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Managing Boreal Forest for Timber and Wildlife in the Tanana Valley of Eastern Interior Alaska

Thomas F. Paragi, Julie C. Hagelin, and Scott M. Brainerd

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Alaska Department of Fish and Game Division of Wildlife Conservation

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Cover Photo: Early fall view of boreal forest from the Parks Highway between Fairbanks and Nenana, showing the Tanana River and flats, Alaska Range foothills, and Mount Hayes. ©2002 Robert A. Ott.

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Executive Summary

This bulletin presents themes, principles, and guidelines to help integrate forestry and wildlife habitat management for the boreal forest of eastern Interior Alaska.

Competing demands for wood and wildlife in the Tanana Valley highlight a growing need for coordination between the local wildlife management agency, the Alaska Department of Fish and Game (ADF&G) and the management agency for state forests, the Division of Forestry (DOF) in the Alaska Department of Natural Resources. This bulletin is intended to serve as a resource for wildlife and forest managers, researchers, and agency planners interested in pursuing optimal public benefit by engaging in collaborative management. It also provides guidance on incorporating the value of wildlife habitat into forest management planning.

Within the framework of the Alaska Forest Resources and Practices Act (FRPA; Alaska Statute 41.17), we recommend integration of forestry and wildlife objectives through stakeholder engagement. Although ADF&G consultation in the past largely occurred during review of Forest Land Use Plans (FLUPs) for individual timber sales (Appendix A), in the future we envision a more proactive consultation process during development of the Five-Year Schedule of Timber Sales (FYSTS) at the landscape scale.

Types and distributions of wildlife habitat in the boreal forest of the Tanana Valley continue to be shaped largely by natural disturbances, such as wildland fires, insect outbreaks, and flooding. This differs from boreal forests in other regions of the world where humans have effectively reduced frequency or extent of natural disturbances or otherwise modified natural forests, most often to enhance commodity production. In the Tanana Valley, a comparatively small-scale sustainable timber harvest that is primarily for local use occurs near a few forest roads. This highlights the collaborative opportunity for agency managers to provide for timber sales while aiming to maintain a range of wildlife species for human and ecological benefits.

Two events underscored the importance and interrelatedness of both forestry and wildlife habitat management. First, in the mid-2000s, a dramatic rise in oil prices resulted in increased firewood harvest in the Tanana Valley and magnified interest in wood use on a much larger scale, as an alternative fuel for heat and electricity cogeneration. Second, Division of Forestry (DOF) invited authors of this bulletin (T.P. and J.H.) to review reforestation standards for DOF Regions II and III. The work of that review summarized the positive and negative effects that wildlife can have on forest regeneration and highlighted the need and benefits of interagency collaboration. This bulletin builds on that work.

As a core step to creating this bulletin, the authors ("we") reviewed forest–wildlife relationships applicable to management in boreal regions. We used scientific and agency literature from North America and Eurasia to identify practices that can produce mutually beneficial outcomes for timber production and wildlife resources. From the literature review, we interpreted 3 key themes for managing wildlife habitat in boreal forest: 1) maintain natural disturbances that produce young vegetation (early seral), 2) maintain late seral features on managed sites, especially dead wood and both live and dead cavity trees, and 3) maintain connections or proximity among habitat features, especially for wide-ranging species. Managing for diverse and connected forest habitats helps maintain productive forests. For example, maintaining habitat for

vertebrate predators of insects, voles, and snowshoe hares helps prevent overabundance of these prey species and the feeding damage they can cause to young trees, thus making forests more resilient.

In this bulletin, we also summarize key findings as guiding principles for implementing forestry and wildlife habitat management in the Tanana Valley. These principles were designed to be consistent with the intent of FRPA that "allowance shall be made for important fish and wildlife habitat" (Alaska Statute 41.17.060(c)(7)). It is not practical to manage for each wildlife species and type of habitat on individual timber sales. Instead, the principles encourage a proactive approach to wildlife habitat in managed forests, which can maintain many species in a timber sale area. The approach reduces the risk of habitat degradation and thereby avoids loss or decline of individual wildlife species. It thereby reduces future needs to restore habitat, intensively manage species in steep decline, or restrict forestry practices. The overriding goal is to maintain a diverse range of wildlife habitats that enable a diverse range of wildlife species to persist over time and across the managed landscape.

We propose 5 principles and associated guidelines to serve as voluntary best practices to maintain stand-level features and landscape-level habitat connectivity beneficial to both timber production and wildlife in the Tanana Valley:

1. Manage forests for a range of habitat types that support diverse wildlife species, because this is likely to maintain forest ecosystem resilience to environmental disturbances.
    a. Describe habitat features and landscape connectivity to the extent possible from existing environmental data and use this information in forest planning.
    b. Focus new inventory of stands to include habitat features that are important for wildlife and use this information in forest planning.
    c. Design larger timber sales in uplands to emulate wildland fire patterns.

2. An integrated approach to forest and wildlife management at the stand and landscape scales maintains habitat benefits.
    a. Favor diverse woody regeneration that includes willows and deciduous trees.
    b. Maintain snags, cavity trees, and woody debris.
    c. Identify landscape connectivity beneficial to wide-ranging species.

3. Stand-level planning and management of habitat and wildlife can mitigate wildlife damage to desired forest products.
    a. Manage habitat to reduce herbivory.
    b. Maintain habitat for predators of herbivores.
    c. Monitor abundance of vertebrate herbivores and their predators.

4. Landscape-level planning for both wildlife habitat and access management is appropriate given competing interests, the scale of natural disturbances, and desire for a managed forest on state lands.
    a. Include the value of wildlife habitat when considering road access options for timber harvest and wood salvage after natural disturbances.
    b. Involve wildlife stakeholder interests when planning forest road networks.

5. Consider best practices for wildlife habitat conservation in managed forest as hypotheses that can be verified for effectiveness and adjusted over time using an adaptive management approach to optimize desired outcomes for both forests and wildlife.
    a. Involve stakeholders in discussions of options and tradeoffs in monitoring strategies.
    b. Establish a scientific advisory group to guide silvicultural prescriptions and monitoring.
    c. Verify best practices for wildlife habitat using scientific methods; adjust and update using an adaptive management approach.
    d. Utilize suitable techniques and volunteer help to monitor a broad network of sites.

The 5 principles and guidelines consider both stand-level best practices and the planning process for multiple timber sales across the managed landscape. In this bulletin we discuss the scientific reasoning behind each guideline and practical factors of implementation. Applying the guidelines will come through collaborative efforts by DOF and the ADF&G divisions of Wildlife Conservation and Habitat.

Implementation of the guidelines for each of the 5 principles is an important next step. We recommend coordinating implementation with the Citizens' Advisory Committee for the Tanana Valley State Forest. This group can engage stakeholders to identify species priorities, define habitat landscapes and access routes, and engage scientists to help design a monitoring program for wildlife response to future timber harvest. We expect the guidelines presented here will help inform stakeholder discussions of the tradeoffs between timber harvest and wildlife outcomes. ADF&G can help by proactive engagement with DOF during development of the FYSTS and identifying sources of funding for staff capacity and operational costs to inform landscape planning and monitoring for wildlife habitat on managed forests.

Key words: Adaptive management, best practices, biomass energy, connectivity, conservation, ecological resilience, ecosystem services, forestry, habitat guidelines, landscape planning, logging, monitoring, stakeholders, timber salvage.

♦ ♦ ♦

Introduction

The Tanana Valley State Forest (TVSF) of eastern Interior Alaska occurs within a vast boreal region where natural disturbances such as fire dominate compared with the scale of human disturbance regulated by land management (Fig. 1). The boreal region includes some of the largest conservation and wilderness areas in North America, which act as wildlife refugia (Matsuoka et al. 2019). The Tanana Valley represents a globally rare yet enviable situation of an ecosystem that presently has no wildlife species in known peril and relatively limited landscape fragmentation due to human activities. This situation exists even though the TVSF occurs near the existing highway system (Fig. 2).

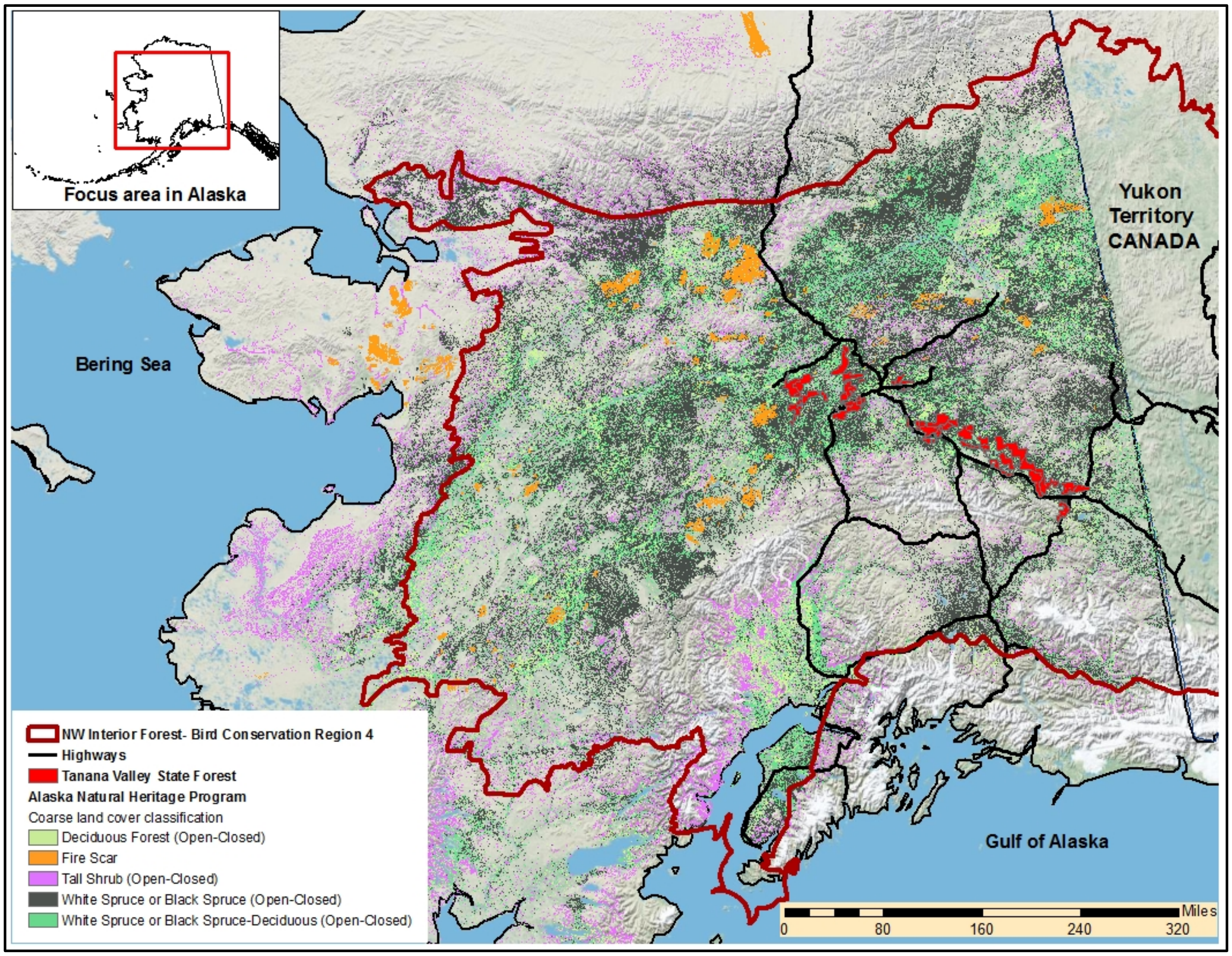
However, Alaskans are considering ways to increase their use of local resources for energy and food to reduce their need to import lumber, food, and other critical commodities from distant sources. An increased use of local resources with potentially competing needs and public values will require collaborative management to integrate conservation of wildlife resources into forest management and achieve optimal public benefit in managing forests for both wildlife and timber resources.

This bulletin provides guidance distilled from the scientific literature for conserving wildlife habitat in boreal forests, specifically focused for application to the Tanana Valley. It aims to identify actions that are mutually beneficial to timber and wildlife management and is presented to assist wildlife and forest managers in collaboratively integrating their separate responsibilities for managing these resources.

An Impetus for This Report: Changing Demand for Wood

A substantial increase in interest for wood energy occurred in the Tanana Valley occurred in the mid-2000s in response to a dramatic rise in fuel oil prices that occurred immediately prior to and for a few years after a U.S. financial recession (Alaska Department of Commerce, Community, and Economic Development [DCCED] 2016). At the same time, the federal government initiated $1.1 billion in federal incentives for bioenergy projects in the 2008 Farm Bill (Stubbs 2010, Association of Fish and Wildlife Agencies [AFWA] 2012). Firewood demand for residential heating rose (Alaska Division of Forestry [DOF] 2007:21), a facility that makes densified wood pellets and logs opened in 2009 near Fairbanks, and queries for wood energy projects to serve community heating needs (e.g., schools and public water stations) increased substantially in Interior Alaska and the Copper River Basin (Alaska Energy Authority [AEA] 2016).

Additionally, private sector proposals for wood energy cogeneration facilities (heat and electricity) were developed for Tok and for Fort Greely near Delta Junction (DCCED 2016). Cogeneration facilities require substantial feed stock and large, multi-year timber sale contracts. DOF responded to demand by revising its forest inventory to estimate the amount of biomass (i.e., equivalent wood volume or acres of timber type) that could be sustainably harvested in the Tanana Valley (Hanson 2013). However, when oil prices dropped again, large wood biomass projects were less economically feasible, and cogeneration proposals did not secure funding. The 2014 Farm Bill also repealed bioenergy initiatives for forest biomass and rural energy self-sufficiency (Bracmort 2017).

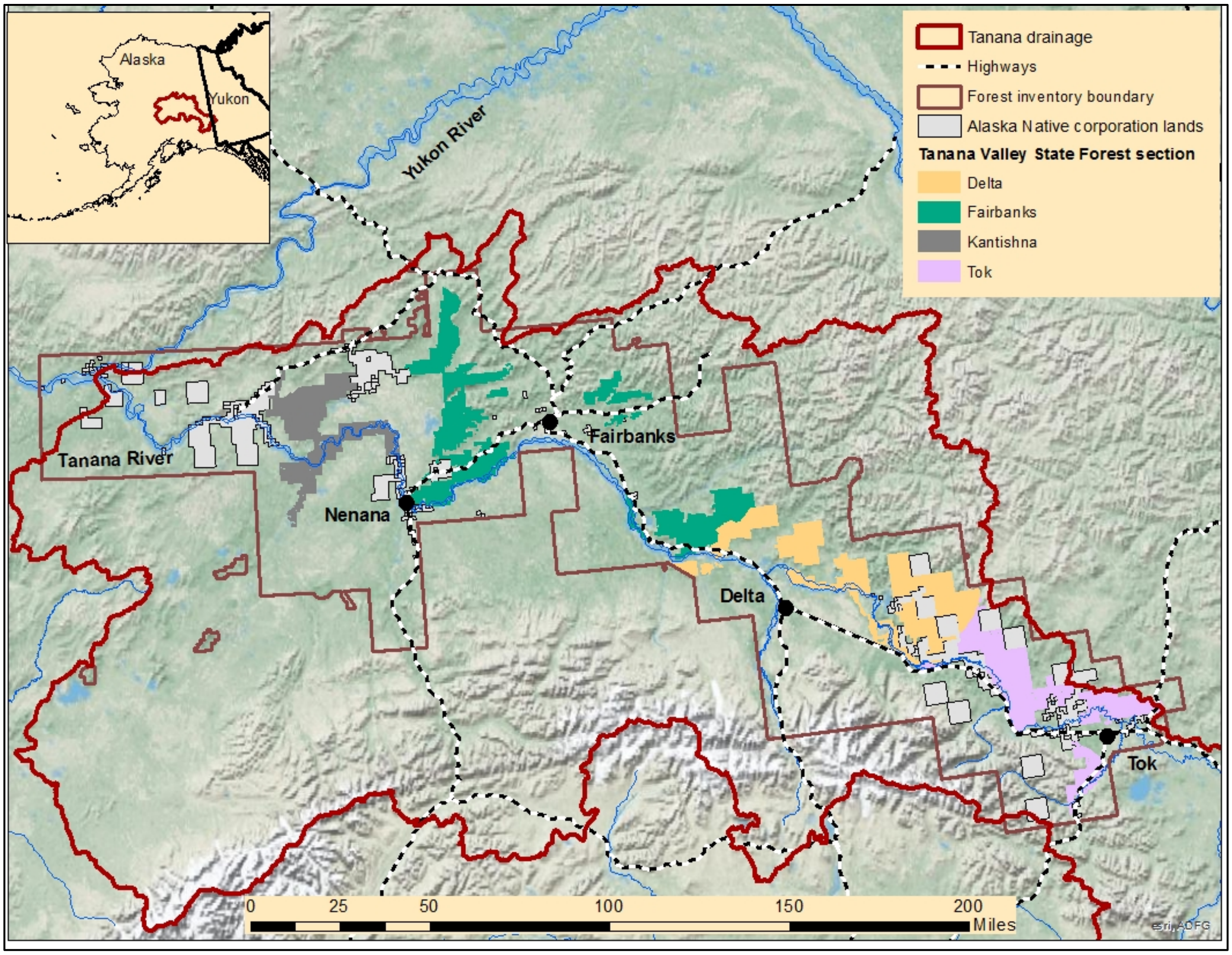


2018 ADF&G map by T. Paragi. Coarse habitat classification courtesy of the Alaska Natural Heritage Program.

Figure 1. Forest types and potential seral forest (recent burns and tall shrub that includes young deciduous trees) that compose the dominant vegetation types in the boreal region of Alaska as defined by Bird Conservation Region 4 (Bird Studies Canada and NABCI 2014).

This history demonstrates that demand for forest biomass has the potential to rapidly increase in the Tanana Valley when: 1) the prices of fossil fuels rise, 2) wood biomass-based renewable energy becomes cost competitive with fuel oil,[1] and/or 3) government policies change in ways that influence harvest levels for a range of wood uses (Wurtz et al. 2006). Supplying a greater demand for wood energy in the Tanana Valley requires increasing the number of harvest areas and building roads to access them. It is expected that any increased harvest would occur, at least initially, on public (mostly state) lands due to highway proximity (Fig. 2).

[1]Davies, J., and M. Misiuk. 2007. Wood heat-an alternative to oil? Slides of presentation at the University of Alaska Fairbanks Museum of the North, Fairbanks, Alaska, December 6. Cold Climate Housing Research Center, Fairbanks, Alaska. http://www.cchrc.org/sites/default/files/docs/MuseumWoodEnergyPresentation12-6-07.pdf (Accessed 9 January 2018).



2018 ADF&G map by T. Paragi.

Figure 2. Map of Tanana River drainage, forest inventory boundary (Hanson 2013), the Tanana Valley State Forest, Alaska Native corporation lands, and larger communities in the Tanana Valley, eastern Interior Alaska.

Public lands are also important to local users of wildlife. The number of people participating in consumptive and nonconsumptive wildlife-related activities continues to increase nationally (U.S. Fish and Wildlife Service 2018) and in Alaska (U.S. Fish and Wildlife Service 2013). Wildlife resources are an important part of culture and the economy in Alaska (ECONorthwest 2014). The 2 demands (wood and wildlife) are competing interests that highlight a growing need for coordination between the Alaska Department of Fish and Game (ADF&G) and DOF.

Building on Earlier Cooperation

In light of the potential for greater use of wood resources, the authors of this bulletin ("we") recognized a need for providing better guidance for wildlife habitat conservation at multiple spatial scales and to highlight examples of how forests managed for both timber and wildlife can help achieve forestry objectives while also benefitting consumptive use and other wildlife values. Bulletin authors T. Paragi and J. Hagelin were invited to participate during 2014–2016 in a review of reforestation standards led by the Alaska Department of Natural Resources (DNR), DOF for Interior and Southcentral Alaska (DOF Regions II and III). Information obtained during that effort was used to prepare a literature compilation and annotated bibliography that included forestry–wildlife relationships (Paragi et al. 2016). Interacting with forestry professionals on the science and technical committee for reforestation standards, and subsequently with timber operators on an implementation group, provided the authors with a broader context of competing interests and pragmatic considerations. The benefits of interagency cooperation became apparent, for example, during consideration of positive and negative effects of wildlife species on forest stand regeneration following live timber harvest or post-logging salvage of dead trees.

What this Bulletin Presents

The information synthesized here reflects our extensive review of scientific literature on boreal forest and wildlife management in Alaska and worldwide. The main text of this bulletin summarizes 3 important themes for managing wildlife habitat in boreal forests and constructs 5 principles and associated guidelines that can be used cooperatively by forestry and wildlife managers in a manner beneficial to both timber production and wildlife. Succinctly summarizing a rapidly growing body of literature and management agency experience in the circumboreal region was challenging because the region is vast and not all work is in the English language.

Detailed technical references provided in Appendices A–J are essential to fully understanding this bulletin. Appendices review the statutory background of wildlife habitat in managed forests in Alaska (Appendix A) and provide an overview of the Tanana Valley State Forest (Appendix B) and ecological concepts and forest–wildlife relationships upon which the principles and guidelines are based (Appendix C). Appendix D specifies key information summarized in the principles and guidelines and describes how forest management choices can influence wildlife populations. Appendix E describes our approach to literature review. Appendix F relates critical lessons learned from boreal forest management worldwide. Appendices G–J provide sources of landscape data, maps of roads and timber sales, and lists of wildlife species relevant to habitat in the Tanana Valley.

Intended Readership and Use

This bulletin will likely be most useful to foresters, wildlife biologists, and planners in state management agencies of Interior Alaska and to other public and private land managers. We believe it also will be useful to stakeholder engagement within the framework of the Alaska Forest Resources and Practices Act (FRPA), which governs forest practices and helps integrate forestry and wildlife habitat objectives in planning and implementation.

Integration of stakeholder perspectives can guide scientific evaluation of management prescriptions for both forestry and wildlife objectives (Beguin et al. 2016). We consider stakeholders broadly as users of forest resources, those representing scientific or management interests, and members of the public representing any other values, perspectives, or interests on forested public lands (Clark 2002; Fig. 3 in Beguin et al. 2016). We expect that key concepts presented here will be useful in engaging stakeholders in identifying their priorities among competing uses.

Wildlife and Timber Management in the Tanana Valley

ADF&G has the authority and responsibility to manage wildlife in the State of Alaska and does so primarily through its Division of Wildlife Conservation (DWC). ADF&G also manages certain habitat matters through its Division of Habitat. State forests are managed by DOF. The Alaska Constitution (Article VIII, Section 4) requires that forests, range, and wildlife be managed on a sustained yield basis and for beneficial public uses. However, presently there are few wildlife habitat recommendations or standards regarding forest management for state, municipal, or private lands.

Forests are managed to provide a range of commodities and other ecosystem services[2] to humans, including wood fiber, wildlife, and recreation (Alaska Division of Forestry 2016:34). FRPA (Alaska Statute 41.17)[3] provides substantial guidance on managing for these multiple uses that includes conservation of fish habitat and water quality (Appendix A). However, its only statutory language for wildlife occurring on state and municipal lands is vague: "allowance shall be made for important fish and wildlife habitat" (AS 41.17.060(c)(7)). Additional guidance on conserving wildlife habitat or uses is provided in DOF forest management policies, but they include neither prescriptive nor regulatory requirements (Appendix A).

FRPA requires that consultations occur between DOF and ADF&G during the planning and operational design of timber sales, forest roads, and reforestation activities, because these actions can affect forest–wildlife relationships. ADF&G consultations with DOF have been fairly limited in scope and focused at the stand scale, such as specifications for fish and wildlife habitat in riparian buffers and providing for retention trees with high wildlife value (Appendix A). Past examples of ADF&G guidance to DOF and harvest operators were described in Haggstrom and Kelleyhouse (1996) and in a 2001 brochure that was recently updated (Paragi and Rodman 2020).

However, consultation involving wildlife habitat has not been a part of the larger landscape-scale planning DOF has conducted for its Five-Year Schedule of Timber Sales (FYSTS; Appendix A), which involves scoping new timber sales and road access. Yet, landscape-scale management of habitat is also important to wildlife. Review of the scientific literature and our professional experience leads us to recommend that even general consultation of DOF with ADF&G during the FYSTS planning process could benefit regeneration of forest habitat (Paragi et al. 2016), as well as maintain wildlife populations by reducing habitat fragmentation (Appendix C).

Much of the timber harvest in eastern Interior Alaska occurs on the Tanana Valley State Forest (TVSF) or nearby state and Alaska Native corporation lands (Fig. 3). Appendix B provides an overview of ecological characteristics and land use within the Tanana Valley.

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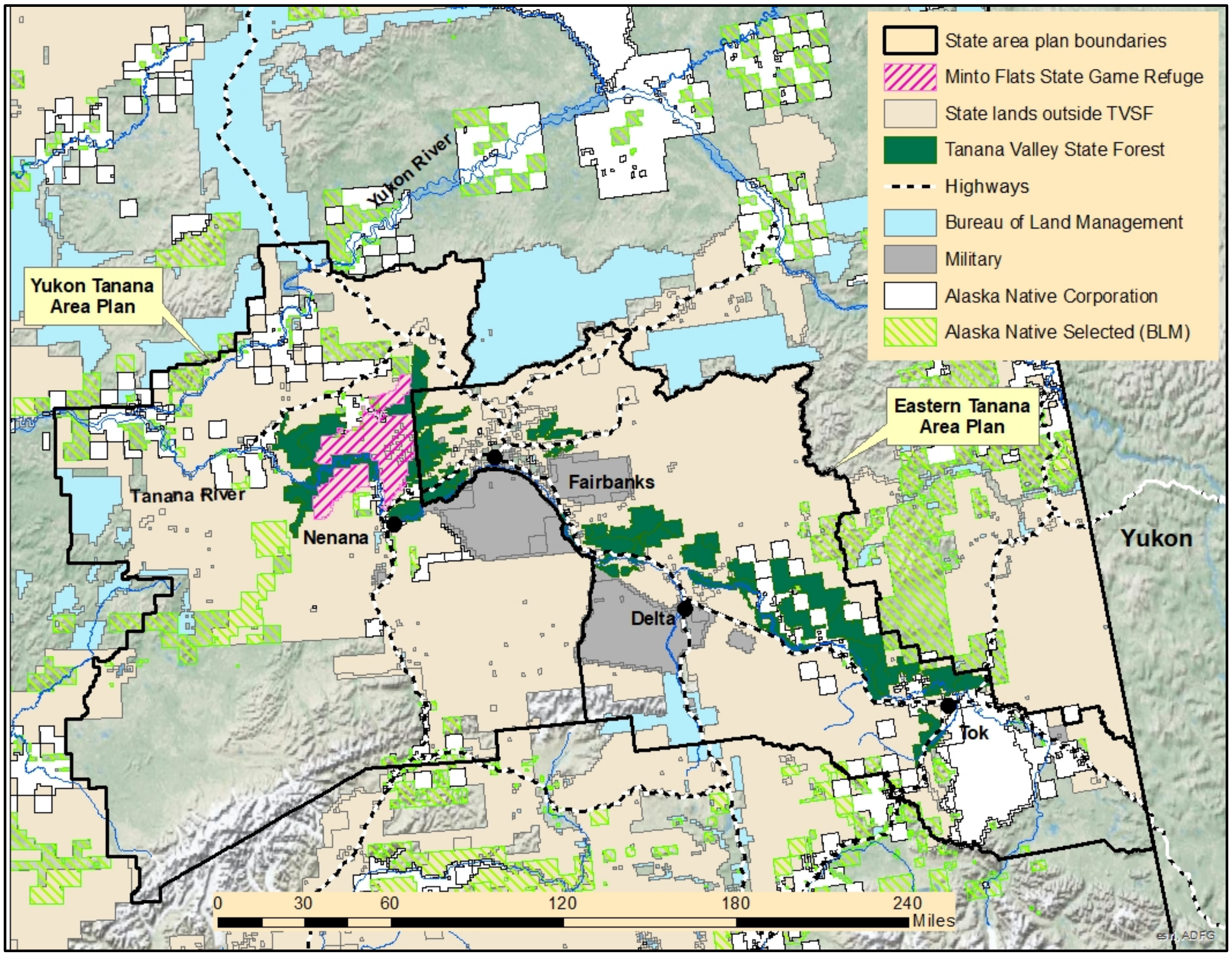
[2] "Ecosystem services" describes benefits (natural or human-caused) that ecosystems, such as forests, provide to humans (e.g., production of forest biomass, pollination, pest regulation; see also Appendix C).
[3] Alaska Department of Natural Resource, Division of Forestry. [n.d.] Alaska Forest Resources and Practices Act. http://forestry.alaska.gov/forestpractices.htm#regulations (Accessed 10 December 2018).



2018 ADF&G map by T. Paragi.

Figure 3. Map of the Tanana Valley State Forest, other state lands commonly having forestry as a designated or co-designated use, state area plans regions, and other lands where forest management may occur in eastern Interior Alaska.

Uses specific to the TVSF are guided by a management plan (Alaska Division of Forestry 2001) and periodic public input to the director of DOF through an appointed TVSF Citizens' Advisory Committee[4] (CAC) representing diverse interests. The plan provides goals for fish and wildlife habitat and public uses that include the following items (excerpted from Alaska Division of Forestry 2001: Chapter 2, page 14):

- Manage the habitat of sufficient suitable lands and waters to provide for the diverse habitat needs of fish and wildlife resources to maintain or enhance public use and economic benefits while maintaining the natural range of species and habitat diversity of the TVSF.

- Ensure access to public lands and waters where appropriate to promote or enhance responsible public use and enjoyment of fish and wildlife resources. Access

[4] Alaska Department of Natural Resources, Division of Forestry [n.d.]: Tanana Valley State Forest Citizens' Advisory Committee: http://forestry.alaska.gov/tvsf_committee (Accessed 24 February 2020).

improvements should be designed to match the public use objectives for the area under consideration.

- When resource development projects occur, reduction in the quality and quantity of fish and wildlife habitat shall be mitigated… using proven fish or wildlife habitat enhancement techniques where appropriate.
- Protect and enhance fish and wildlife resources and habitats to contribute directly or indirectly to local, regional, and state economies through commercial, subsistence, sport, and nonconsumptive uses.
- Enhance the value of habitat to fish and wildlife species through water control projects or through vegetation manipulation, including burning, crushing, timber harvest, and other management practices.

The current forest management plan also identified silvicultural research needs related to wildlife (Alaska Division of Forestry 2001: Chapter 4, page 169): "Cutover areas are widely assumed to produce increased browse and cover, but factors important to use of cutovers by moose, grouse, hare, lynx, etc. need to be studied if logging will be managed to benefit moose and other wildlife."

Our review of recent literature from Alaska and other boreal places offers an opportunity to integrate new information into management considerations in the Tanana Valley. The information highlights scientifically robust examples of how managing habitat for wildlife can also enhance forest regeneration, growth, and resilience to a changing environment.

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Understanding Wildlife Habitat Needs

Wildlife biologists use various terms to describe wildlife habitat needs, but the applicable term that guides forestry management in Alaska is "important" habitat. To help managers prioritize management strategies for forests and wildlife, as well as guide stakeholder input, we sought to clarify ways the term important habitat AS 41.17.060(c)(7) might be interpreted. The following are 2 possible interpretations that come at the question from different perspectives and could lead to different outcomes:

1. Important habitat promotes reproduction and survival (i.e. fitness) of species listed in the TVSF management plan (Appendix C; Chapter 2, Management Guideline E)[5] plus those incorporated in the 2015 Alaska Wildlife Action Plan as Species of Greatest Conservation Need (SGCN).[6]

2. Important habitat applies to the best interest of the economy and general well-being of state residents with respect to wildlife resources.

The first is more about the wildlife itself and the second about human uses or values of wildlife. This bulletin focuses on the first interpretation because it is objective and based on science. We interpret important habitat as providing food, cover, and water in sufficient quantity, quality, and dispersion to enable at least seasonal use of a defined area. Important habitat might enhance reproduction (e.g., Uboni et al. 2017). Its reduction or elimination can reduce potential for occupancy; conversely, its increase may attract existing individuals to an area in greater relative abundance (functional response) or produce an increase in abundance from higher reproductive or survival rates (numerical response; Holling 1959). Measurements of species presence or preference can identify important habitat areas. Braun (2005) and Krausman and Morrison (2016) provide further detail on habitat preference and selection.

We acknowledge the second interpretation as the public choice that can be science-informed but also reflects social and economic values (Decker et al. 2018). "Best interest" might favor abundance of game species for high levels of consumptive use in TVSF (AS 41.17.400(e)) or broad distribution of charismatic species important to wildlife viewing and the tourism industry, balanced against potential detriment such actions might cause for fitness of species identified under the first interpretation. Either interpretation could be applied for a specific forest management effort.

Distinct from either interpretation of important habitat, "critical habitat" is commonly used by biologists and managers to more precisely identify the specific habitat features or areas essential

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[5] Golden eagle and trumpeter swan, other species in the past that were federally threatened or endangered (American and arctic peregrine falcon, bald eagle), and species previously listed by the state in 2001 as Species of Special Concern (olive-sided flycatcher, gray-cheeked thrush, Townsend's warbler, and blackpoll warbler). The state Species of Concern list has since been replaced by the Alaska Wildlife Action Plan. Federal protections remain in effect for all eagles (via the Eagle Act) and all migratory birds (via the Migratory Bird Treaty Act).

[6] These species are identified in Appendices A and B of the 2015 Alaska Wildlife Action Plan: http://www.adfg.alaska.gov/static/species/wildlife_action_plan/2015_alaska_wildlife_action_plan.pdf No bird or mammal federally listed as threatened or endangered in Appendix A currently occurs in the boreal region. Species in Appendix B that occur in central Alaska boreal forest are identified in Appendix I and Appendix J of this bulletin. Every state in the USA, including Alaska, reviews the species list and revises its action plan at least every 10 years.

for the successful reproduction and survival (fitness) of individuals in a species (Appendix C). Elimination of or a decrease in critical habitat can cause local absence or reduced occurrence of a species in a particular area. Conversely, an increase of critical habitat features at the appropriate spatial scale can increase species abundance. Identifying critical habitat requires a higher standard of evidence than important habitat but is more informative of fitness (Gaillard et al. 2010). Critical habitat therefore has more value as a functional indicator of wildlife response that result from habitat change (Kneeshaw et al. 2000). For example, a reduction in the number of cavity trees could impact survival and reproduction of many wildlife species that rely on standing dead wood for nesting or denning sites (e.g., woodpeckers, some forest raptors, flying squirrels). Loss or retention of cavity trees is a critical habitat feature relevant to wildlife monitoring efforts (Thomas and Verner 1986:87) that aim to quantify the impact of different forest practices on a suite of cavity-dependent species.

