook 2007).

Southern red-backed voles consistently occupy recently precommercially thinned stands on Wrangell Island, presumably supported by the cool, moist climates of this region, along with woody debris, herb, and shrub enhancements from thinning (Smith and Nichols 2004, Smith et al. 2005b). However, greatest red-backed vole use of these thinned stands coincided with higher population levels as well as lower body mass, number of reproductive females, and juvenile recruitment compared to old-growth stands, so demographic concerns may exist (Smith and Nichols 2004). Longer-term effects as thinned forests close in again are also uncertain (Smith and Nichols 2004). Mycophagists tend to incur short-term impacts from commercial thinning with subsequent recovery (e.g., Suzuki and Hayes 2003, Carey 2003). This pattern is reflected in initial reductions of hypogeous fungi likely due to mechanical disturbance of fungal mats, loss of photosynthate due to removal of host trees, loss or damage to coarse woody debris, and/or changes in microclimate (Colgan 1997, Colgan et al. 1999, Carey 2003, Gomez et al. 2003) with subsequent recovery of fungi within about 5-6 years post-treatment (Carey 2003, Pilz et al. 2006).

Young-growth management more generally tends to have positive or neutral effects on small, ground-dwelling mammals, with positive effects particularly on generalists, insectivores, and herbivores (see synopsis in Table 3, starts on page 76). Positive or neutral effects were documented in Pacific Northwest forests with precommercial thinning (Sullivan et al. 2001, 2009, Suzuki and Hayes 2003, Eckrich 2016), commercial thinning (Carey and Wilson 2001, Garman 2001, Larson 2001, Carey 2003, Slauson 2013) and small gap creation (Gitzen and West 2002). On the Tongass, small mammal densities were not affected by precommercial thinning, but shrew populations became more stable and less susceptible to changes in mice densities in precommercially thinned stands compared to unthinned stands, likely due to improved habitat quality (Eckrich 2016). Young-growth management that concentrates in the short term on providing multispecies canopies, coarse woody debris, and well-developed understories in restoration of old-growth conditions are likely to be most effective in conserving small mammal biodiversity (Carey and Johnson 1995).

H. River Otters

River otters use forested habitat on the Tongass for resting and pupping. Resting burrows are typically located within about 750 feet of the beach, on convex shorelines, under large snags or trees (mean DBH 33 inches), and in areas with less shrub cover (0-5% *Rubus*), more canopy closure (>25%), steeper slopes (41-80% at burrow sites), and abundant large snags and trees (Larsen 1983). River otters generally avoid placing their burrows in clearcuts, presumably due to high shrub cover and slash (Larsen 1983). There is no relationship between resting burrow locations and tree densities (Larsen 1983). River otters use slash-free older young-growth (60-70 years old) and old-growth forests for resting in proportion to their availability (Larsen 1983), though burrow density was highest in low-volume old growth (Larsen 1983) and old growth is a key habitat component of above-ground resting sites, called latrine sites (Bowyer et al. 1995).

Natal dens sites used for pupping in Southeast Alaska typically occur farther inland, averaging 0.5 miles from beach shorelines, on well-drained sites near small streams (Woolington 1984). The streams are used as travel corridors between den sites and foraging areas on the coast (Reid et al. 1994). Predominant vegetation at den sites in Southeast Alaska was uneven-aged old-growth forest (Woolington 1984).

Young-growth management within and near beach fringe and riparian areas that aims to accelerate development of old-growth conditions should benefit this species in the long term.

I. Martens

Another group of species, martens, use forested habitats influenced by young-growth management. The Tongass supports two marten species. After the last glaciation, the American marten (*Martes americana*) naturally colonized the mainland and Etolin, Kuiu, Kupreanof, Mitkof, Revillagigedo, Woewodski, and Wrangell islands, but now also occupies the remaining larger islands, except Admiralty, owing to transplants (MacDonald and Cook 2007). The Pacific marten (*Martes caurina*) is currently extant only on Admiralty and Kuiu islands (MacDonald and Cook 2007) with evidence of hybrids on adjacent Kupreanof Island (Colella et al 2018). There is indirect evidence from nematode parasites that suggests the historical range of the Pacific marten also included Chichagof Island (Koehler 2006) and possibly other islands (Dawson et al. 2007, MacDonald and Cook 2007, Hoberg et al. 2012). Kuiu and Admiralty harbor a significant portion of the Pacific marten species genetic diversity owing to novel variation from isolation of these populations (MacDonald and Cook 2007, Dawson et al. 2017). The two marten species hybridize on Kuiu and Kupreanof islands where their ranges overlap (Small et al. 2003, Colella et al. 2018a). Evidence suggests hybridization may be maladaptive or result in decreased survival to adulthood, especially in females (Colella et al. 2018a). While 80% of Kuiu Island marten samples were Pacific marten, unidirectional, asymmetric introgression favoring American marten leads to concerns about potential future viability of Pacific marten on the island due to directional gene flow (Colella et al. 2018a, 2018b). Evidence also suggests the Pacific marten population on northern Kuiu Island is still low and probably below sustainable levels (Flynn et al. 2012b).

Both species are considered generalist predators, eating a variety of prey. On Chichagof Island, marten abundance fluctuates with the abundance of small mammal prey, especially of long-tailed voles on Chichagof Island (Flynn and Schumacher 2009), though voles are uncommon on Kuiu Island (Flynn et al. 2004). Pacific martens have facial structures that allow them to take more marine prey items in addition to terrestrial forage (Colella et al. 2018a). Martens will switch to alternative prey such as salmon when preferred small rodents are not readily available (Ben-David et al. 1997).

Both species of martens inhabit structurally complex forests with abundant large trees, snags, logs, shrubs and canopy cover that promote resting, denning, thermal cover, food availability, and predator avoidance (Suring et al. 1992b, Slauson et al. 2007, Flynn and Schumacher 2016). Large diameter trees, snags, stumps, and logs averaging 30 to 35 inches in DBH were selected as reproductive dens and resting sites by martens on Chichagof Island (Schumacher 1999). On Kuiu Island, important predictors of marten habitat at landscape scales include lower elevation, closed canopy old-growth forest in areas with higher densities of salmon streams and nearer to the coast (Koch 2016). On Prince of Wales Island, martens were most abundant in old growth and unthinned stands, less abundant in stands precommercially thinned, and least abundant in clearcuts (Ben-David et al. 2014). Martens cross openings reluctantly (Cushman et al. 2011) and change their movement patterns when they do (Moriarty et al. 2015). Landscapes with joined networks of complex forests are therefore thought to be critical in maintaining functional connectivity for marten (Moriarty et al. 2015). Marten occupy large home ranges (mean = 2.41 square miles for males on Chichagof Island, Flynn and Schumacher 2001) with few openings (Moriarty et al. 2016). Loss of >25-40% of forest landscapes to openings typically leads to population declines (Hargis et al. 1999, Potvin et al. 2000, Fuller 2006, Moriarty et al. 2016).

Given their sensitivities to canopy openings and that martens are less abundant in precommercially thinned stands than unthinned stands on Prince of Wales Island (Ben-David et al. 2014) and they prefer high volume, closed canopy forest over more open and precommercially thinned habitat on Kuiu Island (Koch 2016), some short-term impacts are expected from young-growth management on these species. Managed openings in the canopy from thinning and other treatments in the short term will likely impact marten movement patterns, habitat selection, and connectivity. Care should therefore be taken to ensure habitat connectivity for these species, especially in areas with Pacific marten sustainability concerns (i.e., Kuiu Island). Leave patches and corridors will help alleviate this issue as will planning corridors to maintain connectivity of canopy cover through space and time, especially of old growth but augmented as needed with older young-growth forests. Young-growth management that accelerates development of late-seral conditions, especially stand complexity and large tree characteristics should benefit martens in the long term. Efforts to retain and recruit large trees, snags, stumps, and logs, and to enhance understory vegetation for prey should also help martens. Road management issues related to young-growth management mentioned for wolves also apply to martens as these species are highly vulnerable to trapping along roads (Flynn and Schumacher 2009, Flynn et al. 2012b).

J. Bats

Bats also have habitat characteristics influenced by young-growth management. Six species of bats live in Tongass forests, including silver-haired bats (*Lasionycteris noctivagans*) and five myotis species: California myotis (*Myotis californicus*), long-eared myotis (*M. evotis,* note that Keen's myotis is now considered part of this species: Lausen et al. 2019), little brown bat (*M. lucifugus*), long-legged myotis (*M. volans*), and Yuma myotis (*M. yumanensis*) (Parker et al. 1997, Olson et al. 2014). A seventh species, hoary bats (*Lasiurus cinereus*), additionally use the Tongass during migration (Blejwas et al. 2014). Concerns exist about White Nose Syndrome, caused by a fungal disease which has now spread to Washington State and decimated bat populations in the eastern United States and Canada. Bats play important roles in insect control, including mosquitoes (Wray et al. 2018).

Key habitat characteristics relevant to young-growth management include large trees and snags for roosting and low tree densities for flying. Tongass bat species will roost in deep fissures in bark of large diameter, old-growth trees in western Oregon and Washington (Christy and West 1993), and may use these features in addition to rock crevices, root wads, karst caves, and buildings on the Tongass. Open, clutter-free flightpaths are also key, with markedly lower bat activity shown above 445 stems/acre (Blakey et al. 2016). Tongass bats typically forage within riparian areas and use old-growth stands for commuting, with very low activity in young growth in stem-exclusion stages (Parker et al. 1996). Bat activity is higher in thinned than in unthinned stands (Humes et al. 1999; Blakely et al. 2016). Therefore young-growth management that includes thinning stem densities and promoting development of old growth conditions should benefit this species in short and long terms.

K. Queen Charlotte Goshawks

The Queen Charlotte goshawk is a subspecies of the northern goshawk that nests in coastal temperate rainforests of Southeast Alaska and British Columbia. The British Columbia distinct population segment is federally listed as threatened due to combined timber harvest and projections of future harvest totaling 59% of the original productive old growth forest preferred by this species (USFWS 2012). The Tongass old-growth conservation strategy that includes an old-growth reserve network with connective habitat and measures that protect goshawk nests and associated old-growth habitat were largely influential in the determination not to federally list the Alaska populations (USFWS 1995, 2012). This species is included on the Regional Forester's Sensitive Species list for the Tongass.

Goshawks are highly adapted to nesting and foraging in old-growth forest; they are dependent on 1) large trees suitable for nests, 2) clear, subcanopy flight-lines that support their perch-flight, attack-style foraging, and 3) structurally diverse forest that sustains a multitude of goshawk prey. Key habitat characteristics include moderate to high density old-growth forest with an open subcanopy layer on flat to moderate slopes at lower elevations (Titus et al. 1994). Nests occur in large conifers (mean DBH 31 inches), generally in old growth (89%), but occasionally in 90+ year old young growth (11%; Titus et al. 1994). Nests are often re-used in consecutive or non-consecutive years and new nests are often built in the same stand.

Young-growth management that accelerates development of old-growth conditions is likely to support long-term nesting and foraging habitat for goshawks. In the short term, habitat for prey, such as Steller's jays, sooty grouse, varied thrush, red squirrels, and woodpeckers may be enhanced by variable density thinning with small gaps and unthinned patches.

L. Bald Eagles

Bald eagle populations in Southeast Alaska increased until the late 1980s and have remained stable since (Hodges 2011). The Bald and Golden Eagle Protection Act protects bald eagles and active and inactive bald eagle nests (USFWS 2016) and the USFWS developed guidelines to help agencies avoid impacts (USFWS 2007). Bald eagles regularly nest and roost in large conifers and snags, often exceeding 100 feet in height and 40 inches in diameter (Wright and Schempf 2008). They will reuse prior nests, building them up over the years into substantial structures supported by the large trees. Bald eagle nesting, perching, and winter roosting habitat often occurs within the beach fringe and along larger streams, near fish prey (Wright and

Schempf 2008). Young-growth management that accelerates old-growth development in these areas will benefit habitat components for this species over the long term.