There is no indication forest management has caused any terrestrial wildlife species to become either rare or detrimentally abundant in the Tanana Valley. That signifies a high potential for successfully conserving wildlife habitat moving forward. Our bulletin recommends pragmatic concepts and practices to conserve the range of important and critical habitat features in managed forest of the Tanana Valley. We believe this is the best means to meet the statutory requirement that “allowance shall be made for important fish and wildlife habitat” (AS 41.17.060(c)(7)).

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Themes, Principles, and Guidelines for Forest Habitat Management

Key Themes for Maintaining Wildlife Habitat

From our literature review we identified 3 important themes for maintaining or enhancing wildlife habitat in managed boreal forests:

1. Maintain natural disturbances regimes

Early seral habitat is sufficiently common in most areas of boreal Alaska because it is maintained naturally by disturbances that can rarely be precisely controlled, such as wildland fires, insect outbreaks, and flooding that kills mature trees. Natural disturbances, as well as human activities, such as logging, can expose ground to sunlight and favor growth of cover and food for wildlife.

2. Maintain late seral features

Fallen and standing dead trees and cavity trees (dead or live) provide security and reproductive cover and aid foraging by many predatory birds and mammals. These features tend to become less common in managed areas (salvaged for firewood or knocked down during logging operations) unless a proportion of them are identified for retention.

3. Maintain connectivity of habitat features

Eng (1998) described terminology and concepts of landscape ecology and scale for managed forests. The landscape includes many stands in various successional stages and interspersed communities (wetlands, meadows, barrens, subalpine, etc.). Connectivity considers not only the distance between important or critical habitat features (patches) for a wildlife species in a landscape, but also the biological and physical nature of the intervening terrain (matrix) that must be successfully navigated by the animal for successful reproduction (Taylor et al. 1993). Landscape diversity promotes wildlife diversity (Hunter 1990, Oliver 1992). Connectivity between habitat patches in a fragmented landscape benefits wider-ranging birds and mammals. Corridors can be maintained (or created over time) through recognition of broad-scale vegetation patterns while planning the location of timber sales, particularly as forest road networks expand into new areas of fire-prone landscapes.

A forest with the full diversity of wildlife habitats at multiple spatial scales (from tree to stand to landscape) can maintain ecological processes, functions, and patterns of bird and mammal distribution (Appendix C: Applying Scale and Diversity Concepts). This diversity provides ecological resilience to short-term stressors, such as logging or fire, and can allow adaptation to long-term changes, such as climate (Appendix D). Species diversity promotes resilience in forest ecosystems because predator-prey relationships are natural buffers against destabilizing events, such as insect outbreaks that cause widespread tree mortality (e.g., Zeilinski et al. 2005, Fischer et al. 2006, Thompson et al. 2009, Chapin et al. 2010). In contrast, forests with fewer species and simpler ecosystems are more prone to instability (e.g., McCann 2000), which can be detrimental to desired outcomes of forest management, such as timber production or reduction of wildland fire risk.

Principles and Guidelines for Forestry Practices

We recommend 5 principles and associated guidelines based on the 3 themes that provide broad strategies for integrating wildlife habitat best practices into the planning, implementing, and monitoring of timber sales. They are not intended to promote wildlife conservation as a priority over other forest uses on state and municipal lands. Rather, they are intended to generate reliable knowledge to help stakeholders and decision-makers weigh consequences and balance outcomes for wildlife conservation in areas where timber harvest is proposed. Paragi presented the principles and guidelines to the Alaska Board of Forestry (BOF) in July 2018 and to the TVSF CAC in October 2018.

The principles and guidelines are informed by science and focus on boreal systems. We recommend reviewing Appendix D for detailed background and citations from which the principles and guidelines are derived. We also recognize that, ultimately, decisions in forest management commonly include social and economic factors; thus, recommendations for policy or management decisions are appropriately described as “science-informed” (Decker et al. 2018).

The goal is to achieve the benefits of forest resilience and regeneration by maintaining diverse forest–wildlife relationships and functions and to avoid less predictable or destabilizing outcomes, such as large swings in herbivore populations that can affect regeneration and forest health (Appendix C). There is no universal management objective or prescription for wildlife habitat (Oliver 1992), given that every wildlife species has different requirements for survival and reproduction, making it impossible (for practical purposes) to provide every habitat feature for each species in a defined area at the same time. However, our literature review underscores that it is possible to retain important forest habitat features that maximize the greatest benefit for many wildlife species.

Guidelines described below will not necessarily be applied simultaneously on a given site. We discuss this point in more detail later in the section Application of Guidelines to Timber Sale Planning.

Principle 1. Manage forests for a range of habitat types that support diverse wildlife species, because this is likely to maintain forest ecosystem resilience to environmental disturbances.

Rationale: Environmental stressors such as wildland fire and insect irruptions are expected to increase in boreal forest as a result of climate change (Appendix B). However, a diverse forest “retain[s] ecological processes, functions, and patterns to provide resilience to short-term stresses and adaptation to long-term change” (Society of American Foresters 1993:14). Species diversity promotes food web linkages that provide an important natural buffer against destabilizing events and thereby ensures a more resilient forest system (Appendices C and D). In contrast, forests with fewer species and simple structures are more prone to instability that is detrimental to desired forest outcomes. The following guidelines can serve as best practices to maintain the natural diversity of habitats and promote resilience of managed forests.

Guideline 1a: Describe habitat features and their landscape connectivity to the extent possible from existing environmental data and use this information in forest planning.

Wildlife managers can improve the utility of existing environmental inventories by calculating spatial metrics of landscape patterns. These metrics may describe the natural distribution and relative abundance of stand types and age classes and their habitat features for wildlife species groups in the Tanana Valley with an emphasis on defining rare habitat types or features (Appendix G). Understanding relative proportions of key habitat types, connectivity, and rare features provides the opportunity for managers to maintain them at natural levels.

Guideline 1b: Focus new inventory of stands to include habitat features that are important for wildlife and use this information in forest planning.

Forest inventories are periodically updated based on information needs and new technology (e.g., Hanson 2013). Wildlife managers can consult with foresters on inventory design. Joint planning by foresters and wildlife biologists will result in efficient information gain for both forest and wildlife management. When feasible, wildlife managers can secure additional funding to also inventory priority habitat features judged to be most beneficial for species fitness, especially features that are rare, important for rare species, or at risk to management disturbance, but which can be maintained via patch retention (e.g., cavity trees, large expanses of slow growing lichens, etc.; Guideline 2b; Appendices C and D).

Guideline 1c: Design larger timber sales in uplands to emulate wildland fire patterns.

Wildlife managers can recommend parameters for retention patches within larger logging sites to help maintain habitat patterns for wildlife species in fire-driven ecosystems, such as unburned inclusions. Such inclusions can include rare or important habitat features from Guidelines 1a and 1b. There will be pragmatic limits to emulating larger fires based on market capacity and public acceptance of harvest unit size.

Principle 2. An integrated approach to forest and wildlife management at the stand and landscape scales maintains habitat benefits.

Rationale: Integrated forest and wildlife management on lands designated primarily for forest production can promote reforestation and tree growth objectives while maintaining wildlife species that provide tangible and intangible benefits to humans.

Guideline 2a: Favor diverse woody regeneration that includes willows and deciduous trees.

Foresters can use scarification and other mechanical practices to stimulate natural regeneration of willows and deciduous trees that benefit many wildlife species and make the landscape less prone to fire spread by fragmenting larger expanses of conifer forest.

Guideline 2b: Maintain snags, cavity trees, and woody debris.

Foresters can ensure practices that produce and retain woody debris as small mammal security cover, which promotes inoculation of key mycorrhizal fungi for tree roots. Practices that retain access beneath the snow surface by smaller carnivores in winter will help control populations of small herbivores. Foresters can enhance conservation value by using practices that produce and retain appropriately distributed snags and cavity trees for avian hunting perches and nesting habitat and as natal dens for smaller mammalian predators that feed on invertebrate and vertebrate herbivores.

Guideline 2c: Identify landscape connectivity beneficial to wide-ranging species.

Wildlife managers can use local inventory data and scientific findings from other boreal regions to inform forest planning for the purpose of maintaining habitat connections needed by species with large home ranges or migration patterns.

Principle 3. Stand-level planning and management of habitat and wildlife can mitigate wildlife damage to desired forest products.

Rationale: Inadvertent forest practices may create habitats at the stand level that promote damage of crop trees from excessive herbivory, particularly when herbivores, such as hares or moose, are abundant. Hunting is an opportunity to enhance human food resources and reduce vertebrate herbivory.

Guideline 3a: Manage habitat to reduce herbivory.

Wildlife managers can reduce potential for vertebrate herbivory on commercially valuable tree species by providing guidance to foresters on how to manage vegetation on regeneration sites.

Guideline 3b: Maintain habitat for predators of herbivores.

Predators can aid in controlling vertebrate and invertebrate (insect) herbivores that can cause damage to trees and other forest vegetation. Wildlife managers can provide foresters with guidance to buffer forest damage by maintaining or improving habitat for predators.

Guideline 3c: Monitor abundance of vertebrate herbivores and their predators.

By monitoring trends in herbivore and predator populations (e.g., hares and lynx), wildlife managers can help foresters time reforestation activities to mitigate potential browsing damage and to alert hunters of peak opportunities for hunting.

Principle 4. Landscape-level planning for both wildlife habitat and access management is appropriate given competing interests, the scale of natural disturbances, and desire for a managed forest on state lands.

Rationale: Unlike much of the northern hemisphere, the boreal ecosystem of Alaska has experienced little anthropogenic habitat fragmentation outside urban centers. This is because the road network is limited, and development is restricted in national parks and wildlife refuges (Appendix B: Fig. B2). Wildland fire remains the dominant disturbance agent affecting habitat at the landscape scale, even in the most managed sections of the TVSF. The TVSF Management Plan (Alaska Division of Forestry 2001:70) expressed the goal of a managed forest with all-season and winter road access for timber harvest and silvicultural practices. Much of the public use dispersed throughout the TVSF is concentrated near roads, trails, and river corridors (Alaska Division of Forestry 2001:30). Landscape-level scoping can inform decisions on forest management and forest road expansion to meet a range of future societal needs.

Guideline 4a: Include the value of wildlife habitat when considering road access options for timber harvest and wood salvage after natural disturbances.

Wildlife managers can provide information to mitigate potential effects of logging disturbance on habitat features during DOF scoping of the Five-Year Schedule of Timber Sales. This can also inform the public about options for road and harvest network expansion that define tradeoffs among potential forestry and wildlife outcomes.

Guideline 4b: Involve wildlife stakeholder interests when planning forest road networks.

Forest planners can use scenario evaluation of winter and all-season road networks to illustrate options for how access for timber harvest might occur in the management units of the TVSF. This would help focus public input on preferences among possible access routes that incorporate various uses of the forest. Scenario consideration may help guide access for salvage options in the event of large disturbances (e.g., wildland fire, insect-caused mortality). Wildlife managers can engage wildlife regulatory and advisory bodies and other public interests to provide input to the TVSF CAC.

Principle 5. Consider best practices for wildlife habitat conservation in managed forest as hypotheses that can be verified for effectiveness and adjusted over time using an adaptive management approach to optimize desired outcomes for both forests and wildlife.

Rationale: Adaptive management (Walters and Holling 1990) is a scientific approach in which goals are set, outcomes of treatment sites are measured relative to control sites, and management objectives (or best practice effectiveness) are reassessed based on new knowledge (Appendix D). Best practices often represent a compromise among competing public interests to achieve specified goals, such as timber production and wildlife outcomes. The interest group that must give up their chosen management practice to accommodate another interest has a reasonable expectation that the management agency has evaluated the effectiveness of a best practice in meeting the specified goal. Agencies, in turn, have constraints in operating costs and must evaluate priorities among competing tasks, including diligence in monitoring effectiveness of best practices. Appendix A lists 4 principles for balancing interests adopted by DNR during a review of FRPA. Adaptive management is best supported and most instructive when public values and stakeholder questions are incorporated during planning.

Guideline 5a. Involve stakeholders in discussions of options and tradeoffs in monitoring strategies.

The CAC for the TVSF engages the public to discuss options and recommend desired outcomes, acceptable practices, and agreed-upon metrics for monitoring forest and wildlife responses to management. New proposals should be addressed within this process. This is most likely to occur as specific proposals are presented in the FYSTS every other year or during infrequent revisions of the management plan for the TVSF.

Guideline 5b. Establish a scientific advisory group to guide silvicultural prescriptions and monitoring.

Foresters and wildlife managers are encouraged to assemble a voluntary group of agency, university, and other interested scientists to provide advice on monitoring forest and wildlife responses to management practices.

Guideline 5c. Verify best practices for wildlife habitat using scientific methods; adjust and update using an adaptive management approach.

Unless specific knowledge is available for managed forest in the Tanana Valley, managers are advised to consider best practices that they recommend for wildlife habitat conservation as testable hypotheses. Adopting a best practice provides an important scientific opportunity to determine whether the hypothesis achieves the wildlife or forestry management objective. Hypothesis testing involves comparing treatment sites (subject to the best practice) to control sites (e.g., Do cavity nesting woodpeckers have greater nest success in areas where operators maintain snags?). An adaptive management framework (Walters and Holling 1990) facilitates refinement and iterative testing as new data emerge or management objectives shift.

Guideline 5d. Utilize suitable techniques and volunteer help to monitor a broad network of sites.

Given the cumulative increase in number of timber sales to monitor at a time of reduced budgets, foresters and wildlife managers are encouraged to identify methods of rapid assessment and consider using citizen science volunteers to monitor more of the managed landscape in different stages of post-logging succession. This is not meant to replace research that often occurs on a few sites to gain detailed scientific information but to complement such research by verifying patterns among the broader suite of managed sites to confirm that research findings are broadly representative.

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Implementing Cooperative Management Approaches

We recommend 5 scientific and planning strategies for implementing the principles and guidelines. Used together, these strategies (akin to Beguin et al. 2016) will help foresters and wildlife managers cooperatively achieve mutually beneficial outcomes:

1. Clarify options and recommend approaches for achieving specific outcomes for forest products and wildlife ecosystem services at stand and landscape scales that are desired by the public and expressed in policy or planning documents.
2. Inform the public and decision-makers about tradeoffs in how forest practices, such as road expansion, timber harvest, and regeneration activities, can positively or negatively influence different wildlife species in managed boreal forest.
3. Maintain key ecological processes and services of forests that are beneficial to Alaska residents and promote resilience of forests to disturbance or other stressors, such as climate change.
4. Facilitate forest regeneration following timber harvest by managing for habitat types that maintain beneficial ecosystem services of wildlife.
5. Monitor forest and wildlife responses to timber harvest to identify pragmatic, effective, and efficient practices that can be verified for intended outcome or refined through adaptive management.

Application of Guidelines to Timber Sale Planning

Not all guidelines apply to every forested site. Tables 1 and 2 chart guidance reflecting forestry and wildlife management perspectives. Table 1 shows how specific forest management actions can promote and maintain diverse wildlife habitat via the principles and guidelines described previously. Table 2 describes how to promote specific wildlife groups through management of forest habitat types.

Input from stakeholders and cooperative guidance from agency managers is required for implementation of guidelines and actions. For example, promoting a diverse woody regeneration (Guideline 2a) may conflict with mitigating herbivory risk on selected tree species from moose or hares (Guideline 3a) on a single site. However, if managed at the larger landscape scale of the FYSTS (Table 1), both regeneration and herbivory can be favored at different sites across the state forest. Bunnell and Houde (2010:413) characterized an appropriate habitat management strategy in simple terms: "Don't do the same thing everywhere."

Applicable guidelines become evident after establishing wildlife habitat objectives in landscape planning (FYSTS) and individual timber sales (FLUP). Providing habitat objectives for wildlife is comparable to site-specific silvicultural prescription for timber management. A general proactive way to reduce risks of destabilizing events, such as herbivory damage of irruptive insects or small mammals, is to retain connected patches or "islands" of habitat with late seral features to promote activity of existing predators in a manner consistent with natural disturbance (Principles 1 and 2). More specific habitat objectives are applicable to the stand level (Principles

3 and 4; see also Table 1) and include hunter opportunity to reduce herbivory risk, particularly from moose that provide substantial meat yield to hunters.

Depending on stakeholder input (Principle 5), different approaches to wildlife habitat can occur at different sites. For example, enhanced herbivory risk through increased hardwood sprouting (Table 2) may be acceptable at a site with high hunter accessibility, if a goal is to increase moose hunting opportunity. However, planting spruce seedlings at this site would carry greater economic risks to forest regeneration because hares are also attracted to dense hardwood vegetation and can girdle small conifers. At sites less accessible to hunters, managers might reduce herbivory risk to young conifers by avoiding treatments that enhance hardwood sprouting and instead retain key habitat features, such as snags, that promote predators of hares (e.g., medium-sized mammalian predators, owls and raptors; Table 2). Planted spruce seedlings at these sites would have a greater chance of survival, which could be enhanced even further if planting occurs during a low in the hare population cycle (regeneration activities, Table 1).

We expect specific strategies for planning, implementing, and monitoring of timber sales to evolve as agency partners 1) consider workload efficiency, priorities, and staffing capacity, and 2) consider input from the TVSF CAC, the forest industry, the engaged public, the BOF, and elected officials. Tables 1 and 2, Appendix D, and the citations in this bulletin, along with those in an associated EndNote library,[7] contain a wealth of information to guide habitat management for wildlife species.

Benefits of Adaptive Management and Hypothesis Testing

Processes for effectiveness and compliance monitoring exist in FRPA for protection of fish habitat and water quality.[8] With limited information from the TVSF, our recommendations on voluntary practices for wildlife habitat management should be considered biologically relevant hypotheses (Bunnell 1997). Reliable information is produced when monitoring is based on mechanistic theory (such as best practices) that can be expressed as testable hypotheses (Hanley 1994). We propose to monitor wildlife responses (e.g., increased reproductive success) as "evaluative" indicators of functional response (Kneeshaw et al. 2000). Such responses address the effectiveness of hypotheses contained in best practices for evidence-based conservation (Bliss et al. 2001, Toms and Villard 2015). Monitoring only habitat attributes as "prescriptive" indicators of compliance with standards (e.g., Work et al. 2003) may not address public concerns about potential negative effects of land management on wildlife species (Bunnell 1997). Recent efforts have begun to integrate forest inventory data with habitat assessment and wildlife species monitoring on managed forests in Ontario (Brown and Pollock 2019). As forest–wildlife relationships are validated, monitoring stationary, albeit perhaps seasonally dynamic, habitat features may be less costly than monitoring wildlife species that may be seasonal residents, cryptic, or have seasonally dynamic patterns of habitat use.

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[7] A PDF list of citations in the associated EndNote library is provided as an attachment to the PDF electronic version of this bulletin (open the navigation pane and go to attachments). The bulletin PDF can be found via the Division of Wildlife Conservation publications search on the ADF&G website: www.wildlifepublications.adfg.alaska.gov Also, the EndNote file may also be obtained from bulletin authors.

[8] Alaska Department of Natural Resource, Division of Forestry. [n.d.] Alaska Forest Resources and Practices Act. http://forestry.alaska.gov/forestpractices.htm#regulations (see "Monitoring FRPA implementation and effectiveness," Accessed 24 February 2020).

Table 1. Forestry management actions, spatial scale, and best practices to produce desired outcomes for wildlife habitat and wildlife species.

Forestry management action(s)	Scale implication for wildlife habitat	Best practice to produce or maintain desired wildlife habitat conditions (and associated Principle or Guideline)	Outcomes for wildlife[A] or forest habitat across different stages of post-logging succession[B]	Early seral	Mid seral	Late seral
Planning: Five-Year Schedule of Timber Sales (FYSTS)	Landscape	Guide size, shape, and location of timber sales so their proportion, spatial dispersion, and characteristics complement a natural disturbance regime, retain key habitats[C] and features, and provide habitat connections across the landscape (Principle 1, Principle 2, Principle 4).	**Maintain wildlife diversity on a landscape scale**: Provides habitat for large and small predators that feed on large and small herbivores. Species diversity can maintain forest resilience to environmental change. Predators also naturally promote forest regeneration by reducing or moderating herbivore abundance.	✓	✓	✓
Layout: Forest Land Use Plan (FLUP)/ Detailed Plan of Operations (DPO)	Stand	Retain live trees within retention patches of differing size, shape, age, and location for cover in proximity to forage ("edge" habitat; Guideline 1c).	**Maintain wildlife diversity within a stand:** Provides habitat for large and small predators that feed on large and small herbivores (see details under planning).	✓	✓	✓
		Retain dead-wood habitat features (snags, larger debris) and cavity trees within patches (Guideline 2b).	Provides habitat for large and small predators that feed on large and small herbivores (see details under planning).	✓	✓	✓
		Minimize ground disturbance on site of high lichen biomass, which is a key late seral feature used by caribou as winter range[D] (Appendix D, Guideline 1a).	Maintains important habitat features for caribou.			✓
Forest operations	Stand	Minimize disturbance during period of migratory bird nesting and other reproductive activities.[E]	Promotes birds, which are predators of herbivorous insects and small mammals. Avian predators are likely to minimize risks of herbivore irruptions and herbivory damage.	✓	✓	✓
		Fell aspen and crush willows to regenerate concealment cover and browse (Guideline 2a).	Creates cover and forage for herbivores, including small game (hares, grouse) and large game (moose) in areas accessible to hunters.	✓		
		If using whole tree skidding, conduct in cold weather to break limbs for scattered debris[F] (Guideline 2b).	Creates habitat for small herbivores (voles) which can inoculate soils with fungal spores that promote seedling regeneration.	✓		

Forestry management action(s)	Scale implication for wildlife habitat	Best practice to produce or maintain desired wildlife habitat conditions (and associated Principle or Guideline)	Outcomes for wildlife[A] or forest habitat across different stages of post-logging succession[B]	Early seral	Mid seral	Late seral
		Avoid driving machinery over ground dens with >12″ diameter openings when ground is thawed (Guideline 3b)	Protects denning sites of medium and large predators.	✓	✓	
		Retain non-merchantable live trees to provide snags, cavities, and larger debris over time (Guideline 2b).	Maintains habitat for small and medium-sized predators of insects and small mammals to minimize herbivory damage.	✓	✓	✓
Regeneration activities (e.g., scarify, plant seedlings, etc.)	Stand	Optimize regeneration by considering small herbivore abundance cycles, as well as mast crops, to achieve desired tree stocking density (Guideline 3c).	Avoids peak years of small herbivores (i.e. hares) to reduce risk of conifer herbivory.	✓		
		Minimize scarification that would stimulate deciduous tree and shrub cover near conifer regeneration sites (Guideline 3a).	Minimizes habitat for large and small herbivores (hares) that feed on regenerating conifers.	✓		
		Retain some ground debris[G] (Guideline 2b).	Creates habitat for small herbivores (voles), which can inoculate soils with fungal spores that promote seedling regeneration.	✓		
		Scarify to increase birch and willow regeneration when not planning conifers (Guideline 2a). Scarification is not needed for aspen or poplar.	Creates habitat for small game (grouse, hares) and browse for large game (moose).	✓		

[A] Examples of wildlife species groups: large herbivores (moose); small herbivores (snowshoe hare, voles); small predators (marten, short-tailed weasel, woodpeckers, northern shrike, flycatchers); medium-sized predators (great horned owls, eagles, hawks, fox, lynx) and large predators (wolf, coyote, black bear, brown bear).
[B] Phases of stand development following disturbance (Oliver and Larson 1996). Early seral represents stand initiation; Mid seral represents stem exclusion and understory re-initiation; Late seral represents complex, older forest.
[C] Retaining late seral patches will be an increasing challenge if the fire frequency continues to increase (Appendix B: Fig. B5).
[D] Applicable only to the Tok area of the Tanana Valley State Forest.
[E] Timing recommendations for land disturbance and vegetation clearing: Planning ahead to protect nesting birds [chart]. May 2017. U.S. Fish and Wildlife Service, Region 7. https://www.fws.gov/alaska/sites/default/files/2019-05/Timing_Recommendations_Land_Disturbance_Vegetation_Clearing.pdf Accessed 10 December 2018).
[F] Smaller debris should remain dispersed across site, recognizing that larger debris will accrue mostly at log skidding landings.
[G] Minimize green conifer debris >5 inches in diameter to mitigate infestation risk by the northern spruce engraver beetle, *Ips perturbatus* (Fettig et al. 2013).

Table 2. Management considerations for wildlife species and expected resulting impact on humans or forests.

Wildlife species or group	Management impact on humans or forests: (+) positive (-) negative	Best practices to produce or maintain important habitat features for wildlife (and associated Principle or Guideline) applicable to the stand scale	Function of habitat features at different stages of forest succession after timber harvest [A]	Early seral	Mid seral	Late seral
Moose	(+) Human food resource Hardwood herbivory: (+) thinning of seedlings[B] (-) seedling damage (+) Human wildlife viewing[C]	Enhance hardwood sprouting through 1) harvest of younger birch or clearcutting *Populus,* and 2) seed germination through post-harvest scarification, especially if grass is present (Guideline 2a).	Deciduous woody cover provides concealment and forage.	✓	✓	
		Retain patches of late seral forest within stands (Guideline 1c).	Canopy gives shade to prevent thermal stress in late winter and summer.		✓	✓
Caribou[D]	(+) Human food resource	Where ground lichen is abundant, consider winter logging, as snow cover can reduce mechanical damage.	Ground lichens (in open areas) and arboreal lichen (in stands >60 years old) provide winter forage.	✓	✓	
	(+) Human wildlife viewing	Retain some existing connections between stands with high lichen biomass (Guideline 2c).				✓
Large predators (bears, wolves)	(+) Human fur and/or food resource (+) Mitigate moose density, reduce hardwood seedling damage. (+) Human wildlife viewing	Protect den holes ≥12 inches in diameter from machinery collapse during tree harvest that occurs when ground is thawed (Guideline 3b). Retain patches of late seral forest within logged stands that provide optimal interspersion of moose habitat as a prey resource (Guideline 1c).	Maternal dens of large predators can occur in all forest stages.	✓	✓	✓
Small mammalian predators (e.g., short-tailed weasels, marten)	(+) Human fur resource (+) Forest resilience against irruptions of small mammalian herbivores (voles) (+) Human wildlife viewing	Retain patches in larger cuts with pole or larger conifers as predator reproductive habitat (Guideline 1c) and seed trees for natural regeneration.	Conifer canopy acts as security cover against avian predation on dependent young predators. Edge habitats are important for small mammal prey (cover proximity).	✓	✓	
		Retain patches with snags and larger debris, including when salvage logging occurs after fire or insect mortality of mature trees (Guideline 2b).	Grass beneath open canopy provides prey forage and cover. Leaning debris provides subnivean access to prey, and snags provide escape cover and cavity trees for maternal dens (e.g., marten).		✓	✓

Wildlife species or group	Management impact on humans or forests: (+) positive (-) negative	Best practices to produce or maintain important habitat features for wildlife (and associated Principle or Guideline) applicable to the stand scale	Function of habitat features at different stages of forest succession after timber harvest [A]	Early seral	Mid seral	Late seral
Medium-sized mammalian predators (e.g., red fox, lynx)	(+) Human fur resource (+) Forest resilience against irruptions of small mammalian herbivores (voles, hares). (+) Human wildlife viewing	Retain some patches of mature white spruce as seed trees	Mature white spruce seed is a major food of red squirrels, which are alternative prey of medium-sized predators during years of low vole and hare abundance.	✓	✓	
		Retain scattered fallen trees and root wads (Guideline 2b). Leave logging debris at landings, other sites (balance with hindrance to scarification needs; Guideline 2b).	Debris piles and natural holes are used as maternal dens.		✓	✓
		Protect large dens from machinery collapse during tree harvest that occurs when ground is thawed (Guideline 3b).				
Raptors, owls	(+) Forest resilience against irruptions of small mammalian herbivores (voles and hares). (+) Human wildlife viewing	Retain forested patches with snags and cavity trees dispersed across harvested sites (Guideline 1b).	Snags serve as hunting perches and cavity trees act as nesting structure for avian predators of small mammals (especially near forest openings which can serve as foraging areas).	✓	✓	✓
		Retain some standing dead during salvage logging after fire or insect mortality of large trees (Guideline 2b).				
Insectivorous birds	(+) Forest resilience against insect irruptions and herbivory damage (+) Human wildlife viewing	Retain forested patches with snags and cavity trees dispersed across harvested sites (foraging distances from nests) (Guideline 2b).	Snags serve as hunting perches and cavity trees act as nesting structure for avian insectivores (especially near forest openings which can serve as foraging areas).	✓	✓	✓
		Retain some standing dead during salvage logging after fire or insect mortality of mature trees (Guideline 2b).				
Grouse	(+) Human food resource (+) Seed dispersal for soft mast (+) Human wildlife viewing	Enhance hardwood sprouting through harvest of younger birch or clearcutting *Populus* (Guideline 2a).	Dense stems provide brood cover in proximity to mature forest. Large debris provides male grouse with drumming sites	✓	✓	
		Maintain mature aspen stands in the managed landscape (Guideline 2c).	Mature aspen stands provide winter buds and a soft mast understory community			✓

Wildlife species or group	Management impact on humans or forests: (+) positive (-) negative	Best practices to produce or maintain important habitat features for wildlife (and associated Principle or Guideline) applicable to the stand scale	Function of habitat features at different stages of forest succession after timber harvest [A]	Early seral	Mid seral	Late seral
Voles	(+) Provide fungal spore dispersal that facilitates seedling establishment and growth. (+) Prey for medium predators (provides for species diversity)	Retain dispersed woody debris to enable vole movements into open harvested areas, especially where conifer regeneration is desired, such that voles inoculate soils with fungal spores (Guideline 2b).	Small-medium woody debris acts as security cover against predators.	✓	✓	
	(-) Seed predation, girdling of woody seedlings (generally not extreme in central Alaska) [E]	Scarify if grass is abundant to aid tree establishment. Reduced grass cover also reduces habitat for *Microtus* voles, which can feed on seedlings (Guideline 3a). Note: It will be difficult to time regeneration to avoid peak abundance in voles (every 3 to 4 years).	Disfavoring *Microtus* voles on some harvest units will create temporary spatial diversity in vole abundance.	✓		
		Scarify logged sites and retain late seral patches to ensure berry production across seral stages and potentially mitigate tree seed predation.	Berries are a food resource for red-backed voles in all successional stages.	✓	✓	✓

[A] Phases of stand development following disturbance (Oliver and Larson 1996). Early seral represents stand initiation; Mid seral represents stem exclusion and understory re-initiation; Late seral represents complex, older forest.
[B] Seedlings are <1inch diameter at breast height or are shorter than breast height (4.5 feet above ground).
[C] Value of human wildlife viewing in the Tanana Valley State Forest (TVSF) is expected to be relatively high, given accessibility of the forest to motorized vehicles and proximity to Interior residents. At present, any impact of wildlife viewing is assumed to have no negative consequences on forests or wildlife, given relatively low human population and use levels.
[D] Applicable only to the Tok area of the TVSF.
[E] Paragi et al. 2016:122–123.

Concluding Remarks

Our 5 principles and guidelines recommend proactive management at boreal forests for both timber and wildlife interests by maintaining a range of wildlife habitats and ecosystem services at stand and landscape scales. Habitats and landscapes have been degraded through human activity in boreal regions outside of Alaska, which has negatively impacted bird and mammal species and in some instances required costly restoration efforts. Proactive efforts in Alaska can prevent this from occurring in the TVSF. By maintaining a diverse range of forest stand types and age classes on the landscape, managers will ensure conservation of a range of soil types, wood decay classes, and habitat and landscape features needed by a broad diversity of invertebrate and vertebrate species that aid forest regeneration. Predators benefit timber interests by keeping herbivore populations in check and generally contribute to the biological diversity that is known to make forests more resilient to environmental or human-caused changes. Hunters serve in this role by harvesting moose.

Public demand for specific ecosystem services from boreal forests may increase over time, particularly if the human population increases in boreal Alaska. This may result in increased use of local resources for energy and food within ecological limits of productivity.

We share the cautious optimism of Haggstrom and Kelleyhouse (1996) about opportunities to use logging and fire to manage wildlife habitat features in the context of a changing environment (e.g., wildland fire risk or insect irruptions). However, we have concerns about the effect of scale, location, and methods of timber harvest on wildlife species if demand for timber increases dramatically before informed considerations are made for integrating wildlife habitat needs into forest management plans. Regardless of whether climatic changes manifest as trends or increased variability with respect to recent historic periods, society will benefit from informed adaptation to natural disturbances that optimize public values for ecosystem services.

Consultation in the past largely occurred during review of Forest Land Use Plans (FLUPs) for individual timber sales in DOF administrative areas and TVSF management units (Appendix A). However, in the future, we envision a more proactive consultation process during development of the FYSTS at the landscape scale: 1) DOF assesses industry needs and proposes timber harvest areas and access roads to meet those needs, 2) ADF&G provides considerations for wildlife habitat in the proposed areas and helps DOF frame options for timber harvest and roads, and 3) both agencies engage stakeholders to discuss tradeoffs between timber and wildlife among proposed options and, where necessary, make recommendations to stakeholders on objectives and monitoring strategies.

Ideally, the principles and guidelines presented here will be considered also during discussions of proposed timber sales on other habitat landscapes defined by the public. Setting wildlife habitat objectives for species or guilds may vary among landscapes based on natural dispersion of stand types, habitat features within stands, timber harvest objectives based on market demands, and public priorities for abundance and distribution of certain wildlife species. We expect the public may have different goals or objectives for wildlife habitat in different geographic areas, just as there are different goals for wildlife abundance and harvest allocation among game management units as regulated by the Alaska Board of Game following public input. Both public input processes, for forest management and for wildlife harvest management, contribute to adaptation of land use and wildlife management when environmental, economic, and social conditions change on state and municipal lands. Our voluntary guidelines for wildlife habitat conservation on public lands may also be applied to private lands, such as those owned by Alaska Native corporations and the Alaska Mental Health Trust, at the discretion of shareholders or managers. Private land managers making decisions on forest practices to meet objectives for timber revenue can consider habitat features in surrounding public lands when addressing wildlife habitat objectives on private lands.

To complement the detailed summary of scientific and institutional knowledge in this bulletin, we created a flyer that describes key habitat concepts (Alaska Department of Fish and Game 2020). We anticipate the flyer will be useful for engaging public stakeholders to provide input to planning processes and comments on management proposals, particularly through the CAC for the TVSF. ADF&G outreach on the principles and guidelines to the BOF, CAC, and potentially other public venues (e.g., local fish and game advisory committees)[9] will be necessary to identify which wildlife species or habitat issues are of primary concern and how to best move forward with prioritized efforts. The flyer was inspired by a brochure focused on northern hardwoods of eastern North America[10] that provides an example of how wildlife research has helped understanding of how forest management can be guided toward specific habitat outcomes for songbird communities. A recently revised ADF&G brochure describes recommended practices to maintain or enhance habitat features at the stand scale (Paragi and Rodman 2020).

It is imperative for DOF and DWC staff to work with stakeholders to clearly define the target issues, wildlife species, and questions to address. We recommend that biologists remain aware of regional or continental monitoring efforts for species and inform stakeholders about which species or guilds might be most at risk for local or regional effects from fire or land management policies. As stakeholder guidance occurs or species conservation risks emerge, biologists can recommend priority species or guilds for monitoring to verify positive impacts of best forest practices. Agency managers must then balance recommendations with available staff and financial resources. Scientific merit is an important component of identifying appropriate monitoring or research, but agency directives and public values can influence whether support continues for monitoring programs once implemented.

The challenge of limited staff to monitor the effectiveness of best practices is not unique to Alaska (B.C. Forest Practices Board 2017). We recommend ADF&G take the lead in identifying funding for additional staff capacity and operational costs to inform landscape planning and monitoring for wildlife habitat on managed forests.

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[9] Alaska Department of Fish and Game. Board Process: Advisory Committees. http://www.adfg.alaska.gov/index.cfm?adfg=process.advisory (Accessed 20 March 2020).

[10] Wildlife and forestry in New York northern hardwoods: A guide for forest owners and managers. Audubon New York. https://www.nyfoa.org/application/files/6614/7948/5977/WildlifeandForestryinNYNorthernHardwoods.pdf (Accessed 24 February 2020).

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Appendix A. Administration of forest practices and policy guidance on wildlife habitat.

The Alaska Constitution on Managing Renewable Resources

The Alaska Constitution (Article VIII, Section 4) specifies that renewable resources (fish, forests, wildlife, grasslands) be managed for sustained yield. The Alaska Land Act (AS 38.05) requires that state land be managed for sustained yield, which is "the achievement and maintenance in perpetuity of a high level of annual or regular periodic output of the various renewable resources of the state land consistent with multiple use" (AS 38.04.910). For wood this is described as the annual allowable cut (AAC), traditionally expressed in merchantable volume for lumber (log tops ≥4-inch diameter) and more recently also as biomass (trees ≥1.5-inch diameter at breast height [dbh], Hanson 2013:19). An older timber inventory based on late 1970s aerial photography was recently updated using satellite imagery and additional validation plots to better incorporate wood biomass in the Tanana Valley (Hanson 2013). The inventory lists AAC estimates for the 4 management areas of the TVSF (management areas are shown in Fig. 2, this bulletin).

The Alaska Forest Resources and Practices Act

The Alaska Forest Resources and Practices Act (FRPA) governs how timber harvesting, reforestation, and timber access occur on state, private, and municipal lands, applying to commercial timber sales ≥40 acres on land ownerships >160 acres in Interior Alaska (11 AAC 95.190). In FRPA the Alaska Legislature declared that forest resources including wildlife "are among the most valued resources in the state" (AS 41.17.010). FRPA and associated regulatory guidelines[11] incorporate best management practices to maintain fish habitat and water quality. Implementation of FRPA by the Alaska Division of Forestry (DOF) with guidance by the Alaska Department of Fish and Game (ADF&G) has incorporated scientific uncertainty in judging possible adverse effects of timber harvest, reforestation, and associated forest practices by balancing the needs of fish and water resources at stake in regulatory decisions. The balance of interests among stakeholder interests during negotiation of acceptable regulatory standards has included 4 principles adopted during a review of FRPA (Alaska Department of Natural Resources 1989:7–8):

1. Fairness: Any successful system must be based on shared risk and incentives for both timber owners and regulators to make it work.

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[11] Alaska Department of Natural Resources. 2010. Alaska Forest Management Statutes and Regulations effective May 2013. http://forestry.alaska.gov/Assets/pdfs/timber/2013_For_mgmt_stat_and_reg_TEXT_UPDATE.pdf (Accessed 24 February 2020).
Alaska Department of Natural Resources. 2017. Alaska Forest Resources and Practices Regulations 11 AAC 95, March 2017. http://forestry.alaska.gov/Assets/pdfs/forestpractices/FRPA%20regulations%20-%20GREEN%20BOOK%20May%202018.pdf (Accessed 24 February 2020).
Alaska Department of Natural Resources. 2017. Implementing Best Management Practices for Timber Harvest Operations, November 2017 http://forestry.alaska.gov/Assets/pdfs/forestpractices/2017%20update%20FRPA%20fieldbook-FINAL.pdf (Accessed 24 February 2020).

2. No “Big Hit:” Neither fish nor timber should bear an inordinate share of the burden; that a balance must be found. No private landowner should have to bear an unusually large burden.

3. Enforceable: Standards and regulations should be understandable and measurable for ease in implementation.

4. Professional management: To provide optimum utilization of manpower and some system flexibility for fish and water quality protection, and timber management, the new system would require careful planning and targeted field effort.

Forest Management Policies and Plans

AS 41.17.230(a) states that forest management plans must consider and permit nontimber forest uses to the extent compatible with timber use, including “consumptive and nonconsumptive uses of wildlife.” The only statutory guidance on standards for wildlife habitat on state and municipal forest lands exists in AS 41.17.060(c)(7) as “allowance shall be made for important fish and wildlife habitat.” AS 41.17.910 additionally directs the Alaska Department of Fish and Game (ADF&G) to “work cooperatively with private forest landowners and timber owners to protect, maintain, and enhance wildlife habitat to the maximum extent practicable, consistent with the interests of the owners in the use of their timber resources.” Cooperative work on private lands is further described as assistance in identifying and protecting wildlife habitat through voluntary management techniques. AS 41.17.400(e) lists a management objective in the TVSF for “production of wildlife for a high level of sustained yield for human use through habitat improvement techniques to the extent consistent with the primary purpose of a state forest under AS 41.17.200.” Notably, this statute, although focused on game, does not clarify species priority.

Policy documents provide guidance on desired outcomes for wildlife habitat to maintain ecological functions and public uses in Alaska forests. In the past, stakeholders identified the importance of non-timber resources and public uses on the TVSF and public process in forest planning and management decisions (Dawe et al. 1994). The State Forest Action Plan (Alaska Division of Forestry 2016) is updated every 5 years to identify strategies for addressing key issues identified in the Statewide Assessment of Forest Resources. The plan reflects forest conditions and trends along with findings from stakeholder outreach to identify issues for DOF to address and prioritize in a strategic plan to conserve working forest landscapes, protect forests from harm, and enhance public benefits from trees and forests (Ashley Reed List, Forest Planner, DOF, email to Thomas Paragi 3 December 2019). Stakeholders have identified issues that broadly apply to forestry–wildlife interactions and public uses of wildlife. An example was “bird populations and habitats are important ecological components, help control damaging insects, and provide viewing opportunities for tourists and residents” (Alaska Division of Forestry 2016:10). The action plan concluded by noting that successful implementation of forest management requires continued public support (“social license” for state agencies; Thomas 1999) and funding at the state and national levels.

Policy guidance is provided by the Alaska Board of Forestry (BOF), which is composed of appointed members who represent a range of interests, with the state forester serving as exofficio chair.[12] It advises the state on forest practices issues and provides a forum for discussion and resolution of forest management issues on state land. Board members also review all proposed changes to FRPA and its regulations.

The TVSF management plan (Alaska Division of Forestry 2001:14–18) provides management guidelines on habitat enhancement, mitigation where wildlife populations or habitats are adversely affected, and topics primarily regulated by federal agencies (waterfowl habitat, wetlands, threatened and endangered species, eagles, and trumpeter swans). "Land use activities that could potentially affect State endangered species, or species of special concern,[13] will be identified as part of interagency consultations during review of forest land use plans or other land use plan or permit actions" (Alaska Division of Forestry 2001:16). A goal for forest protection further specified the intent for fire management "to identify additional areas where wildland fire can be allowed or prescribed fire can be used to reduce costs of fire suppression, reduce risk of damaging fires, and maintain natural diversity and productivity of forest stands" (Alaska Division of Forestry 2001:49).

Much of the State of Alaska public domain[14] is available for multiple uses, including forest management. The 2014 update of the Yukon Tanana Area Plan[15] and 2015 update of the Eastern Tanana Area Plan[16] (Fig. 3 this bulletin) describe classification of land to designate intent of use. Forestry and habitat are among several designated uses and may be co-designated with other uses to balance potential conflicting interests. In specific locations certain uses may be discouraged or prohibited. Goals and management guidelines for wildlife habitat in these plans are similar to those in the TVSF management plan last revised in 2001, but these more recent updates of area plans also include a goal for provision of wood biomass for public purposes such as renewable energy.

Planning for Commercial Timber Harvest

Planning of commercial timber harvest occurs in 2 steps germane to habitat scales. First, harvest areas on state or municipal lands are offered in a Five-Year Schedule of Timber Sales (FYSTS; AS 38.05.113), with exceptions for land cleared for conversion to other purposes or salvage of timber following natural disturbances (e.g., fire, insects, pathogens, wind). This landscape scale process must propose a schedule every 2 years, and DOF may not offer a timber sale unless it has appeared on at least 1 of the 2 FYSTS immediately preceding the sale. Sales are exempt from

[12] Alaska Department of Natural Resources. [n.d.] Alaska Board of Forestry. http://forestry.alaska.gov/alaskaboardforestry (Accessed 24 February 2020).
[13] Alaska Department of Fish and Game. 2015. Alaska State Wildlife Action Plan. (Present terminology is Species of Greatest Conservation Need) http://www.adfg.alaska.gov/static/species/wildlife_action_plan/2015_alaska_wildlife_action_plan.pdf. (Accessed 24 February 2020).
[14] State land managed by the DNR Division of Mining, Land, and Water that has not been reserved or withdrawn from multiple use management (under Title 38 of the Alaska Statutes) by either an act of the state legislature or by an administrative action (in compliance with limits set by AS 38.05.300).
[15] Alaska Department of Natural Resources. 2014. Yukon Tanana Area Plan. http://dnr.alaska.gov/mlw/planning/areaplans/ytap/ (Accessed 24 February 2020).
[16] Department of Natural Resources. 2014. Eastern Tanana Area Plan http://dnr.alaska.gov/mlw/planning/areaplans/etap/pdf/etap_prd_complete.pdf (public review copy was adopted by DNR Commissioner on 28 August 2015; Accessed 24 February 2020).

this requirement for ≤160 acres, conversion of forest to other land uses, or emergency salvage. Market conditions, sale preparation problems, emergency salvage, logistical constraints, funding, and other considerations may cause some proposed sales to be dropped or moved between years.

Second, eligible sale offerings require a Forest Land Use Plan (FLUP; AS 38.05.112) prior to harvests >10 acres. The FLUP includes "identification and protection of important wildlife habitat" and "uses of fish and wildlife" and is the opportunity to recommend strategies or techniques to create, maintain, or enhance wildlife habitat features at the stand scale. Timber sales on private lands undergo a similar regulatory oversight through the development of a Detailed Plan of Operations that may specify objectives for wildlife habitat.

FRPA has riparian standards in statute (AS 41.17.118) and regulation (11 AAC 95.260-280) that include the boreal forest of the Interior (DOF Region III). The standards restrict harvest of timber up to 100 feet from the water depending on classified type of water body and use by anadromous or high-value resident fish (definitions in AS 41.17.950). Although primarily intended to protect water quality and fish habitat, riparian standards also function to maintain late seral features for wildlife habitat on a limited portion of riparian stands that may otherwise extend back hundreds of yards from the water. Specifications for wildlife habitat in boreal riparian buffers (Type III water bodies) include harvest of timber being "consistent with the maintenance of important fish and wildlife habitat as determined by the commissioner [of the Department of Natural Resources] with deference to the Department of Fish and Game" (AS 41.17.118(3)) and "retention trees must include, to the extent feasible, trees with high value for wildlife habitat, including snags, forked trees, and trees with multiple stems" (11 AAC 95.275(f)(1)).

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Appendix B. Overview of Interior Alaska, the Tanana Valley State Forest, and resource management considerations.

Physical Setting

The Tanana Basin in eastern Interior Alaska is a major tributary of the Yukon River (Brabets et al. 2000; Fig. 2 this bulletin). Upper reaches of the mainstem Tanana River receive glacial input from the Alaska Range (Wahrhaftig 1965). Many clear water tributaries and portions of the Tanana mainstem support salmon spawning (Borba et al. 2017; R. J. Brown et al. 2017).[17] Research from Southeast Alaska has demonstrated how salmon are utilized by a range of wildlife species. Spawned salmon carcasses are a source of marine-derived nutrients beneficial to productivity of floodplain forests (Helfield and Naiman 2001) with the marine nitrogen isotope measured up to several hundred yards from streams (Gende et al. 2002).

The Tanana Valley State Forest (TVSF)[18] encompasses 1.81 million acres, is 90% forested, and contains about half (1.1 million acres) of the productive forest land in the Tanana Valley (Alaska Division of Forestry 2001). A volume increment $\geq$20 ft^3/acre/year is considered of "commercial" value (Labau and van Hees 1990, cited in Morimoto 2016). About 85% of the TVSF is within 20 miles of the highway system (Alaska Division of Forestry 2001), yet the maintained forest road network to access timber harvest remains relatively limited in most units of the state forest (Appendix H). The TVSF is primarily in the Yukon–Tanana uplands north of the Tanana River, although a few management blocks of the Kantishna and Delta areas exist south of the Tanana River; these include Kuskokwim lowlands, and the Tok River block is in the Alaska Range foothills (Wahrhaftig 1965).

Goals to promote scientific understanding in the TVSF management plan (Alaska Division of Forestry 2001:37–41) include designation of research natural areas,[19] experimental forests,[20] harvest reserves, and other values such as opportunities for scientific investigation and public education. Uses incompatible with research and experimental areas, including timber harvest, require authorization; there are presently no harvest reserves.

The Fairbanks North Star Borough represents the largest human population in the Tanana Valley; it had an estimated 97,121 residents in 2018.[21] The second largest community is Delta Junction with about 950 residents. Delta Junction is located on the western edge of the Delta Agricultural Project, where about 29,000 acres of state land within the forest inventory area are

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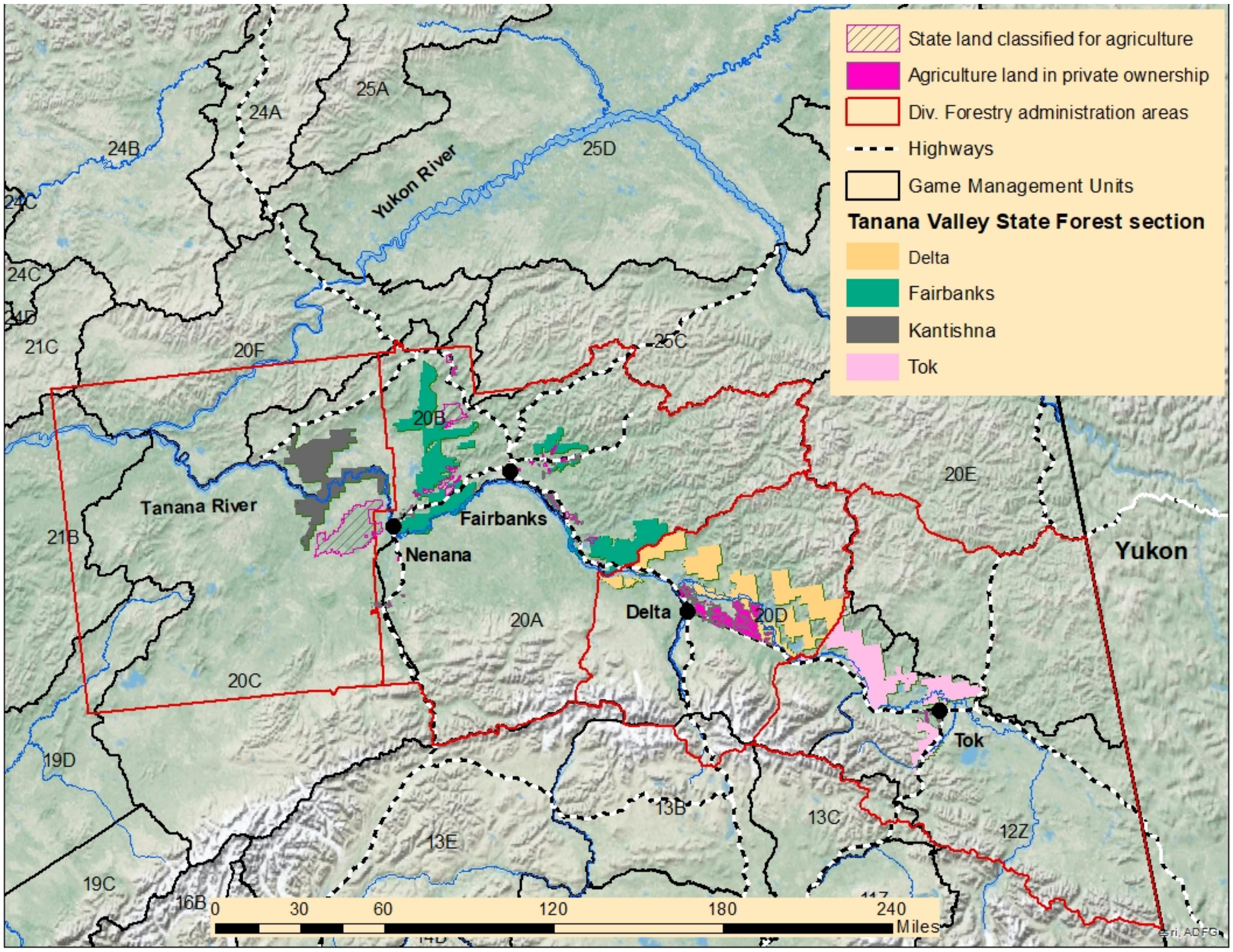
[17] Details may be found in the Catalog of Waters Important for the Spawning, Rearing, or Migration of Anadromous Fishes, https://www.adfg.alaska.gov/sf/SARR/AWC/ (Accessed 24 February 2020), with additional sources of spawning areas from the Division of Commercial Fisheries upon request.
[18] Alaska Department of Natural Resources. [n.d.] Alaska's State Forests. http://forestry.alaska.gov/stateforests (Accessed 24 February 2020).
[19] There are 6 RNAs of roughly 1,000-3,000 acres each for a total of 11,141 acres.
[20] University of Alaska Fairbanks. [n.d.] Bonanza Creek LTER. Research activities that include the Bonanza Creek experimental forest are described. http://www.lter.uaf.edu/ (Accessed 24 February 2020).
[21] Alaska Department of Labor and Workforce Development. [n.d.] Research and Analysis. http://live.laborstats.alaska.gov/pop/ (Accessed 12 May 2019).



2018 ADF&G map by T. Paragi.

Figure B1. Administration areas for state forestry, agricultural lands, and game management units for the Tanana Valley.

designated private agricultural lands (Fig. B1) enrolled in the Conservation Reserve Program (Davies 2007). About 8% of the 17,382 mi^2 forest inventory area (Fig. 2, this bulletin) is owned by Alaska Native corporations; not all is forested, but it represents a majority of the private land subject to forest management.

Wildlife Values and Uses

Wildlife is important in Alaska culture for a range of consumptive and nonconsumptive uses. Wildlife generated $3.4 billion in spending during 2011 (ECONorthwest 2014). A key game species is moose. Moose are attracted to early seral conditions in boreal forest and are an important food resource to many Alaska residents. During 2010–2014 the annual harvest by Alaska residents averaged a total of 2,053 moose in game management units that cover the Tanana drainage, Units 12 and 20 (Fig. B1). This harvest represented 27% of the statewide total harvest by residents and nonresidents.[22] With an average meat yield of 500 pounds per animal and an assumed replacement value of $3.50 a pound, Wurtz and Zasada (2001) calculated the average annual meat value to residents from this Tanana Valley moose harvest was $3.6 million; this activity also brings value to the area in the form of expenditures on commercial services and the intrinsic value of the hunting experience. Moose meat as a “forest product” has provided a greater economic return than white spruce fiber in boreal Alaska (Wurtz and Zasada 2001). The sustainable harvest of moose and other game species is regulated through AS 16.05, with protection or enhancement of habitat within the regulatory authority of the Alaska Board of Game (AS 16.05.255(a)(7)). Most game management units in the Tanana Valley have regulatory objectives for moose abundance and harvest (5 AAC 92.108). Habitat enhancement techniques to achieve or maintain elevated harvest of ungulates are commonly understood to include prescribed fire and forest practices (AS 16.05.255(j)(4)).

Some wildlife species elicit strong societal values, based on their ecosystem service to humans or how land management affects their distribution or abundance. Agencies are challenged to engage the public to clarify management goals and define acceptable practices for achieving goals (e.g., logging practices or predator control). Charismatic megafauna like moose, caribou, wolves, and bears provide consumptive use opportunity yet also provide viewing and photography opportunity to residents and nonresidents, all of which provide substantial revenue to Alaska (ECONorthwest 2014). Disagreement on wildlife uses may require regulatory allocation among competing interests, such as decisions made by the Alaska Board of Game regarding moose harvest quotas for resident and nonresident hunters. Management agencies encourage public engagement through advisory committees (e.g., Fish and Game, TVSF CAC) to find broad consent on the implementation strategy or means to achieve goals when practices may be controversial, such as with predator control on bears or wolves or with logging.

Alaska Wildlife Action Plan

Alaska’s State Wildlife Action Plan (SWAP, ADF&G 2015) guides conservation priorities for species in Alaska that generally are not hunted or trapped. Appendix A of the SWAP provides a list of “Species of Greatest Conservation Need” (SGCN), many of which are in steep decline. This document also describes the ecological role and conservation status of vegetation communities that provide important habitat features for wildlife in Alaska. The overriding goal of Alaska’s SWAP is to reduce the number of species listed as threatened or endangered under the federal Endangered Species Act (ESA). Although no terrestrial wildlife species in boreal Alaska is currently listed under the ESA, one important way to minimize the risk is to adopt practices that promote wildlife diversity and “keep common species common” (ADF&G 2006:83). Maintaining key habitat features, as outlined in the guidelines contained in this bulletin, is akin to maintaining the natural diversity of forest conditions, as the SWAP recommends. Habitat diversity in boreal forest shows a close relationship to wildlife diversity (e.g., Kessel 1998 for birds), so maintaining one helps to maintain the other.

[22] Calculation from moose harvest data found in species management reports for Units 12 and 20. Species management reports can be found on the Alaska Department of Fish and Game department website via the search for Division of Wildlife Conservation publications: http://www.adfg.alaska.gov/index.cfm?adfg=librarypublications.wildlifepublications&sort=all&species=Moose&publicationtype=Species+Management+Report+%28and+Plan%29&submit=Search (Accessed 24 February 2020).

The justification for scientific input regarding effective species conservation to land management is multifold: First, species presently considered common will benefit from the conservation of all the various habitats in a diverse landscape. Second, a major goal of Alaska's SWAP is to minimize the number of species listed under the ESA and maintaining a diverse landscape reduces the risk that a species will become threatened or endangered. Finally, reducing landscape fragmentation, habitat conversion, the occurrence of introductions and establishments of invasive species, and other broad-scale threats will benefit many species and their habitats.

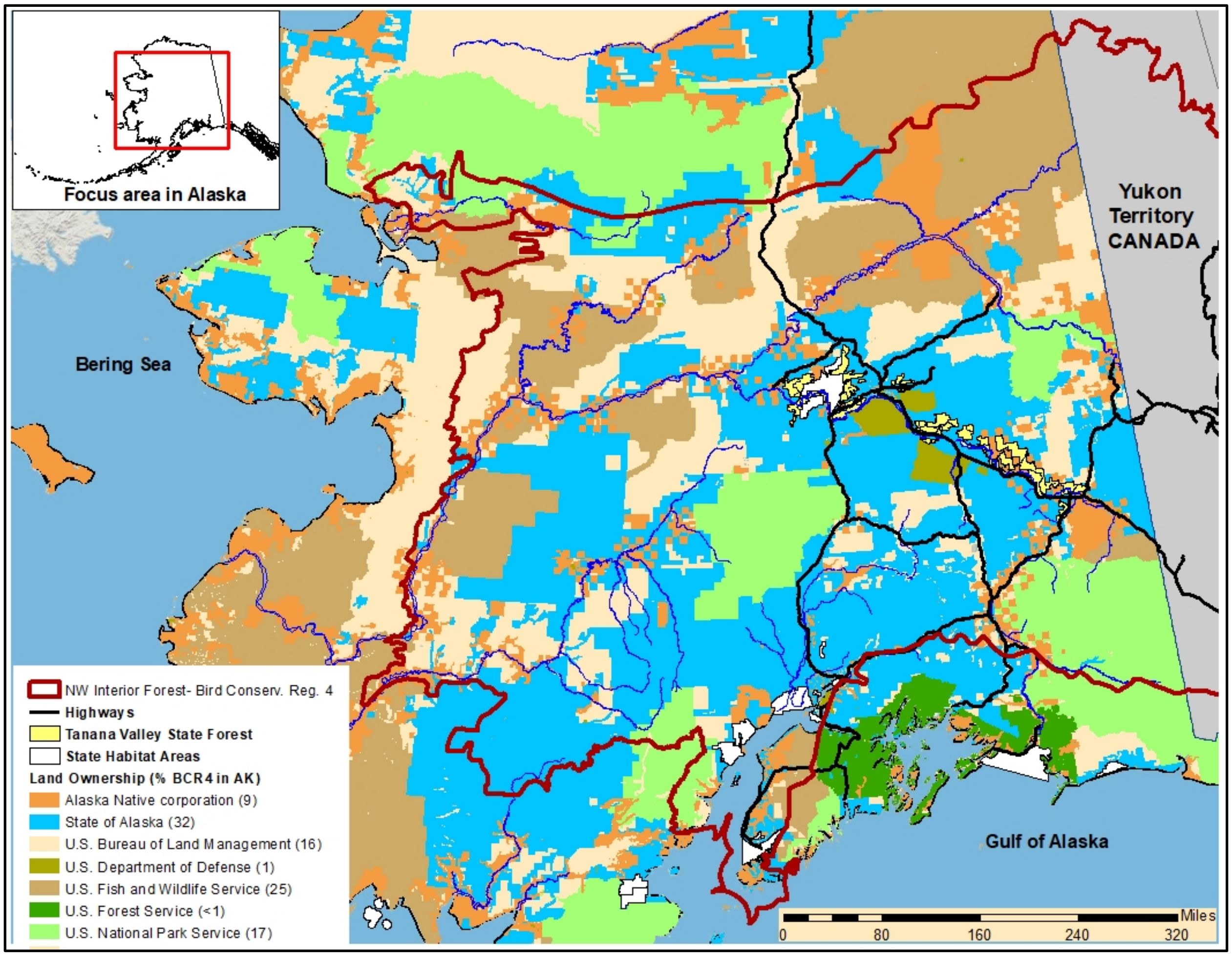
Habitat Management and Conservation

Alaska contains 11% of the boreal forest in North America (Brandt 2009). Boreal forest is the most common biome in Interior and Southcentral Alaska (Fig. 1, this bulletin) across several bioclimatic zones (Jorgenson and Meidinger 2015). The Tanana Valley contains 17% of the boreal forest biome in the state.[23] In Alaska, 89% of this biome is in public lands, of which nearly half (40% of biome) is in federal protected[24] areas (parks and preserves, refuges, wilderness areas; Fig. B2) where commercial logging is not allowed and natural processes are expected to influence biological diversity and resilience (Gauthier et al. 2015). To our knowledge, this is the highest proportion of boreal protected lands in any similar-sized jurisdiction in the world (Appendix F). Commercial timber harvest does not occur on national parks or wildlife refuges and rarely occurs on U.S. Bureau of Land Management or state lands off the highway system in Alaska. This offers a unique collaborative opportunity for forest and wildlife managers to maintain species on the relatively small managed portion of boreal forest in Alaska.

Timber harvest in the Tanana Valley is unlikely to negatively affect wildlife conservation across the state because the vast majority of boreal forest in Alaska is remote and has no commercial timber harvest. However, much of the public access for wildlife-related recreation and consumptive uses in the Tanana Valley occurs on roads and rivers within or near the state forest and other forested state lands (Appendix H). Public use patterns for wildlife viewing and hunting activities highlight the need for public awareness of proposed forest management. Some timber harvest may affect forest–wildlife relationships, so it would be best that forest management decisions be informed through the TVSF CAC or other public forums. For migratory species such as birds facing ecological effects of climate change, international and cross-agency collaborations will be needed to anticipate and mitigate declines of some species and to maintain connectivity of habitats across boreal landscapes (Matsuoka et al. 2019).

[23] We define the boreal forest biome as Bird Conservation Region 4 in Alaska (Bird Studies Canada and NABCI 2014).

[24] Protection is a tool of conservation, where conservation refers to the range of activities, tools, and approaches for achieving forest health and biological diversity objectives.
Natural Resources Canada. [n.d.] Conservation and protection of Canada's Forests. https://www.nrcan.gc.ca/forests/canada/conservation-protection/17501 (Accessed 21 November 2019).



2018 ADF&G map by T. Paragi. Source data from Bird Studies Canada and NABCI.

Figure B2. Land ownership in Alaska within the Northwest Interior Forest Bird Conservation Region 4 (Bird Studies Canada and NABCI 2014). Bureau of Land Management (BLM) lands in this region include those selected by Alaska Native corporations (1.3% of region) and the State of Alaska (4.6%) that are not presently conveyed, thus still managed as BLM lands.

Natural Disturbance Agents, Salvage Logging, and Habitat Changes

Natural sources of tree mortality in boreal forests (fire, insects, pathogens) create dead wood that provides structural features used by wildlife, and the resulting canopy gaps allow sunlight to warm soils and enhance understory vegetation. Tree mortality in accessible areas creates an economic salvage opportunity that may be prudent to reduce further risk of tree mortality where insect irruptions could emanate from dying trees (we describe preventative measures for engraver beetles in the footnotes of Table 1, this bulletin). Land management practices can also influence habitat features in a more controlled fashion.

Wildland Fire Regime

Fire is the most common natural disturbance agent in the TVSF. Fire-adapted ecosystems such as the boreal forest of Alaska are subject to periodic large fires that influence vegetation dynamics

(Johnson et al. 2001). However, the incidence, severity, and extent of wildland fire in the Interior have increased substantially since 2001, in part because of warmer drier conditions that have extended the fire season (Chapin et al. 2008; see Climate Change and Variability section, this Appendix). Historically, Alaska Natives in the eastern Interior intentionally set fires for several purposes, including enhancement of game habitat to improve future hunting success (Natcher et al. 2007).

Contemporary fire management occurs within a decision framework. The framework determines when and where 1) suppression of wildland fires protects identified resources at risk, and 2) use of prescribed fires fosters key ecosystem services created by fire (Alaska Wildlife Fire Coordinating Group 2018). The decision for an initial suppression response or "initial attack" upon fire detection depends on zoning: Critical, Full, Modified, and Limited. Improved fire detection and effective fire suppression efforts since the 1970s (Todd and Jewkes 2006) have reduced the rate of disturbance by wildland fire by reducing the size of human-caused fires in areas zoned for initial attack near the developed portions of Interior Alaska (DeWilde and Chapin 2006, Kasischke et al. 2010, Calef et al. 2015). Despite improvements in detection and suppression, in the last half century there has been a regional doubling of annual area burned to 2 million acres (Kasischke et al. 2010), largely driven by lightning fires. Years of warmer and drier conditions since 2000 have allowed large or late season fires, some severe, to burn upland sites and actually increase the annual area burned in Full, Modified, and Limited zones surrounding the Critical suppression zone near communities (Calef et al. 2015).

Although 80% of the TVSF is under Full protection and 13% Modified zoning, extreme fire seasons often require triage decisions by suppression agencies to protect human life and property. We examined the Alaska Large Fire Database[25] and found 326 fires during 1963–2013 that occurred within a 20-mile buffer around the TVSF, an area chosen to include most of the larger fires that overlapped the state forest (Fig. B3). Eight of the fires (429,078 ac) were of unknown origin, but the 181 (55%) fires of lightning origin composed 73% of the 8.5 million acres burned within the buffer over that period. Although perimeters of larger fires typically include a mosaic of burn severities with some areas not burned (Eberhardt and Woodard 1987, Kolden et al. 2012), on average the fire size in and near the TVSF was 3 orders of magnitude greater than that of timber sales. During the 50 years after statehood, the area burned was 2.4 times the area logged in the TVSF (Fig. B4); this is in stark contrast to Alberta where the area of logging and fire were similar and additive by the 1990s (Lee and Bradbury 2002). Much of the burned area in the TVSF includes noncommercial black spruce that dominates lowlands with cold soils, but during dry conditions fires can spread into areas that support commercial timber types, such as white spruce, that occur in floodplain habitat (Magoun and Dean 2000). Time between fires (i.e., the fire cycle) in the Tanana Valley has been generally decreasing since modern fire records have been kept[26] (Fig. B5). A greater frequency of fires is coincident with warmer and drier conditions (see prior paragraph).