M. Other Raptors

Other raptors that breed in coniferous forests on the Tongass include the sharp-shinned hawk, red-tailed hawk, merlin, western screech-owl, great horned owl, northern pygmy-owl, barred owl, and northern saw-whet owl (Johnson et al. 2008). Measures in the Forest Plan protect active raptor nests, both from habitat modification and from disturbance during breeding. These raptors tend to nest in large conifers or snags. For example, western screech-owls on Mitkof Island nest in natural cavities in dead or dead portions of live western hemlocks that average 27 inches DBH, often the largest trees in the stand (Kissling and Lewis 2009). Forested habitat within valley bottoms near large streams are particularly important for some species (Johnson et al. 2008, Kissling and Lewis 2009). Young-growth management that accelerates large tree and snag development will benefit habitat components for these species over the long term. Treatments that promote hawk and owl prey, such as small mammals, birds, small vertebrates, and insects are also likely to benefit these raptor species.

N. Vancouver Canada Geese

While Vancouver Canada geese are closely associated with water, this subspecies is unique in that they nest and raise their broods within the forest (Lebeda and Ratti 1983). However, only about 3% of suitable Vancouver Canada goose habitat on the Tongass, defined as hydric soils below 1,000 feet in elevation, has been harvested for timber (range 0-6% among Game Management Units; USDA 2007). Key nesting and brood rearing habitat features include dense canopy cover ranging from 66-88% and dense understory vegetation for forage and escape cover (Lebeda and Ratti 1983, USDA 2007), near muskegs (Hupp et al. 2011). Doyle et al. (1988) and Alaback (1984) hypothesized that young-growth stands in stem exclusion likely provide sufficient canopy cover, but insufficient understory vegetation for Vancouver Canada goose forage. Young growth in less productive, hydric soils will have more natural diversity and structural heterogeneity in the canopy and understory than more productive stands.

Owing to the small proportion of harvested Vancouver Canada goose habitat, short-term management tradeoffs between canopy cover and understory growth, and the higher natural heterogeneity of hydric goose habitat, young-growth management is not likely to focus on this species but may generally benefit geese by accelerating development of old growth near water.

O. Marbled Murrelets

Marbled murrelets are one of two murrelet species that occur on the Tongass. Kittlitz's murrelets nest in remote glacial mountainous areas that are unvegetated or sparsely vegetated (Kissling et al. 2015), sites not relevant to young-growth management. Marbled murrelets in Southeast Alaska nest in approximately equal numbers on ground sites on cliffs, steep alpine scree, or rocky slopes near or above tree line and on tree sites within old-growth forests (Barbaree et al. 2014).

Tree nest sites occur in large old-growth conifers (>50-inch DBH, >118 feet tall, Grenier and Nelson 1995), especially in Sitka spruce, on large moss-covered platforms, in spots where foliage shields the nest from above (Naslund et al. 1995). A majority of nests in the Pacific Northwest are within 328 feet of saltwater, but a few are much further inland (Hamer and Nelson

1995). Nests are often found near streams and other openings, suggesting possible use of these features as travel corridors (Hamer and Nelson 1995). The key forest habitat feature for marbled murrelets is large trees with large mossy branches (Hamer and Nelson 1995), big enough to serve as nest platforms for this seabird and provide flight paths to the sites. Key forest habitat characteristics also include the largest tree-size and volume classes in areas with larger and higher densities of dominant trees, higher canopy closure, more suitable nest platforms, and greater epiphyte coverage (Grenier and Nelson 1995, Naslund et al. 1995). The number of suitable nest platforms correlates with the number of canopy layers and with mistletoe abundance (Grenier and Nelson 1995). There may also be some level of site fidelity and clumped or semi-colonial nesting (Naslund et al. 1995).

Marbled murrelets use nest platforms on large branches (Hamer and Nelson 1995). Large branches develop on widely spaced trees or on trees adjacent to gaps or openings (Maguire et al. 1991, Hayes et al. 1997, Altman and Hagar 2007). Therefore, variable density thinning and/or small gaps should promote development of this and other key habitat features for marbled murrelets. In recent young-growth management aimed at promoting marbled murrelet habitat, the Chugach National Forest used a 16X16 foot spaced thinning with 50% variance, retained 5-10% untreated forest within units greater than 4 acres, and kept dominant trees with vigorous canopies to promote lateral branch development (Nathan Wesely, unpublished data, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop).

Another technique called radial tree release has recently been explored in young growth timber management in Oregon for marbled murrelets and large tree and branch development particularly in mind (Deanna Williams, Siuslaw National Forest Wildlife Biologist, personal communication). The strategy essentially involves retaining a large tree inside small, thinned gaps. The leave trees are those with the deepest crowns and largest or most complex limb structures, often notably different from the trees with the largest DBHs. Apart from snags, minor species, and nest trees, all trees within a 30-foot radius around the focal trees are harvested to release the growth potential of these deeply crowned leave trees. On the Siuslaw and Mt. Baker Snoqualmie National Forests, this strategy has been applied in their timber programs, as initial, older (~40 year-old) commercial entries. They mark 10 focal trees per acre and leave all intervening habitat outside of the cut radii unthinned. They cite economic benefits of attaining variable-density thinning and gaps with minimal tree marking. The technique of leaving a tree within gaps has been applied on the Tongass as well. Adjustments to distances and leave tree numbers may be necessary to apply this strategy to Tongass growing conditions and to manage for old-growth objectives. Applications of radial tree release gaps within Old-Growth Habitat LUD and beach fringe could be implemented similarly to small gap treatments: small in area (approximately <70-feet diameter as per Wolf Technical Committee 2017; <0.1 acre), dispersed across the stand and landscape as applicable, and aim to create about 4-13% of the forest area as gaps, depending on the forest dominance type (Hocker 1990 cited in Ott and Juday 2002, Ott 1997, Alaback 2010, also see Natural Scale and Distribution of Disturbance section).

P. Other Forest Birds

Key habitat characteristics of other Tongass forest birds have relevance to young-growth management. A number of species are attracted to heterogeneous stands composed of multi-layered foliage and complex canopy structure (Kessler 1979, Kessler and Kogut 1985, Sidle 1985). Cavity-nesting birds such as the hairy woodpecker, red-breasted sapsucker, and others are influenced most by abundant large snags (Mannan and Meslow 1984, Brown 1985) and these features may be particularly important along riparian corridors (Kessler and Kogut 1985). As with deer, snow interception from conifer branches is important for wintering birds; high use of old growth relates to winter severity (DellaSala et al. 1996) and wintering birds disproportionately thrive in low elevation mature forests compared to high (Herbers et al. 2004).

Tongass forest birds that predominantly occur in old growth include brown creepers, Pacific-slope flycatchers, golden-crowned kinglets, and red-breasted sapsuckers (DellaSala et al. 1996). Brown creepers selectively breed in mature forest with high canopy cover and abundant large-diameter trees and snags (Mariani and Manuwal 1990, Poulin et al. 2013). The key habitat feature for brown creepers is large trees and snags with sluffing bark and bark crevices, important for nesting and foraging (Poulin et al. 2013), especially for foraging spiders that frequent deep bark fissures (Hayes et al. 1997). Brown creepers do not use Tongass young growth (DellaSala et al. 1996). Pacific-slope flycatchers select habitats characterized by large-diameter trees and high shrub cover (Sakai and Noon 1991), and golden-crowned kinglets prefer multi-layered tree canopies (Swanson et al. 2012). Red-breasted sapsuckers nest in large, predominantly Sitka spruce snags (mean DBH on Mitkof Island = 34 inches, Wagner 2011; Joy 2000), but prefer placing sap wells for foraging on intermediate-sized western hemlocks with abundant deep bark furrows, conks, and mistletoe, possibly due to higher sap production and arthropod availability with these features (Wagner 2011). Therefore, both Sitka spruce and western hemlock tree species and both large and intermediate-sized trees are important for the sapsuckers (Wagner 2011).

Two other forest birds, red crossbills and pine siskins also occur in higher numbers in Tongass old growth (DellaSala et al. 1996). These two species closely follow cone and seed crops and tend to irrupt in numbers when food is plentiful (Adkisson 1996, Dawson 2014). Mature conifer forests and conifer seed availability are key habitat characteristics of red crossbills (Adkisson 1996). Pine siskin breeding range habitat is primarily open coniferous forests (Dawson 2014).

Variable-density commercial thinning enhances habitat and abundance of many birds with minimal effects on others (Artman 2003, Carey 2003, Hagar et al. 1996, 2004, Haveri and Carey 2000, Hayes et al. 2003, Slauson 2013, also see synopsis in Table 3, starts on page 76). Shrub and ground nesters particularly benefit in the short term (Hayes et al. 1997). Thinning stimulation of cone production (Puritch 1977) should benefit bird species that rely on cone crops as soon as young trees reach cone-bearing age. Gaps and other treatments that promote *Vaccinium* and salmonberry shrubs could provide nectar sources for rufous hummingbirds (USDA 2016c) as well as fruit eaters such as the thrushes, sparrows, and waxwings. Retention of unthinned patches, creation of small gaps, use of variable-spaced thinning, and protection of large trees and snags, especially remnants are recommended to improve habitat for a multitude of bird species.

Thinning does not generally increase the numbers of useable snags and logs for cavity nesting over the short term (Hayes et al. 1997). However, populations of hairy woodpecker and red breasted nuthatch increase after commercial thinning (Hagar et al. 1996), likely due to more food availability (Weikel 1997). The importance of minimizing damage to snag and log legacies during thinning operations is emphasized (Hayes et al. 1997).

Precommercial thinning and gap creation produces few measurable short-term benefits for birds (DellaSala et al. 1996, Matsuoka et al. 2012). This may be due to high annual variation in bird abundance leading to spurious or unclear trends in short-term studies (Yegorova et al. 2013). It is also possible that assessments are done too early in the successional phase to realize thinning benefits (Matsuoka et al. 2012). Regardless, young-growth management that accelerates development of large trees, shrub cover, multi-layered canopies, and healthy conifer seed crops, or primes younger forests to allow for such manipulations later (Harris 1989, USDA 2014) is likely to benefit Tongass forest birds in the long term. Long-term bird habitat should also benefit from intermixing thinning with unthinned patches and small gaps, and from retention of red alder, cottonwood, a mix of conifer species, and large-diameter snags and logs.

Q. Amphibians

Young-growth management may also affect Tongass amphibians. Species native to the Tongass include the wood and Columbia spotted frogs, western boreal toad, long-toed and northwestern salamanders, and the rough-skinned newt. Amphibians are a taxa of concern owing to recent and ongoing global (Scheele et al. 2019) and likely local (Carstensen et al. 2003, Anderson 2004, Pyare et al. 2007, Ream 2016, Surdyk and Waldo 2018, Ream et al. 2019) population declines, devastating emergent diseases (Miller et al. 2011, Scheele et al. 2019), known impacts and anticipated future threats from climate change (Pounds et al. 2006, Sodhi et al. 2008), and the potential for beneficial and negative forest management influences (e.g., Dupuis and Waterhouse 2001, Rundio and Olson 2007, Semlitsch et al. 2009).

Young-growth management is less relevant for the Columbia spotted frog as this species associates closely with, and overwinters in aquatic habitat (Waters 1992, MacDonald 2003). All the other amphibians on the Tongass have terrestrial stages that overwinter in forested cover, typically near aquatic breeding habitat (Waters 1992). Some migrate long distances overland between aquatic breeding sites (e.g., 1+ mile by long-toed salamander; Waters 1992). Terrestrial amphibians require forest canopy and understory cover such as logs, leaf litter, moss, and deep soils for a stable microclimate (Chen et al. 1993, Butts and McComb 2000, Grialou et al. 2000). Populations from coastal British Columbia and elsewhere decline substantially when these microhabitats are removed with timber harvest (deMaynadier and Hunter 1995, Dupuis et al. 1995), and juvenile and adult terrestrial stages are most affected (Semlitsch et al. 2009). Terrestrial amphibians may select connected forest habitat with dense understory vegetation for upland movements between breeding sites (deMaynadier and Hunter 1999). Cool, moist environments on northeast-facing slopes offer the most suitable terrestrial habitat in the Pacific Northwest (Aubry 2000), though these microclimates may be more generally ubiquitous in temperate rainforests on the Tongass.