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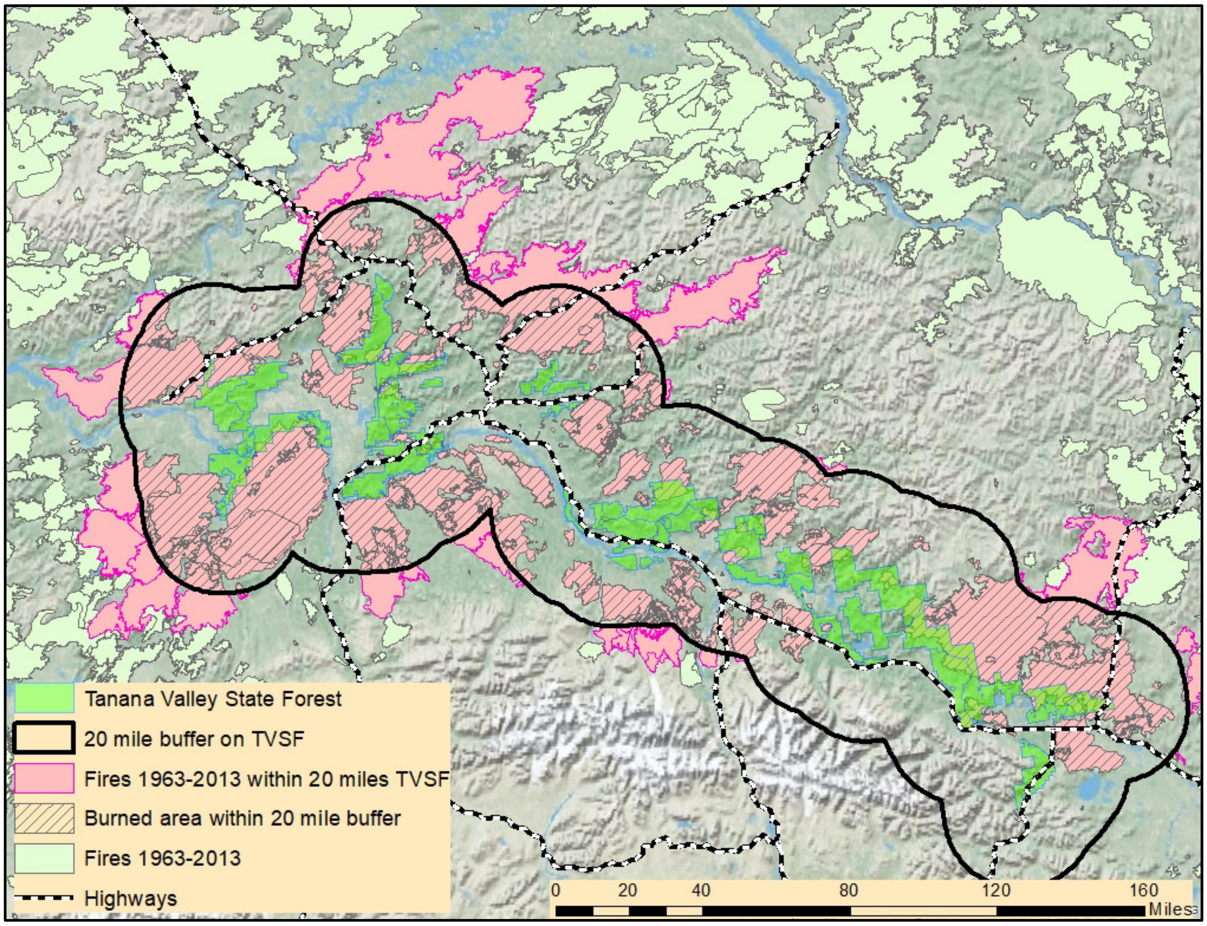
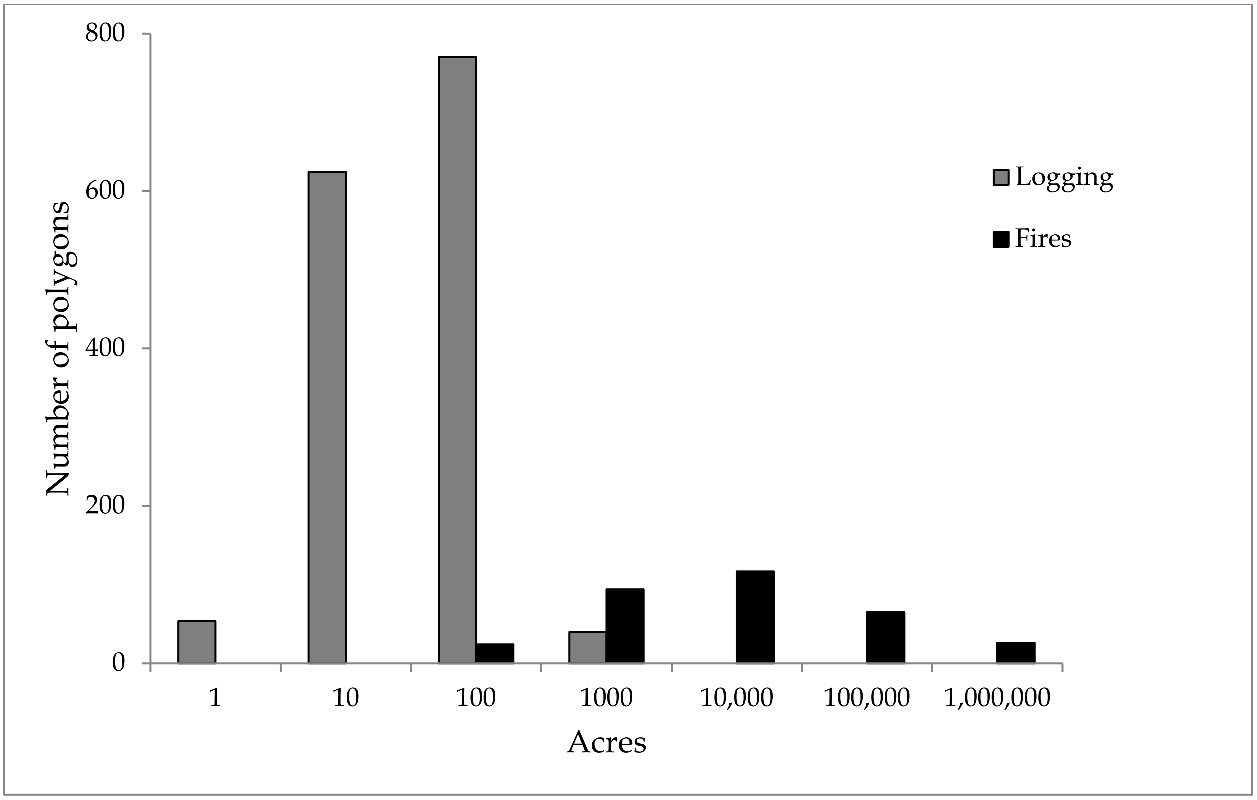
[25] Alaska Interagency Coordination Center (AICC). [n.d.] https://fire.ak.blm.gov/ (geospatial data; Accessed 24 February 2020).
[26] Trends in regional fire cycles for Alaska, 1943–2016. Frames Resource Catalog. https://www.frames.gov/catalog/60487 (Accessed 20 March 2020).



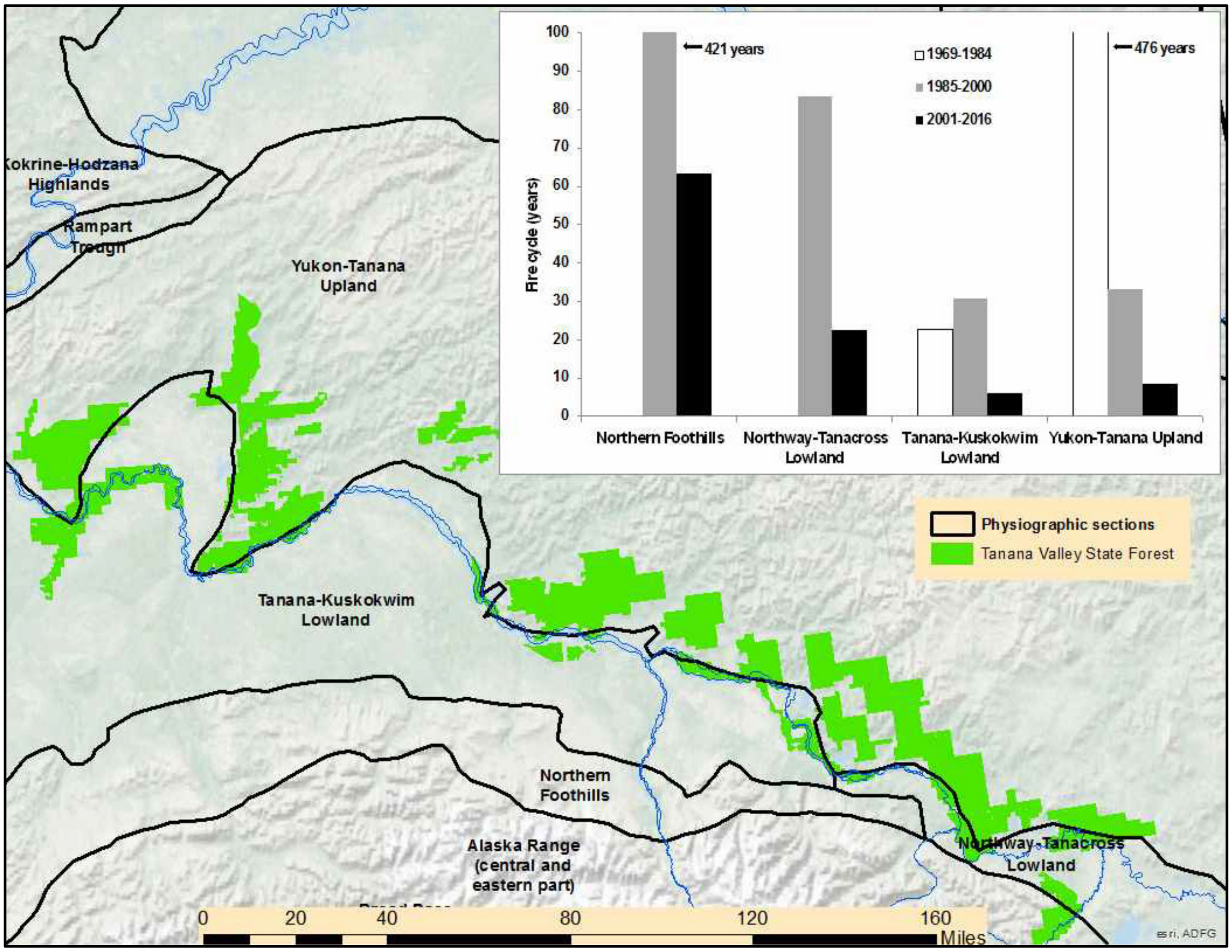
2018 ADF&G map by T. Paragi.

Figure B3. Fire perimeters during 1963–2013 within a 20-mile proximity to the Tanana Valley State Forest. The map shows large fires that overlapped the state forest and the developments along the road system. Timber sale perimeters are too small to be visible at this scale.



2018 ADF&G graphic by T. Paragi.

Figure B4. Distribution of binned size for logging sites (e.g., <1 ac, ≥1 and <10 ac, etc.) and wildland fires in the Tanana Valley state forest and a surrounding 20-mile buffer (Fig. B3), 1963–2013. Logging sites averaged 24 acres (35,000 acres total, *N*=1,488; Alaska DOF) compared with fires that averaged 26,045 acres (8.5 million acres total, *N*=326; Alaska Large Fire Database). Note x-axis is logarithmic.



2018 ADF&G graphic by T. Paragi. Source data: Alaska Large Fire Database, Alaska Fire Service, U.S. Bureau of Land Management.

Figure B5. Physiographic sections (Wahrhaftig 1965) for the Tanana Valley State Forest in which fire cycle was calculated for 3 periods since modern fire records were kept. Fire cycle is the years required for a defined area to burn (area of evaluation x evaluation period / area burned in evaluation period; Gabriel and Tande 1983). Blanks for 1969–1984 indicate <10 fires in period (Alaska Large Fire Database, courtesy Alaska Fire Service, U.S. Bureau of Land Management).

Insects and Other Agents

The next most extensive disturbance agent of living trees in the Tanana Valley has been periodic irruptions of invertebrates. In recent decades, outbreaks of spruce beetles in the Interior have been most common west of the Tanana Valley in the middle Kuskokwim and Yukon drainages (U.S. Forest Service 2017:11–12), but these were far short of the dramatic levels experienced in Southcentral Alaska (Berg et al. 2006, Werner et al. 2006). Since the 1990s, defoliators of aspen, birch, and willow have been more prevalent than conifer engraving insects along detection flight routes in the Tanana Valley. Irruptive insects feed on the photosynthetic and nutrient transport tissue of trees and can cause stand-level mortality that in drainages can achieve the scale of large fires (U.S. Forest Service 2016). Irruptions often coincide with weakening of tree defense mechanisms during periods of climatic warming that cause drought stress (Csank et al. 2016). At a stand scale, pathogens and extreme winds (microbursts) can also cause tree damage and mortality. Occasionally, widespread wind events prompt considerations of salvage in part to reduce collateral damage to living trees if irruptions of engraver beetles occur in weakened or dead trees (Alaska Division of Forestry 2013:22–23). Werner et al. (2006) reviewed effects of beetle kill on wildlife in Southcentral Alaska.

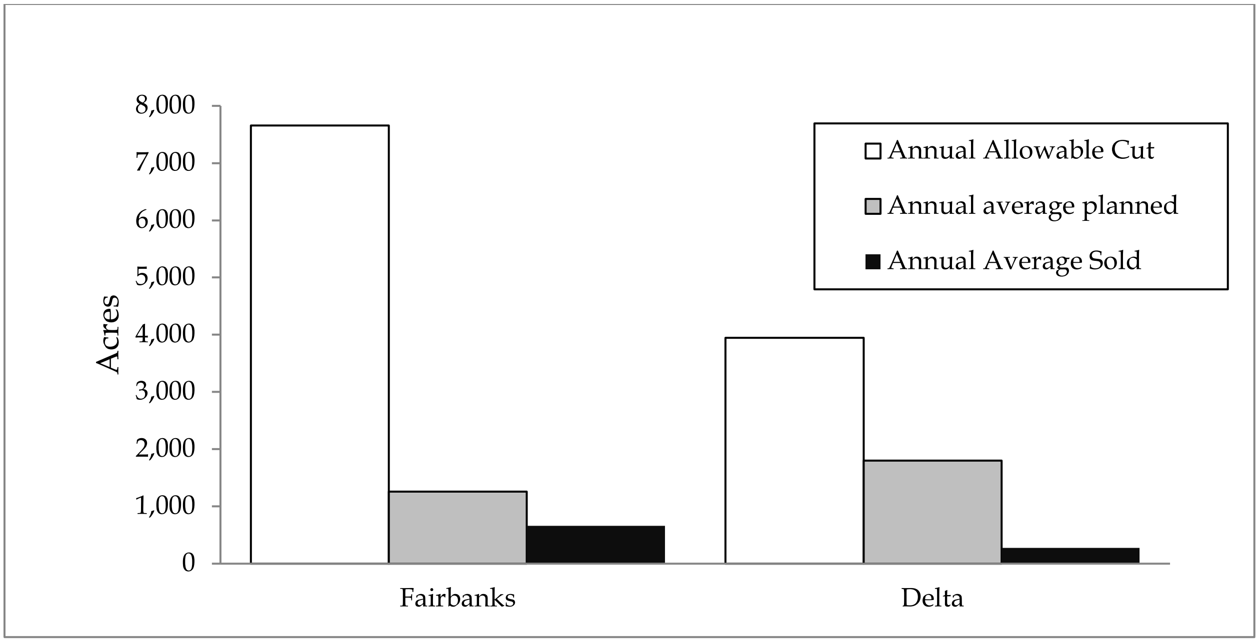
Flooding events influence riparian forest during spring ice scouring and silt deposition, heavy summer rains, or periods of increased glacial melt due to prolonged high temperatures. Erosion at outside bends increases debris falling into the river (Ott et al. 2001) and provides silt for accretion at inside bends or in silt caps during periodic flooding. These new surfaces allow primary succession, but flooding can cause tree mortality if inundation is prolonged. Salvage of standing trees killed by flooding can occur within the constraints of riparian buffer standards in FRPA. Timber harvest in riparian buffers is restricted to standing trees, whereas fallen trees and those leaning over rivers must remain as large woody debris for fish habitat.

Historical and Present Demands for Wood

The boreal forest provided Alaska Natives with food, fuel, and shelter for thousands of years prior to European exploration of Interior Alaska beginning in the nineteenth century. During the Gold Rush era of the early twentieth century, wood was intensively harvested along rivers navigable by larger boats and near Fairbanks. Wood was used for building materials, support for mine shafts, railroad ties, and fuel for space heating, electricity generation, steam engines used in river and rail transportation, and melting permafrost in placer mining (Roessler and Packee 2000). Coal and then fuel oil became more prevalent energy sources during the mid-twentieth century, but timber harvest for local lumber, occasional export markets, and to a lesser degree cordwood continued after statehood in 1959 (Wurtz et al. 2006). The cost of fuel oil and coal used in Interior Alaska reflects supply and demand in the global market (Reynolds 1997). In contrast, because wood has lower energy density (British Thermal Units/lb) compared with oil and coal (Reynolds 1997:183) and is costly to transport it is priced based on local regional demands in Alaska.

Timber rotations to produce saw logs (timber ≥9 inches dbh) suitable for milling dimensional lumber in the Tanana Valley are presently about 70 years for deciduous trees and 120 years for white spruce.[27] The sustained yield of 'green' (live) timber is calculated as the Annual Allowable Cut (AAC; Appendix A) by acreage on state land. Morimoto (2016) calculated harvest volumes for the Tanana Valley since statehood of 11%, 1%, and 0.2% of AAC for white spruce, birch, and aspen, respectively. During 2010–2014 approximately 26% of the AAC had been planned for sale in the Fairbanks and Delta areas combined, but the resulting harvest based on limited market demand has been only 30% of that offered or 8% of AAC (Fig. B6). Morimoto (2016:67) calculated that across the TVSF during 1972–2002 the harvest of spruce was <11% of AAC and the harvest of birch and aspen was ≤1% of AAC.

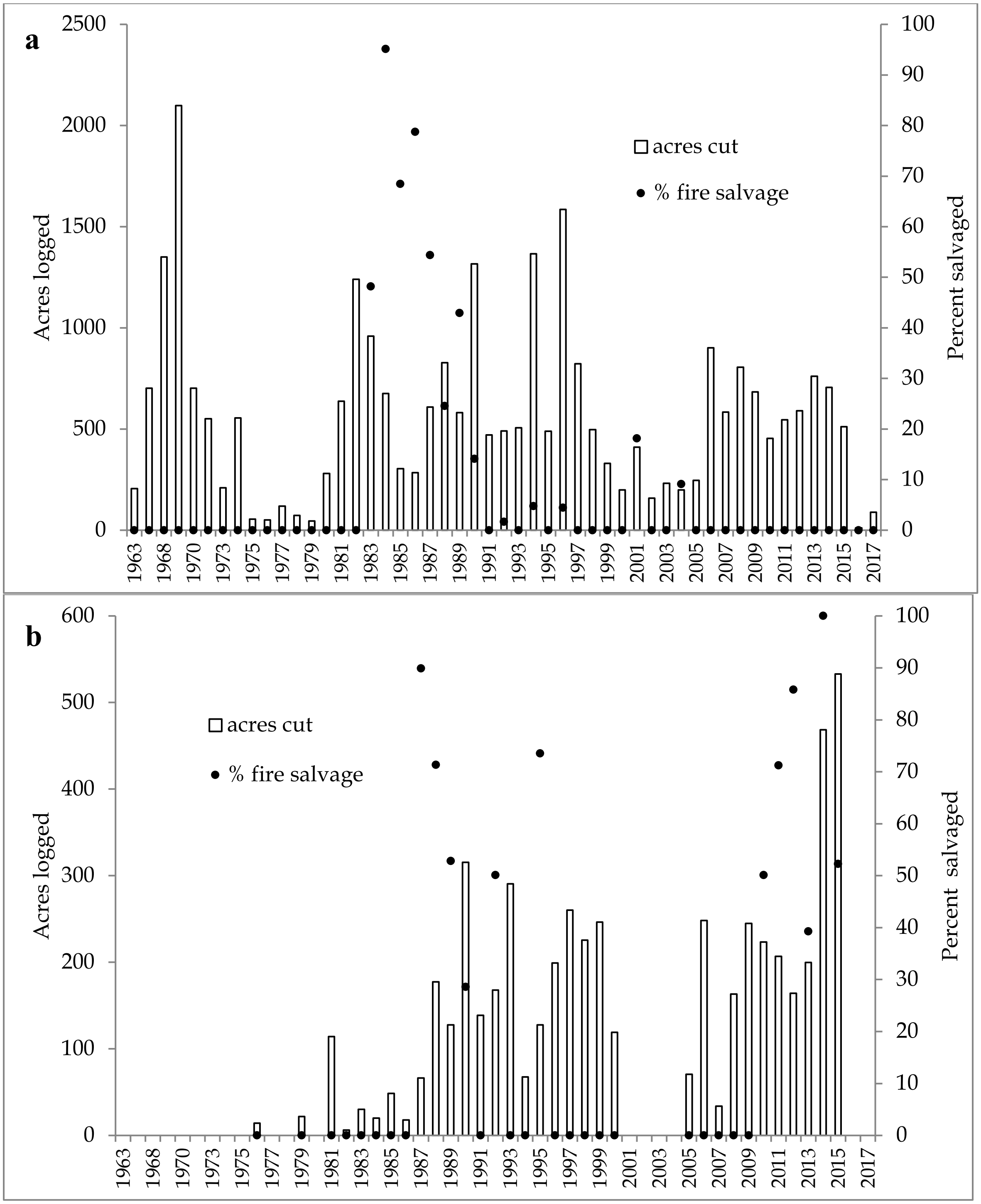
[27] Hanson, Doug. [n.d] "Sustainable harvests and harvest standards in the Tanana Valley State Forest, Alaska" PowerPoint Presentation, Division of Forestry (Obtained 21 June 2018).



2018 ADF&G graphic by T. Paragi. Data courtesy Alaska Division of Forestry.

Figure B6. Comparison of Annual Allowable Cut (estimated sustainable harvest), the planned harvest in the Five-Year Schedule of Timber Sales, and the annual average sale of timber for state land in the Fairbanks and Delta areas of the Tanana Valley, Alaska, 2010–2014. Data are courtesy of the Alaska Division of Forestry (DOF). The greater disparity between planned and sold timber in the Delta area reflects a high degree of fire-killed tree salvage in recent years (Fig. B7); larger units were offered but salvage harvest occurred in a relatively limited portion. This reflects in part the feasibility of access to pockets with greater timber volume (P. Keech, Regional Forester, DOF, personal communication, 17 July 2018).

Post-fire salvage can compose a large portion of harvested volume following extreme fire years (Fig. B7). If oil prices increase sufficiently and an alternative fossil fuel (e.g., natural gas) is not available at a competitive price, we anticipate the demand for wood fuel to again increase, at least until such time that other renewable sources are cost competitive. A combined demand for cogeneration fuel, pellet feed stock, residential firewood, and dimension lumber could utilize substantially more of the AAC in the Tanana Valley.



2018 ADF&G graphic by T. Paragi.

Figure B7. Annual acreage of live timber harvest and percentage judged to be fire salvage in (a) Fairbanks and (b) Delta areas of the Tanana Valley, 1963–2017. Much salvage occurred from the 1983 Rosie Creek fire near Fairbanks (6,849 ac), and the 1986 Rapid Creek (4,588 ac), 1987 Granite Creek (45,275 ac), and 2010 Gilles Creek (19,443 ac) fires near Delta. Timber sale data courtesy of the Alaska Division of Forestry.

Climatic Change and Variability

Forest and wildlife managers are aware of recent and forecasted changes in vegetation communities occurring with changes in temperature and moisture regimes (Alaska Division of Forestry 2001:4–5, Alaska Department of Fish and Game 2015, Robertson and Fresco 2016). Climate forecast scenarios suggest that years of substantial wildland fire will likely continue in Alaska (Veraverbeke et al. 2017, Young et al. 2017, Schultz et al. 2019), at least until spruce-dominated landscapes might transition to less-flammable fuels such as deciduous trees (Johnstone et al. 2010). Other research suggests that even with increased fire a biome shift from conifer to deciduous is unlikely, although spatial dynamics may change depending on site-specific fire and environmental characteristics (Roland et al. 2019).

Changing climate can influence incidence of other natural disturbances, such as flooding (Beltaos et al. 2006) and defoliating insect irruptions (Berg et al. 2006, Werner et al. 2006). Drought and heat stress have also negatively influenced growth rate and survival of white spruce and Alaska birch and created potential for novel or exacerbated influence of plant pathogens affecting trees or shrubs (Juday et al. 2005). Climate change is not a uniform trend of temperature and moisture; it includes increased variation as reflected by frequency of extremes (Wendler and Shulski 2009).

Climate-driven changes also appear to have resulted in drying effects in boreal regions during the last half century, including a 25% decrease in lake surface area across national wildlife refuges (Riordan et al. 2006, Roach et al. 2013). There has also been a regional decline in forest productivity of Interior Alaska consistent with a biome shift (Beck et al. 2011).

Present Understanding of Forest–Wildlife Relationships

Natural disturbances and biome shifts resulting from changing climate are already influencing the distribution, structure, and productivity of boreal bird communities in upland habitats (Matsuoka and Handel 2007, Mizel et al. 2016). We also expect that climate-driven changes in forested landscapes can influence other wildlife habitat features and potentially wildlife populations.

We also might expect further impacts from anthropogenic disturbances related to forest or wildlife harvest (e.g., Song 2002). However, there is presently no formal assessment of how timber harvest during recent decades in the fire-dominated boreal forest of the Tanana Valley in eastern Interior Alaska has influenced bird or mammal abundance or the type and dispersion of habitat features for any wildlife species. Separating climate effects from anthropogenic effects of land management, including harvest of timber or game species, would require an appropriate monitoring design to show causation.

Collins (1996) investigated techniques for enhancing moose forage and cover in boreal Southcentral Alaska. He found higher sprouting of deciduous trees and willows on timber harvest sites where dormant aspen was clearcut and a higher proportion of canopy was removed, especially where scarification created germination sites. Collins (1996) also provided several recommendations on forest practices to enhance deciduous regeneration and on monitoring design for timber sales. Paragi (2010) estimated the density and size characteristics of snags, cavity trees, and spruce rust brooms among timber types in the Fairbanks area to assess potential loss if hazardous fuels were reduced by mechanical shearing, but few of the sampled sites had recent timber harvest. Magoun and Dean (2000) conducted a comprehensive review of floodplain ecology and identified research needs for wildlife and habitat for managed forest in the Tanana Valley.

Despite the lack of information for wildlife populations within TVSF, we judge that the limited amount and overall dispersion of timber harvest since statehood along the sparse forest road system in the Tanana Valley has not had a detectable landscape-level effect, positive or negative, on abundance or distribution of any bird or mammal. Fortunately, no species is presently threatened or endangered at the federal or state level in this area (footnotes 5 and 6, this bulletin).

♦ ♦ ♦

Appendix C. Concepts of forest–wildlife relationships and habitat management.

This appendix defines general terms and concepts important for understanding wildlife–habitat relationships in forests. There is an extensive literature on the relationships among wildlife populations, habitat, and forest management in the circumpolar boreal biome. This biome (Fig. C1) is the largest on earth (~10% of the ice-free global land cover) and among the least densely settled by humans (Chapin et al. 2006b). In addition to wildlife–habitat relationships, we describe below how types and scales of disturbances to vegetation can affect suitability of habitat for wildlife species. An understanding of ecological concepts of various natural and human disturbances provides insights on how to maintain diverse forest types, stand age classes, and structure as wildlife habitat.

We encourage readers to refer to other appendices in this bulletin for more in-depth treatments of the concepts presented here. Appendix D provides detailed discussion of the scientific literature specific to the 5 principles and guidelines stated in this bulletin. Appendix B describes the ecological and management situation germane to the Tanana Valley and to boreal Alaska in general—both comprise an ecosystem little-affected by land management. By contrast, Appendix F gives a global context and "lessons learned" from Eurasia and Canada, which highlight how land management and forest practices, such as road access at extensive scales, have degraded wildlife habitats, and the mitigation steps that have reduced impact.

Forestry

Silviculture uses a set of methods for establishing and maintaining healthy communities of trees and other vegetation to meet societal objectives (Nyland 2002:1). A forest **stand** is a silvicultural concept of categorizing vegetation communities by dominant canopy species (white spruce, mixed conifer and deciduous, etc.) that are distinct from one another by recognizable characteristics in a continuous area and as an entity large enough to manage efficiently (Nyland 2002:279). The stand concept aids planning management treatments based on objectives for resource yield in a specified time period. **Forestry** is the science, business, art, and practice of purposefully organizing, managing, and using forests and their resources to benefit people (Nyland 2002:1).

Forest practices broadly define creation of forest road networks, the associated timber harvest, and reforestation following harvest as defined in Alaska Forest Resources and Practices Act (FRPA). These activities are planned disturbances that can change landscapes and forest structure. Some changes may benefit wildlife species associated with early seral habitat but may be detrimental to species more dependent on late seral habitat. Detrimental effects may be extensive enough to require modified practices or mitigation to ensure conservation of affected species.

Clearcutting is a silvicultural prescription that removes mature trees to regenerate an even-age stand (Nyland 2002:277–278), which emulates response to stand-replacement disturbances such as wildland fire. It is often perceived as a clearing of all live vegetation and potentially even snags to reduce shading competition, as might be done with a shear blade in a **hazardous fuel**

break. Partial harvest or 'clearcut' is often prescribed in forest land use plans in the Tanana Valley for commercial timber as a "diameter limit harvest" of all trees of a target species larger than a specified size (Morimoto 2016). The remaining vegetation after partial harvest depends on the stand composition and may provide wildlife habitat features in a patchy combination of understory species, capacity for advanced regeneration, and retention of "defective" trees of the target species and remaining age classes of other tree species without merchantable value. Conservation of residual live trees increases structural diversity within harvested sites and provides attributes of mature forest habitat that develop sooner than in sites managed by clearcutting (McComb et al. 1993).

Map republished with permission from the Natural Resources Defense Council.

Figure C1. Extent of boreal forest among major countries of the northern hemisphere.

Silvicultural systems include low degrees of live-tree **retention** with partial harvest (e.g., seed tree and shelterwood reserves within harvest units). Steeger et al. (1999) described the rationale behind the combination of patch retention and partial harvest. **Patch retention** can benefit conservation of late seral wildlife habitat that requires time to develop (e.g., lichen biomass), maintain mycorrhizal fungi for dispersal by small mammals, and improve worker safety by reducing proximity to hazard trees where decay may cause tops to break off if the bole is disturbed. **Partial harvest (thinning** of individual trees) can benefit forest health by managing tree density and species composition to reduce susceptibility to pathogens and insects. Single tree or small group selection emulates gap dynamics, such as where individual trees fall after natural mortality, but it requires a more extensive area to harvest a given timber volume, thus more roads and skid trails (Thomas 1999). Greater road density with a more dispersed harvest may also reduce snag abundance for safety along roads (DeLong et al. 2004).

Salvage of timber following natural disturbances often occurs based on wood demand. There is a financial incentive to harvest dead trees before decay reduces value. Salvage may be prioritized in certain areas to reduce hazardous fuels in the event of fire or insect outbreaks, particularly in proximity to communities where accidental fire ignitions may exceed lightning ignitions. The timing, proportion, and spatial extent of dead wood removal following widespread mortality can influence the rate of regeneration by remaining live trees (advanced regeneration) and thus hydrology, conservation of biological diversity, and other ecosystem services of interest to local residents (e.g., Dhar et al. 2016). Whereas habitat conservation can be proactive when planning green tree harvest, habitat conservation is more reactive during salvage harvest, because natural mortality events are stochastic and unique.

The Society of American Foresters debated the implementation of ecosystem management in forests based on different perspectives of **forest health** and productivity. An initial task force report provided recommendations on the scientific knowledge and professional skills needed to sustain the various ecosystem services and encouraged working to "retain ecological processes, functions and patterns to provide resilience to short-term stresses and adaptation to long-term change" (Society of American Foresters 1993:14). This definition of forest health remains consistent with a recent international review specific to boreal forests (Gauthier et al. 2015). However, subsequent to the initial (1993) task force, a committee report by the Society of American Foresters (1997) concluded that "forest health" is an informal and technically inexact term and recommended that natural resource professionals should work closely with the stakeholders to clarify objectives before attempting to resolve forest health issues. Spruce bark beetle outbreaks on the Kenai Peninsula and Copper River Valley in the 1990s prompted a workshop sponsored by the Alaska Boreal Forest Council, the Alaska Cooperative Extension Services, and the Forest Sciences Department of the University of Alaska, Fairbanks to discuss definitions of "forest health" and identify potential objectives. Discussion included the risk of outbreaks in the Interior, the exacerbating effects of climate change, and whether humans could respond to meet forest health objectives in an area that is largely unmanaged due to limited access (Paragi and Wheeler 1998).

Sustainable Forest Management (SFM) seeks to integrate ecological, economic, and social values to provide for the needs of people (Angelstam et al. 2004b; Rempel et al. 2004; Gauthier et al. 2009c). Conserving biological diversity benefits ecosystem resilience to natural or human-induced change and continues to provide ecosystem services for human benefits. "Sustainability" requires striking the right balance between conservation and utility. Forests can be managed for a range of products and outcomes that are not mutually exclusive, including biological diversity (Society of American Foresters 2019). Management objectives are a matter of societal choices, and SFM should seek the appropriate balance between conservation and use of biological diversity to ensure broad public support.[28] The establishment of a clear set of desired values, goals, and objectives with stakeholders is critical to SFM (Rempel et al. 2004) and to designing adaptive management (Allen and Gunderson 2011).

Habitat

Habitat is the physical and biological surroundings of an organism in the context of a species or guild. Habitat may be defined specific to a life history stage, such as brood rearing or seasonal foraging. **Habitat features** are components; some can be managed (living or dead vegetation that provides cover and forage) whereas others generally cannot (topography). Dispersion of all habitat features used by an individual defines the scale and shape of its home range.

Dead wood is an important habitat feature, as it is often utilized by wildlife. **Snags** are standing dead trees that provide birds with a perch for hunting or nesting platforms. Snags may be merchantable for lumber shortly after death of a healthy tree or for fuel several years after death. **Debris** is fallen or leaning dead wood that provides smaller mammals with cover for thermoregulation or predation security and with moisture on dry sites when debris is in latter stages of decay.

Leaning debris creates a space beneath, allowing weasels and martens access to the **subnivean** space below the snow surface for hunting small mammals. Debris in advanced decay may contain more living biomass in the form of saprophytes (bacteria, molds, fungi) and invertebrates than the heartwood of the previously live tree (Maser 1989:78–97, Vaillant 2005:192), with invertebrates being an important forage source for some birds and mammals. Debris can be large, intact, trees but typically has limited value as fuel because of decay unless kept dry by being suspended above ground contact. **Cavities** are hollow internal portions of live trees or snags where advanced decay becomes soft and are most often excavated by northern flickers and woodpeckers. Cavities provide thermoregulation or protection for **altricial** young (defenseless and requiring parental care) of some birds and mammals and can serve as maternal roost sites for bats[29,30] or food caches.