Studies of commercial thinning effectiveness for amphibians have generally yielded short-term negative or neutral results (Grialou et al. 2000, Garman 2001, Suzuki 2001, Wessell 2005, Rundio and Olson 2007, Kluber et al. 2008, 2013, Verschuyl et al. 2011, Olson 2013; also see Table 3, starts on page 76). Possible direct machine impacts, soil compaction, and loss of down wood have been cited as negative influences (Grialou et al. 2000, Rundio and Olson 2007) and low-mobility species may be most vulnerable (Wessell 2005). One study showed species richness was higher in stands that were recently precommercially thinned compared to those thinned less recently and closing in again (Aubry 2000). Both of these precommercially thinned stands had lower species richness than older commercially (+ previously precommercially) thinned stands, which corroborated results indicating older stands had highest species richness, biomass, and abundance (Aubry 2000). Amphibians were highlighted in a multi-taxa synthesis of young-growth effectiveness as taxa warranting further study (Verschuyl et al. 2011). Preservation of down wood, riparian buffers, and unthinned patches have been suggested to help alleviate negative effects of young-growth management on this taxon (Wessell 2005, Rundio and Olson 2007, Kluber et al. 2008, 2013) though relations to down wood are inconsistent (Aubry 2000). Smaller (¼ and ½ acre) unthinned patches within thinned stands resulted in higher amphibian species richness than large (1 acre) unthinned patches, the opposite effect of that observed for forest arthropods (Wessell 2005).

R. Forest Arthropods

Management of young-growth may also influence forest-dwelling arthropods such as insects and spiders. Though knowledge of these taxa is still rudimentary, there are presumably a number of species native to Tongass forests. One study of Prince of Wales Island identified 213 beetle species and 57 spider species (Stockbridge 2014) and it is estimated that 6,000 species of arthropods may be found in Pacific Northwest forests (Lattin 1993). These taxa provide a variety of functions to forest ecosystems, including nutrient cycling, pollination, litter decomposition, and pest control (Kremen et al. 1993, Kwon et al. 2013). Major subcommunities include the arboreal, stem zone, and forest floor, and all have a multitude of associated predators and parasitoids (Schowalter 2017). The arboreal subcommunity is comprised of herbivores and fungivores that regulate primary production and nutrient fluxes, the stem zone is dominated by bark-and wood-boring species that initiate decomposition of coarse woody debris, and the forest floor subcommunity is made up of detritivores, fungivores, and burrowers that are critical to litter decomposition (Schowalter 2017).

Forest arthropods reach their highest diversity in old-growth forests owing to stable, moderate temperature and relative humidity and the rich variety of resources represented by high plant species richness and structural complexity (Schowalter 2017). Many arthropods use highly localized areas and specific microhabitats (Kremen et al. 1993). Tongass beetle and spider species assemblages most closely associate with leaf area index, a measure of light filtration to the understory (Stockbridge 2014). Similarly, litter-dwelling arthropods, including spiders, carabid beetles, and millipedes are positively associated with litter moisture (Yi and Moldenke 2008). Further, abundance of spiders and some insects increase with depth of furrows in bark of old growth conifers (Mariani and Manuwal 1990).

Arthropods tend to respond quickly to forest changes due to short generation times, high mobility, and dependence on temperature (Kremen et al. 1993, Schowalter et al. 2003, Kwon et al. 2013). Responses to young-growth management can be positive, negative, or neutral, depending on species response to changes in temperature, humidity, plant growth, foliage chemistry, exposure to predators, host spacing, dispersion of volatile chemicals, and other factors (Schowalter et al. 2005). Low mobility, late-successional species may be prone to negative effects, and unthinned patches are recommended for these species, with larger (1 acre) unthinned patches resulting in higher species richness and densities than smaller (½ or ¼ acre) patches (Wessell 2005). On the Tongass, precommercial thinning had neutral effects on old-growth specialist species of spiders and beetles; these species were similarly found in both thinned and unthinned young growth stands (Stockbridge 2014). Other studies in Pacific Northwest forests have reported varied results and the full gamut of positive, neutral, and negative effects on a variety of different forest arthropods (Witcosky et al. 1986, Schowalter et al. 2003, 2005, Wessell 2005, Yi 2007, Yi and Moldenke 2005, 2008, 2011; see synopsis in Table 3, starts on page 76). Thinning is thought likely to maintain beneficial insects and increase biological diversity by increasing understory vegetation that provides food for adult stages (Hard 1974). Given greatest diversities in old-growth forests (Schowalter 2017), young-growth management that accelerates development of old-growth characteristics and improves plant diversity is likely to benefit most forest arthropods in the long term.

S. Karst Arthropods

Young-growth management may also affect karst-dependent arthropod species, including taxonomically and geographically unique karst cave amphipods (Crustacea). Karst soils drain well and associate with highly productive forests, which have been disproportionately logged on the Tongass (Baichtal and Swanston 1996). Specific water infiltration rates, sediment production, debris transport, and water chemistry characterize functioning karst habitats. Surface-disturbing activities and logs and other debris near caves, sinkholes, losing streams (surface streams that contribute water to the karst system in localized areas) and collapsed channels may impact function.

Precommercial thinning is expected to hasten a return to more desirable stand conditions for karst and could be safely conducted on low and moderate, and possibly selected high vulnerability karst sites (Griffiths et al. 2002). Thinning and other restoration to karst features could have important off-site benefits, such as increased downstream aquatic productivity (Griffiths et al. 2002). Commercial thinning has the potential to cause more site disturbance to soils and hydrology, so additional studies and monitoring should be considered (Griffiths et al. 2002), but commercial thinning is generally viewed as appropriate on low to moderate vulnerability karst lands when karst management objectives can be met. Conducting a karst resource inventory to assess the openness of the underlying karst system, the system's vulnerability to surface disturbance, and the likelihood of additional sediment production or runoff from thinning is recommended prior to work. Young-growth management should also avoid dropping or placing slash or debris in identified high vulnerability karst features, remove by hand any slash or debris that is introduced into karst features or losing streams, and generally avoid thinning on high vulnerability lands, such as within 100 feet of a cave entrance, a karst feature accepting surface flow, or on the edge of a sinking or losing stream within 0.25 mile upstream of their swallow hole or loss point. A zone equal to one tree height should be left untreated to ensure that no material will be placed in these features.

IV. Management Approaches

The Tongass has used combinations of commercial and precommercial thinning, strip thinning, variable density thinning, retaining unthinned corridors and patches, treating slash, creating or enhancing canopy gaps, girdling, pruning, and planting or retaining red alder as means of young-growth management for wildlife. Treatments aim to:

1) accelerate the development of late-seral characteristics to promote long-term wildlife habitat and ecological function, and

2) improve key habitat characteristics to foster important management species as well as biocomplexity, abundance, and diversity of Tongass forest-dwelling wildlife species within even-aged stands.

The Desired Condition and Key Habitat Characteristics section and Tables 2 and 3 show that introducing structural and species diversity to even-aged forests through young-growth management provides short-term benefits to many Tongass wildlife species as well as long-term benefits through accelerated development of old-growth characteristics. There may be ecological consequences to not intervening in stands that do not attain growth rates and late-seral size-attributes without management (Hayes et al. 1997, Tappeiner et al. 1997, Poage and Tappeiner 2002, Altman and Hagar 2007, Sensenig et al. 2013). However, higher inherent stand variability and microsite heterogeneity on the Tongass compared to Pacific Northwest forests due to differences in precipitation and drainage may alleviate this issue (Mike Sheets and Damien Zona, personal communication). Leveraging inherent variability and incorporating unthinned patches, stands, and corridors into precommercial and commercial thinning will promote key habitat characteristics over both short and long terms. Using precommercial thinning as a sort of primer, with unthinned patches and corridors and possibly along with pruning, and then using commercial variable-density thinning, small gaps, pruning, unthinned patches and corridors to later mold stands and landscapes will best meet old-growth management objectives. When done along with thinning early enough to keep slash diameters small (e.g., most <5 inches DBH, none >8 inches DBH; Martin et al. 2019, unpublished data), this strategy will best address winter forage, slash, and snow interception impacts for deer, as well as provide the greatest benefits and least impacts to other Tongass wildlife species. Here are some additional detailed recommendations:

- Landscape planning for young-growth management should address movement and habitat connectivity needs for deer and other wildlife. Within focal watersheds, map, assess, and plan treatment stands and leave corridors using applicable data on home range sizes, movement patterns, existing travel pathways, slash loads, important core, seasonal, or connective habitat (e.g., deer winter range), key habitats (e.g., remaining old-growth, alpine, muskeg, riparian, beach meadows), LUDs and conservation areas (e.g., beach fringe, goshawk nest buffers), and young-growth stand conditions (e.g., treated vs untreated plus ages, prior treatments and treatment dates, and any info on slash loads or stem exclusion conditions). Treatments are typically planned at landscape (watershed) scales and designed at stand scales. Treatments should not be applied homogeneously across landscapes. See details on prioritizing watersheds and stands for treatment in the Prioritizing Treatment Needs section.
- In designing stand treatments for precommercial thinning to promote biocomplexity and accelerate development of late-seral conditions with minimized short-term impacts, incorporate:
    - a range of residual tree-to-tree distances, leveraging existing heterogeneity (e.g., 14X14 foot spacing with 50% variance for residual trees 7-21 feet apart, and with cedar to cedar spacing for additional complexity),
    - unthinned patches (e.g., 5-10% untreated forest within units greater than 4 acres as per Nathan Wesely, unpublished data, Chugach National Forest, presented in the virtual 2020 Region 10 Silviculture-Wildlife Workshop;

consider ¼-1 acre unthinned patches as Wessell 2005 used for commercial thinning),
    - unthinned leave corridors ideally placed along existing movement pathways to minimize impacts from slash, loss of snow interception, and diminished habitat connectivity for a multitude of mobile wildlife species and especially elevational corridors between alpine and beach for deer,
    - possible pruning along with precommercial thinning to extend understory benefits without additional slash or snow interception impacts.
- Time precommercial thinning to minimize slash impacts, loss of understory vegetation, and seedling flush. Precommercially thin towards the end of the stem initiation phase or very early in the stem exclusion phase, after the majority of trees are cuttable height (e.g., 3-4 feet high or more) and dominance is starting to get expressed, but before slash diameters get too big and understory plant species are lost to stem exclusion. Aim to thin when most slash is <5 inches DBH and avoid thinning when slash is >8 inches DBH (as per Martin et al. 2019, unpublished data). Slash treatments such as bucking, chipping, and other methods are very cost prohibitive, so slash impacts must be minimized instead by precommercially thinning when slash diameters are small, incorporating leave patches and corridors, and using other treatment methods for stands that have grown beyond these diameters (see items below).
- Aim to precommercially treat roughly 1,440 acres annually within Old Growth Habitat LUD and beach fringe to address these areas before they age out of the typical precommercial thinning window of 15-30 years (Table 4). The bulk of these acres will age out within the next 5 years, so needs are pressing and immediate. While age may be used as an initial proxy for treatment needs, size of slash is critical in averting slash impacts and should be paramount for precommercial thinning work on the ground.
- To enhance understory vegetation in stands with larger diameter trees that would not meet precommercial thinning slash diameter goals, are in or approaching stem exclusion (may or may not have been precommercially thinned), and cannot wait for treatment until they reach commercially viable sizes, create small gaps or radial tree release gaps. Also consider pruning for additional side lighting. Some focused, small-scale girdle thinning may be considered, but girdle-thinned trees can come down quickly with strong winds so slash impacts could be substantial. Directionally fall trees outside of gaps to promote gap access by deer and other wildlife. Leverage existing heterogeneity and site gaps on remnant understory vegetation and where slash treatments will not be necessary. Site radial tree release gaps on trees with the broadest canopies and most developed branch structure (may not be the trees with the largest DBH). Both regular gaps and radial tree release gaps should be dispersed across the unit with about 4-13% forest area in gaps, depending on forest dominance type (Hocker 1990 cited in Ott and Juday 2002, Ott 1997, Alaback 2010, also see Natural Scale and Distribution of Disturbance section).
- To accelerate development of old-growth conditions within commercial-sized stands, use variable-density commercial thinning (e.g., 14 to 18-foot spacing with 50% variance, fine-tuned based on height of trees), possibly with small, dispersed gaps or radial tree release gaps (e.g., up to approximately 0.1 acre and 70 feet diameter, vary slightly based on height of trees; with about 4-13% of forest area in gaps; see Natural Scale and Distribution of Disturbance section), unthinned leave patches (e.g., ¼-1 acre unthinned patches and 5-10% untreated forest within units greater than 4 acres), and possibly leave corridors within identified travel pathways (though these won't be as critical as with precommercial thinning).

Work with silviculturalists and others involved to ensure commercial treatment projections accelerate the development of late-seral characteristics in the Old-Growth Habitat LUD and beach fringe as per management direction in the Forest Plan.

- In both precommercial and commercial treatments, retain (ignore for spacing) alder and cottonwood, favor a mix of conifer species including cedars, hemlocks, and firs (where applicable) in addition to spruce, and retain other minority tree species, as well as deformed and diseased trees to increase species diversity, vertical structure, and future development of microhabitat sites.
- Continue to retain any large live tree, snag, and log legacies retained in original clearcuts and two-age systems to benefit a number of species that rely on these features.
- Minimize soil disturbance and prevent introduction of invasive weeds, especially during commercial treatments.
- Work with silviculturists to determine vegetation treatments that move priority stands towards desired conditions. Also see detailed management considerations for site types provided in the Overview to Exhibits 1-3 (USDA 2014).

Table 4. Total acres of young-growth within Old Growth Habitat LUD and beach fringe within age classes 15-20 years, 20-25 years, and 25-30 years and annual estimated treatment acres needed to address these acres before they age out of the typical precommercial thinning window of 15-30 years. A rough annual target of 1,440 acres within Old Growth Habitat LUD and beach fringe would be needed to treat these acres before they age out of the typical precommercial thinning window of 15-30 years.

Age Class	Total Acres	Annual Treatment Acres Needed
15 to 20 Years	705	47
20 to 25 Years	1,793	179
25 to 30 Years	6,066	1,213
Total	**8,564**	**1,440**

V. Prioritizing Treatment Needs

This document has presented details on when and how young-growth management should be done to most benefit Tongass wildlife. The final question is where should work be prioritized? This is an important question due to limited funding and capacity for work. Several considerations exist in prioritizing young-growth treatment areas for Tongass wildlife. Below is a suggested list of priorities for where to focus young-growth management for Tongass wildlife. These priorities are also shown as ranking criteria in Figure 7. These criteria are generally presented in order from broad to fine scales, inform values of treating and risks of not treating, and should be considered together to come to the final decision of “go” (generally stands with the most yeses) or “no go” (generally stands with the fewest yeses or most no’s). Some criteria may be more heavily weighted. For example, criteria related to partner and community interests, pressing ecological needs, and financial and logistical feasibility are likely to hold heavy weightings. Similarly, stands with low site productivity or high alder compositions are unlikely to need treatment, so would lead to ‘no go’ decisions. National Environmental Policy Act

(NEPA) clearance, at least for precommercial work, is typically done more broadly across districts, so the decision process in prioritizing specific watersheds and stands for treatment described here would typically occur post NEPA. Projects with high ranks should inform regularly updated district 3- and 5-year plans, and be included as priority young-growth restoration projects.

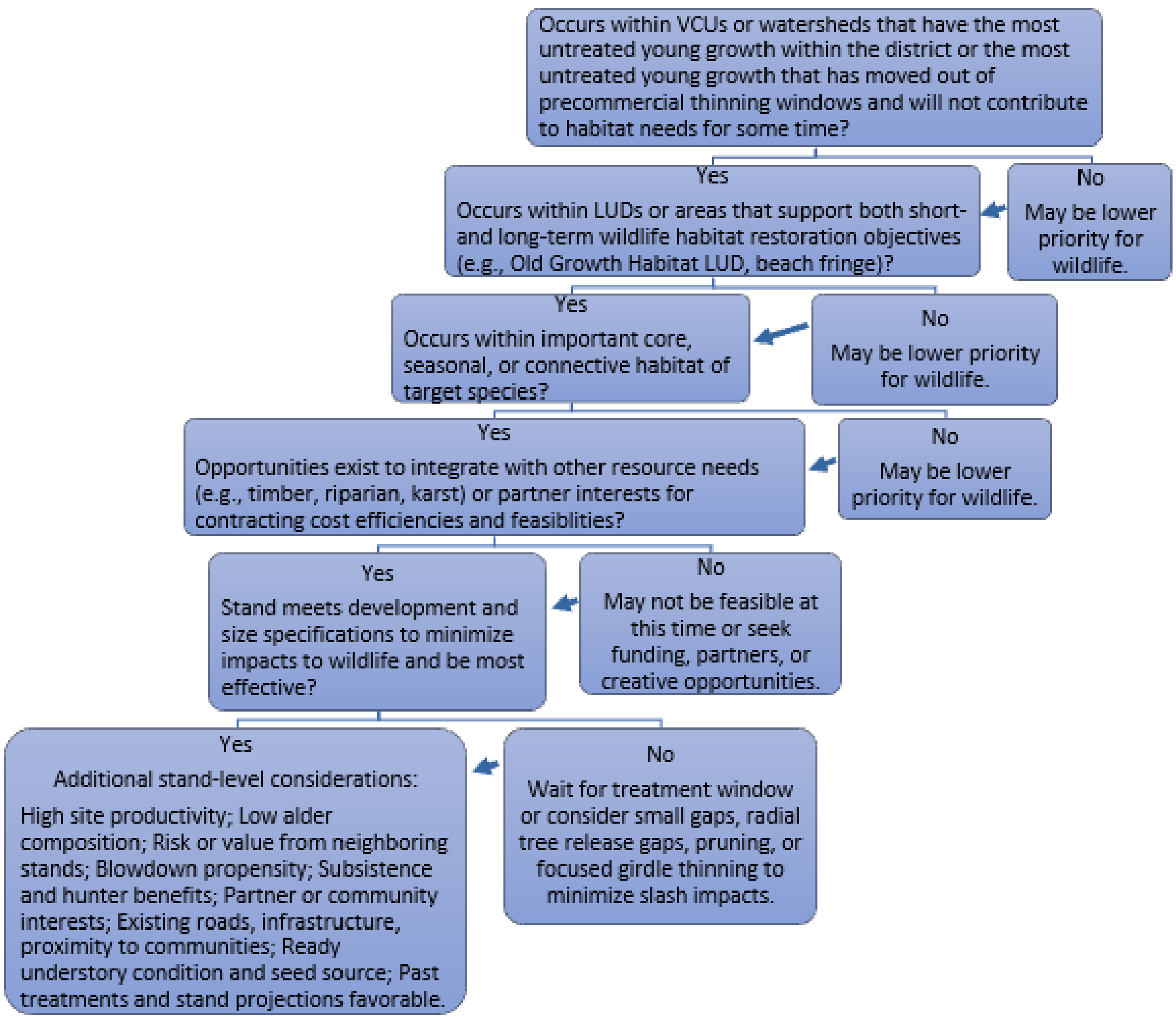


Figure 7. Ranking criteria for prioritizing young-growth treatment areas for Tongass wildlife. Criteria are generally presented in order of broad to fine scales and should be considered together.

A. Criteria for Ranking Priority Areas for Tongass Wildlife

- VCUs and Watersheds within each district with the most untreated young growth. Alternatively, watersheds with the most untreated young growth that has moved out of the precommercial thinning window and will not be contributing to habitat needs for some time, to make sure areas around and within those get precommercial thinned and otherwise treated when opportunities arise.

- Areas where both short- and long-term wildlife habitat objectives will benefit (e.g., Old Growth Habitat LUD, beach fringe, and Riparian Management Areas). These areas are managed for old-growth conditions and contribute to core and connective habitat integral to the conservation strategy.
- Areas within or near core, seasonal or connective habitat for sensitive, vulnerable, endemic, or dispersal-limited wildlife species. Examples include connections between old-growth reserves, beach fringe and Riparian Management Areas and reserves, low and high elevations, travel corridors, deer and mountain goat winter habitats, low elevation and low slope topography preferred by a number of species (e.g., wolves, female goshawks, marten), near muskeg or wetlands with unthinned patches, and geographical pinch points with leave corridors (e.g., peninsula necks).
- Areas with stands at the right size and developmental stage for precommercial or commercial treatments (see details in the Management Approaches section).
- Areas with opportunities to coordinate with other projects and resources (e.g., young-growth treatments for riparian, karst, or timber resources) for cost, planning, and contracting efficiencies. Stands that can be treated to accelerate old-growth conditions while also producing timber byproducts.
- Areas and stands with higher site productivity (e.g., site types 2 and 6, Poletimber – Stem Exclusion – High/Medium Site; USDA 2014 Overview to Exhibits 1-3) and/or lower alder composition. Sites with low productivity or high alder composition (site type 12 Alder dominated and site type 13 Alder-conifer mixed stands with > ~40% alder cover) will have higher natural structural and species diversity, making them lower priority for young-growth treatments and better addressed by natural succession processes. Commercial-aged stands that have started to push through to understory reinitiation stages or otherwise have pockets of heterogeneity from blowdowns, remnant patches, or riparian or road features may also be lower priority for young-growth treatments and better left to natural succession given costs involved with commercial treatments.
- Stands in which treatments will complement neighboring stands in improving habitat heterogeneity and connectivity, based on risks and values from neighboring stands.
- Stands and topographies that are stable enough to support desired commercial treatments and accelerate development of old-growth conditions without blowdown. Precommercial thinning will help stabilize stands, so may be prioritized in wind-prone areas to promote healthy forest development and subsequent treatment opportunities.
- VCUs or other areas identified as important for subsistence and hunter uses may also be prioritized. While hunters typically avoid recently thinned stands (Brinkman et al. 2009), thinned stands may help sustain deer in watersheds that contain characteristics that hunters favor such as access, proximity to communities that rely on deer, and preferred hunting

habitats (e.g., muskeg, young clearcut, alpine, old growth forest, shoreline; Brinkman et al. 2009).

- Partner interests and partnership opportunities, including of communities and tribal entities. Benefits are evident in employing a collaborative approach to ecological restoration (Christensen 2012).
- Also consider proximity to existing roads and infrastructure to reduce operational costs and increase merchantability for commercial treatments.
- Consider the condition of the existing understory vegetation as well as proximity of seed sources. Stands that are likely to have good success in understory reinvigoration would be higher priority than those for which treatments are likely to have little effect.
- Past treatments and stand projection models will also influence stand priorities. Work with silviculturists to determine which stands have the best potential to achieve the desired outcomes for the longest periods of time with the least amount of effort and the greatest probability of success.

VI. Monitoring

While this strategy emphasizes both the large amount of information on young-growth management effects already available as well as using limited funds to get priority restoration work done on the ground, some monitoring is recommended to continue to understand and improve management effectiveness using adaptive management concepts (e.g., McClellan 2008).