Habitat quality varies spatially within the occupied landscape of a given species (Fig. C2) and depends upon the habitat features present. Of all habitats used or occupied by a species, there are subsets having greater ecological importance to the **fitness** of an organism (survival and

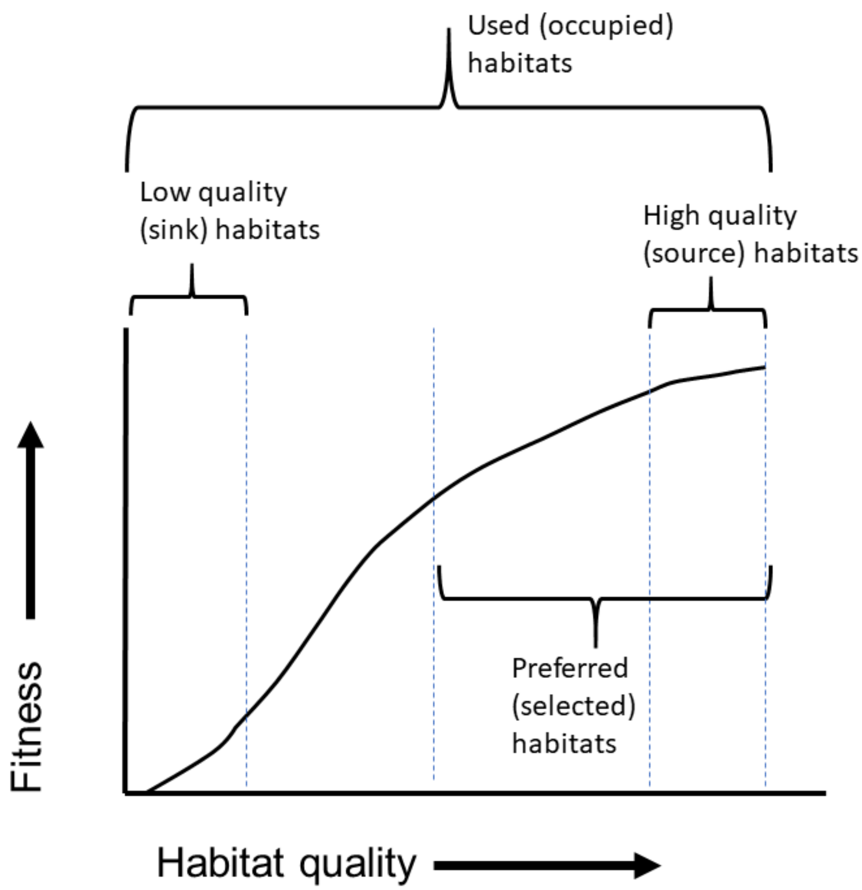
[28] There are 12 "Malawi principles" from a 1998 international convention on biological diversity: Convention on Biological Diversity. [n.d.] Principles. https://www.cbd.int/ecosystem/principles.shtml (Accessed 12 May 2019).

[29] Which came first in Alaska: cabins or bats? 7 November 2019 https://www.gi.alaska.edu/alaska-science-forum/which-came-first-alaska-cabins-or-bats (Accessed 24 February 2020).

[30] Natural and anthropogenic roost-use by *Myotis lucifugus* (little brown myotis) in Interior Alaska. Abstract of unpublished study by J. Pelham et al. presented at Alaska Chapter of The Wildlife Society, 13 February 2020. http://twsalaskameeting.com/2020_meeting/ (Accessed 18 March 2020).

reproduction) than others. High quality habitat, for example, is best suited for a species and therefore results in the greatest reproductive output per individual (Fig. C2). Definition and discussion of both **important habitat** and **critical habitat** has been provided earlier in this bulletin (see Understanding Wildlife Habitat Needs, this bulletin).

Spatial variations in reproduction and survival for a species are far more informative metrics of habitat quality than simply knowing the spatial variation in occupancy or density of individuals. Occupancy or density alone can be misleading indicators of habitat quality when individuals with low reproductive fitness (e.g., nonbreeding subadults) are relatively abundant in poor habitat (Van Horne 1983, Tyre et al. 2001, Bock and Jones 2004, Thompson et al. 2012). However, gathering data on reproductive output or survival can sometimes require substantially more field effort than surveys for habitat occupancy or density.



2018 ADF&G graphic by T. Paragi, based on Thompson (2004).

Figure C2. Low-quality, preferred (often important), and high-quality (sometimes critical) habitat as subsets of all habitats used or occupied by individuals of a species. Spatial disparity in fitness can establish source–sink dynamics that complicate understanding of habitat quality at the landscape scale.

Source populations occupy high quality habitats that enhance fitness and produce demographic surpluses, whereas **sinks** are lower quality habitats where fitness is poor, and populations cannot be sustained without immigration from source habitats (Fig. C2; Heinrichs et al. 2016). Hence, source habitats are "net exporters" of individuals and sinks are "net importers" for a given species. Species persistence in poor habitat may result from source-sink dynamics (Pulliam 1988, Dias 1996). However, direction of dispersal may change over time between optimal and suboptimal habitats for species with fluctuating abundance (Sullivan 1979, Krohn 1992).

Retaining cavity trees that multiple species use for feeding and/or reproduction, can benefit multiple species at once. The act of conserving a range of both important and critical habitat features in managed landscapes as a means of providing for the needs of many species is known as a **coarse filter** (multiple species) approach (Noss 1987, Hunter 1990). The coarse filter is also a best practice that uses available scientific information to proactively keep common species common. It focuses on maintaining a "natural" or existing diversity of habitat features (types, amounts, dispersion, connectivity) to help ensure a "natural" or existing diversity (number and relative abundance) of wildlife species in the target landscape as human land uses may increase (Noss and Harris 1986). It is a strategy most likely to work in landscapes that are relatively intact, i.e., limited fragmentation of habitat features by land uses or road networks. In contrast, a **fine filter** (single species) approach is required to conserve individual species not served by the coarse filter, often because of highly specialized habitat requirements (Noss 1987). A fine filter may become necessary to mitigate a dramatic decline in abundance or distribution of a species as a result of habitat disturbance from natural or human causes. Forest road networks, in particular, have the potential to fragment landscapes and potentially increase human disturbance to wildlife or habitat through firewood salvage of snags or cavity trees, hunting or trapping, animal disturbance, etc. (Forman 1995).

Wildlife

Biological diversity includes variations in all life forms (genetics, species), biological processes, and ecological structures and functions in a defined area that extends to the scale of landscapes (Oliver 1992, Society of American Foresters 2019). Multiple methods are used to describe biological diversity (Hunter 1990:9) but are beyond the scope of our review. In this bulletin we describe **species diversity** as the abundance and distribution of birds and mammals (wildlife) in a defined area and period (e.g., summer bird breeding habitat includes neotropical migrant birds, winter season only includes year-round residents). Vascular and nonvascular plants, fungi, invertebrates, and other species are important to boreal ecosystem function and to wildlife (Pastor et al. 1996) but are also beyond the scope of species diversity in this bulletin.

Ecological benefits of maintaining species diversity through a coarse filter approach (described above) are based on complexity of food webs that describe nutrient and energy flow through soil, plants, herbivores, carnivores, and detritivores back to soil. Simplified ecosystems are more prone to destabilization, whereas complex food webs have greater feedback mechanisms and structure, conferring greater resistance to short-term perturbations or stressors (McCann 2000). Therefore, ecological complexity creates **ecological resilience** (Pimm 1991, Thompson et al. 2009, Chapin et al. 2010). For example, carnivores are important elements of species diversity because of their role in transferring energy and nutrients, and because, to a degree,[31] they keep communities of prey species in check (Zielinski et al. 2005). Although land management practices that lead to simplified or less diverse landscapes can achieve economic efficiency and productivity, there is greater risk of other, potentially catastrophic stressors, such as herbivorous pest outbreaks. If resilience is a goal, managers must understand the properties that enable an ecosystem, as a complex adaptive system, to maintain its integrity in the face of changing environmental conditions or human disturbance (Levin 1998, McCann 2000). Resilient ecosystems can provide **ecosystem services** to society, including biomass production, habitat, pollination, seed dispersal, resistance to wind storms, fire regulation and mitigation, pest regulation of native and invading insects, carbon sequestration, and cultural values in relation to forest type, structure, and diversity (Brockerhoff et al. 2017).

A **guild** is a group of species that uses the environment in a similar way (e.g., for feeding, breeding, or resting), either by exploiting the same resources or different resources in the same way (Simberloff and Dayan 1991). Guild members often perform a similar biological function within a forest. For example, many different and unrelated species of birds feed on insects from foliage or dead wood, which can increase plant biomass, reduce tree mortality, and lower the risk of insect outbreaks (Fayt et al. 2005, Mäntylä et al. 2011). Guild members can have similar habitat needs and responses to habitat change (Thomas and Verner 1986), thus defining a **habitat guild**. In contrast, guild members can produce similar ecological functions but have different habitat needs and different responses to habitat changes (e.g., red foxes benefit more from early seral habitat than martens, but both are predators of small mammals; Lindström et al. 1995, Kurki et al. 1998). We emphasize that selection of **indicator species** or guilds for monitoring ecological change requires careful consideration and an understanding of limitations (McLaren et al. 1998, Bunnell and Huggard 1999, Lindenmayer 1999, Carignan and Villard 2002, Siddig et al. 2016).

Scales and Types of Habitat Disturbance

The scale, type, frequency, and pattern of natural or human-caused disturbances to vegetation are major factors driving the species types, age classes, and physical structure of the forest, and therefore its function as habitat (Angelstam and Kuuluvainen 2004). An understanding of the scaling of ecosystem properties and species–habitat interactions from individual trees to the landscape level emerged in the scientific literature in the 1970s and 1980s (Bissonette 1997). Individual **trees** can provide habitat features, such as food for birds and mammals (e.g., beetle larvae for woodpeckers, ants for bears) and nesting cavities. When individual trees fall, they create canopy gaps. Habitat attributes at the **stand** scale such as vegetation type, amount of edge based on stand perimeter shape, size and dispersion of dead wood and cavity trees, and vertical structure can determine species diversity (Hunter 1999). Fire, fluvial action, or insects can cause mortality of entire stands and trigger forest succession. Patterns of stand dispersion affect ecological function at the **landscape** scale. This scale is relevant to wildlife conservation because it is larger than most species' home ranges yet smaller than their geographical ranges. Thus,

[31] Vertebrate predation plays a partial role (along with food limitation) in regulating or moderating vertebrate prey abundance, but we found no evidence that this predation can <u>prevent</u> irruptions of voles or hares. Vertebrate predators have population dynamics that respond to prey after a time lag because typically only a single litter is born each year, whereas voles, hares, and some insects can have multiple litters in a growing season and thus much higher reproductive rates even at high latitudes (Krebs et al. 2001).

landscape scale is important for considering how forest management relates to species fitness or its occurrence at a site (Bestelmeyer et al. 2003).

Data collected at one scale may not detect changes at larger scales. For example, Bissonette and Hargis (1995) noted that marten may persist in isolated pockets with high density of small mammals even as the surrounding landscape becomes unsuitable for marten. Thus, monitoring is needed at both stand and landscape scales to understand conservation risks for wildlife species.

Landscape ecology considers the causes and ecological consequences of spatial patterns in landscapes. Landforms such as drainages have resources (water, nutrients) and fluvial disturbances that produce characteristic structures and communities in riparian forests (Magoun and Dean 2000). Riparian forests are an example of habitat **connectivity** across a landscape for wildlife movements, gene flow, and ultimately species persistence (Marcot et al. 1994, Olson and Burnett 2013). These forests may provide the only trees in a dry landscape or the largest or oldest trees in a forest prone to upland fire. The opposite of connectivity, **fragmentation**, also influences movements and ultimately species diversity (Rolstad 1991, Cushman and McGarigal 2003). Understanding dispersal and other adaptations of species to fragmentation can inform design of managed landscapes (Niebuhr et al. 2015). Research on connectivity continues to validate theorized mechanisms for how species move through landscapes (Stewart et al. 2019).

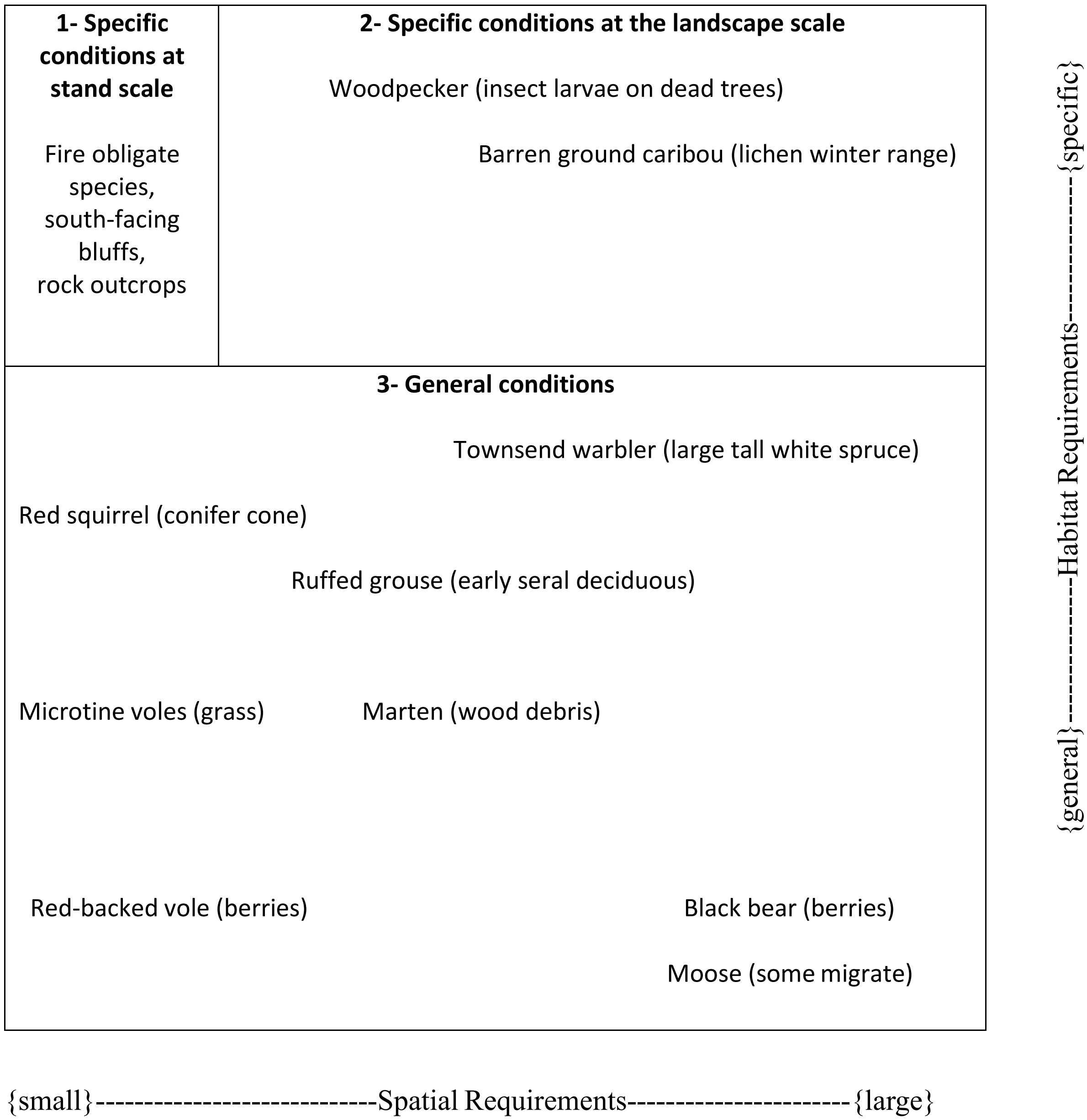
Edge effect occurs when habitat features (e.g., cover, forage, water, nesting structures) are in proximity at the border of 2 or more vegetation types or seral stages. Habitat edges often result from disturbance and attract colonizing species, such as at the borders of logging areas or burns where early and late seral features abut (Marcot et al. 1994). Edge effect is a primary emphasis of habitat enhancement for herbivore game species that utilize early seral vegetation in proximity to concealment cover. Roads in forests create a canopy edge that can also serve as a corridor for colonizing edge species to penetrate closed forest (Gucinski et al. 2001). However, disturbance fragments older stands and more contiguous vegetation types, which can be detrimental to species that have their greatest fitness deep within forest habitats, more distant from edges (Aune et al. 2005).[32]

Human-caused fragmentation tends to be more important where canopy gaps are the primary disturbance instead of stand-replacing fires (Nilsson and Ericson 1997). Consequently, the magnitude of edge effect may be relatively less in boreal forests where natural disturbances are fairly common on the landscape and interior habitats are still abundant, due to a low degree of timber harvest (Schmiegelow et al. 1997). Minimum patch size may be important to monitor for some species with highly specialized habitat needs.

Individual wildlife species can be characterized by the combination of spatial requirements and degree of specialized habitat associations they require (Fig. C3). Effects of habitat change in terms of scale (stand, landscape, etc.) can therefore be judged relative to their predicted impact on a wildlife species (Fig. C3). Likewise, land management activities can also be judged relative to how well they might complement (mimic) or diminish (e.g., fragment or remove) natural

[32] Fragmentation can sometimes lead to increased species diversity by benefitting species adapted to colonize disturbances at specific scales, even nonnative species. This paradox between fragmentation and species diversity should be discussed by stakeholders when setting management objectives (Swallow 1996).

disturbance regimes at different scales, and therefore impact or enhance habitat features upon which a species relies.



2018 ADF&G graphic by T. Paragi, based on Aanderaa et al. (1996:34)

Figure C3. Two-factor habitat space for characterizing gradients in spatial requirements and degree of specialized associations of birds and mammals in boreal forest of Interior Alaska. Species listed are those likely to occupy landscapes dominated by forest with timber volume sufficient to support commercial logging. Important habitat features likely to increase fitness are in parentheses (Fig. C2).

Applying Scale and Disturbance Concepts to Maintain Forest and Wildlife Diversity

An understanding of scale is central to landscape ecology because it can determine the persistence of a species, specifically a metapopulation (Levin 1992). A **metapopulation** is a group of spatially separated populations of the same species that interact at some level. A challenge to applying scale strategies to forest and wildlife managers is the integration of species with ecosystem management. Two examples from the literature are useful here. First, forest–wildlife relationships at different scales were used to propose strategies of ecosystem management applied to large-scale forestry situations in North America (Thomas 1979; Hunter 1990, 1999; Kohm and Franklin 1997) and in Europe (Angelstam and Pettersson 1997). Second, Marcot et al. (1994:5–16) provided a case study of modeling management for a forested landscape. Management scenarios were aimed at 2 outcomes: 1) creation of "edge" or fragmented habitats which favor elk, and 2) creation or maintenance of "interior" habitats that guilds of multiple species require for breeding. This scenario approach may be useful in Alaska where we seek to manage for timber and find an acceptable balance between hunter desires for access to abundant moose and public desires for other species or guilds that provide valued ecosystem services.

Other management strategies involve not only stand-level conservation of habitat features (snags, cavity trees, woody debris) but also apply principles of landscape ecology to identify how wildlife use multiple stands based on their juxtaposition and connectedness. The challenge is to balance objectives for timber (and other outcomes in boreal communities, such as reduction in hazardous fuels) with allowance for natural disturbance that can provide wildlife and other desired outcomes. This has led to proposed ways in which forest harvest and management could partly emulate the scale and pattern of natural fire regimes, and thereby provide a natural diversity of stand types, age classes, and habitat features that provide landscape-level connectivity (e.g., Hunter 1993, DeLong and Tanner 1996).

However, some unique communities and conditions found in burns are not necessarily feasible to replicate with logging (Rees and Juday 2002, Song 2002). Fire salvage can emulate the natural effects of fire disturbance more than green timber harvest. Hence, prescribed fire could be a further step on a post-logging site treatment to emulate disturbance of natural fire (Van Wilgenburg and Hobson 2008). Our experience in Alaska, however, is that prescribed fire after timber harvest is unpopular because of the extra cost (staff time for planning and standby of suppression resources during the fire season) and risk of fire escape in a timber management area. Stochastic natural disturbances and even prescribed fire can scarify to enhance tree regeneration, but they are less precise in location and depth than mechanical treatments, so are less predictable for regeneration of desired crop trees. In fire-prone landscapes, protection of rare and localized habitat features (e.g., rock crevices used as bat roosts, mineral licks) and immediate surroundings against fire might be aided by reducing hazardous fuels nearby. The location of rare features that are critical habitat for a species of high conservation priority should be provided to DOF as a "known site" for fire protection.

Timber harvest over long periods shifts the average age of managed stands to the timber rotation period. Age of rotation is typically less than the oldest naturally occurring stands. The challenge in a managed landscape is planning harvest locations to ensure that some older stands are retained in appropriate locations to help maintain the full range of wildlife habitat features across the landscape. Lee and Barker (2005) modeled the effect of different scenarios for riparian buffers in a managed Alberta landscape and found that the location of late seral forest shifted over time from the harvested to the riparian land base. Even where riparian buffers serve purposes other than wildlife habitat (Appendix A), this example illustrates the need for late seral retention on upland sites. Maintaining a mix of young to old stands collectively contributes a range of unique habitat characteristics that can result in greater wildlife species diversity across the landscape than from any single stand age, although late seral stands tend to have the highest diversity (Hunter 1990:48–54, Schieck and Song 2006). The spatial dynamics of stand ages changing over time through natural and human disturbances and forest succession in a landscape are described as a **shifting mosaic** (Borman and Likens 1979, Hunter 1990:48–54).

Chambers (1983: chapter 9, page 1) characterized 3 goals of wildlife habitat management that are not only pertinent to scale, but also important for stakeholders to understand when clarifying intended (or acceptable) management outcomes:

1. Create or maintain all required features for a species to increase its abundance on the managed area.

2. Create or maintain only a portion of required features with an expectation it will complement features in the surrounding area to increase species abundance on the managed area.

3. Manage features of an area to attract a species without necessarily increasing its abundance.

The first 2 goals increase wildlife abundance, which can, for example, result in increased hunting opportunity at a greater sustained yield or, potentially, aid recovery of a species of conservation concern. The third provides for hunting without an increase in sustained yield or wildlife viewing opportunities by attracting or concentrating individuals into an area, but without increasing the population size. The 3 goals are also pertinent to a discussion of scale. The first goal could apply to a species with a very small range (e.g., voles), for which all required habitat features can be managed within a timber sale boundary at the stand scale. The second applies to species that range more widely (moose, furbearers, some birds) and require habitat management considerations at a landscape scale, such as a unit of the TVSF or ADF&G game management unit. For many migratory songbirds, however, scale extends far beyond the TVSF to continents, but bird use of boreal forest for breeding habitat is still a local management concern and applicable to the second goal. The third goal describes a common outcome in which enhancing key habitat features over a small spatial extent attracts individuals to an area but does not necessarily increase fitness; thus, the management outcome only creates the perception of increased abundance.

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Appendix D. Synthesis of information on the principles and guidelines for managing forest–wildlife relationships in boreal Alaska.

This appendix provides an in-depth treatment of the 5 principles and guidelines provided earlier in the text. We provide a discussion of the supporting scientific literature, examples, and commentary to highlight the extent to which our synthesis is supported for boreal forest systems. Our discussion also highlights key ways in which wildlife activities within forests can actually benefit forestry objectives by promoting regeneration and creating a forest ecosystem that is more resilient to environmental stressors.

Principle 1. Manage forests for a range of habitat types that support diverse wildlife species, because this is likely to maintain forest ecosystem resilience to environmental disturbances.

There is support within the scientific community that greater species diversity within an ecosystem provides a wider array of "checks and balances" in the form of species guilds. Species diversity creates a more stable ecosystem because there are more species and species interactions to respond to and counterbalance potentially destabilizing factors (McCann 2000, Hooper et al. 2005). Greater stability lowers the likelihood of dramatic short-term change and facilitates resilience, the ability to recover from short-term change. Resilient (i.e., "healthy") forests are expected to provide greater benefits to humans. For example, a forest with high species diversity contains a complex food web. This structural complexity contains trophic feedback mechanisms (carnivores and insectivores) that have a greater chance of mitigating damage caused by dramatic overabundance of herbivorous small mammals or insects. A simpler system with fewer predators is less able to cope and would have a greater probability of experiencing relatively more tree damage from herbivory.

We expect that maintaining a diverse set of forest–wildlife relationships will help avoid less predictable or destabilizing outcomes (e.g., McCann 2000; see also Appendix C for "ecological resilience"). For example, maintaining some small mammals that disperse fungal spores beneficial to tree regeneration will also favor predator populations that keep small mammal populations in check and reduce herbivory risk to timber resources (Paragi et al. 2016; see also Guideline 2b, below). Even if climate change increases wildland fire and a need for salvage logging, or demand increases in the wood energy market, it will still be important to continue retention practices for dead wood that maintains both small mammal and predator habitat. Maintaining resilience may also, at times, require wildlife management beyond habitat conservation alone. For example, when applied to larger herbivores like moose, balance must be found between public desires for greater moose abundance and potential browsing damage to regenerating hardwoods that provide habitat for other species as well as a renewable source of wood energy or other commercial use of wood fiber.

Guideline 1a: Describe habitat features and landscape connectivity to the extent possible from existing environmental data and use this information in forest planning.

Identifying the most appropriate coarse-filter approach (Appendix C) for planning timber harvest and maintaining wildlife diversity in the Tanana Valley requires knowledge of existing habitat features across the landscape. One can then assess how features may change due to harvest activities and long-term changes in climate and fire regime. Wildlife biologists should work with forestry professionals to examine the utility of existing inventory data for defining important habitat features to boreal species. The forest inventory for the Tanana Valley (Hanson 2013) focuses on live timber polygons where diameter categories in white spruce and hardwoods are a rough proxy for stand age class and the size and density of woody features (Paragi 2010). The forest inventory polygons might also be utilized for calculating landscape metrics (McGarigal and Marks 1995, McGarigal 2015). For example, DeLong and Tanner (1996) calculated a shape index that standardized the perimeter-to-area ratio of polygons and found fires had an increasing shape complexity with increase in size (as did Eberhardt and Woodard 1987) compared with timber sales. DeLong and Tanner recommended increasing the shape complexity of larger harvest units to yield more edge habitat. Mahon et al. (2016) used multivariate analysis of landscape metrics and found that a high proportion of variance in boreal bird distribution and community-level associations was found along gradients of moisture-vegetation productivity and stand age-structural complexity. Brown and Pollock (2019) describe integration of forest and wildlife inventories and how forest inventory and habitat data can complement one another.

Describing late seral habitat features associated with older forest stages is key to both wildlife and timber management. Lee and Bradbury (2002) identified 2 coarse-filter paradigms that can be applied based on efficacy at meeting their biotic goals, social acceptability, and economic feasibility. An old seral stage paradigm attempts to retain important habitat features within stands and across the landscape by minimizing effects of timber harvest on existing biota. Older stands often contain unique structural features achieved through time, such as tall trees, large cavity trees, or exceptional lichen biomass utilized as caribou winter range. Schieck and Song (2006) demonstrated that older seral stages of aspen, spruce, and mixed-wood forest habitats support unique avian communities with diverse species. Steeger et al. (1999) noted the generally greater biological diversity associated with late seral forest was a factor of high structural diversity and variability, seral-specific plant associations, and time for species colonization and dead wood recruitment. Partial harvesting of stands can mimic gap dynamics (individual tree mortality) or be a broader thinning to reduce competition and improve growth rate, thus speeding structural achievement in younger stands. For example, partial harvesting can remove insect-affected trees while retaining healthy trees.[33] Some species associations and other attributes of late seral forest (e.g., lichen biomass) simply require time to develop despite changes in vertical structural. Patch retention, groups of uncut trees within harvest units, can maintain late seral attributes in proximity to early seral conditions during post-logging regeneration. This strategy provides edge habitat for the range of species similar to those found in natural disturbance patterns, such as unburned islands within large burns.

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[33] Ministry of Forests, Lands, Natural Resource Operations and Rural Development, British Columbia. 2017. Stand and landscape-level retention for harvesting in response to spruce beetle outbreaks. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/retentionguidance_spruce_beetle_20sept2017.pdf (Accessed 24 February2020).

The natural disturbance-succession paradigm is another coarse filter. However, it accepts that seral changes will occur through management and attempts to design harvest patterns that emulate successional trajectories of natural disturbance, thus creating or maintaining habitat dispersion at the landscape scale (Guideline 1c, below). Fire in the Tanana Valley is a substantially greater disturbance than logging (Appendix B: Figs. B3 and B4), but disturbance pattern can vary at the landscape scale (e.g., size, location, and forest type of unburned islands within burns). Riparian forest may have greater intervals between stand-replacement fire compared with upland stands due to soil moisture and associated vegetation types that affect potential to burn (Magoun and Dean 2000). Riparian forests are not rare but are a limited feature in most management units and provide unique vertical structure often greater than surrounding timber types. Sometimes the size and age of trees within riparian forests provide better habitat for certain wildlife species than other timber types. Matsuoka et al. (Matsuoka et al. 1997a; Matsuoka et al. 1997b) found that Townsend's warblers in the Chugach Mountains had the greatest fitness in the largest diameter and tallest white spruce trees used for nesting. Cotton and Parker (2000) similarly found that northern flying squirrels in northwestern British Columbia used trees (predominantly Engelmann-white spruce hybrid) for winter nesting that were larger diameter, older, and taller than randomly available. They found nests occurred in spruce rust brooms (as did Mowry and Zasada 1984), cavities, and constructed nests or "drays."

A social challenge of implementing a natural disturbance paradigm is finding stakeholder agreement on defining a starting point in time for boreal Alaska when conditions were "natural" (e.g., European settlement, statehood, etc.). Present patterns of forest structure, wildlife diversity and abundance have been influenced since the early 1900s in boreal Alaska by both natural disturbances (fire, insects, flooding) and by human actions intended to provide for or enhance consumptive uses, including logging (Roessler and Packee 2000) and wildland fire suppression (Todd and Jewkes 2006). Once a "natural" starting point is defined, managers can implement harvest strategies and scientists can use historical data and careful monitoring designs to evaluate whether and how conditions have changed due to site-specific human effects such as logging and/or a changes in the regional environment (e.g., climate change or fire regime).

Determining the best coarse-filter approach(es) for planning and managing timber harvest to conserve wildlife habitat in the Tanana Valley will require several steps: 1) assess habitat features or stand/community types that might be most at risk of reduction at the landscape scale due to human and/or natural causes, 2) get public input on the abundance and distribution of which wildlife species might be priorities to enhance, maintain, or reduce,[34] to meet forest and wildlife objectives, particularly for road-accessible areas, 3) identify spatial scale and type of logging (trees species and size class) that are feasible given market demands, Annual Allowable Cut (AAC), and agency capacity for forestry and wildlife administration, and 4) assess the degree of public acceptance of road network extension and the size, configuration, and landscape pattern of timber sale boundaries. We further advise that scientific consultation and stakeholder involvement be engaged to define "landscapes" for design of inventory and monitoring strategies that result from implemented best practices (Guidelines 5a and 5d, below).

[34] Species that become abundant to the point of being detrimental to forestry objectives (e.g., herbivores that kill tree seedlings) may be reduced through habitat modification or harvest by humans.

Leitão and Ahern (2002) reviewed approaches and metrics to inform landscape planning. Forman (1995) and McGarigal (2015) provided detailed rationale for landscape ecology metrics that describe connectivity, fragmentation, and other aspects of the patch-corridor-matrix model relevant to understanding the relationship of form or pattern (e.g., habitat structure and distribution) and resulting function (e.g., wildlife abundance and distribution). Trapp et al. (2019) provides an applied example of integrating landscape characteristics (logging scenarios) with wildlife behavior parameters to simulate potential for dispersal by flying squirrels. We do not recommend a specific size for a landscape or a suite of landscape metrics. That should be discussed in a planning process with stakeholders identifying desired wildlife species, future conditions, and outcomes for the target landscape.

Guideline 1b: Focus new inventory of stands to include habitat features that are important for wildlife and use this information in forest planning.

Wildlife managers should work with researchers and foresters to identify metrics and methods for landscape-level inventory of wildlife habitat features that can be integrated with the Alaska Division of Forestry (DOF) forest inventory (Hanson 2013) to aid planning. Various spatial data sets may be useful in these discussions (Appendix G). Identifying gradients in habitat features (e.g., snag density) or landscape metrics (e.g., patch density or shape, distance to or connectedness among similar types) may help monitoring efforts aimed at detecting thresholds in wildlife response to habitat changes after timber harvest in a broader context of natural disturbance patterns (Appendix C). Finally, validating habitat features within stand types to understand rarity of type, size, or use (e.g., Paragi 2010) might be a priority in the portions of the state forest closest to the present forest road system. This information could inform drafting of the Five-Year Schedule of Timber Sales (FYSTS) and Forest Land Use Plans (FLUPs) when considering expansion of road networks.

New inventory could be jointly planned by foresters and biologists so complementary (efficient) information gain occurs across needs for forest management and wildlife species. Biologists should identify rare or critical habitat features systematically by species or guilds to ensure a comprehensive list of desired parameters to optimize new inventory design. Rock clefts, for example, are a rare natural feature used by little brown bats for maternal roosts (Slough and Jung 2008). Likewise, Keisker (2000) and Bunnell and Houde (2010) each used a tabular approach to comprehensively define critical habitat in wildlife trees (snags, cavities, witch's brooms, etc.) and coarse woody debris for British Columbia. These approaches could be modified for boreal Alaska to define and prioritize inventory objectives. Manning et al. (2001) provides similar detail for aspen and mixed forest of northeastern British Columbia. Criteria for inclusion in the inventory might consider durability of a habitat feature—whether it is ephemeral/seral (e.g., woody debris) vs. static (e.g., mineral licks, rock clefts), or whether it occurs in areas highly prone to fire (upland conifer stands) or less prone to fire (floodplain or hardwood forest). Older stands occur most often in floodplains and islands but are also found in isolated upland sites of fire-prone environments, possibly due to microsite variation in soil moisture and topography (Quirk and Sykes 1971). An analysis of stand age from DOF inventory plots and other stand monitoring sites (e.g., Malone et al. 2009; Forest Inventory and Analysis[35]) could illustrate what proportions of older forest are in floodplain and upland sites (Magoun and Dean 2000:44).

[35] U.S. Department of Agriculture Forest Service. 2018. The Pacific Northwest Forest Inventory and Analysis (PNW-FIA). https://www.fs.fed.us/pnw/rma/fia-topics/inventory-data/ (Accessed 24 February 2020).

Whitman and Hagan (2007) developed an index to classify late seral forest based on density of large (>40 cm dbh) live and dead trees.

Patterns of burned forest and fire severity within fire perimeters are important to inventory, as fire strongly affects boreal habitat and wildlife populations. Fire severity can influence production and use of browse by moose (Lord and Kielland 2015; C. L. Brown et al. 2017). Remnant unburned forest within burns varies greatly in disturbance patch size (Eberhart and Woodard 1987, DeLong and Tanner 1996, Kolden et al. 2012), tree density (DeLong and Kessler 2000), and volume of coarse woody debris (Clark et al. 1998, DeLong and Kessler 2000). Finer resolution of area burned within fire perimeters and definition of unburned island patterns could be quantified via remote sensing classifications of burn severity[36] for potential emulation with harvest retention (Guideline 1c, below). However, several articles in an issue of *International Journal of Wildland Fire* (Vol. 17, 2008) highlighted concerns with inferring accuracy of imagery-based severity categories if ground validation of severity classes is not done within a couple of growing seasons post-fire. Whitman et al. (2018) described an alternative modeling technique to reduce classification errors of burn severity from remote sensing products.

With increasing resolution and decreasing cost per area for remote sensing data, wildlife managers should consult with foresters on mutually beneficial options for raster data acquisition that can be classified for timber and ecological uses. Instead of hand typing of stands from aerial photos or imagery, classification can be done from raw imagery using supervised object-oriented analysis (Baatz et al. 2001). An alternative or complement to the patch-mosaic model of analyzing landscape structure from categorized patches such as stands (e.g., Forman 1995) is a gradient analysis of continuous field variables in raster data, i.e., pixels in satellite imagery (Cushman et al. 2010). The gradient paradigm integrates categorical and continuous perspectives to map the environment for modeling the ecological niche for a species based on known locations of animals, rather than making assumptions about habitat suitability of a fixed categorized polygon (e.g., stand type composed of many pixels). The gradient approach also utilizes an information-theoretic approach that can more readily incorporate spatial patterns and scales of environmental variables (vegetation, soil, water, climate, etc.) for spatially predicting species occurrence (Cushman and Huettmann 2010). Predictions can be done for entire landscapes and subsequently validated for accuracy by wildlife occupancy surveys and, if feasible, assessment of species fitness.

Guideline 1c: Design larger timber sales in uplands to emulate wildland fire patterns.

Patterns of larger harvest areas with large retention patches of unharvested forest have been proposed for boreal regions dominated by large disturbances such as fire (Hunter 1993, DeLong and Tanner 1996). This mimics situations where the proportion of unburned forest area or “islands” tends to increase with fire size (Eberhardt and Woodard 1987), particularly with fires of low to moderate severity (Kolden et al. 2012). Within a harvest unit, “habitat islands” containing late seral features intermixed with live trees are likely to be less vulnerable to wind-throw than individual isolated snags. Unlike retention of individual trees or clumps of trees, uncut patches have the added benefit of not requiring further vigilance or effort by loggers to avoid disturbance during harvest operations. Recommendations on what features to retain, how many, size of patch, and what spacing of patches will require clarifying the habitat objectives for

[36] Monitoring Trends in Burn Severity (MTBS). [n.d.] https://www.mtbs.gov/ (Accessed 24 February 2020).

a particular sale and then visiting the site before harvest to confirm existing conditions and what is feasible for timber and wildlife purposes. For example, Larsen et al. (2019) analyzed the distribution of grizzly bear forages with respect to distance from edge of retention patches and timber sale boundaries in managed forest in Alberta. Joint field visits by foresters and wildlife biologists will be most productive in developing recommendations.

Fedrowitz et al. (2014) conducted a meta-analysis of 78 studies from North America and Europe, comparing responses of a range of biota (birds, mammals, amphibians, insects, lichens, etc.) to timber harvest retention of varying degrees. They found that the mean effect size (benefit) of retention on species abundance and diversity was actually greater for boreal forest than for temperate forest. They speculated this outcome for boreal species was caused by greater fitness through adaptation to fire or from boreal vegetation regenerating more slowly after logging than in temperate forest. Slower regeneration is a thought to be a prolonged benefit effect of retained mature features when compared with surrounding regeneration. Retention forestry also reduced declines in species considered forest habitat specialists, whereas forest generalist species did not differ between retention harvest and clearcuts. Total species and abundance of forest habitat specialists were greatest in unharvested forest, intermediate in retention cuts, and lowest in clearcuts. The analysis found overall benefits of retention harvest for species diversity compared to clearcuts, although some forest specialists did not remain in retention cuts. They also found an increase in number of forest specialists and more species of forest specialists over time, post-logging, with an increase in proportion of forest retained within timber sales. These authors did not recommend a single threshold for proportion of retention to enhance biological diversity, noting that it will vary among species or species groups.

Gustafsson et al. (2012) emphasized that variable retention systems should include stands, not just particular trees, to serve as biological legacies that provide late seral habitat features as refugia in harvest units, thus helping maintain wildlife species diversity. Late seral features like snags can harbor specialist predators that rely on cavities for nesting, denning, or roosting (e.g., little brown bat; reviewed in Magoun and Dean 2000). These features contribute to the positive relationship between stand age and the abundance of some boreal mammals (Fisher and Wilkinson 2005). Large patches containing both late seral features and uncut trees within timber sales maximize wildlife diversity by maintaining proximity to a variety of habitats, including both open and forested conditions. Mature conifer canopy may enhance fitness of smaller mammalian predators by providing concealment against avian predation on young (reviewed in Paragi et al. 1996). Larger patches of retained habitat are also less vulnerable to wind-throw than individual isolated snags or leaning debris. The patches serve as concealment cover for herbivores utilizing regenerating forage in the cut areas (Guideline 2a), so the size and dispersion of patches could be optimized for both early and late seral wildlife within timber sale boundaries.

At the stand scale, there will be practical limits of using forest practices to emulate larger fires because of market demands, industry capacity, and likelihood of acceptance by the public (DeLong 2002). Recently the State of Alaska approved a negotiated timber sale for wood energy that has larger units (ca. 340–400 acres; Alaska Division of Forestry 2015) than the historical average for saw logs (ca. 24 acres; Fig. B4 in Appendix B), thus providing opportunities for larger patch retention sizes that could also provide wildlife benefits. Song (2002) concluded that retention patches of >12 acres were most effective at maintaining wildlife species in boreal Canada, and Cooke and Hannon (2012) recommended patches mostly >33 acres to retain the cavity-using guild in late seral upland forest. Response of bird and mammal communities in naturally burned vs. harvested stands showed greatest differences the first 10 years post-disturbance but converged over time, suggesting that logging can mimic some aspects of natural disturbance. Residual trees within cutblocks (an alternative term common in Canadian literature for 'harvest unit'), such as snags and downed wood, while beneficial for mammals (as denning sites or cover for prey), did not function well as "lifeboats" for forest specialist birds. Finally, if snags are to successfully serve as wildlife habitat, recognize that snags tend to be extensively salvaged in areas open to public firewood gathering closest to road access. Retention patches with snags should be located distant from all-season roads or across from road-accessible sides of a river where harvest occurs near the floodplain (Wisdom and Bate 2008).

Landscape-scale retention should be considered in long-term planning of live timber harvest in the FYSTS and when considering salvage after large fires or insect outbreaks. For fire-driven ecosystems, Welke (2009) recommended retention of 25% in landscapes with salvage areas of 2,500 acres. This proportion was also part of a sliding scale that increased proportion of retention with increased salvage area after insect irruptions in British Columbia,[37] which matches the pattern of increasing proportion of unburned patches as size of wildland fires increases in boreal forest (Eberhardt and Woodard 1987). Cooke et al. (2019) reviewed literature pertinent to the Yukon Territory and recommended 50% retention from post-fire or post-insect event salvage for larger landscapes, with allowances for less retention in more accessible areas. Definition of "landscape" will be an important step in considering this scale of retention.

At the stand scale in the Tanana Valley, boundaries of fire salvage areas are often relatively large compared with green tree sales, but operators generally harvest only those portions with larger merchantable trees or favorable ground access (P. Keech, Regional Forester, DOF, personal communication, 17 July 2018). Understanding density or characteristics of stands with rare features, such as large cavity trees, in burned landscapes may help inform the need for patch retention if large portions of burns are not harvested. Insect mortality on conifers may create similar situations where incomplete salvage situations might maintain rare features. Intensive patch salvaging with retention of the remaining landscape might be mutually beneficial to timber and wildlife outcomes if deciduous regeneration provides moose forage and adequate numbers of dead wood features are retained for predators of smaller herbivores (e.g., Phase III in Crawford and Frank 1986).

Principle 2. An integrated approach to forest and wildlife management at the stand and landscape scales maintains habitat benefits.

Successfully integrating forest and wildlife management requires resolving the values stakeholders bring to the process so that decisions can be made about what action to implement. Scientists and resource managers have a challenging task to use the current public process to objectively inform policy decisions in resource management. The perception that timber harvest and wildlife conservation are sometimes incompatible may be informed and either validated or

[37] Ministry of Forests, Lands, Natural Resource Operations and Rural Development, British Columbia. 2017. Stand and landscape-level retention for harvesting in response to spruce beetle outbreaks. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/retentionguidance_spruce_beetle_20sept2017.pdf (Accessed 24 February 2020).

refuted with biological data for a particular circumstance. Recognize that conflicts resulting from differing values cannot be resolved with factual information.

Timber is an obvious ecosystem service (Appendix C) of managed forests, but so are habitat values either produced (early seral; browse, cover) or retained (late seral; snags, debris) according to objectives in the FLUP (Appendix A). In addition to tangible values to which economic valuation can be assigned, there are nonmarket values, such as berries or game as local food resources, and hazardous fuel reduction in a fire-prone landscape that contains other resources that the public desires to protect. Nonmarket values may be difficult to quantify yet can exert strong influence on political decisions (Kline et al. 2013).[38] We do not address market valuation, but Principles 2 and 3 identify practices that may help managers optimize a balance between timber and wildlife based on stakeholder input.

Guideline 2a: Favor diverse woody regeneration that includes willows and deciduous trees.

Collins (1996) provided several recommendations to stimulate willow and deciduous tree regeneration on logged boreal sites in Southcentral Alaska, particularly where grass proliferates on moist sites after canopy removal and impedes tree regeneration. Whole-tree logging during the snow-free seasons was most effective as a method that produces its own scarification process. Collins (1996) also suggested methods for stand-scale data collection during site assessment and layout activities of timber sale planning that can help interpret causative factors influencing post-harvest regeneration. Paragi and Haggstrom (2007) conducted aspen felling trials in the Tanana Valley and found that debris removal simulating harvest extraction reduced soil shading and resulted in greater sprouting of aspen compared with leaving non-merchantable debris on site. Recent experimentation by the Alaska Department of Fish and Game (ADF&G) and DOF with dozer crushing and roller chopping of young (ca. 20-year-old) aspen-willow in recent burns demonstrated robust response by deciduous woody species in the Tanana Valley.[39] Where maintaining fuel breaks is desired, especially in recent burns, crushing during cold (<10º F) temperatures seems to snap both young conifers and deciduous species, favoring re-sprouting by the latter. Avoiding such treatments during summer (when scarification creates conifer germination sites), or when temperatures are warmer or snow sufficiently deep to hinder conifer snapping, should maintain a deciduous-dominated type for a few decades. Roller chopping is one of the oldest habitat enhancement methods (Stoddard 1937) and may be suitable for maintaining hazardous fuel breaks around maturing spruce stands in managed forest and private property in the wildland–urban interface.

When aspen debris salvage is not feasible, Nichols (2005) recommended aspen felling treatments not exceed 75–100 m (246–328 ft) from any mature forest edge to optimize forage availability for moose (Weixelman et al. 1998) and develop brood cover at a scale beneficial for ruffed grouse production (Gullion 1984). Creating patches of young aspen at Nenana Ridge southwest of Fairbanks also increased abundance and species diversity of songbirds (many of them

[38] The practice of incorporating economic valuation to tradeoffs in ecosystem management is based on complex and sometimes counterintuitive situations in economics and ecology (Swallow 1996).
[39] Cook Inlet Chapter, Alaska Society of American Foresters. 2017. Summary of the 12–14 September 2017 Alaska aspen workshop.
http://www.alaska.forestry.org/sites/default/files/ak/2017%20Alaska%20Aspen%20Workshop%20Summary.pdf (Accessed 24 February 2020).

insectivores), compared with an adjacent landscape dominated by mature aspen (Walker 2002). It is possible that birds were attracted to insects that feed on young woody foliage as well as the structural diversity created by adjacent stand types.

Guideline 2b: Maintain snags, cavity trees, and woody debris.

Retained, single snags are more subject to wind-throw than those surrounded by live vegetation and lack the "island" of habitat surrounding a snag that is a justification for patch retention (Song 2002, Gustafsson et al. 2012). Habitat conservation occurs by leaving snags and surrounding habitat in place at a frequency in which they naturally occur on the landscape (Cline et al. 1980, Zarnowitz and Manuwal 1985). Production and retention of appropriately distributed snags and cavity trees can promote predator fitness by providing roosts and hunting perches for raptors and nesting cavities for martens and woodpeckers (Bunnell et al. 2002) and a large variety of forest bird species (Newton 1994). Snags trunks and bark substrate also provide habitat for prey of insectivores. Post-fire snag retention is another important consideration for wildlife; snags of all sizes are at risk of harvest during wood energy salvage.

Natural cavities are relatively rare on the landscape and associated with late seral stands. However, hole-nesting birds and mammals typically experience an even greater shortage of cavities in managed forests (Newton 1994) for 2 reasons: First, trees are cut at a relatively young age before cavities develop. Second, snags are often removed to reduce risk of fire, operator injury during logging, or undesirable insects. Actively managing for snag retention can increase cavity availability for wildlife, though some additional "recruitment" of new standing dead wood may still be important over time. A 30-year study in Finland found that woodpecker use of natural cavities as nest sites decreased rapidly a few years after excavation, suggesting more snags were needed to maintain suitable nest cavities (Pakkala et al. 2018). Similar findings occurred for artificially created snags in Oregon (Barry et al. 2018).

Fallen trees create snow shadows beneath the bole that allow mustelid access to the subnivean space for hunting small mammals and foraging vegetation in winter (Pulliainen 1981, Paragi et al. 1996). Root wads of fallen trees create shelter for maternal dens of lynx and facilitate digging of ground dens by larger omnivores such as bears and wolverines (Jokinen et al. 2019).

A recent review of reforestation standards for boreal Alaska described the importance of voles in dispersing tree-root (mycorrhizal) fungi onto harvested sites and the beneficial role of woody debris as vole habitat (Paragi et al. 2016). Sullivan and Sullivan (2014) found that species diversity of small mammals increased with structural complexity afforded by green tree retention on clearcut sites in southern British Columbia. Productivity of southern red-backed vole populations was also higher on sites with green-tree retention and windrows of woody debris. Bunnell and Houde (2010) reviewed studies from the Pacific Northwest outside of boreal forest and found that small mammal responses to changes in dead wood volume or density were too variable to define thresholds but discussed potential reasons for the variability that can benefit future study design. The authors also suggested retaining 50% of naturally occurring down wood on managed landscapes as a method of emulating natural landscapes.

Insect-caused mortality of conifers increases the number of snags and debris and allows sunlight to reach understory vegetation. McDonough and Rexstad (2005) speculated that insect mortality in spruce stands would need to exceed 50% of an area before it had a strong habitat influence on demographics of northern red-backed voles in the Copper Basin of Southcentral Alaska. Werner et al. (2006) reviewed other studies of tree mortality caused by spruce beetles and the resulting impact on small mammals and passerines in Southcentral Alaska.

Snags and woody debris provide not only cavities, roosts and cover for vertebrates, but also specialized habitats for a high diversity of other organisms, e.g., invertebrates, plants, fungi, and microbes. These organisms interact with dead wood and ultimately produce key ecosystem services and functions within forest systems, including soil development, nutrient release, moisture retention, and erosion protection (reviewed in Berch et al. 2011).

Guideline 2c: Identify landscape connectivity beneficial to wide-ranging species.

Riparian forest and mature deciduous forest are sources of habitat connectivity in fire-prone environments because the habitat does not experience stand-level replacement fires like upland conifer forest. Flooding and ice scouring are spatially predictable disturbances on a landscape compared with stochastic fires in upland forest, and often the oldest and largest trees occur in the nutrient-rich floodplain, providing some of the greatest continuous vertical structure in a landscape and larger dead wood features (Magoun and Dean 2000). Uneven-aged stands tend to have greater variation in vertical structure than even-aged stands (Hunter 1990). Post-logging or post-fire regeneration of vertical structure ≥4 feet tall that provides horizontal concealment cover against predators may be required for moose to fully or efficiently utilize forage resources distant from mature cover (Stelfox et al. 1976, Collins and Helm 1997, Weixelman et al. 1998).

Retention of mature stands for landscape connectivity is possible through “set aside” areas outside of the timber base or through “rolling harvest” of managed forest to ensure a specified amount and location of vertical structure remains at a given time. The latter has been achieved in the mosaic harvest regime on Crown lands in Quebec that required woody regeneration in first-pass cutblocks to attain 9 feet before second-pass cutblocks were harvested (Drapeau et al. 2009). This has been used to mimic natural disturbance regimes such as fire and is proposed to increase social acceptability of large cutblock sizes (Perron et al. 2009) and to ensure some security cover for ungulates remains over time (DeLong and Tanner 1996).

The Tok River value-added timber sale (NC-837-T, 880 acres) was designed in the late 1990s but not harvested on the intended schedule. However, the revised FLUP (Alaska Division of Forestry 2003) would have allowed further harvest from riparian forest when ≥10% of white spruce regeneration among all the sale units attained 4-inch diameter at breast height or 30-feet tall. This approach was to ensure vertical canopy structure for birds and horizontal concealment cover for moose. The upper Tanana Valley is a well-documented migration corridor for many species of birds that nest in forests, including raptors (McIntyre and Ambrose 1999) and passerines (Cooper and Ritchie 1995). Moose migration also occurs through the Tok River management unit of the TVSF (Alaska Division of Forestry 2001:148), and both the Porcupine Creek and Tok River management areas contain caribou winter range (Alaska Department of Fish and Game 1986).

Caribou is a migratory[40] herd species that often uses older open canopy conifer forest with dense ground or arboreal lichen as winter range. Lichens are rich in carbohydrates and highly digestible by caribou, thus providing greater energy than other winter foods (Russell and Martel 1984). Timber-harvesting plans for caribou winter range must consider the need for adequate habitat area to avoid predators and provides lichens (Smith et al. 2000). Lichen biomass attractive as winter range takes several decades to develop, and caribou tend to avoid or increase movements near recent burns (Joly et al. 2003) or logged areas (Cumming and Beange 1993, Smith et al. 2000) when lichen biomass is reduced. Caribou, however, may utilize insect-killed forest where ground lichens persist (Cooke et al. 2019). Timber harvest or wood salvage of insect-killed forest in the Porcupine Creek management area of the TVSF should be coordinated with the Tok Area wildlife biologist to mitigate potential effects of logging (lichen disturbance, timing of activities) on use of winter range by the Fortymile and Nelchina caribou herds.

Principle 3. Stand-level planning and management of habitat and wildlife can mitigate wildlife damage to desired forest products.

Forest practices can inadvertently create habitats at the stand level that increase damage to crop trees through excessive vertebrate herbivory. Likewise, inappropriate timing of regeneration efforts (e.g., coincident with peaks in herbivore cycles) can also result in crop damage. The Applied Mammal Research Institute[41] in British Columbia has brochures and scientific publications with recommendations to mitigate herbivory in managed stands, largely by maintaining predator habitat and minimizing attractions to herbivores. Recommendations include methods to enhance habitats for both birds of prey and small carnivores, including retention of snags, stub trees, and debris piles.[42]

Guideline 3a: Manage habitat to reduce herbivory.

Paragi et al. (2016) reviewed small and large herbivore damage to boreal trees and provided management recommendations, including the advantages of forest resilience, created when predators of herbivores are maintained in forest ecosystems as a means of keeping herbivore irruptions in check. Given prevalence in the literature, our understanding is that vole herbivory in boreal forest of North America is relatively less important, compared to greater intensity of snowshoe hare herbivory on young trees (including conifers) during population peaks, or moose herbivory at high density. Of tree species subject to herbivory risk, white spruce is the primary species desired for commercial saw log harvest and Alaska birch is secondary. However, wood energy can utilize a broader mix of species, including black spruce and balsam poplar.

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[40] Much of the literature on caribou–forestry relationships is on woodland caribou that occur in smaller, nonmigratory herds largely remaining in forest ecosystems from far east-central Alaska to Newfoundland. Most of Alaska, including the upper Tanana Valley near the TVSF, is occupied by barren-ground caribou that occur in larger migratory herds that often seasonally occupy alpine or tundra ecosystems.

[41] Applied Mammal Research Institute. 2010. https://appliedmammal.com/ (Accessed 1 February 2020).

[42] Voles, hares and protection of forest plantations. https://appliedmammal.com/content/brochures/VoleBrochure-FINAL.pdf (Accessed 1 February 2020).

Guideline 3b: Maintain habitat for predators of herbivores.

Backhouse and Manning (1996) recommended options for enhancing habitat of avian and mammalian predators in British Columbia forests where late seral features had become rare. Their information provides useful considerations for retaining desirable stand-level features such as snags and cavity trees, and landscape patterns such as connectivity and edge effect, applicable to forests of Interior Alaska. In addition, larger (>50 cm [about 19.7 inches] diameter) spruce rust or "witch's" brooms have been documented as nesting platforms for great horned owls (Rohner and Doyle 1992) and hawk owls (Shook 2002) and as resting sites for martens (Bull and Heater 2000).

Large ground dens (holes ≥12 inches diameter) used for maternal dens by wolves or winter dens by dormant bears are relatively rare. If dens are spotted during timber crushing, they can be flagged so machinery operators might avoid collapsing the holes when the ground is thawed. Unmarked dens spotted by machinery operators when snow is absent can also be avoided.

Thompson et al. (2012) reviewed studies of North American marten and found the landscape scale was most strongly related to habitat selection, suggesting a strong connection between home range composition and individual fitness. Although American martens are not restricted to mature and old mixed-wood and conifer forests, most studies have suggested that older forest types receive the greatest relative use. Marten use of managed landscapes is common where 1) sufficient cover and structural features important to fitness are present, and 2) individuals can exhibit landscape-scale selection to maintain 70% or more of home ranges in suitable habitat conditions. However, marten abundance is expected to decline for ≥40 years in forests where >25–30% of the forest is composed of regenerating stands. An analysis of marten harvest in a managed landscape concluded that at least 45% closed conifer forest is necessary for fur trapping success (Webb and Boyce 2009).

Guideline 3c: Monitor abundance of vertebrate herbivores and their predators.

Wildlife biologists associated with several agencies/organizations (e.g., ADF&G Small Game Program, National Park Service, University of Alaska–Fairbanks,) collect data on abundance and trends of voles and snowshoe hares that can inform forestry timing decisions, such as when to plant seedling trees or use natural regeneration. Small herbivores can vary widely in abundance over large regions every few years in "cycles" that are not necessarily amenable to human control through public harvest. Regional abundance trends can provide foresters with a coarse index of risk for planting schedules and existing regeneration. ADF&G can summarize this information annually for the Tanana Valley and provide it to the DOF on request.

Moose density is closely monitored by ADF&G to estimate sustainable harvest by hunters and can be adjusted by managing hunting pressure. However, the public may desire relatively high moose abundance that is detrimental to hardwood regeneration. Managing risk in this instance requires a stakeholder process to find common ground on acceptable tolerance (Beguin et al. 2016; see Principle 4, this appendix). Where lower moose density is acceptable, hunts can be spatially targeted to reduce herbivory. It is important to note that herbivory "risk" is a relative concept. For example, peaks in herbivore abundance may not always be detrimental, but rather could facilitate pre-commercial tree thinning in areas where seed crops are expected to result in overstocking.

ADF&G does not broadly monitor abundance of raptors and furbearers, although it does monitor furbearer harvest levels and wolf and bear abundance and harvest to varying degrees.[43] Assessment of predator abundance is often quantified in association with research projects. [44]

Principle 4. Landscape-level planning for both wildlife habitat and access management is appropriate given competing interests, the scale of natural disturbances, and desire for a managed forest on state lands.

We encourage agencies and the public to engage scientists in discussing options for defining "landscapes" for management situations (Appendix C; also, Guideline 5b, this appendix). They can then collectively consider specific landscape scenarios for how public lands suitable for forest management in the Tanana Valley can be developed compatibly over time within the range of public desires for wildlife values. Expansion of the forest road network can be a central theme for exploring scenarios of land management at a landscape scale. Markets for energy or minerals may also drive investment of all-season road access for exploration in forested areas.

The 2013 forest inventory area (Fig. 2, this bulletin) that includes the TVSF and adjacent state lands where forestry is a designated or co-designated use (Fig. 3 this bulletin) might define one option of a landscape for scoping sustained yield of multiple ecosystem services. The drainages that compose game management subunits (Fig. B1 in Appendix B) might be smaller landscapes within the inventory area that incorporate other ecological factors than timber type.

Once management landscapes are defined, a next step would be scoping potential routes for all-season primary access roads into all management units of the TVSF. Approximate routes could be proposed by DOF area foresters and road engineers based on existing knowledge of timber and soil types, terrain, rock sources, and other factors, ideally to design standards that support primary access for logging operations and reduce long-term maintenance costs.[45] This scoping would provide a basis for how timber harvest patterns might proceed in the FYSTS through options for all-season or winter-only[46] secondary and spur roads. These proposed routes would not be an obligation but could serve as a starting point for discussing tradeoffs among options in expanding the transportation network for timber sale areas, ideally during the FYSTS process (see also Guidelines 4a and 4b). Actual routes and road standards might be influenced by other future uses, such as energy or mineral development, which are addressed during area planning

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[43] Harvest reports can be found using the search for Division of Wildlife Conservation publications on the ADF&G website and selecting Specific Publication Type = Harvest Report: http://www.adfg.alaska.gov/index.cfm?adfg=librarypublications.wildlifepublications&sort=all&publicationtype=Harvest+Report&submit=Search (Accessed 24 February 2020).

[44] Research publications can be found using the search for Division of Wildlife Conservation publications on the ADF&G website (above footnote) and selecting Common Publication Type = Research Report. Search return results can be further constrained by species, region, specific publication type or other characteristics.

[45] Rationale and benefits of well-designed forest roads were addressed in the workshop "Public use of state forest roads: who pays for construction and maintenance?" on 26 March 2015, which was sponsored by the Alaska Society of American Foresters. The agenda, opening remarks, and discussion notes are available from T. Paragi.

[46] Duration of useful period for winter forest roads may continue to decrease if freezing occurs later and thaw occurs earlier, especially on low elevation wet areas underlain by permafrost.

(Appendix A; Fig. 3, this bulletin). Areas with higher potential for near-term management activities could be prioritized for road scenarios.

Forest roads also provide access for hazardous fuels management or practices designed to enhance early seral wildlife habitat. Hazardous fuel reduction is typically not part of timber harvest because it often involves thinning or clearing dense small-diameter spruce or dead wood that is not merchantable as lumber. The desired outcome is reduction in coniferous crown fuels for as long as possible; conversion to willows, Alaska birch, aspen, or poplar is desirable for a prolonged reduction in fire risk (thus delay in need for a maintenance treatment), for forage, and for cover attractive to herbivores utilized as game (grouse, hares). Larger diameters may have public value as cordwood but may be too dispersed for commercial salvage. Often the debris following timber harvest is piled prior to burning or simply left scattered. Utilization of debris as wildlife habitat for small mammals may be desirable (Paragi et al. 2016; Guideline 2b, this appendix).

Guideline 4a: Include the value of wildlife habitat when considering road access options for timber harvest and wood salvage after natural disturbances.

The FYSTS is a scoping document, not a formal "plan" or decision document subject to appeal (M. Freeman, Deputy Director, DOF, personal communication, 23 May 2018). However, it allows DOF staff to identify potential market needs of the timber industry and where additional all-season and winter road access would be necessary for new harvest sites, including salvage. Thus, it provides the public with a starting point to consider alternative options of timber harvest locations and access routes for meeting projected wood needs and wildlife values. Forestry and wildlife professionals can help the public evaluate tradeoffs.

Guideline 4b: Involve wildlife stakeholder interests when planning forest road networks.

During the Gold Rush of the early twentieth century, the level of timber harvest near Fairbanks was unsustainable. Hunting for fresh game meat was also high to supply towns and remote mining operations and avoid high costs of ship and river freighting of food supplies (Rawson 2001:28). However, the forest near Fairbanks regenerated to the point of appearing "natural" by the late twentieth century (Roessler and Packee 2000), given relatively low human density after the Gold Rush and increased use of coal and diesel for fuel, delivered via the Alaska Railroad.

New access to timber also improves hunter access in forested areas, especially with improvements in motorized vehicles, navigational technology, and satellite communication. Although game harvest is managed within sustained yield, new access can create user conflicts with hunters or other resource users who already had access by means other than forest roads. New forest roads are likely to be permanent given human density, recent patterns of public mobility, and advances in transportation technology. Thus, public consultation when creating or enhancing road access is an important aspect of the FYSTS.

Stakeholder discussions should include public uses (firewood cutting, berry picking, hunting, recreation, etc.) and how levels of public use may affect road use for forest practices, which is the primary intent of forest road construction on the TVSF. Tradeoffs become important when there is limited funding for road maintenance, particularly when timber harvest in a section of the state forest is finished for a period. DOF is required to maintain roads to FRPA standards to protect fish habitat and water quality even when not actively used for silvicultural purposes.

Continued or cumulative road expansion into a management unit for green timber harvest might need to be adjusted for unexpected events in tree mortality. Scenarios for access should consider best practices for wildlife habitat during salvage harvest because of the frequency and scale of natural disturbances and the fact that salvage can sometimes compose the bulk of harvest (Appendix B: Fig. B7; Cooke et al. 2019).

Principle 5. Consider best practices for wildlife habitat conservation in managed forest as hypotheses that can be verified for effectiveness and adjusted over time using an adaptive management approach to optimize desired outcomes for both forests and wildlife.

Evaluation of best practices in managed forests that are intended to demonstrate effectiveness in wildlife conservation can be implemented with new timber sales. This approach would be a responsible use of our recommendations for learning, rather than a constraint on forest management. Properly designed adaptive management (Walters and Holling 1990) can provide reliable knowledge of managed system dynamics and evaluate the reasons for unintended outcomes. Adaptive forest management requires explicit objectives for tree and wildlife species and multiple, plausible, cause-effect mechanisms for treatment variables before logging and reforestation activities begin. Ideally, monitoring designs include: 1) control sites that receive no treatment to discern possible confounding of treatment effects by environmental variables, 2) treatment sites with multiple replicates to include natural variation, and 3) a context for spatial scale when interpreting outcomes at specified future dates. Finding empirical thresholds of habitat change that produce undesired changes (up or down) in abundance or distribution of a species or habitat guild are instructive for setting habitat guidelines to avoid such outcomes (Kneeshaw et al. 2000). Studies of cumulative effects can include many factors and approaches (Smit and Spaling 1995); there are case studies in aquatic systems (Bisson et al. 1992, MacDonald 2000) and terrestrial systems (Yamasaki et al. 2008, Houle et al. 2010). Data from monitoring wildlife populations, not just habitat attributes, can also be used to address public concerns about potential harm to wildlife from land management practices (Bunnell 1997).

In the Tanana Valley, monitoring implementation of timber sales might be feasible for hypothesis testing to determine 1) the optimal number, size, and dispersion of retention patches to maximize wildlife species diversity and achieve desired abundance for identified species or guilds of wildlife at the stand scale, and 2) the optimal dispersion of important habitat features that sustain wildlife populations on a landscape scale while providing for commercial wood output and ecosystem services via forest–wildlife relationships, such as predation on herbivores and soil inoculation of fungi. However, a current challenge for adaptive management in the Tanana Valley is the relatively small extent of timber harvest that can hinder adequate replication and timely implementation of experiments. This situation could change with a transition to greater harvest for wood energy if oil prices increased for a long period. In addition, there are many options for how foresters may adapt forest management in a changing climate to meet societal desires for forest composition and products or outcomes (Morimoto and Juday 2018).

Our hope is that our guidelines can help stakeholders and scientists identify key questions to address for implementing a monitoring program *prior to* a substantial increase in timber harvest.

Adaptive management functions best when systems are uncertain yet controllable, yielding potential for learning from a system that is amenable to manipulation. Systems with high uncertainty but low potential for control are more amenable to scenario modeling (Allen and Gunderson 2011). Adaptive management is a poor fit for solving problems of intricate complexity, strong external influences (e.g., climate effects potentially confounding experimental effects),[47] long time spans, high system uncertainty (i.e., between ecological variables), or low confidence assessments (Gregory et al. 2006). If climate change produces novel or unexpected vegetation responses or wildlife responses, it may hinder successful application of adaptive management (Gauthier et al. 2015). It may be prudent to discuss with stakeholders the tradeoffs of adaptive management and scenario modeling for managed forests in the Tanana Valley and potentially focus on scenarios until timber harvest is at an adequate level to enable robust experimental design.

Guideline 5a. Involve stakeholders in discussions of options and tradeoffs in monitoring strategies.

Case histories illustrate how adaptive management fails without public stakeholders helping define the questions to address on controversial topics (McLain and Lee 1996, Allen and Gunderson 2011) or fails when scientists, managers, and the elected or appointed policymakers cannot agree on what defines Sustainable Forest Management (SFM; Nelson et al. 2003). Policymakers should evaluate intended and unintended outcomes of policies on levels of public satisfaction while agency staff should focus on objective scientific evaluations of the outputs (efforts and products) of management programs (Birkland 2005). Several countries that manage boreal forests (Fennoscandia, Russia, Canada) provide useful case studies of accommodating public desires for wildlife while identifying best management practices and a commitment to SFM (Appendix F).

The temporal scales for managing forests can range from years to decades, depending on rate of succession and the biological outcomes of interest. Wildlife populations and regulation of consumptive uses of wildlife operate on a much faster cycle than timber harvest. Outcomes requiring decades for achievement (e.g., timber rotation, large cavity trees, lichen biomass suitable for caribou winter range) are also decoupled from short-term goals or desires of society that may change rapidly in the future. Decoupling potential exists with adaptation to changing climate (e.g., Ayers and Lobardero 2018), human population flux driven by economic opportunity, urbanization, and globalization of trade. Stakeholders who prioritize efforts, however, must likewise recognize tradeoffs. For example, enhancing habitat features of early seral vertebrates for 1 to 2 decades can degrade conditions in the same area for species that require late seral features for occupancy, until the forest ages sufficiently for late seral features to appear again. Chapin et al. (2006a) and Chapin et al. (2010) provide considerations germane to natural resource management, including limits to resilience and cautions of short-term cost-

[47] In terms of range expansions, as many as 40 songbird species are projected to colonize boreal Alaska (Stralberg et al. 2017). Thus, public discussion of "native" vs. "naturalized" species diversity should be engaged when setting objectives and metrics for monitoring, because colonizing species could confound testing habitat guidelines for species diversity over time.

benefit analysis. However, those authors also consider how societies can adapt to changing ecological conditions in boreal forest.

Guideline 5b. Establish a scientific advisory group to guide silvicultural prescriptions and monitoring.