- Monitoring is particularly relevant with more novel, unstudied approaches, such as of leaving elevational corridors uncut in precommercial thinning to support seasonal deer movements.
- Additional monitoring of the persistence of understory benefits with precommercial thinning, small gaps, and pruning are needed for a better understanding of long-term effects as well as to determine when subsequent treatments are needed. Assessment of snow and slash differences among young-growth treatments are also needed.
- There are also taxa such as amphibians which warrant additional study due to potentially concerning, but uncertain effects of young-growth management (Verschuyl et al. 2011). Knowledge is also still incomplete regarding interactions among deer, bear, and wolves in precommercial thinning, deer response to precommercial thinning and gaps, interactions between snow and slash on deer, and the characteristics of effective travel corridors between good habitat patches. GPS data and LiDAR wildlife-habitat models have particular promise in furthering understanding.
- Further, given that the use of commercial treatments to accelerate the development of old-growth conditions while also providing commercial byproducts in Old-Growth Habitat LUD, beach fringe, and Riparian Management Areas is new on the Tongass with the 2016 Forest Plan, short-term monitoring of our treatments and long-term modeling of the effectiveness of these treatments is particularly important to ensure treatments in these areas are trending toward desired future conditions.

- More information is additionally needed regarding the influences of not treating on tree growth rate potentials on the Tongass, especially related to the development of large trees, branches, snags, and logs. Greater inherent stand variability and heterogeneity may alleviate this issue on the Tongass, but further assessment and comparison with Pacific Northwest values is warranted.
- Finally, we also need to better understand how young-growth management can best help communities, hunting success, and hunter perceptions, by fostering communication and by repeating hunter surveys like those done by Brinkman et al. (2009).

Regardless of the question, monitoring objectives should directly link to further understanding and improving our management approaches and be done with careful design to adequately answer the questions being asked.

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Table 2. Synopsis of studies assessing the effectiveness of young-growth treatments on development of old-growth forest characteristics in the Pacific Northwest.

Habitat Feature	Citation	Location	Key Findings
Vertical and Horizontal Structural Diversity	Bailey 1996; Bailey and Tappeiner 1998; Bauhus et al. 2009; Carey 2003; Christensen 2012; Curtis et al. 1998; Deal et al. 2017; DeBell et al. 1997; Dodson et al. 2012; Garman et al. 2003; Kuehne and Puettmann 2008; Kuehne et al. 2015; McComb et al. 1993; Rapp 2002; Puettmann et al. 2016; Seidel et al. 2016; Sullivan et al. 2006	Pacific NW	Variable density thinning, small gaps, unthinned patches, and alder retention can be used to manipulate structural diversity. Modifications in residual trees and spacing distances, including intentional small openings and unthinned patches and remnants, can increase size and species diversity and accelerate stand differentiation and structural complexity.
Tree Species Diversity and Composition	Bauhus et al. 2009; Carey 2003; Curtis et al. 1998; Davis et al. 2007; Deal et al. 2017; DeBell et al. 1997; Garman et al. 2003; Hayes et al. 1997; Kuehne and Puettmann 2008; Kuehne et al. 2015; Puettmann et al. 2016; Rapp 2002; Sullivan et al. 2006	Pacific NW	Precommercial and commercial thinning can be used to manipulate tree species diversity and composition by favoring retention and promoting increased growth of minority species, including red alder.
Stand Stability	Christensen 2012; Harris 1989; Mitchell 2000; USDA 2014	Southeast AK	Precommercial thinning reduces tree height to diameter ratios, promoting stability towards wind, snow, and ice, and increasing feasibility of future management options such as commercial thinning. And, high-intensity commercial thinning increases the likelihood of windthrow and such treatments should be avoided on highly exposed sites (Garman et al. 2003; western OR)
Large, Wide Trees	Alaback 2010; Altman and Hagar 2007; Bailey 1996; Barbour et al. 2005; Curtis et al. 1998; Davis et al. 2007; DeBell et al. 1997; DeMars 2000;	Pacific NW including Southeast AK	Precommercial and commercial thinning, and greater thinning intensities, produce larger diameter trees more quickly.

	Farmer and Kirchhoff 2007; Garman et al. 2003; Harris and Farr 1974; Hayes et al. 1997; McComb et al. 1993; Mitchell 2000; Newton and Cole 2012; Poage 2008; Puettmann et al. 2013		
Historical Growth Rates and Large Tree Potential	Altman and Hagar 2007; Curtis et al. 1998; Hayes et al. 1997; Poage and Tappeiner 2002; Sensenig et al. 2013; Tappeiner et al. 1997	Pacific NW	Thinning can promote growth rates that more closely approximate those historically found in developing old-growth stands (Hayes et al. 1997; Tappeiner et al. 1997). Size of large, old trees in old-growth stands was strongly related to their growth rate and size at 50 years of age (Poage and Tappeiner 2002, Sensenig et al. 2013). Early silvicultural intervention may be needed for dense, young forests to ever achieve some defining old-growth characteristics such as large trees and branches (Curtis et al. 1998; Altman and Hagar 2007).
Large Branches	Altman and Hagar 2007; Briggs et al. 2008; Curtis et al. 1998; DeBell et al. 1994; Harris and Farr 1974; Lowell et al. 2014; Maguire et al. 1991; McClellan 2005; Hayes et al. 1997; Newton and Cole 2012; Seidel et al. 2016	Pacific NW including Southeast AK	Large branches develop on trees widely spaced by precommercial thinning or on trees adjacent to gaps or openings.
Large Crowns	Bailey 1996; Barbour et al. 1997; Hayes et al. 1997; Long and Smith 1984; Marshall et al. 1992; Puettmann et al. 2013; Sullivan et al. 2006	Pacific NW	Precommercial and commercial thinning promote development of large crowns in dominant and codominant trees.

Large Snags; Deformed, Decadent and Diseased Trees	Altman and Hagar 2007; Bauhus et al. 2009; Carey 1995, 2003; DeBell et al. 1997; Dodson et al. 2012, 2013; Garman et al. 2003; Lewis 1998; McComb et al. 1993; Pollock and Beechie 2014; Rapp 2002	Pacific NW	Thinning and gaps reduce tree mortality, especially of small trees, resulting in decreased or unchanged snag and log recruitment (Dodson et al. 2012, 2013; Pollock and Beechie 2014). Thinning intensities resulted in a tradeoff between the time for stands to reach large tree and structural and species diversity and the need to artificially create dead wood (heavier thinning = sooner and more snag/log creation needed, Garman et al. 2003). Multiple thinning strategies through time and across the landscape are best (Garman et al. 2003), including areas of natural regeneration (Pollock and Beechie 2014) and unthinned patches of high tree density (Altman and Hagar 2007, Dodson et al. 2012). Gaps, leave islands, variable density thinning, and retention of deformed, decadent, and diseased trees may promote earlier recruitment of large snags over the long term, though further long-term data are needed (Dodson et al. 2012). Snag creation methods (Lewis 1998) may be needed to meet target values in shorter timeframes (Dodson et al. 2013) but had little to no effect on long-term levels (e.g., 260 years; Garman et al. 2003).
Tree Microhabitats (Cavities, Conks, Bark Features)	Michel and Winter 2009; Sheridan et al. 2013	Pacific NW	Silvicultural practices including retaining large trees, snags, logs and old decadent trees, increasing growing conditions by creating small openings and thinning, maintaining hardwood species, or creating snags may be used to increase microhabitats in managed forests. These features are slow to develop in young trees, so benefits of legacy retentions are emphasized.
Large Logs	Bauhus et al. 2009; Carey and Johnson 1995; DeBell et al. 1997; Dodson et al. 2012; Garman et al. 2003; McComb et al. 1993; Rapp 2002	Pacific NW	Precommercial and commercial thinning with large tree and snag retention may help promote large log recruitment over the long term, though further long-term data are needed (Dodson et al. 2012). See additional info under Large Snags; log recruitment mirrors snag recruitment (Garman et al. 2003).
Adaptive Capacity and Ecosystem Resilience	Ares et al. 2010; Neill and Puettmann 2013	western OR	Thinning resulted in increased cover of drought-, fire-, and heat-tolerant plant species within 6 years post-treatment of 50-80-year-old stands, suggesting that ecosystem functions induced by thinning are more likely to be maintained under climate change conditions (Neill and Puettmann 2013). Thinning resulted in a higher diversity of understory conditions within 11 years post-treatment of 45-66-year-old stands, suggesting increased ecosystem resilience by enhancing functional effectiveness and diversity of response options (Ares et al. 2010).

Riparian Habitat	Carey et al. 1999b	Olympic Peninsula, WA	Systems modeling suggest managing young-growth forests for conservation of biodiversity, which includes precommercial thinning, legacy retention, coarse woody debris and cavity-tree management, and variable density commercial thinning treatments allows for the best enhancement of riparian systems, accelerated development of late-seral forest, and support for riparian species most sensitive to forest management, compared to preservation with no manipulation broadscale or as part of buffers.
Riparian Habitat	Ruzicka et al. 2014	Western OR	Tree growth and vigor in riparian buffers can be improved to a limited spatial extent by upslope thinning.
Understory Vegetation	Alaback 1984	Prince of Wales Island, Southeast AK	Response of understory vegetation to thinning following canopy closure (e.g., 25-35 years) and elimination of understory vegetation is much slower than to thinning prior to canopy closure. The principal understory species that respond to thinning at widest spacings (16 feet for younger sites, 20 feet or more for the oldest sites) are western hemlock and Alaska blueberry. In heavily thinned stands that experience subsequent windthrow (common in older stands), western hemlock is the principal understory species to respond.
Understory Vegetation	Alaback 2010	Prince of Wales Island, Southeast AK	Small gaps (40-150 feet diameter, commonly placed in natural openings) had higher understory species diversity, density, and cover, forb biomass, and recent shrub growth compared to immediately adjacent (to 80 feet from edge of gap) thinned and unthinned young growth, about 20 years post gap-creation. Adjacent stands thinned at an average of 27 years of age, and measured 17 years (mean) post-thinning, had no detectable differences in understory vegetation compared to similarly aged unthinned stands adjacent to gaps. Author suggests a 12-15-year lifespan for precommercial thinning effects on understory vegetation.

Understory Vegetation	Alaback and Herman 1988	western OR	Increased abundance of saplings, particularly following heavy precommercial thinning, led to a two-layered overstory canopy and little effect on the loss of understory species relative to controls in 30-year-old stands 17 years post-treatment. Early thinning without subsequent treatments are not likely to maintain stable herb and shrub populations.
Understory Vegetation	Alaback and Tappeiner 1984, also detailed in Hanley et al. 1989 and Hanley 2005	Southeast AK	Heavily commercially thinned stands age 39 to 72 years at 5-7 years post-thinning increased understory biomass by about 14 times that in lighter thinning, mostly in shrubs and a second layer of western hemlock seedlings. Shrub response was greatest to commercial thinning in middle-aged stands 30-50 years old compared to younger and older stands, owing to the continued presence of remnant shrubs prior to thinning but few competitive tree seedlings due to earlier stem exclusion losses. Precommercial thinning of younger stands age 20-30 years without canopy closure had some shrub response, but existing tree seedling growth response (not recruitment) was paramount and often resulted in decreased shrub growth. Older stand ages beyond 50-60 years had few shrubs prior to thinning and minimal shrub response after commercial thinning. Herbs showed little response to precommercial thinning, but herb biomass was highest in the heaviest commercial thinning treatment compared to medium and light. Thinning had little effect on vertical distribution of understory vegetation.
Understory Vegetation	Ares et al. 2009	western OR	Variable density commercial thinning and gap creation in 40-60-year old stands increased understory vegetation richness, including early seral and forest herbs, and both low and tall shrubs at 6 years post-treatment. Increased overstory variability encouraged development of multiple layers of understory vegetation.
Understory Vegetation	Ares et al. 2010	western OR	Variable and fixed density commercial thinning with leave islands and gap openings 11 years post-treatment of 45-66-year-old stands contributed to the development of a diverse plant understory. Thinning increased species diversity and plant diversity groups based on successional status, growth form, and structure. Tree seedling regeneration was variable, but generally increased with thinning. Thinning did not trigger plant invasions.
Understory Vegetation	Bailey 1996; Bailey and Tappeiner 1998	western OR	8-60% (average 32%) volume removal by commercial thinning increased shrub and herbaceous cover and species richness in 50-120 (average 80) year old stands thinned 10-24 (average 18) years previously.

Understory Vegetation	Berger et al. 2012	western OR	Second-thinning entry 20 years after initial thinning and 1 and 6 years post second-thinning treatment of 60-90-year-old stands resulted in greater amounts of fern, graminoid, and open-site, early-seral species, but not other aspects of understory vegetation or tree regeneration. Vegetation trends were already influenced by the previous thinning treatments and impacts of the second thinning were not as easily detectable.
Understory Vegetation	Cole et al. 2010	Chichagof, Prince of Wales, and Long islands, Southeast AK	Stands precommercially thinned at 16-18 years of age resulted in greater understory cover during all of 7 years of post-treatment sampling compared to unthinned controls. Understory cover increased for the first 2-4 years, then declined over the next 3 years, reaching pre-treatment levels by year 7 that were still significantly higher than unthinned. Thinning increased summer and snow-free winter deer forage, but winter forage was unaffected when forbs were buried by snow. All thinning spacings led to similar understory cover.
Understory Vegetation	Crotteau et al. 2020a	Southeast AK	Precommercial thinning of 15-25, 25-35, or 35-50-year-old stands resulted in twice the understory biomass of unthinned stands at least through 10 years post thinning.
Understory Vegetation	Crotteau et al. 2020b	Southeast AK	Precommercial thinning of 15-25-year-old stands resulted in 3-6X more understory biomass through 16 years post-thinning compared to unthinned controls. Total biomass varied by thinning treatment intensity (14 feet v 18 feet spacing) at 5-years but not at 10- or 16-years post-thinning. Thinning changed species compositions, but all functional classes (graminoid, forb, fern, shrub, tree) had greater biomass in thinned units than controls. Overall understory biomass decreased with time since thinning, with some variation likely due to climate. The proportion of understory biomass in units that were thinned (higher proportion) vs unthinned (lower proportion) remained stable across all 3 measurements and did not diminish within 16 years post-thinning.
Understory Vegetation	Davis and Puettmann 2009	western OR	Commercial thinning in 30-50-year-old stands resulted in initial declines of bryophytes, tall shrubs, and low shrubs 1 year post treatment, likely due to damage during harvest operations, followed by subsequent recovery and growth at 5-7 years. Herbs displayed little response at year 1, but early-seral species were more abundant in thinned stands by 5-7 years.
Understory Vegetation	Deal and Farr 1994	Southeast AK	Heavy thinning in older even-aged stands promoted dense germination and growth of understory conifers making it difficult for other understory nva to become established.

Understory Vegetation	Deal 2007; Deal et al. 2017	Southeast AK	Though alder would not mitigate issues related to winter habitat for deer, increasing alder via seeding or planting and by retaining it in thinning may provide benefits to understory vegetation.
Understory Vegetation	DellaSala et al. 1996	Prince of Wales Island, Southeast AK	20-year-old stands precommercially thinned 3-5 years previously had higher forb and shrub cover than gapped and control stands of similar age.
Understory Vegetation	DeMeo et al. 1990	Prince of Wales Island, Southeast AK	Up to 49 feet wide gaps established in understory-depauperate, 26 to 34-year-old, productive spruce-hemlock stands 1-4 years prior had greater key deer forb cover in gaps or gap edges compared to adjacent (thinned and unthinned) young growth, but levels were lower than in old-growth forest. *Vaccinium* cover and recent growth of *Vaccinium* was also greater in gaps or gap edges than in adjacent young growth.
Understory Vegetation	Doerr and Sandburg 1986	Big Level Island (near Kupreanof Island), Southeast AK	Stands precommercially thinned at 16 years of age and sampled 18 years post-thinning increased cover of deer browse and forbs. Both heavy and moderate thinning spacing promoted a release of conifers in the understory that were predicted to shade out understory forbs and shrubs without further treatment.
Understory Vegetation	Farmer and Kirchhoff 2007	Heceta Island, Southeast AK	Stands that were precommercially thinned at about 20 years post-logging and 10 years prior to sampling had higher shrub growth and biomass of deciduous and evergreen forbs than 20-39-year-old unthinned stands.
Understory Vegetation	Hanley et al. 2013	Southeast AK	Precommercial thinning at a) narrow and wide spacing in 15-25-year-old stands, b) medium spacing with and without pruning in 25-35-year-old stands, and c) wide spacing with and without slash treatment, and with girdling in >35-year-old stands had higher understory biomass compared to untreated controls 4-8 years post-treatment. Treating at 15 to 25 years was more effective than at 25 to 35 years and least effective >35 years. Planting of red alder in 1-5-year-old-stands had no effects 4-8 years post treatment.

Understory Vegetation	Harris and Barnard 2017	Chichagof Island, Southeast AK	Small gaps (150-430 m^2, mean width 18.3m) in 81-year-old stands increased understory plant biomass through at least 23 years post treatment with no apparent peak (possibly still increasing).
Understory Vegetation	Krueger 1960	western WA	Understory ground cover in light and moderate commercial thinning of two 108-year-old Douglas fir stands dropped immediately after thinning due to mechanical damage and did not change significantly between 2- and 8-years post thinning.
Understory Vegetation	Lindh and Muir 2004	western OR	40-year-old stands that were precommercial thinned 20 years earlier had higher frequency of late-seral herbs and had distinct compositions that were more like old-growth stands, than unthinned stands. Changes in the understory were likely precipitated by the transient increase in resource levels following thinning, rather than by long-term changes in stand structure.
Understory Vegetation	Neill and Puettmann 2013	western OR	Thinning resulted in increased understory cover of flowering, fleshy fruit, and palatable leaf-producing plant species (wildlife food) within 6 years post-treatment of 50-80-year-old stands.
Understory Vegetation	Puettmann et al. 2013	western OR	Commercial thinning decreased tall shrub cover in the short term, likely due to harvesting damage. Some recovery of tall shrubs was evident within a decade, but values still remained lower than in controls. Herbaceous cover increased quickly after thinning. Higher species richness was also observed after thinning, mainly attributable to early-seral species. Exotic species increased slightly after thinning operations but cover typically remained below 2%.
Understory Vegetation	Thomas et al. 1999	western WA	Precommercial thinning increased understory vegetation cover and species richness at 12-16 years post-thinning of 21-27-year-old Douglas-fir plantations.
Understory Vegetation	Thysell and Carey 2001	western WA	Variable density commercial thinning of 55-65 year-old stands initially (1 year after treatment) had lower understory cover that recovered within 3 years. Species richness increased >150% at 3 years post-treatment. Initially 20 native and 11 exotic species increased in importance. At 3 years, 4 exotic species persisted with increased importance, while 8 native species increased and 7 native species decreased.

Understory Vegetation	Wessell 2005	western OR	Commercial thinning in stand ages 50-70 years at 2-4 years post-treatment had higher total vascular plant and herb species richness, diversity, and total, herb, and tree ground cover compared to unthinned stands. The number and percent cover of early-successional species and exotic plant species were higher with thinning, while cover and percent of late-successional species were lower with thinning.
Understory Vegetation	Wilson et al. 2009	western OR	Slight to moderate increase in understory vegetation response of commercial thinning studies was strongly dependent on site-specific pre-treatment conditions and life form. Herb cover generally increased with thinning, while shrub cover increased when initially sparse but decreased when initially more abundant. Emphasized need to protect tall shrubs from mechanical damage in commercial thinning.
Understory Vegetation	Witler 1975	western OR	Total herbaceous species cover was highest in heavily and moderately thinned plots and increased with thinning intensity in 55-66-year-old Douglas-fir stands thinned commercially 2-17 years prior. Trends in herbaceous biomass were similar, but with larger error estimates. Biomass and stem density of large woody shrubs also increased with thinning intensity but there were no clear responses in cover or frequency. Though dominant understory shrub species and herbaceous species frequencies differed, no important species that attained high cover or frequency on any treatment decreased with thinning intensity.
Understory Vegetation	Zaborske et al. 2002	Kuiu and Prince of Wales islands, Southeast AK	Commercial thinning by individual tree selection of 42-95-year-old stands increased shrub, forb and conifer sapling biomass and deer forage availability at 13-14 years post-treatment compared to unthinned controls.

Table 3. Synopsis of studies assessing the effectiveness of young-growth treatments relevant to Tongass wildlife species.

Species	Citation	Location	Key Findings
deer	Alaback 2010	Prince of Wales Island, Southeast AK	Gaps were predicted to provide 4 times the deer carrying capacity of thinned stands in summer and 8 times the deer carrying capacity of thinned stands in winter. Typical gap treatments of 5-10% gap habitat in even-aged units predicted up to 50% increase in winter deer carrying capacity.
deer	Carey et al. 1999b	Olympic Peninsula, WA	Systems modeling suggest managing young-growth forests for conservation of biodiversity, which includes precommercial thinning at 15 years, legacy retention, and variable density commercial thinning treatments, allows for slightly higher deer populations compared to preservation with no manipulation. Young-growth harvest with riparian buffer strategies had slightly higher deer populations than biodiversity conservation [but note differential snow effects in clearcuts for deer at Tongass latitudes (Nelson et al. 2008).]
deer	Cole et al. 2010	Southeast AK	Stands precommercially thinned at 16-18 years of age increased summer resource values for deer through 7 years post-treatment compared to unthinned controls. Winter deer forage increased for snow-free conditions but was unaffected for conditions when herb-layer forbs were buried by snow.
deer	Crotteau et al. 2020a	Southeast AK	Precommercial thinning of 15-25, 25-35, or 35-50-year-old stands resulted in higher deer forage than unthinned stands through 10 years post thinning, but thinning-induced differences faded with increased winter snowfall scenarios, especially in older stands.
deer	Crotteau et al. 2020b	Southeast AK	Deer forage in precommercially thinned 15-25-year-old stands was variable across treatments (14 feet and 18 feet spacing), years (5, 10, and 16 years post-thinning), and Forage Resource Evaluation System for Habitat (FRESH) deer model scenarios, but was always significantly greater than controls except in the 31- and 39-in snowfall scenarios 5 years post-thinning. There was much greater cover of 1-2 very important deer forage species in thinned treatments than in unthinned controls. Recommend future use of 14 feet spacing given a lack of detectable differences in deer forage with 18 feet spacing and less expense and less detriment to timber quality of 14 feet spacing.
deer	Doerr and Sandburg 1986	Big Level Island, Southeast AK	Stands precommercially thinned at 16 years of age and sampled 18 years post-thinning ('most slash decomposed') had higher deer use based on pellet group counts and deer browse than unthinned stands.
deer	DeMeo et al. 1990	Prince of Wales Island, Southeast AK	Up to 49 feet wide gaps established in 26 to 34-year old productive spruce-hemlock stands 1-4 years prior had significantly greater deer browse than in adjacent (thinned and unthinned) young growth. Browse on gap edges was highest, despite significantly greater slash at edges.
deer	Farmer et al. 2006	Heceta Island, Southeast AK	Use of 29-30-year-old stands precommercially thinned at 15-20 years of age increased fawn malnutrition and mortality risk. High slash levels (large amounts of woody slash covered forest floor; piles often 3-6½ feet high) reduced forage accessible to fawns.