Substantial guidance is available for design of wildlife habitat monitoring in forested ecosystems (e.g., Rowland and Vojta 2013) and for monitoring wildlife response to forest practices (e.g., Krebs 1999, Braun 2005). However, applied research capacity for forest management in central Alaska has declined in the last 2 decades (Appendix F), and there are fewer personnel in ADF&G and DOF available to design and conduct forest and forest wildlife monitoring. Research assistance through university training of graduate students requires funding but yields both information and trained professionals that are potential new employees. During funding shortfalls for university assistance, agency staff should still solicit input on monitoring design from other scientists (agency, university, nongovernment organization, or independent) willing to volunteer their expertise. Awareness of ongoing efforts and even short-term or limited collaborations can potentially generate results useful for soliciting collaborative research funding, particularly where co-production of knowledge involving scientists and stakeholders is favored (Beier et al. 2016). The ultimate goal is to provide stakeholders with awareness of tradeoffs in monitoring design to evaluate forest and wildlife management strategies.

Guideline 5c. Verify best practices for wildlife habitat using scientific methods; adjust and update using an adaptive management approach.

We recommended evaluation of existing forest–wildlife relationships or wildlife responses to land management actions along a gradient of habitat feature(s) to identify thresholds of response, ideally using fitness (this appendix, Guideline 1a). Validation promotes efficiency, and veracity garners respect for reliable knowledge and achievement of stated objectives. Design of threshold monitoring requires consideration of detection power and ability to separate cause and effect from confounding factors (e.g., Guénette and Villard. 2004, Villard and Jonsson 2009, Müller and Bütler 2010).

For more wide-ranging species that use landscapes containing both logging and natural disturbance types, experimental designs can be complex to account for individual effects from both types separately, interactions between the two, and different spatial scales of disturbance. Boutin et al. (2001) described the practical challenges of experimental design for measuring wildlife responses to manipulated food supply and predation in a boreal environment. A team approach to study design (Guideline 5b) could bring diverse expertise and help ensure a monitoring project is feasible to accomplish given the available resources.

Guideline 5d. Utilize suitable techniques and volunteer help to monitor a broad network of sites.

Counts or measurements are made using standard procedures in forest mensuration and habitat surveys. The approach allows for continuity in data sets over time, but the amount of labor required can restrict replication among sites, thus limiting the ability to monitor a full suite of treatments. Rapid assessment of some criteria can complement quantitative assessments on a limited number of sites and represents data collection using both intensive field plots and larger-scale remote sensing (Davis et al. 2016). Training observers in ocular estimates of stem density for a subset of quantified responses in plots can also increase efficiency (Collins 1996:34).

Alternatively, georeferenced digital images at archived locations can be readily interpreted by a lay person (Hall 2001a, 2001b) for threshold vegetation responses in height or horizontal cover. Fire managers often use calibrated photo series to gauge fuel biomass loading (black spruce and hardwoods with spruce for Alaska),[48] which may be suitable for gross inferences on forage and cover. Sampling with images should be approached in a rigorous fashion (e.g., random, stratified random, or uniform) to avoid spatial bias. Stand-level validation of cover type is now possible with high resolution aerial imagery acquired from aircraft or unmanned aerial vehicles.

Use of volunteers for wildlife monitoring requires structured data collection for results to be sufficiently robust for conservation (Kamp et al. 2016), but successful applications exist, including loons in Alaska (McDuffie et al. 2019), the Bering Sea ecosystem[49] and Yukon, Canada.[50] Accessible areas may permit sufficiently frequent visits by volunteers trained in species identification to record wildlife observations for estimating trends in abundance that could complement similar efforts by agency staff in more remote areas. Biologists and foresters should examine potential for observational data on some wildlife species (Hochachka et al. 2000, Boutin et al. 2001) to be combined with collection of habitat or forestry data.

We recommend that the planning of sampling effort in monitoring a forestry–wildlife management system should involve assistance from a biometrician to understand the required statistical power to detect specified magnitude of change in the topic of interest (e.g., Reynolds et al. 2011). Managers and researchers should collaboratively and explicitly define "rules of thumb" (parameters) in the monitoring design for linking data collection and management actions to inform a decision framework (Fraser 1985). This will better result in managers gaining practical application for techniques suited to agency capacity for monitoring. It also avoids uncertainty in how to incorporate knowledge gained via a pure research perspective or through techniques not amenable to frequent management application.

Environmental monitoring and modeling species occupancy at the landscape scale using the information-theoretic approach (Humphries et al. 2018) can complement the traditional before-after-treatment-control design of field experiments. The latter are often costly, thus limited to comparatively few sites with an expectation that findings will be applicable to broader circumstances. Cushman and McKelvey (2010) provide recommendations on environmental monitoring to support spatial modeling of species occurrence. We expect advances in remote sensing technology will enable classification of vegetation species and forest structures at finer resolution and lesser cost per unit area (Appendix G). Additionally, raster data can be paired with plot data to improve inventory precision and resolution by modeling of selection probability in sampling designs (Särndal et al. 1992). The scientific and professional literature contains debate over 2 approaches. The first estimates species occupancy using static type classification with accuracy validation that must tolerate atypical characteristics (Arney 2018). The second employs

[48] United States Department of Agriculture (USDA) Forest Service Fire and Environmental Research Applications Team. [n.d.] Digital Photo Series (DPS). https://depts.washington.edu/nwfire/dps/ (Accessed 24 February 2020).
[49] Indigenous Sentinels Network. [n.d.] https://www.beringwatch.net/ (includes online data collection protocols, database, and reports; Accessed 24 February 2020).
[50] Krebs, C. J. 2011. Biodiversity monitoring in Canada's Yukon: the community ecological monitoring program. https://www.zoology.ubc.ca/~krebs/papers/269.pdf (Accessed 1 February 2020); see also annual reports (2008–2016) for The Community Ecological Monitoring Program. http://www.env.gov.yk.ca/publications-maps/plansreports.php#misc (Accessed 1 February 2020).

predictive modeling of habitat niches with raster data over landscapes. It is beyond the scope of our review to evaluate these different analytical approaches, but we recommend that attempts to inventory wildlife habitat at the landscape scale should consider merits of both the classification and modeling approaches such that raster data may complement the existing timber typing categories used by DOF.

♦ ♦ ♦

Appendix E. Methods of information gathering.

Literature Review

To synthesize the information contained in the 5 principles and guidelines described in Appendix D, we obtained published scientific papers or books and agency gray literature (reports, guidelines, etc.) on habitat relationships and implications of forest management applicable to birds and mammals in boreal Alaska. We focused on Alaska and northwestern Canada but included information broadly applicable to boreal forest in North America and Eurasia. S. Brainerd translated abstracts or materials that were in Norwegian and Swedish that lacked English summaries. Russian language texts were machine translated using Google Translate. Citations and abstracts were compiled in EndNote, annotating as appropriate to clarify pertinence to Alaska forests, wildlife, or management situations.

We chose search terms for key words for 1) species of public interest (e.g., game that is hunted) or contained in the State Wildlife Action Plan, 2) taxonomic groups with functional effects at the ecosystem level (e.g., small rodents that may girdle seedlings or disperse mycorrhizal fungi), and 3) specific themes of forest–wildlife relationships (e.g., mimic natural disturbance). Some search terms used an asterisk as a wildcard (e.g., predat* for predator, predators, predatory, or predation). We also used literature cited searches to uncover other key papers.

Example Search Terms

For wildlife: moose, ungulate, passerine, woodpecker, bird*, furbearer, vole, hare, small mammal*, arvicoline, cavity AND nest*, rodent*, gallinaceous, mesocarnivore, caribou, marten, lynx, fox.

Other related topics: boreal, Alask*, Canada*, logging, damage, wildlife, diversity, abundance, population*, herbiv*, resilience, silvic*, ecosystem service, landscape, *divers*, forest*, guild, retention, conserv*, mycorrhiz*, truffle*, biotic AND interact*, regulat*, spruce AND beetle*, facilitat*, meta-analysis, indirect effect*, regulation*, seed AND predat*, spore*, mutualism*, bmp, best management practice*, forest-wildlife interaction*, mimic natural disturbance*.

Landscape-Scale Data Sources

We also identified vegetative classifications or spatially explicit environmental data that may help design wildlife habitat inventories or research on forest–wildlife relationships. These data can help incorporate potential habitat values or wildlife functions in landscape planning on state lands with commercial logging potential in the Tanana Valley so that future timber sales can test hypotheses. Our goal was to define landscape gradients of habitat characteristics such as stand-level diversity of tree species, tree sizes, snags, and woody debris, and structure or density of such features. We also sought to define existing modeled gradients of species diversity. Monitoring forest–wildlife relationships across habitat gradients on timber sales and in landscapes of managed forest will help define thresholds of important wildlife habitat to guide effective timber sale design and forest practices implementation to achieve wildlife conservation (e.g., Brown and Pollock 2019).

Appendix F. Lessons and perspectives from boreal forest management worldwide.

We can learn from the experiences gained from other parts of the developed world where commercial, industrial forestry is practiced in boreal forest landscapes, primarily in Fennoscandia (here defined as Finland, Norway, and Sweden), Russia, and Canada (Gauthier et al. 2015). The amounts of boreal forest in commercial and protected statuses vary substantially among jurisdictions (Table F1). Finland, Sweden, and Canada have among the highest net export trade of any forest products globally;[51] forest management in these countries represents major national industries for which we expect sustainable practices would be paramount. In those countries, ecologists, government regulators, and private and public land managers have identified best management practices that address the landscape, stand, and tree scales in accommodating wildlife needs and the desires of wildlife users or advocates. Many boreal jurisdictions have commitments for Sustainable Forest Management (SFM; Burton et al. 2003b), and there may be concepts of SFM suitable to consider in managing Alaska boreal forest. The brief review in this appendix describes the legislative framework for best practices or regulation and illustrates the approaches to how wildlife species are being accommodated elsewhere in managed boreal forests. Guidelines specific to wood biomass harvest occur globally but tend to focus more on forestry operations (soil compaction, erosion, reforestation, etc.) rather than wildlife habitat.

Fennoscandia

Boreal forests have been utilized for centuries in Fennoscandia (Angelstam and Pettersson 1997). After World War II, industrial forestry practices intensified with an aim to maximize sustainable timber and pulpwood production through clearcutting or heavy thinning of remaining late seral forests, pre-commercial thinning (often repeatedly), drainage of mesic sites, and regeneration primarily in even-aged monocultural plantations of pine and spruce. Yrjölä (2002) provided a thorough review of forest management guidelines and practices. Lindstad (2002) compared forestry between Fennoscandia and the United States and noted that most productive forest in Fennoscandia was in silviculture with $\leq$5% protected against logging. Most commercial forest land in these 3 countries is in private or corporate ownership, with lesser proportions owned by the government. For updated forest statistics, see the footnoted links for Finland,[52] Norway,[53] and Sweden.[54]

[51] Natural Resources Canada. 2019. Overview of Canada's forest industry. http://www.nrcan.gc.ca/forests/industry/overview/13311 (Accessed 24 February 2020).
[52] Natural Resources Institute of Finland, Luke. 2016. Statistical yearbook of forestry. http://www.metla.fi/julkaisut/metsatilastollinenvsk/index-en.htm (Accessed 24 February 2020).
[53] Statistics Norway. 2019. The national forest inventory. https://www.ssb.no/en/lst (Accessed 24 February 2020).
[54] Sveriges officiella statistic. 2018. Skogsdata 2018. https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/skogsdata/skogsdata_2018_webb.pdf (Accessed 24 February 2020).

Table F1. Area of political jurisdiction and proportions of area in boreal ecozone, forested, timber productive (commercial), logged at least once, and where commercial logging is prohibited. Calculations based on Table 1.1 in Burton et al. (2003b:3), who cautioned that estimates outside of North America were considered less reliable.

Country Region	Area (mi^2)	Boreal ecozone (%)	Ecozone in forest (%)	Forest in timber (%)	Ecozone logged (%)	Ecozone protected (%)
Canada	**3,751,650**	**59**	**74**	**38**	**17**	**8**
Yukon	184,139	98	59	18	8	11
NWT and Nunavut	1,312,708	31	64	20	7	17
British Columbia	360,586	32	71	54	14	17
Alberta	252,614	69	85	60	32	14
Saskatchewan	248,487	63	76	40	20	3
Manitoba	247,251	89	72	36	11	5
Ontario	410,838	84	90	36	25	9
Quebec	580,366	81	75	46	24	1
NF and Labrador	154,661	96	71	41	8	2
USA Alaska	608,185	41	80	17	5	10 [A]
Russian Federation	**6,517,328**	**73**	**73**	**77**	**54**	**1**
European Russia	1,462,519	90	58	75	52	0
Western Siberia	1,108,740	81	74	62	56	1
Eastern Siberia	2,758,015	71	77	84	49	1
Russian Far East	1,188,053	50	91	75	67	1
Norway	123,748	27	95	87	90	6
Sweden	171,742	61	72	80	68	4
Finland	129,063	65	98	90	93	16
Iceland	39,313	1	23	0	23	15
Total	11,341,029	66	74	63	42	4

[A] This estimate is conservative given that about one-fourth the proportion of boreal Alaska is national parks, preserves, and wildlife refuges where commercial logging is not allowed (Appendix B: Fig. B4).

In Sweden, forests are managed under the direction of the Swedish Forest Agency.[55] This organization is responsible for overseeing SFM on private and state lands throughout the country. It implements government forest policy and cooperates with the forest industry and the environmental sector to achieve economically and ecologically sustainable forestry. In Norway, national laws and regulations dictate forest practices (Lindstad 2002), which are overseen by the government at the national, county, and local levels.

The Norwegian Institute for Land Inventory[56] and the Forestry Department[57] of the Agricultural Ministry collaborate with Statistics Norway in nationwide assessments of forest resources (Lindstad 2002). The National Forest Inventory (NFI) provides information on the condition and development of forest resources in Norway, based on a nationwide survey of permanent sample plots visited every 5 years.[58] The Norwegian Forestry Extension Institute[59] plays an important role in extension and education services to forest owners with small parcels of land. In Finland, the Ministry of Agriculture and Forestry[60] is responsible for forest management and policy. The sustainability of forest management is assessed and monitored using the Pan-European Criteria and Indicators for Sustainable Forest Management. [61] The National Forest Inventory (NFI),[62] the monitoring system for forests and forest resources, produces a variety of information on Finnish forests. NFI results are widely used in assessing the sustainability of forest management.[63] Maintaining and enhancing biological diversity of forests is an integral element of Finnish forest policy, legislation, and practices. In Finland, participatory processes engage voluntary certification systems and agreements that are widely used—independent of any public authority requirement—to ensure the sustainability of forest management; among the certification systems used are the Pan European Forest Certification **(**PEFC)[64] and the certification system of the Forest Stewardship Council (FSC).[65]

Forests of Fennoscandia provide other non-wood resources of economic value, including salable game meat and associated recreational harvest opportunity. For example, in Sweden, a country dominated by forested landscapes, roughly 260,000 hunters annually harvest about 15 million kg (33.07 million lb) of meat annually, the estimated value of which exceeds $8.4 billion. The associated recreational value is estimated at twice that amount (Bernes 2011). Game meat and other products such as leather are commercially important in Fennoscandia because they can be sold on the open market (Brainerd and Kaltenborn 2010). Hunters must lease property and/or

[55] Swedish Forest Agency. [n.d.] https://www.skogsstyrelsen.se/en/about-us/ (Accessed 24 February 2020).
[56] Now part of the Norwegian Institute for Bioeconomy Research (NIBIO). https://www.nibio.no/en (Accessed 30 January 2020).
[57] https://www.statskog.no/ (Accessed 31 January 2020).
[58] National Forest Inventory, Norway. 2019. https://www.nibio.no/en/about-eng/our-divisions/division-for-forestry-and-forest-resources/national-forest-inventory (Accessed 24 February 2020).
[59] Forestry Extension Institute. [n.d.] http://www.skogkurs.no/english/engelsk.html (Accessed 24 February 2020).
[60] Ministry of Agriculture and Forestry Finland. [n.d.] https://mmm.fi/en/frontpage (Accessed 24 February 2020).
[61] http://www.fao.org/3/AC135E/ac135e09.htm (Accessed 8 March 2020).
[62] Natural Resources Institute of Finland, Luke. 2013. National Forest Inventory (NFI). http://www.metla.fi/ohjelma/vmi/info-en.htm (Accessed 24 February 2020).
[63] Ministry of Agriculture and Forestry Finland. [n.d.] Sustainable forest management. http://mmm.fi/en/forests/forestry/sustainable-forest-management (Accessed 24 February 2020).
[64] Programme for the Endorsement of Forest Certification (PEFC). [n.d.] https://www.pefc.org/ (Accessed 24 February 2020).
[65] Forest Stewardship Council (FSC). [n.d.] https://us.fsc.org/en-us (Accessed 24 February 2020).

purchase permits to hunt on private or state property. In addition, hunters must pay landowners a fee based on the meat value of harvested game (Brainerd and Kaltenborn 2010). Balancing the production of moose with that of timber is a challenge for land managers (Wam et al. 2005).

Pertinent to the Alaska situation, moose densities in much of Finland, Norway, and Sweden have been favored by intensive silvicultural practices that have provided an abundance of early seral stage vegetation, primarily Scots pine, a favored forage species (Lavsund et al. 2003). Absence of large predators has also played an important role in this context. High-density moose populations, while providing commercially valuable meat and recreational opportunity, pose serious concerns for biodiversity management (Edenius et al. 2002, Lavsund et al. 2003). Heavy browsing can negatively affect generation of the deciduous shrubs and trees on which many species of forest vertebrates and invertebrates depend.

Negative effects of commercial, industrial-scale forestry on stand features, stand structure, and landscape pattern have been of concern in Fennoscandia for several decades. A large body of research has been generated on how forestry practices affect the life history and populations of many forest-dependent species (e.g., Angelstam and Mikusiński 1994), particularly those associated with late seral or uneven-aged stands. Major compilations for European boreal forest include on the ecology of woody debris (Jonsson and Kruys 2001), methods of biodiversity evaluation (Larsson and Danell 2001) and landscape analysis (Angelstam 1997), and design of monitoring programs for adaptive management (Angelstam et al. 2004a).

Historically, forest fires occurred frequently throughout Fennoscandia (Zakrisson 1977, Niklasson and Granström 2000). However, fire has been subdued over many centuries in Scandinavia due to increased timber value and discouragement of slash-and-burn cultivation (Storaunet et al. 2013). Emulation of fire effects has been considered to preserve biodiversity associated with burns (Granström 2001).

Large-scale clearcutting has created landscapes dominated by forests in various stages of regeneration. Andrén (1994) reviewed the effects of habitat fragmentation on birds and mammals and found that the scale, patterns, geometry, and proportion of mature stands removed at the landscape scale will have varying impacts on the abundance of species, dependent upon their spatial and habitat requirements. Conversion of mature forest habitat with tree gap dynamics to clearcuts and regenerating plantations favors generalist predators such as red fox (Hansson 1994). Nest predation by corvids (ravens, crows, jays) on interior, ground nesting bird species increases in fragmented forest with abundant edge (Andrén 1995). Red fox populations were shown to have a strong negative influence on numerous species that are associated with mature, relatively unfragmented forest habitat (Lindström et al. 1994, 1995). In addition, monocultures of regenerating Norway spruce or Scots pine can hinder the maintenance of biodiversity, particularly when deciduous components are removed through intensive and repeated pre-commercial thinning practices to reduce competition between stems. General fire suppression in Fennoscandia has had implications for fire-dependent species, such as certain species of fungi (Dahlberg 2002).

During the past 30 years, more emphasis has been placed on mimicking or maintaining natural processes at the landscape and stand levels in managed Fennoscandia forest. For example, the program "Richer Forest"[66] was instituted in Sweden[67] (Persson 1990) and later in Norway (Aasaaren 1991) as a cooperation between forest owner organizations and respective governments to identify and implement forestry practices that aim to preserve biodiversity as a component of forest management (Aanderaa et al. 1996). The program "Living Forests"[68] sought to develop standards to that end. This has largely been a voluntary effort and has met with limited success.

At this time, standards for stand- and landscape-scale forest planning, while supported within the general framework of national legislation, are still largely noncompulsory. Angelstam et al. (2011) concluded that "Swedish policy pronouncements capture the contemporary knowledge about biodiversity and conservation planning well. However, the existing area of protected and set-aside forests is presently too small and with too poor connectivity. To bridge this gap, spatial planning, management and restoration of habitat, as well as collaboration among forest and conservation planners need to be improved."

As an economic incentive, forest owners have been encouraged to get certification through either PEFC or FSC certification programs (Johansson and Lidestav 2011). However, practical science-based guidelines have been developed specific to the ecology of Fennoscandia boreal forests (e.g., by the Swedish forestry company Holmen)[69] that can be instructive when considering such measures in the context of Interior Alaska forests. Guidelines for forest management from Fennoscandia have been mostly based on either PEFC or FSC standards. Forest companies prefer less stringent PEFC standards, whereas environmental organizations prefer the FSC standards. In Norway, there has been resistance from forest owners to implementation of either standard, and the process stalled in 2010.[70] In Sweden, all major forest companies are using the FSC standard and about 50% are FSC-certified. As of 2005 there was still a substantial disparity regarding features important to biodiversity in natural forests relative to those that are FSC-certified in Sweden.[71] In Finland, an FSC standard was formally recognized in 2011 and has been updated to conform to improved standards.[72] However, Finnish environmental groups have been skeptical of these standards.[73]

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[66] "Rikare Skog" in Swedish or "Rikere Skog" in Norwegian.

[67] Swedish University of Agricultural Sciences. [n.d.] https://www.slu.se/institutioner/skoglig-resurshushallning/omraden/Landskapsstudier/rikare-skog/rikare-skog-swe/ (Accessed 24 February 2020).

[68] http://www.pfcyl.es/sites/default/files/biblioteca/51Levende_Skog_standard_Engelsk.pdf

[69] Guidelines for sustainable forest management, 2007. https://www.yumpu.com/en/document/read/19696039/sustainable-forestry-holmen (Accessed 30 January 2020).

[70] Sabima. [n.d.] Miljøsertifisering av norsk skogbruk. https://www.sabima.no/miljosertifisering-norsk-skogbruk/ (Accessed 24 February 2020).

[71] Dahl, L. [n.d.] Naturhänsynen i FSC-standarden – vetenskap eller gissningar? (Nature considerations in the FSC standard – science or guessations?) https://stud.epsilon.slu.se/10978/1/dahl_l_170919.pdf (Accessed 24 February 2020).

[72] Finnish Forest Industries. 2017. Forest certification promotes responsible forestry. 30 May 2017. https://www.forestindustries.fi/in-focus/environment-and-sustainibility/forest-environment/forest-certification-promotes-responsible-forestry/ (Accessed 24 February 2020).

[73] Finnish Association for Nature Conservation [n.d.]. https://www.sll.fi/mita-me-teemme/metsat/tiedostot/certifyingextinction.pdf (Accessed 24 February 2020).

Russia

Boreal forests have been utilized for centuries in Russia (Elbakidze et al. 2013). In the broader context of European forestry, sustained yield principles have been applied in Russia since the eighteenth century (Elbakidze et al. 2013). In the former Soviet Union, 5-year plans instituted in 1928 led to a strong increase in harvest volumes and the role of forest legislation as a safeguard was weakened (Norberg et al. 2013). Russian forests are primarily harvested through clearcutting with natural regeneration and minimal investments in silviculture (Elbakidze et al. 2013).

Russian Federation lands contain 20% of the total forest area in the world.[74] In Russia, virtually all productive forest is owned by the government (Elbakidze et al. 2013). Forest management is regulated by law and the government determines annual allowable cut (AAC) for all state forest management units. Private forest companies lease these lands and use AAC as the upper limit for timber harvest. The Scandinavian model of sustained yield forestry has been adapted as the most economically profitable model (Elbakidze et al. 2013). The official definition of AAC has a multi-stakeholder perspective, because it requires "…multi-purpose, efficient, continuous and sustainable use of forests, according to the established age of final felling requirements for biodiversity conservation, maintenance of water protective (sic) and protective functions and other benefits of forests" (Elbakidze et al. 2013). Large regions of the Russian boreal forests are severely affected by an accelerated harvesting of wood during the 1980s and 1990s (Elbakidze et al. 2007), and the intact forest landscapes of northwest Russia were shrinking by 3% annually during 1980–2000 due to logging (Mayer et al. 2005). Wildfire still has a predominant influence on Russian forests compared, for example, to forests in Sweden (Elbakidze et al. 2013).

The Russian Federation has a large area of FSC-certified forest at 11,328 mi^2, with half of that in the European portion of the country (Elbakidze et al. 2011). Russia is a signatory to many international conventions and has developed a national strategy for biodiversity conservation.[75] A case study of implementing FSC standards found that in Russia the forestry practices accommodated area-sensitive species by maintaining larger patches of older forest than in corresponding areas of Sweden (Elbakidze et al. 2011). However, a recent review of forest certification standards in Russia highlights bad practices.[76]

Canada

About 78% of forest cover in Canada is boreal.[77] During European settlement the commercial harvesting of boreal forest began near water transportation where most settlement occurred and spread farther inland as road or rail infrastructure developed. About 90% of forested land in

[74] Food and Agriculture Organization of the United Nations. 2010. Global Forest resources assessment 2010, main report. http://www.fao.org/docrep/013/i1757e/i1757e.pdf (Accessed 24 February 2020).
[75] National strategy for biodiversity conservation in Russia. Ministry of Nature resources of the Russian Federation, Moscow. https://www.cbd.int/doc/world/ru/ru-nbsap-01-p1-en.pdf (Accessed 8 March 2020).
[76] Conniff, R. 2018. Greenwashed timber: how sustainable forest certification has failed. YaleEnvironment360. https://e360.yale.edu/features/greenwashed-timber-how-sustainable-forest-certification-has-failed (Accessed 24 February 2020).
[77] Natural Resources Canada. [n.d.] How much forest does Canada have? https://www.nrcan.gc.ca/forests/report/area/17601 (Accessed 24 February 2020).

Canada is owned by federal, provincial, or territorial governments.[78] Forests dominated by spruce, pine, and poplar are used for local lumber or energy needs, product manufacturing including paper, or export. On most government (Crown) lands where timber harvest is regulated, wood supply is the estimated sustainable yield over a rotation period based on timber volume or area that can be harvested during a shorter period.[79] Timber harvest is predominantly on public lands and occurs among the 10 provinces under auspices of a variety of forest tenures that are agreements that outline conditions between companies, a community or individual, and the government.[80] However, the tenure system may be increasingly evaluated for its relevance in delivering policy outcomes for sustainability in a changing society and economic competitiveness in global fiber markets (Haley and Nelson 2007).

In the last 20 years, the total area of protected lands in Canada has increased by almost 70%, to 11% of land area,[81] but not all of that is in forest. Land uses outside of protected areas where development is restricted or prohibited (parks, reserves, or other designations)[82] are a major factor in landscape planning of forest management in boreal Canada (Johnson and Miyanishi 2012). In addition to seral effects of logging, removal of forest cover for agricultural expansion, development of minerals and hydrocarbon fuels, and attendant creation of surface access or seismic lines for subsurface geophysical exploration, can increase human access and differently affect habitat use and thus interactions between predators and prey (e.g., Neufeld 2006, Latham et al. 2011, Wasser et al. 2011). Inundation behind dams constructed for hydropower can also result in loss of forested ecosystems and associated uses on sometimes extensive areas (e.g., the James Bay project in Quebec flooded 69,140 mi^2). These flooded areas may be remote from larger settlements when supporting electricity for mines (Johnson and Miyanishi 2012).

Fire, insects, wind, and other natural disturbance agents generally continue to play a dominant role in boreal forest in Canada.[83]An exception may be that the burn rate (mean annual proportion of area burned) in eastern Canada has decreased in recent decades, likely from a combination of increasingly effective suppression and climate change (Gauthier et al. 2009a; Girardin et al. 2009). Commercial salvage of timber commonly occurs after fire and insect mortality to utilize wood fiber before decay reduces suitability for dimension lumber or other uses. For economic efficiency, clearcut logging was the predominant practice on public lands in British Columbia

[78] Precise proportion depends on source: National Forestry Database [n.d.] http://nfdp.ccfm.org/en/index.php (Accessed 24 February 2020); Natural Resources Canada. [n.d.] Forest Land ownership. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/sustainable-forest-management/forest-land-ownership/17495 (Accessed 24 February 2020); Natural Resources Canada. 2010. The State of Canada's Forests. https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/31835.pdf (Accessed 24 February 2020; see also Haley and Nelson 2007).

[79] National Forestry Database, wood supply. http://nfdp.ccfm.org/en/data/woodsupply.php (Accessed 24 February 2020).

[80] National Status [Canada]. 2005. Criteria and indicators of sustainable forest management in Canada. http://www.ccfm.org/ci/rprt2005/english/pg89-115_5-2-1.htm (Accessed 24 February 2020).

[81] Environment and Climate Change Canada. 2017. Canadian environmental sustainability indicators, Canada's protected areas. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators.html (Accessed 8 March 2020).

[82] Environmental Reporting BC. 2017. Land Designations that contribute to conservation in B.C. state of environment reporting. Ministry of Environment and Climate Change Strategy, British Columbia, Canada. http://www.env.gov.bc.ca/soe/indicators/land/land-designations.html (examples for British Columbia; Accessed 24 February 2020).

[83] National Forestry Database, Canada. http://nfdp.ccfm.org/index_e.php (Accessed 24 February 2020; by province or territory in http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/31835.pdf)

until the 1990s, when a rapid transition to clearcutting with reserves was implemented.[84] Exceptions to retention occurred with large clearcuts in the extensive salvage response to record widespread mortality from mountain pine beetles beginning in the 1990s and more recently from spruce bark beetles in northcentral B.C., with bark beetle mortality of trees presently at a 45-fold increase over pre-outbreak levels in 2013.[85] The pine beetle outbreak is attributed to effective fire suppression that created vast areas of mature pine susceptible to attack and warming conditions that have allowed distributional shift of pine beetles during climatic conditions conducive to irruptions (Taylor and Carroll 2004). Concerns have been raised over the potential effects from a high proportion and spatial extent of dead wood salvage on local or regional hydrology, biological diversity, and other ecosystem services (Dhar et al. 2016). Bunnell et al. (2004) advised when monitoring effects of large-scale salvage that resources be prioritized to address questions with the greatest ecological or economic uncertainty and potential impact, and they provided examples of indicator metrics.

Research to develop guidelines for emulating natural disturbance regimes with forest management in Canada has occurred for the eastern and mid-continent boreal forest dominated by black spruce, jack pine, and quaking aspen (Gauthier et al. 2009b). The western boreal forest dominated by mixed forest of lodgepole pine, quaking aspen, and white spruce with balsam fir, balsam poplar, black spruce, and paper birch is closer in composition to Alaska boreal forest. The Ecosystem Management Emulating Natural Disturbance Project (EMEND),[86] located near Peace River, Alberta, is a large-scale variable retention harvest experiment designed to answer questions about how retention of green tree residuals affects harvest cost, forest regeneration, patterns of succession, biodiversity (including avian response), nutrient cycling, ground water characteristics, and public perception. EMEND is a long-term project that began in 1998 and is forecasted to run for 1 stand rotation of 80–100 years.

Canada has pledged to implement SFM.[87] At the end of 2016 Natural Resources Canada reported the country had about 48% (656,250 mi^2) of its forested land independently certified for legal and sustainable practices, the highest proportion of any country and about one-third of the global total for certified forest lands.[88] Burton et al. (2003a) compiled substantial information on social, economic, and ecological facets of SFM for Canada, including recommendations for implementation. One mechanism is through model forests (part of an international network) that are voluntary partnerships based on dialog, experimentation, and innovation.[89] Another is the

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[84] Environmental Reporting BC. [n.d.] Land & forests: Trends in silviculture in B.C. [web page} http://www.env.gov.bc.ca/soe/indicators/land/silviculture.html (Accessed 4 March 2020).

[85] Kurjata, K. 2018. B.C. spruce beetle outbreak now largest in recorded history. Canadian Broadcasting Corporation. 9 January 2018. http://www.cbc.ca/news/canada/british-columbia/spruce-beetle-spread-1.4478589 (Accessed 4 March 2020).

[86] University of Alberta, Canada. [n.d.] EMEND Project: Ecosystem based research into boreal forest management. Department of Natural Resources. https://emend.ualberta.ca/ (Accessed 20 March 2020)

[87] Government of Canada. [n.d.] Sustainable forest management [web page]. Natural Resources Canada. https://www.nrcan.gc.ca/forests/canada/sustainable-forest-management/13183 (Accessed 4 March 2020)

[88] Government of Canda [n.d.] Forest certification in Canada [web page]. Natural Resources Canada. https://www.nrcan.gc.ca/forests/canada/certification/17474. (Accessed 4 March 2020). Additional information on certification by province is available in the publication "The State of Canada's Forests" at http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/31835.pdf (Accessed 4 March 2020).

[89] Government of Canada. [n.d.] Canada and the International Model Forest Network [web page]. Natural Resources Canada. http://www.nrcan.gc.ca/forests/canada/sustainable-forest-management/13181 (Accessed 4 March 2020).

Canada Boreal Forest Stewardship Agreement[90] signed in 2010 as a partnership between the forest industry, government jurisdictions, and First Nations.

British Columbia

Our review of wildlife habitat guidelines and reported evaluations of SFM policy with a strong wildlife component suggested the most comprehensive and prescriptive effort in boreal forest close to Alaska was in British Columbia. A wildlife tree[91] committee was formed in 1985 with resource professionals and worker safety representatives (Keisker 2000) and a workshop convened to establish the state of knowledge for conserving stand-level biodiversity (Bradford et al. 1995). Sampling of wildlife trees and coarse woody debris occurred in a range of seral stages (recently cut to mature) to characterize baseline conditions (Manning et al. 2001). The province issued a retention policy for wildlife trees[92] in 2000 as part of its Forest Practices Code for "over 80 vertebrate species known to be critically dependent on wildlife trees." To guide implementation, a detailed review (Keisker 2000) described in summary tables the habitat functions of wildlife trees and coarse woody debris and the habitat requirements of 133 vertebrate species from north-central B.C. Although it has additional tree and wildlife species not found in Alaska, this comprehensive resource provides context for application to Alaska, including insight on habitat connections (travel corridors) and notes where data on feature size or other factors were insufficient at the time of writing. Further guidance on stand- and landscape-level practices were provided in a biodiversity guidebook (B.C. Forest Practices Code 1995)[93] and monitoring protocols (B.C. Forest Practices Code 1999)[94] and by Voller and Harrison (1998). Recent fires also prompted guidance on post-disturbance retention (Nicholls and Ethier 2018).