deer	Hanley et al. 2013	Southeast AK	Precommercial thinning at a) narrow and wide spacing in 15-25 year-old stands, b) medium spacing with and without pruning in 25-35 year-old stands, and c) wide spacing with and without slash treatment, and with girdling in >35-year-old stands had higher deer habitat values as modelled by FRESH (Hanley et al. 2012) compared to untreated controls 4-8 years post-treatment. Treating at 15 to 25 years was more effective that at 25 to 35 years and least effective >35 years. Planting of red alder in 1-5-year-old-stands had no effects 4-8 years post treatment.
deer	Harris and Barnard 2017	Chichagof Island, Southeast AK	Small gaps (150-430 m2, mean width 18.3m) increased deer days modelled with FRESH. Gaps provided more deer days in winter than estimated for thinning studies.
deer	Martin et al. 2019, Unpublished Data	Chichagof Island, near Hoonah, Southeast AK	Deer abundance decreased as slash biomass increased; deer densities were lowest in recently precommercially thinned stands due to slash often >10 feet in height. Slash volume generated, the amount of time it takes for slash to decompose, the status of understory biomass, and the amount of time before deer will begin to use the habitat all depend on tree sizes at thinning: <5 inches DBH => less slash, sooner and greater deer use; >8 inches DBH => more slash, delayed and lesser deer use. Deer density was highest at 6-9 years post precommercial thinning compared to other thinning treatments (15 years post, unthinned, and 2 years post) due to excellent forage biomass, no significant slash barriers to movement, and a mild winter without snow influences. Emphasizes importance of slash and snow, thinning at smaller DBHs, and implementing secondary or tertiary treatments to extend benefits.
deer	Zaborske et al. 2002	Kuiu and Prince of Wales islands, Southeast AK	Commercial thinning by individual tree selection of 42-95-year-old stands increased deer habitat values at 13-14 years post-treatment compared to unthinned controls. FRESH deer models suggested the thinned stands could support about 5 times as many deer as the untreated stands.
wolves, deer inference	Roffler et al. 2018	Prince of Wales Island, Southeast AK	Wolves avoided stands thinned at 6-52 years of age (average 24 years) during winter and did not display patterns of selection for thinned stands during other seasons.
black bears	Kimball et al. 1998	western WA and OR	Thinning and fertilization caused sugar concentration of vascular tissues in the lower boles of trees to increase, suggesting improved spring conifer vascular tissue forage for bears.
black bears	Perry et al. 2016	coastal NW CA	Precommercial thinning increased black bear forage (and damage) on conifer vascular tissues.
black bears	Schmidt and Gourley 1992	western OR	Black bear forage (and damage) on conifer vascular tissues is higher in young stands that have been thinned or fertilized, or both, compared to heavily stocked stands.
martens	Ben-David et al. 2014	Prince of Wales Island, Southeast AK	Martens were most abundant in old growth and unthinned stands, less abundant in stands precommercially thinned, and least abundant in clearcuts.

martens	Koch 2016	Kuiu Island, Southeast AK	Martens selected for high volume, closed canopy forest over more open and precommercially thinned habitat, in proximity to coastline and salmon streams.
bats	Blakey et al. 2016	Multi-continent synthesis	Thinning improves flight paths for bats. Supports clutter threshold (Adams and Law 2011) of about 445 stems/acre above which bat activity is markedly lower.
bats	Humes et al. 1999	western OR	Bat activity is higher in thinned than in unthinned stands (50-100 years old).
small ground-dwelling mammals	Carey 2003	western WA	Immediate positive effects from commercial variable-density thinning of 56-66 year-old-stands on forest-floor mammals.
small ground-dwelling mammals	Carey and Wilson 2001	western WA	Commercial variable-density thinning (4 years after) increased populations of deer mice, creeping voles, and vagrant shrews; no species declined with thinning.
small ground-dwelling mammals	Eckrich 2016; Ben-David et al. 2014	Prince of Wales Island, Southeast AK	Small mammal densities exhibited no relation to precommercial thinning. However, shrew populations were more stable and less affected by changes in mice densities in precommercially thinned stands than in unthinned stands likely due to improved habitat quality. Increased stability suggests that thinning either commercially or as an active management tool may reverse the homogeneity resulting from clearcut logging, increase habitat quality, and help conserve species diversity, especially of ground-dwelling small mammals.
small ground-dwelling mammals	Garman 2001	western OR	Commercial thinning had little influence on structure and composition of most ground-dwelling vertebrates in 3 years post-treatment sampling. Exceptions included positive effects 1-2 years post-thinning for the deer mouse, negative response of the Trowbridge's shrew to heavy thinning in 1-2 years post-thinning with apparent recovery in year 3, and possible delayed positive effects on Townsend's chipmunk.
small ground-dwelling mammals	Gitzen and West 2002	western WA	Small gaps (up to 1/4 acre in 90-year-old stands; 5-7 years post-treatment; branches, foliage and some boles removed) did not affect abundance of species characteristic of closed-canopy conditions compared to same-aged adjacent forest without gap treatments.
small ground-dwelling mammals	Larson 2001	western OR	Commercial thinning (5-6 years post-thinning) enhanced habitat quality for most species, had positive effects on densities of some species and neutral effects on others. Need to retain some unthinned stands for species that prefer closed canopies.
small ground-dwelling mammals	Slauson 2013	coastal NW CA	Higher abundance in commercially thinned than unthinned stands; response rapid within 5 years post-thinning and evident at least 30 years post-thinning.

small ground-dwelling mammals	Smith and Nichols 2004	Wrangell Island, Southeast AK	Stands age 20-25 years-old that were precommercially thinned 0-2 years prior were consistently occupied by southern red-backed voles, especially when population levels were high. Southern red-backed vole abundance in thinned young growth was higher than expected based on their reputed association with old-growth forests, possibly because of woody debris, herb, and shrub enhancements from thinning as well as because the cooler, wetter climate of Southeast Alaska mitigates desiccation effects typical elsewhere. However, mean adult body mass, number of reproductive females, and juvenile recruitment into the autumn population were lower in thinned young growth compared to old growth, suggesting possible demographic concerns. Use of young growth was also higher when population levels were higher. Uncertainty exists regarding the value of older young growth, after thinned canopies close in again and benefits to understory diminish. This study also focused on Keen's mouse, which is considered a habitat generalist and had highest densities in recently thinned young growth compared to two old growth habitats. Unthinned treatments were not assessed.
small ground-dwelling mammals	Sullivan et al. 2001	South-central BC, lodgepole pine forests	Large-scale precommercial thinning, and higher intensity thinning of lodgepole pine forests at stand ages 17-27 years increased small mammal abundance, species richness and diversity 10 years post-treatment associated with increases in tree diameter, crowns, and structural diversity of understory vegetation. Late-seral specialist, southern red-backed voles had consistently lower abundance in unthinned stands compared to old-growth stands, but in 7 of 9 cases, abundance did not differ between thinned and old-growth stands.
small ground-dwelling mammals	Sullivan et al. 2009	South-central BC, dryer lodgepole pine forests	Precommercial thinning of 20-25-year-old lodgepole pine stands 6-10 years prior compared to unthinned stands had neutral effects with all sampling years combined on abundance of red-backed vole, mice, chipmunk, heather vole, shrew, and ermine species and positive effects on early-seral specialists meadow and long-tailed voles. Abundance of late-seral specialist red-backed vole was higher in unthinned than thinned stands during two of the five sampling years, and consistently higher in mature and old-growth forests compared to thinned, thinned with fertilization, and unthinned stands.
small ground-dwelling mammals	Suzuki 2001; Suzuki and Hayes 2003	OR coastal forests	Precommercial thinning (2 years post-thinning) did not have substantial detrimental effects on any species and had positive effects on several. Relative abundance of western red-backed voles (*Myodes californicus*) decreased within 2 years post-thinning but recovered to similar abundance in stands 7-24 years post-thinning, compared to unthinned. Reproductive performance of red-backed voles was higher in thinned than unthinned stands.
small ground-dwelling mammals	Wilson and Carey 2000	western WA	Young-growth forests >65 years old that were managed with thinning had 1.5X the individual small mammals and 1.7X the small mammal biomass of similar forests managed with live tree, log, and snag legacy retentions without thinning.

small mammals, northern flying squirrels	Wilson and Forsman 2013	Pacific Northwest	Review of ecology, why thinning can have negative short-term effects, and long-term management options for 4 key spotted owl prey. For flying squirrels, midstory tree cover and connectivity are important in inhibiting predator detection and providing protective cover. Precommercial thinning of young forests <25 years can stimulate midstory development and is not likely to affect existing flying squirrel populations as they avoid highly stocked young forests. Also recommend keeping some young, high-density forest on the landscape and exploring the use of skips and gaps.
northern flying squirrels	Carey 1995	western WA and OR	Flying squirrels are 2 times more abundant in old forests than in young, managed forests without old-forest legacies (large live trees, large snags, and large decaying fallen trees), while populations in young forests with legacies and understory development may equal those in old forests.
northern flying squirrels	Carey 2000	western WA	Northern flying squirrels were 2X more abundant in 70-year old unthinned stands with large tree, snag and log legacies retained at original clearcutting compared to stands without legacy retention that were conventionally thinned two times with even spacing >10 years prior.
northern flying squirrels	Carey 2001	western WA	Variable density commercial thinning of 56-66 year-old stands within 5 years of treatment had neutral effects on northern flying squirrel abundance within previously conventionally thinned stands compared to controls for that treatment, but had negative effects followed by recovery to control levels in stands with legacy trees, snags and logs retained at clearcutting. The two previous conventional, even-spaced thinning treatments within the thinned stand and associated controls altered ecosystem function such that low flying squirrel populations failed to respond to the subsequent variable density thinning treatment. Repeated, even-spaced thinning treatments may place a stand on an undesirable trajectory of forest development. However, withdrawing a forest from active management after clearcutting also may not achieve ecosystem goals. Widespread simultaneous application of variable density thinning should be avoided. Recommends extended rotations, legacy retention, and variable density commercial thinning for effective landscape management.
northern flying squirrels	Carey 2003 - synthesis of prior published results by same author	western WA	Northern flying squirrels decreased in abundance in 55-66-year-old thinned stands immediately after variable-density thinning but recovered within 5 years. Recommends retaining unthinned patches.
northern flying squirrels	Garman 2001	western OR cascades	Commercial thinning had consistent negative effects on northern flying squirrel in 3 years post-treatment sampling. No flying squirrels were recorded in heavily thinned stands, and post-treatment capture rates were low in other thinning treatments compared to the uncut control.
northern flying squirrels	Gomez et al. 2005	OR coastal forests	Commercial thinning did not have measurable short-term effects on density, survival, or body mass of flying squirrels.

northern flying squirrels	Larson 2001	OR coastal forests	Commercial thinning (5-6 years post-thinning) had negative effects on abundance of northern flying squirrels. Need to retain some unthinned stands for species that prefer closed canopies.
northern flying squirrels	Manning et al. 2012	OR cascades	Lower densities in stands (55-65 years of age) at 11-13 years post-commercial thinning; lower densities in heavily thinned stands compared to lightly thinned stands.
northern flying squirrels	Ransome et al. 2004	South-central BC, lodgepole pine forests	Large-scale precommercial thinning at various intensities of 17-27-year-old lodgepole pine forests resulted in no differences in recruitment, movement, or survival of northern flying squirrels 12-14 years after thinning compared to unthinned and old-growth stands. Abundance was highest in the low-intensity thinning (high density retained), intermediate in old-growth and medium-intensity thinning, and lowest in the high-intensity thinning. However, adult male body mass was higher in old growth than in the low-intensity thinning.
northern flying squirrels	Sullivan et al. 2017	coastal and interior BC forests	Mean flying squirrel densities were highest in old growth stands (80-250 years old), followed by low- and medium-density thinned stands (high- and moderate-intensity thinning), then by high-density stands (low-intensity thinning), and flying squirrel densities were lowest in unthinned stands.
hypogeous fungi	Carey 2003 – synthesis	western WA	Mechanical disturbance destroyed fungal mats but impacts on truffle production were brief and variable density commercial thinning increased sporocarp diversity to a richness like that in old growth. Recommends retaining unthinned patches.
hypogeous fungi	Carey et al. 2002	western WA	Truffle biomass did not differ, though truffle diversity was higher in soils and in northern flying squirrel feces in 70-year old unthinned stands with large tree, snag and log legacies retained compared to stands without legacies that were conventionally thinned two times with even spacing >10 years prior.
hypogeous fungi	Colgan et al. 1999; Colgan 1997	western WA	Overall fungi biomass declined in 55-65-year-old stands during the first 3 years following variable-density commercial thinning compared to controls. However, diversity increased with light-intensity treatments and truffle abundance during times of lowest abundance (winter) as well as of some of the most nutritious for small mammals and flying squirrels increased with variable-density thinning. Short-term reductions in overall biomass may be explained by mechanical damage to fungal mats, loss of photosynthate due to removal of host trees, and changes in microclimate.
hypogeous fungi	Gomez et al. 2003	OR coastal forests	Commercial thinning reduced sporocarp frequency, number of species fruiting, and the number of species at 2-3 years post thinning. Sporocarp abundance was associated with abundance of coarse woody debris. Recommend retention of coarse woody debris in commercially thinned sites.
hypogeous fungi	Pilz et al. 2006	OR cascades	Commercial thinning of 50-year-old stands resulted in lower Chanterelle numbers and weight immediately after thinning, with lower values in heavier thins than lighter thins. Differences disappeared within 6 years.
Red or Douglas squirrels	Carey 2003; Carey 2001	western WA	Douglas squirrels did not respond to variable density thinning of 56-66-year-old stands within 5 years post-treatment compared to controls.