British Columbia took a managed landscape approach for habitat conservation rather than the simple dichotomy of protected vs. managed areas; the latter implicitly assumes protected areas remain beneficial as wildlife habitat simply because they lack human intervention. Habitat reserves (late seral, riparian, unique feature, etc.) are a means to improve biodiversity conservation in managed landscapes (Steeger et al. 1999). However, wildlife use of reserves may change if the reserves are affected by natural disturbances or small but cumulative human actions in the surrounding landscape (road extension, residential construction, timber harvest, etc.). Some reserves are expected to remain free of management,[95] but if conditions change over time, it may be prudent to implement management actions intended to help meet habitat objectives. Other reserves may be managed after a period during which the surrounding harvested lands

[90] Canfor [n.d.] Canadian Sustainability Report [web page]. https://www.canfor.com/sustainability-report-2016/Environment/Canadian-Boreal-Forest-Agreement (Accessed 8 April 2020).
[91] Wildlife trees are trees with snags, cavities, witch's brooms, etc. that are used by wildlife.
[92] Provincial Wildlife Tree Policy and Management Recommendations, February 2000. https://www.for.gov.bc.ca/hfp/publications/00034/wltpolicyfinalmay15-00.pdf (The policy cited a 1996 estimate by the Chief Forester that implementing this code would result in a reduction in provincial timber supply of 1.8%.)
[93] Forest Practices Code of British Columbia. 1995. Biodiversity Guidebook, September 1995. https://www.for.gov.bc.ca/hfd/library/documents/bib19715.pdf
[94] Managing identified wildlife: procedures and measures, Volume 1, at http://www.env.gov.bc.ca/wld/frpa/iwms/iwms.html (accessed 5 March 2020)
[95] Reserves in managed lands are not necessarily protected areas in the context of national parks or wilderness areas in the U.S. However, wilderness values (e.g., minimal evidence of human activity and restraint in future activities) and wildlife habitat values (Appendix C) are separate concepts.

have regenerated forest to a specified structural objective for habitat value (Appendix D, Guideline 2d).

There was some government evaluation of B.C. forest practices for conserving wildlife habitat through the mid-2000s, including of habitat features (e.g., Bradford et al. 2003) and to a lesser extent wildlife use of retained features (e.g., Mowat 2000). Academic research has continued on the effectiveness of retention practices (e.g., Sullivan and Sullivan 2014). However, we found little information online or in the literature after 2006 about government monitoring of forest practices for wildlife in B.C. except response strategies for insect irruptions.[96] The decrease in public agency monitoring and evaluation of wildlife habitat may have resulted from fewer staff available to do the work and a shift to less prescriptive forest policies to address the mountain pine beetle outbreak. However, 2 recent reports make recommendations for improving forest management. The first evaluated compliance with forest practices (B.C. Forest Practices Board 2014) and the second evaluated the effectiveness of monitoring for wildlife habitat (B.C. Forest Practices Board 2017).

Yukon Territory

The Yukon Territory is immediately east of the Tanana Valley and is the closest jurisdiction to Alaska with forest management guidelines for wildlife habitat. Most timber harvest occurs in the more productive mixed coniferous-deciduous forest types of the boreal cordillera in southern Yukon (Jorgenson and Meidinger 2015, Cooke et al. 2019) where most settlement has occurred along a limited road network at roughly the same elevation as the Tok area and a bioclimate similar to the Tanana Valley (Jorgenson and Meidinger 2015: Fig. 3). A provincial forest strategy and planning framework was created for the environment and economy following agreements between First Nations and the Yukon government with a goal of forest health and several principles and objectives designed to support adaptive management (Yukon Government 1998). There are now 3 Forest Resource Management Plans covering large areas and a fourth is in progress,[97] wherein planning and regulation of resource management within First Nation territories (defined in land claim agreements) receive local input from 10 Renewable Resource Councils. Commercial and personal use harvesting from public land is regulated through licenses and permits.[98]

The Yukon Forest Resources Act prescribes standards[99] for retention area radius around mineral licks, active and inactive bear dens, game trails, and stick or cliff nests for raptors. The Yukon Forestry Handbook (Yukon Government 2015) further provides recommendations for design of harvest blocks to maintain landscape connectivity (minimizing barriers to wildlife movement)

[96] Government of British Columbia. 2017. Omineca Region Guidance: Stand and Landscape-Level Retention for Harvesting in Response to Spruce Beetle Outbreaks. 09 September 2017. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/retentionguidance_spruce_beetle_20sept2017.pdf (Accessed 24 February 2020).
[97] Yukon Government, Energy, Mines, and Resources. [n.d.] Forest Management Plans: Forest Management Planning. http://www.emr.gov.yk.ca/forestry/forest_management_planning.html (Accessed 24 February 2020).
[98] Yukon Government, Energy, Mines, and Resources. [n.d.] Forestry: Licenses and Permits. http://www.emr.gov.yk.ca/forestry/licences_permits.html (Accessed 24 February 2020).
[99] Yukon Government, Energy, Mines, and Resources. [n.d.] Yukon Forest Resources Act. Wildlife Features Standard. http://www.emr.gov.yk.ca/forestry/pdf/Wildlife_Features_Standard_final_2014.02.27.pdf (Accessed 24 February, 2020).

and identifying characteristics of wildlife trees and coarse woody debris that warrant retention as habitat. These practices may be identified in site plans and/or implemented where conflict with utilization of dead timber or reduction of hazardous fuels is reconciled. Recommendations for salvage logging in Yukon (Cooke et al. 2019) provide guidance on wildlife habitat during salvage of dead or injured trees after fires or insect irruptions.

To conclude, the approaches in Canada and Alaska to wildlife research, management, and education are similar. Both areas have low ratios of people to resources and large expanses of public land, and most responsibility for land management is assigned to government agencies. Canadian universities have no clear legal mandate to provide technical knowledge through extension services to resource users and managers (Bunnell et al. 1995).[100] Alaska has had little boreal forest research since the Institute of Northern Forestry at the University of Alaska–Fairbanks closed in 1991, the Alaska Cooperative Extension Service has not employed a forestry specialist since 2016, and the University of Alaska no longer offers a forestry emphasis in natural resource management.

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[100] In 1862 the U.S. Congress passed the Land-Grant College Act (Morrill Act) to finance the establishment of colleges specializing in agriculture and the mechanic arts (https://www.britannica.com/topic/Land-Grant-College-Act-of-1862 [Accessed 3 April 2020]). In addition to teaching and research, such colleges assumed a third responsibility for extension or outreach of technical knowledge to farmers that has broadened to other topics and segments of society over time, including forestry practices (https://nifa.usda.gov/extension [Accessed 3 April 2020]).

Appendix G. Raw imagery, ecological classifications, and modeled species predictions with potential to describe wildlife habitat features and gradients in the Tanana Valley.

Public access satellite imagery

- NASA worldview2 (https://worldview.earthdata.nasa.gov/ [Accessed 3 March 2020]): resolution 0.46 m (18 in) panchromatic and 1.84 m (71 in) 8-band multi-spectral.
- NASA G-LiHT (https://glihtdata.gsfc.nasa.gov/ [Accessed 3 March 2020]): resolution 1 m (39 in) canopy height and digital terrain from Lidar, hyperspectral and thermal sensors in portions of the Tanana Valley.

Cover type classifications

- Tanana Valley stand inventory polygons (Fig. 2 this bulletin) with emphasis on the state forest portion in PDF (Hanson 2013) or geographic information system (GIS) files (available from the DOF; preliminary landscape metric layers were produced from rasterized data available from T. Paragi).
- Alaska Natural Heritage Program vegetation map for northern, western, and interior Alaska (https://accscatalog.uaa.alaska.edu/dataset/alaska-vegetation-and-wetland-composite [Accessed 3 March 2020]): 30 m (102 ft) resolution.
- Circumboreal Vegetation Map (Jorgensen and Meidinger 2015) in PDF (https://www.caff.is/strategies-series/359-the-alaska-yukon-region-of-the-circumboreal-vegetation-map-cbvm/download [Accessed 19 October 2018]) or GIS stand polygons (https://www.sciencebase.gov/catalog/item/5702b1dee4b0328dcb817848 [Accessed 3 March 2020]).
- The National Land Cover Database (https://www.mrlc.gov/ [Accessed 3 March 2020]) contains 16 cover types and type changes (2001 to 2011) for Alaska at 30 m (102 ft) resolution.

Modeled raster predictions of species diversity

- Tree size and species diversity for boreal Alaska: 1 km (0.6 mile) resolution (Young 2012, Young et al. 2017). Data available from brianyoung@landmark.edu.
- Current and future small mammal species distributions and species diversity: 5 km (8 mi) resolution statewide, resampled to 100 m (328 ft) resolution in the Fairbanks area (Baltensperger and Huettmann 2015). Statewide data available from abaltens@alaska.edu; resampled Fairbanks data are available from T. Paragi.

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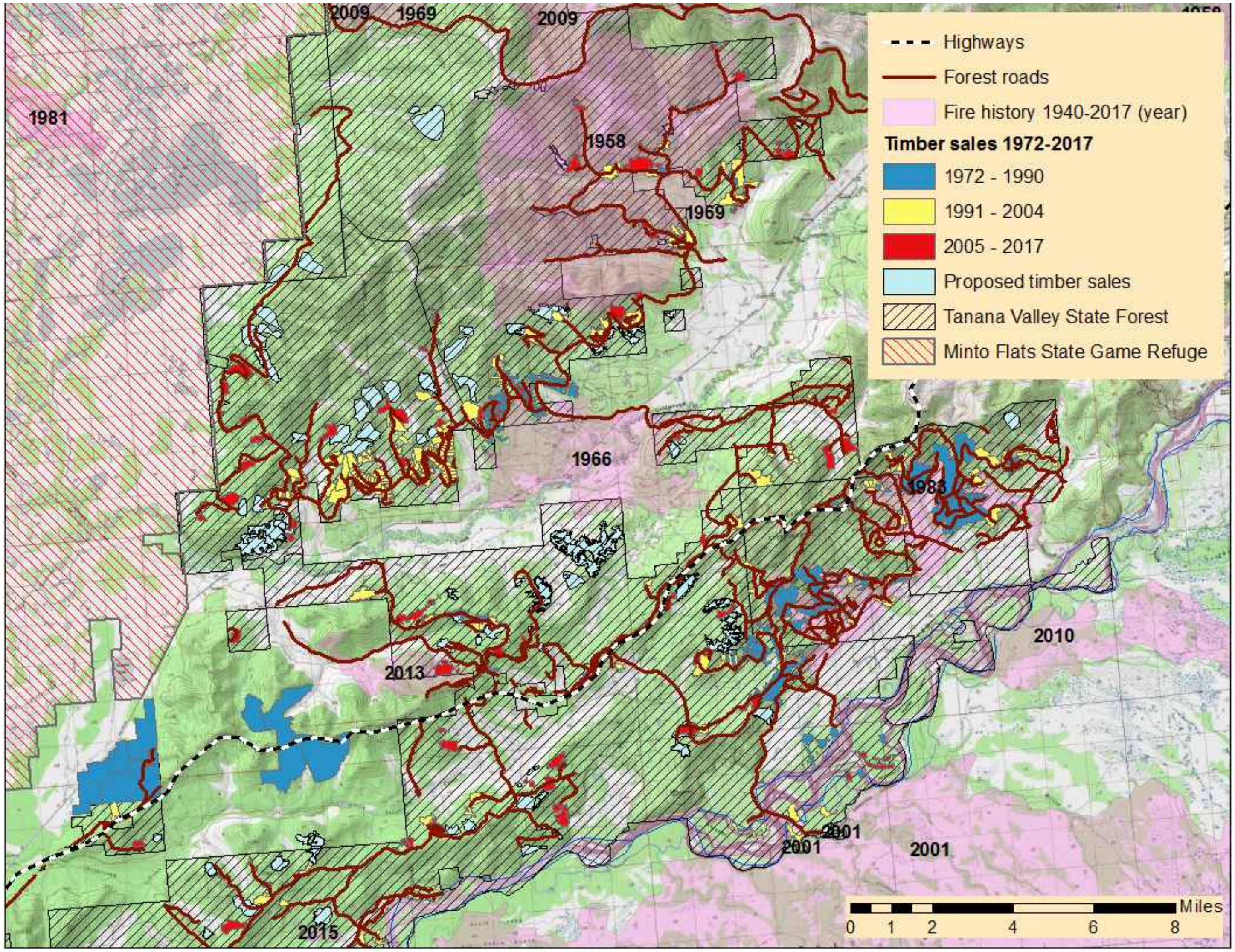
Appendix H. Example maps of timber sales and forest roads.

Example maps[101] of harvested and planned timber sales and historic fires along the forest road network in or near the Tanana Valley State Forest.[102] The roads are mix of all season and winter only; not all are actively used or maintained. Figure H1 shows that the area west of Fairbanks has the most extensive forest road network and timber harvest because of its proximity to town. Extensive fire salvage from the 1983 Rosie Creek burn (Fig. B7, Appendix B) is evident to the right of center, whereas large agricultural clearings in the 1970s occurred to the west along the Parks Highway. Figure H2 shows that most timber harvest in the lower Shaw Creek basin east of the Richardson Highway has been fire salvage along the Pogo Mine road. Figure H3 shows that most harvest from the Tok Cutoff Highway has been near the floodplain of the Tok River. Geographic information system (GIS) data from the Tok Area are presently being updated.

[101] An alternative to mapping is the quantitative approach to illustrate trends in ecology and management as disturbance per annum by fire and logging and grouping by decade as done in Alberta (Lee and Bradbury 2002).
[102] There are no all-season roads in the Kantishna portion of the state forest; most of the comparatively limited harvest in that area has occurred along winter roads near the Tanana River floodplain north of Nenana.

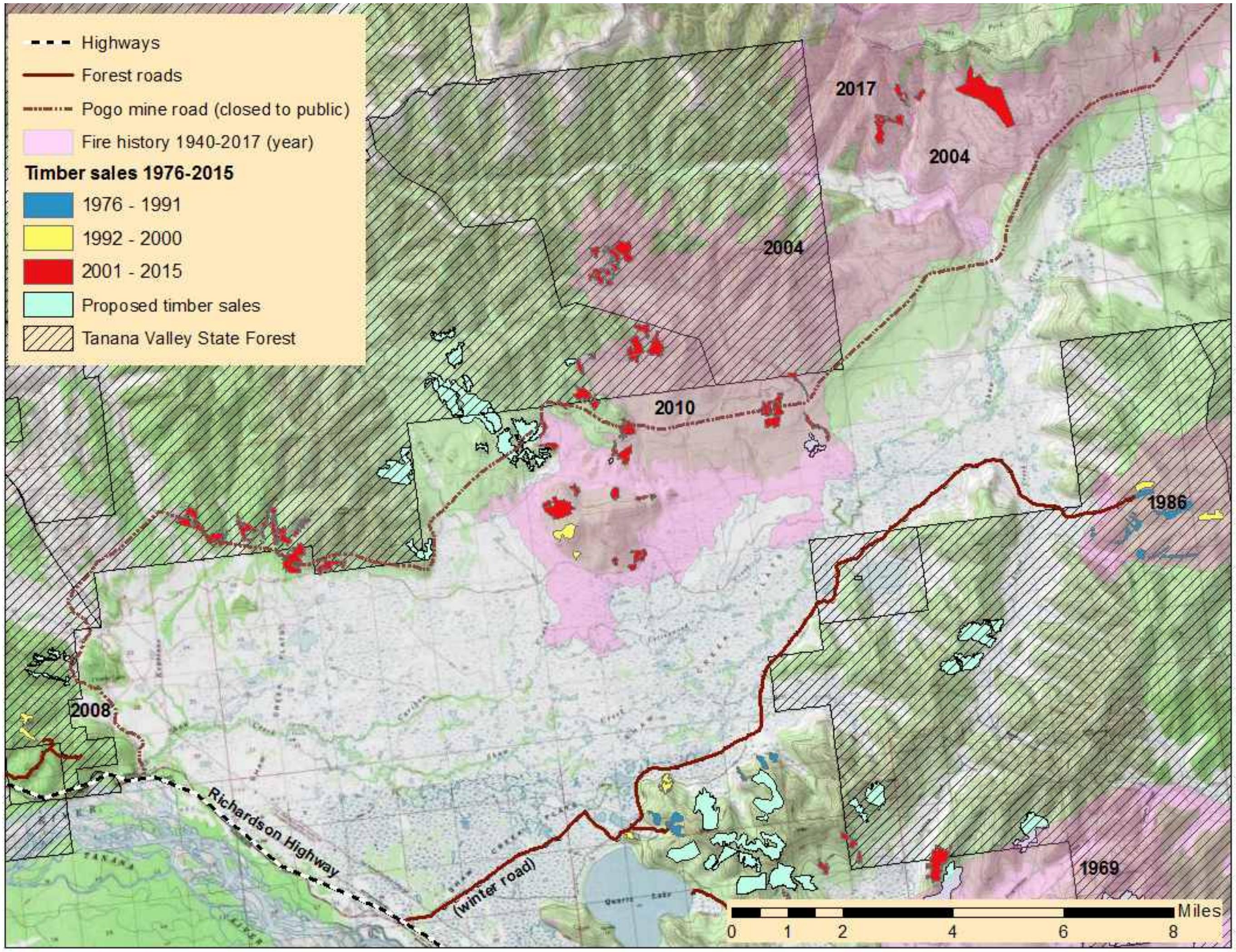
Appendix H continued.



2018 ADF&G map by T. Paragi.

Figure H1. Example map of timber sales 1972–2017 and fire history 1940–2017 in Fairbanks area, Alaska.

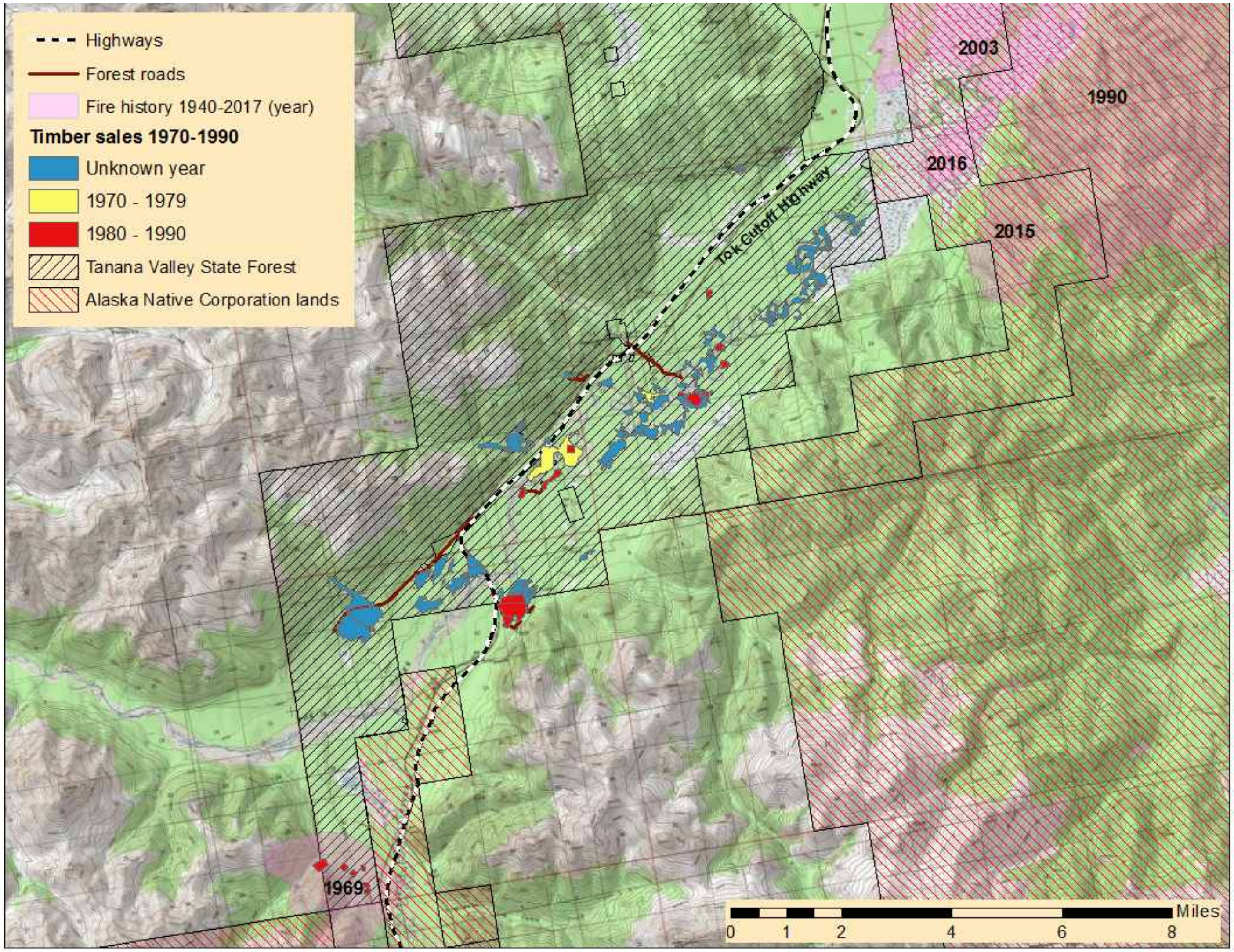
Appendix H continued.



2018 ADF&G map by T. Paragi.

Figure H2. Example map of timber sales 1976–2015 and fire history 1940–2017 in the Delta area, Alaska.

Appendix H continued.



2018 ADF&G map by T. Paragi.

Figure H3. Example map of timber sales 1970–1990 and fire history 1940–2017 in the Tok area, Alaska.

Appendix I. Species of Greatest Conservation Need in eastern Interior Alaska.

Table I1 lists bird and small mammal species likely to occur in managed forests of eastern Interior Alaska that the State of Alaska designated Species of Greatest Conservation Need (SGCN) in its latest State Wildlife Action Plan (Alaska Department of Fish and Game [ADF&G] 2015). Justifications for the SGCNs presented in Table I1 were based on one or more criteria outlined below. SGCNs designated as "Declining" and/or "Species of Concern" were collectively considered "at risk" (ADF&G 2015:30).

Declining

Species were declining significantly in North America, as indicated by long-term survey data (e.g., Breeding Bird Survey[103] [BBS] and/or Christmas Bird Count[104] [CBC]).

Species of Concern

Species were considered of concern based one or both of the following:

a. High-level rank in key conservation reports when the State Wildlife Action Plan was created, such as the Alaska Landbird Conservation Plan, Alaska Shorebird Conservation Plan, or the 2014 State of the Birds Report.
b. An expert scientific/management team, such as the Alaska Raptor Group[105] or the ADF&G Waterfowl program.[106]

Stewardship species

A stewardship species exhibited a large percentage of its population (for birds) or range (for mammals) within Alaska (e.g., >60%) and/or was already identified as a continental or regional stewardship responsibility at the time the Alaska State Wildlife Action Plan was written.

Sentinel species

Sentinel species are important indicators of ecosystem health or environmental changes, as populations and/or distribution are particularly sensitive to change.

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[103] United States Geological Survey (USGS). [n.d.] North America Breeding Bird Survey [web page]. Patuxent Wildlife Research Center. https://www.usgs.gov/centers/pwrc/science/north-american-breeding-bird-survey (Accessed 8 March 2020).
[104] Audubon. [n.d.] Audubon Christmas Bird Bird Count [web page]. https://www.audubon.org/conservation/science/christmas-bird-count (Accessed 8 March 2020).
[105] USGS. [n.d.] Alaska Raptor Group [web page]. Alaska Science Center. https://www.usgs.gov/centers/asc/science/alaska-raptor-group (Accessed 8 March 2020).
[106] ADF&G [n.d.] Waterfowl Program [web page]. https://www.adfg.alaska.gov/index.cfm?adfg=waterfowlhunting.main (Accessed 16 March 2020).

Cultural value

The Alaska State Wildlife Action Plan identified species of high cultural, economic, or commercial value statewide. The latter 2 categories refer to fishing and crabbing industries not applicable to this report. However, some terrestrial SGCNs found in boreal forest of eastern Interior Alaska fell within the “cultural value” category, as identified by the Division of Subsistence at ADF&G.

Ecological value

Species of high ecological value are of central importance to proper ecosystem functioning. The category includes, for example, certain species of small mammals that are a critical food source to many other predators within boreal forest. Hence, the designation includes prey species that exert disproportionate influence on ecosystem structure and/or biological function.

Alaska is fortunate in that no terrestrial species or subspecies is currently listed as threatened or endangered under the Endangered Species Act (ESA). Consequently, no ESA criterion was included in identifying SGCN.

Greater detail for all SGCN criteria, species distribution and habitats, and references are provided in the State Wildlife Action Plan (Alaska Department of Fish and Game 2015:28–32, Appendices A, B, and D).

(See table next page)

Table I1. Bird and small mammal Species of Greatest Conservation need (SGCN) likely to occur in managed boreal forest of eastern Interior Alaska.[A]

			SGCN Justification					
Group	**Common name**	**Scientific name**	**Declining**	**Species of Concern**	**Stewardship species**	**Sentinel species**	**Culturally important**	**Ecologically important**
BIRDS								
Ducks, Geese and Swans	Trumpeter Swan	*Cygnus buccinator*			✓			
Ducks, Geese and Swans	Lesser Scaup	*Athya affinis*				✓	✓	
Ducks, Geese and Swans	White-winged Scoter	*Melanitta deglandi*				✓	✓	
Raptors	Harlan's Red-tailed Hawk	*Buteo jamaicensis harlani*		✓	✓			
Raptors	Bald Eagle	*Haliaeetus leucocephalus*			✓	✓	✓	
Raptors	Golden Eagle	*Aquila chrysaetos canadensis*		✓	✓			
Raptors	Peregrine Falcon	*Falco peregrinus*			✓			
Raptors	American Kestrel	*Falco sparverius*	✓	✓				
Raptors	Northern Harrier	*Circus cyaneus*	✓	✓		✓		
Raptors	Great Grey Owl	*Strix nebulosi*		✓				
Raptors	Northern Hawk Owl	*Surnia ulula*		✓	✓			
Raptors	Boreal Owl	*Aegolius funereus*		✓		✓		
Kingfishers and Woodpeckers	Belted Kingfisher	*Megaceryle alcyon*	✓	✓				
Kingfishers and Woodpeckers	Hairy Woodpecker	*Dryobates villosus sitkensis*[B]			✓			
Kingfishers and Woodpeckers	Downy Woodpecker	*Dryobates pubescens glacialis*[B]			✓			
Kingfishers and Woodpeckers	American Three-toed Woodpecker	*Picoides dorsalis*						✓
Woodpeckers	Black-backed Woodpecker	*Picoides arcticus*			✓			✓
Woodpeckers	Northern Flicker	*Colaptes auratus luteus*	✓	✓	✓			
Cranes	Lesser Sandhill Crane	*Grus canadensis canadensis*			✓		✓	
Sandpipers	Spotted Sandpiper	*Actitus macularius*	✓					
Sandpipers	Lesser Yellowlegs	*Tringa flavipes*	✓	✓				
Sandpipers	Solitary Sandpiper	*Tringa solitaria cinnomomea*		✓	✓			
Sandpipers	Whimbrel	*Numenius phaeopus hudsonicus*		✓	✓			
Sandpipers	Hudsonian Godwit	*Limosa haemastica*		✓				
Gulls and Terns	Mew Gull	*Larus canus brachyrhynchus*					✓	
Gulls and Terns	Herring Gull	*Larus smithsonianus*	✓					

			SGCN Justification					
Group	**Common name**	**Scientific name**	**Declining**	**Species of Concern**	**Stewardship species**	**Sentinel species**	**Culturally important**	**Ecologically important**
Larks, Crows, Jays	Canada Jay	*Perisoreus canadensis pacificus*			✓			
Larks, Crows, Jays	Common Raven	*Corvus corax kamtschaticus*[B]			✓			
Nuthatches, Chickadees and Swallows	Bank Swallow	*Riparia riparia*	✓	✓				
Nuthatches, Chickadees and Swallows	Tree Swallow	*Tachycinetta bicolor*	✓					
Nuthatches, Chickadees and Swallows	Black-capped Chickadee	*Poecile atricapillus*			✓			
Nuthatches, Chickadees and Swallows	Boreal Chickadee	*Poecile hudsonicus*		✓	✓			
Kinglets	Ruby-crowned Kinglet	*Regulus calendula grinnelli*[B]			✓			
Kinglets	Golden-crowned Kinglet	*Regulus satrapa*	✓					
Creepers	Brown Creeper	*Certhia americana alascensis*				✓		
Flycatchers	Alder Flycatcher	*Empidonax alnorum*	✓		✓			
Flycatchers	Olive-sided Flycatcher	*Contopus cooperi*	✓	✓		✓		
Flycatchers	Western Wood-pewee	*Contopus sordidulus*	✓					
Shrikes	Northern Shrike	*Lanius excubitor*			✓			
Thrushes	Swainson's Thrush	*Catharus ustulatus*	✓					
Thrushes	Hermit Thrush	*Catharus guttatus*			✓			
Thrushes	Varied Thrush	*lxoreus naevius*		✓	✓			
Waxwings, Warblers	Bohemian Waxwing	*Bombycilla garrulus*			✓			
Waxwings, Warblers	Orange-crowned Warbler	*Orethlypis celata*	✓					
Waxwings, Warblers	Blackpoll Warbler	*Setophaga striata*		✓	✓			
Waxwings, Warblers	Yellow Warbler	*Setophaga petechia*	✓					
Waxwings, Warblers	Townsend's Warbler	*Setophaga townsendi*			✓	✓		
Waxwings, Warblers	Wilson's Warbler	*Cardellina pusilla pileolata*	✓	✓	✓			
Sparrows	White-crowned Sparrow	*Zonotrichia leucophrys*	✓					
Sparrows	American Tree Sparrow	*Spizella arborea*	✓					
Sparrows	Fox Sparrow	*Passerella iliaca*	✓					

			SGCN Justification					
Group	**Common name**	**Scientific name**	**Declining**	**Species of Concern**	**Stewardship species**	**Sentinel species**	**Culturally important**	**Ecologically important**
Sparrows	Song Sparrow	*Melospiza melodia*	✓					
Sparrows	Lincoln's Sparrow	*Melospiza lincolnii*			✓			
Sparrows	Dark-eyed Junco	*Junco hyemalis oreganus*[B]			✓			
Blackbirds	Rusty Blackbird	*Euphagus carolinus carolinus*[B]	✓	✓	✓	✓		
Grosbeaks	Pine Grosbeak	*Pinicola enucleator flammula*[B]			✓			
Finches	White-winged Crossbill	*Loxia leucoptera*			✓			
Finches	Hoary Redpoll	*Carduelis hornemanni*			✓			
Finches	Common Redpoll	*Carduelis flammea*	✓					
Finches	Pine Siskin	*Spinus pinus*	✓	✓				
MAMMALS								
Squirrels	Northern Flying Squirrel	*Glaucomys sabrinus*						✓
Squirrels	Red squirrel	*Tamiasciurus hudsonicus*						✓
Lemmings	Northern Bog Lemming	*Synaptomys borealis*						✓
Voles	Northern Red-backed Vole	*Myodes rutilus*						✓
Voles	Singing Vole	*Microtus miurus*			✓			✓
Voles	Tundra Vole	*Microtus oeconomus*			✓			✓
Voles	Meadow Vole	*Microtus pennsylvanicus*						✓
Voles	Yellow-cheeked Vole (Taiga Vole)	*Microtus xanthognathus*			✓			✓
Mice	Meadow Jumping Mouse	*Zapus hudsonius*						✓
Hares	Snowshoe Hare	*Lepus americanus*					✓	✓
Shrews	Dusky Shrew	*Sorex monticolus*				✓		
Shrews	Tundra Shrew	*Sorex tundrensis*				✓		
Bats	Little Brown Bat	*Myotis lucifugus*				✓		

[A] Detailed SGCN justification, distribution and habitats are provided in the State Wildlife Action Plan (Alaska Department of Fish and Game 2015; p.28–32, Appendices A, B, and D).

[B] The subspecies listed as SGCN may not extend to Interior Alaska, but the species to which it belongs is a common and biologically relevant part of boreal forest, so is included here. Note that the Alaska State Wildlife Action Plan only considers the subspecies, not the species, to be an official SGCN (ADF&G 2015).

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Appendix J. Common and scientific names for Alaska species listed in text and footnotes.

This appendix lists wildlife and plants commonly found in boreal forest habitats of the Tanana Valley State Forest, including some Species of Greatest Conservation Need that are listed in Appendix I. Bird taxonomy follows Gibson et al. (2018), insect follows Forest Pests of North America,[107] mammal follows MacDonald and Cook 2009), and vegetation follows Viereck and Little (2007)

Birds
American peregrine falcon (*Falco peregrinus anatum*)[108]
Arctic peregrine falcon (*Falco peregrinus tundrius*)
Blackpoll warbler (*Setophaga striata*)
Common raven (*Corvus corax*)
Gray-cheeked thrush (*Catharus minimus*)
Northern flicker (*Colaptes auratus*)
Northern shrike (*Lanius borealis*)
Olive-sided flycatcher (*Contopus cooperi*)
Ruffed grouse (*Bonasa umbellus*)
Spruce grouse (*Falcipennis canadensis*)
Townsend's warbler (*Setophaga townsendi*)
Trumpeter swan (*Cygnus buccinator*)

Insects
Mountain pine beetle (*Dendroctonus ponderosae*)
Spruce beetle (*Dendroctonus rufipennis*)

Mammals
Barren-ground caribou (*Rangifer tarandus granti*)
Woodland caribou (*Rangifer tarandus caribou*)
Little brown bat (*Myotis lucifugus*)
Canadian lynx (*Lynx canadensis*)
American marten (*Martes americana*)
Moose (*Alces alces*)
Northern flying squirrel (*Glaucomys sabrinus*)
Northern red-backed vole (*Myodes rutilus*)
Red fox (*Vulpes vulpes*)
Red squirrel (*Tamiasciurus hudsonicus*)
Snowshoe hare (*Lepus americanus*)
Short-tailed weasel (*Mustela erminea*)
Wolf (*Canis lupus*)
Vegetation

[107] Bugwood. [n.d.] Forest Pests of North America. https://www.forestpests.org/Insects/bark-beetles.cfm (Accessed 22 October 2018)
[108] Peregrine falcon subspecies were identified in the TVSF Management Plan (Alaska Division of Forestry 2001:15-16).

Alaska birch (*Betula neoalaskana*)
Balsam poplar (*Populus balsamifera*)
Black spruce (*Picea mariana*)
Lodgepole pine (*Pinus contorta*)
Quaking aspen (*Populus tremuloides*)
White spruce (*Picea glauca*)
Willow (*Salix* spp.)

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