red or Douglas squirrels	Ransome et al. 2004	South-central BC, lodgepole pine forests	Large-scale precommercial thinning at various intensities of 17-27-year-old lodgepole pine forests resulted in no differences in abundance, mass, recruitment, movement, or survival of red squirrels 12-14 years after thinning compared to unthinned and old-growth stands.
Red or Douglas squirrels	Slauson 2013	coastal NW CA forests	Higher abundance of Douglas squirrels in thinned than unthinned stands 5-30 years post restoration thinning of 17-33-year-old stands; no detections in unthinned stands.
red or Douglas squirrels	Sullivan et al. 2017	coastal and interior BC forests	Overall mean abundance of Red and Douglas squirrels was higher in old-growth (80-250 years old) and in high and low intensity thinned stands than in unthinned stands. Populations in thinned stands were within the range of natural fluctuations of old-growth stands, while those in unthinned stands were not within the range of natural fluctuations in old-growth stands.
Birds	Altman and Hagar 2007	Pacific Northwest	Review of bird thinning literature concluding the following: species are usually not lost as a result of thinning; species that nest in closed canopy forest generally decline while open forest nesters generally increase; thinning creates habitat for several species that are rarely observed in unthinned young growth; species that exhibit short-term or initial declines from thinning often recover within 10 to 20 years or sooner; some species consistently show no response to thinning, while others, especially understory associates respond inconsistently due to local study differences in these characteristics; some species respond to thinning intensity, positively or negatively; species that respond positively to thinning span early-, mid-, and even late-successional associations; species that respond positively to thinning represent a variety of foraging guilds including ground, foliage, bark, and aerial insect foragers.
birds	Artman 2003	WA cascades	Commercial thinning (3-5 years post thinning) of 45 to 55-year-old western hemlock stands enhanced habitat and abundance of some bird species while having minimal effects on others.
birds	Carey 2003	OR coastal forests	Bird species richness remained unchanged with commercial variable-density thinning, but there were positive effects on winter birds and increased habitat quality. Continued low abundance of cavity-nesting birds. Recommends retaining unthinned patches.
birds	DellaSala et al. 1996	Prince of Wales Island	Differences in species compositions were found in recently, uniformly spaced precommercially thinned and gapped stands compared to unmodified stands, but none were clearly more indicative of old-growth communities. Snow interception from accumulation on branches important for birds; high use of old growth related to winter severity. Recommend variable-spaced thinning (with old-growth retention) to increase use of otherwise homogenous young growth by old-growth species.
birds	Hagar et al. 1996	OR coastal forests	Total breeding bird abundance was higher in commercially thinned than unthinned stands (40-55 years old); six species had higher abundance in thinned, one had consistently higher abundance in unthinned, and three others were generally more abundant in unthinned though this varied by season, region, or year. Recommend periodic variable-intensity commercial

			thinning with unthinned strips, patches, and adjacent stands as a tool to improve habitat for all birds sampled.
birds	Hagar et al. 2004	OR cascades	Commercial thinning rapidly promotes diversity of breeding songbirds in young, conifer-dominated stands. Recommend using a variety of thinning intensities and patterns, including no thinning and wide spacing to maximize avian and structural diversity.
birds, winter	Haveri and Carey 2000	WA coastal forests	Commercial variable-density thinning increased area used and species richness; 2 of 8 species increased use of thinned stands, while no species exhibited higher use of unthinned. Recommend variable-density thinning in conjunction with legacy retention, decadence (snag) management, and long rotations to provide habitat for abundant and diverse birds.
birds	Hayes et al. 2003	OR coastal forests	Commercial thinning of densely stocked conifer stands in landscapes dominated by younger stands enhances habitat suitability for several species, but some unthinned patches and stands should be retained to provide refugia for species that are impacted by thinning.
birds	Matsuoka et al. 2012	Prince of Wales Island	Precommercial thinning had few measurable benefits to birds (up to ~16-19 years post-thinning), though it is likely too early in the successional phase to realize thinning benefits related to large trees and snags. Combined densities of 8 understory-nesting species were 1.4 times higher in thinned than unthinned likely due to higher shrub cover, but these benefits were decreasing with succession of thinned forests towards stem exclusion. Recommend partial old-growth harvest and retention of legacy trees and snags as an alternative harvest strategy to clearcutting.
birds	Slauson 2013	coastal NW CA forests	Various thinning treatments of 17-33-year-old stands 5-30 years afterwards increased abundance and species diversity of birds. Species diversity increases reflected increased presence of sub-canopy, shrub, and ground-foraging guilds. Community assemblage of thinned stands was closer to old-growth reference stands than unthinned.
birds	Yegorova et al. 2013	OR cascades	Consistent positive (4 species) or negative (2 species) relationships to vegetation changes following commercial thinning in 6 of 8 bird species, but with highly variable magnitude and some years non-significant. Caution that high temporal variability in bird associations mean important bird-vegetation correlations may be missed in short-term studies.
amphibians	Aubry 2000	WA coastal forests	Species richness was depauperate in older stands that were previously precommercially thinned where canopies had closed in again (little understory vegetation, 30-40 years of age) compared to stands that had precommercial thinning within the past 5 years (12-20 years of age). Commercially thinned older stands (prior precommercial thinning + recent commercial thinning, rotation age 50-70 years) had higher species richness than both of the precommercial thinning categories. All stands were at least within their second rotation and the oldest age classes (rotation

			age stands) had highest richness, biomass, and abundance. Managed stands had different community assemblages than unmanaged stands in the region; higher proportions of some species (including northwestern salamanders) and lower proportions of others. This author found no relationship between amphibian abundance and levels of coarse woody debris on the forest floor.
amphibians	Garman 2001	western OR cascades	Commercial thinning had little influence on structure and composition of most ground-dwelling vertebrates in 3 years post-treatment sampling. Exceptions included positive effects 1-2 years post-thinning for ensatina.
amphibians	Grialou et al. 2000	WA coastal forests	Light commercial thinning of 45-60-year-old stands (<2 years post-thinning) did not affect species compositions or size-class distributions of gravid females but decreased relative abundance of western red-backed salamanders, possibly due to direct machine impacts and soil compaction from skidders.
amphibians	Kluber et al. 2008, 2013	western OR	No treatment effects of upland commercial thinning coupled with riparian buffers on terrestrial salamanders, 5-6 years post-treatment of 40-60-year-old stands.
amphibians	Olson 2013	western OR	Summarizes variable effects on amphibian species abundances with apparent continued persistence (from Wessell 2005, Rundio and Olson 2007, and Kluber et al. 2008). Short-term declines may be acceptable for longer-term restoration gains.
amphibians	Rundio and Olson 2007	western OR	Commercial thinning 1-2 years post-treatment of 45-65-year-old stands resulted in post-thinning declines in 2 terrestrial salamanders by 40% at one site, and no treatment effects at another, possibly owing to abundant down wood at the latter site. Down wood volume and riparian buffers may ameliorate short-term negative effects of thinning on terrestrial salamanders.
amphibians	Suzuki 2001	OR coastal forests	Relative abundance of western red-backed salamanders did not change at 2 years post-thinning but was lower in stands commercially thinned 7-24 years previously compared to unthinned stands.
amphibians	Wessell 2005	western OR	Commercial thinning in stand ages 50-70 years at 2-4 years post-treatment had negative effects on total species richness. Small (¼ acre) and medium (½ acre) uncut leave islands within thinned stands had higher amphibian species richness than large (1 acre) leave islands.
forest floor invertebrates	Schowalter et al. 2003	western WA	Variable density commercial thinning (7-8 years post-thinning) altered species assemblages (2 taxa increased: aleocharine beetles and *Ancotrema sportella* snails) compared to unthinned stands, while these and 7 other taxa were strongly influenced by management history of the stands (multiple earlier thinning treatments vs. legacy retention without earlier thinning prior to experimental commercial thinning and controls). Shifts in relative abundance among species within functional groups may maintain ecological functions.
canopy arthropods	Schowalter et al. 2005	western OR and WA	No changes in abundance from commercial thinning treatments of 65-170-year-old stands about 2-3 years post treatment.

beetles and spiders	Stockbridge 2014	Prince of Wales Island	Numbers of individuals and species tended to be lower in unthinned stands compared to precommercially thinned stands, though differences were not significant. Average number of beetle species was significantly lower in unthinned stands compared to old growth and clearcut stands, while this measure in thinned stands did not differ significantly from other treatments. Precommercial thinning changed spider species assemblages (to a unique assemblage different from unthinned and old growth) but did not affect beetle species assemblages. Precommercial thinning had neutral effects on old-growth specialist species; these species were similarly found in both thinned and unthinned young growth stands.
arthropods, mollusks	Wessell 2005	western OR	Commercial thinning effects, in stand ages 50-70 years at 2-4 years post-treatment, were mixed, with some negative effects from thinning, especially on low-mobility species, and positive effects on other species. Densities and diversity tended to be lower in small (¼ acre) uncut leave islands within thinned stands than in large (1 acre) leave islands. Leave islands may provide refugia for some low-mobility and ecologically sensitive species.
root-colonizing insects	Witcosky et al. 1986	western OR	Precommercial thinning increased abundances of insect vectors of black-stain root disease. Abundance of two species was lower when thinning was conducted in May compared to thinning in September and January.
ground-dwelling arthropods	Yi and Moldenke 2005	western OR	Commercial thinning of 40-60-year-old stands, 5 years after thinning resulted in higher abundance and diversity in heavy thinning and light thinning with gaps than in light thinning without gaps and unthinned treatments. Ants, spiders, camel-crickets, and millipedes preferred more intense thinning treatments, while carabid beetles were more abundant in unthinned stands during the wet season (spring) only.
flying insects	Yi 2007	western OR	Commercial thinning of 40-60-year-old stands resulted in more diverse populations of flying insects, including herbivores and predators, at 4-5 years post-treatment. Greater thinning intensity correlated with higher species richness and diversity.
litter-dwelling arthropods	Yi and Moldenke 2008	Western OR	The abundance and diversity of litter-dwelling arthropods decreased as commercial thinning intensity increased, especially in limited mobility species, and due to increased disturbance to the forest floor (patchy litter and moss cover removal) in the heaviest thinning treatments.
shrub-dwelling arthropods	Yi and Moldenke 2011	Western OR	Numbers decreased as commercial thinning intensity increased in deciduous foliage (vine maple) compounded by significant seasonal effects (wet vs dry season), but there was no response to thinning in coniferous foliage (Douglas-fir and western hemlock).
multiple taxa – species at risk	Carey et al. 1999b	Olympic Peninsula, WA	Systems modeling of upland and riparian forest management strategies suggests managing young-growth forests for conservation of biodiversity allows for the best recovery of sensitive species, compared to other young-growth management strategies, including preservation with no manipulation and maximizing timber harvest with protected wide or narrow riparian buffers. The conservation of biodiversity approach included legacy retention, coarse woody debris and cavity-tree

			management, precommercial thinning, and variable density commercial thinning.
multiple taxa (meta-analysis)	Verschuyl et al. 2011	meta-analysis N. American forests, including PNW forests	Forest thinning treatments had generally positive or neutral effects on diversity and abundance across all taxa. Thinning intensity and type of thinning may at least partially drive the magnitude of response. More research is needed on amphibians.