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Maintaining wildlife habitat in southeastern Alaska: implications of new knowledge for forest management and research

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Abstract

We review results and implications from recent wildlife studies that followed from the 1997 Tongass Land Management Plan (TLMP) and identify information needs and directions for research, development, and application. Sustained population viability of wildlife species was identified as a major issue in the TLMP planning process. Several species were identified as management indicator species, and research was conducted to determine their potential sensitivity to forest management. Southeastern Alaska was found to be a region with an especially high degree of endemism in its small mammal fauna, principally because of the combination of its archipelago geography combined with highly dynamic glacial history. Two species of endemic small mammals selected for demographic study, however, appeared to be less dependent on old-growth forests than had been suspected at the time TLMP was written: the northern flying squirrel (*Glaucomys sabrinus*) because of relatively high suitability of noncommercial, low-volume, mixed-conifer forest; and the southern red-backed vole (*Clethrionomys gapperi*) because of relatively high suitability of precommercially thinned young-growth forest. The northern goshawk (*Accipiter gentilis*) was found to be problematic for "management indicator" status because of logistical difficulties involved in monitoring this relatively rare, highly mobile species that frequently changes nest sites. Sampling protocols were developed for marbled murrelet (*Brachyramphus marmoratus*), although murrelet populations do not appear to be in trouble on the Tongass. The conservation strategy of TLMP for American marten (*Martes americana*) appeared to be sound on Chichagof Island where marten have been studied intensively, but implications for the rest of southeastern Alaska were unclear without further work. Studies of the Alexander Archipelago wolf (*Canis lupus ligoni*) indicated that population density of black-tailed deer (*Odocoileus hemionus*) and road access (to wolf hunters) were the predominant factors affecting wolf productivity and mortality, respectively. Finally, studies of bird community response to timber-harvest alternatives to clearcutting indicated that although creation of forest "edge" may increase nest predation rates, the actual response depends on a broad array of factors and is highly variable.

We suggest that research, development, and application focus on plant and animal communities and management of vegetation to achieve specific objectives for wildlife habitat. We suggest that such efforts emphasize silviculture of second-growth forests, understanding old-growth reserves, distribution of endemic small mammals, and alternatives to clearcutting. Models for evaluating black-tailed deer habitat and populations are needed for subsistence-hunting management, and some work needs to be directed at interactions between tourism and selected wildlife species.
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1. Introduction

Land-management plans that provide for sustainable use of forest resources rank high in importance among issues involving conservation of natural resources (Rauscher, 1999). Management of natural resources for sustained use has become increasingly complex (Murphy and Noon, 1991; Thomas, 1991). Among the challenges is a management goal of continued use of multiple resources without diminishing ecosystem function and biological diversity (Thomas and Dombeck, 1996; Rauscher, 1999). The challenge of sustainable management of forest resources is great in southeastern Alaska where the nation's largest national forest, the Tongass, recently revised its Land and Resource Management Plan (USDA Forest Service, 1997; Everest, this issue). Because of its size (6.9 million ha), and naturally fragmented and isolated nature (Smith, this issue), the Tongass National Forest (hereafter, "the Tongass") has many unique features that challenge forest planners (Everest, this issue). Five significant management issues were identified as strategic in the 1997 Tongass Land Management Plan (TLMP): fish habitat protection, cave and karst resources, alternatives to clearcut timber harvesting, social and economic issues (especially those influencing the subsistence lifestyle of indigenous people of the region), and wildlife viability (Everest et al., 1997; Iverson and René, 1997; USDA Forest Service, 1997).

Wildlife viability ranks high among land-management issues on public lands (Thomas, 1991; Iverson and René, 1997), and consideration of wildlife habitat has shaped the development of land-management alternatives (Forest Ecosystem Management Assessment Team—FEMAT, 1993; Lehmkuhl et al., 1997). The National Forest Management Act of 1976 requires that the USDA Forest Service manage national forest lands without reducing diversity of animals (Thomas, 1991; FEMAT, 1993; Thomas and Dombeck, 1996; Iverson and René, 1997). Maintaining viable populations of all species, widely distributed throughout the forest, is a key requirement.

Large-scale, commercial logging was the major factor affecting changes in wildlife habitat on the Tongass in 1997. Commercial logging's potential effects on wildlife viability within the Tongass were evaluated through several processes. "Conservation assessments" (Iverson and René, 1997) synthesized available information on three management indicator species that were being considered for potential listing as "threatened" or "endangered" under the Endangered Species Act: the northern goshawk (*Accipiter gentilis*), Alexander Archipelago wolf (*Canis lupus ligoni*), and marbled murrelet (*Brachyramphus marmoratus*). Additionally, forest-wide strategies were developed for maintaining habitat to support viable wildlife populations and functional old-growth ecosystems across the Tongass (Iverson and René, 1997). Various combinations of strategies and management options became distinguishing elements of an array of forest plan alternatives that were assessed through an "effect analysis" to determine impacts to various forest resources (USDA Forest Service, 1997). Risk assessment panels were commissioned to evaluate the effects on habitat capability or risk to viability of several old-growth-associated wildlife species (Shaw, 1999). Among those were American marten (*Martes americana*), brown bear (*Ursus arctos*), Alexander Archipelago wolf, northern goshawk, marbled murrelet, and other terrestrial mammals that were evaluated as two groups: widely distributed species, and endemic small mammals. A panel was convened for black-tailed deer (*Odocoileus hemionus*) because of concerns over significant reduction of habitat capability and its potential effects on subsistence hunting and wolf populations, which depend primarily on deer as a prey base (Person et al., 1996). After the writing of TLMP, several studies were initiated to follow up on key information needs identified in the TLMP process.

The purpose of this report is three-fold: (1) to provide a brief background of studies that were initiated as follow-up to the TLMP; (2) to review major findings of those studies; and (3) to identify information needs and directions for future research. Specifically, we summarize the results and implications of studies of evolutionary diversity of endemic small mammals and ecology of endemic populations of the southern red-backed vole (*Clethrionomys gapperi*), the northern flying squirrel (*Glaucomys sabrinus*), the northern goshawk, and the marbled murrelet. We also summarize results of ongoing studies of American marten and wolf ecology that were not TLMP follow-up studies per se, but which generated valuable information relative to future management of the Tongass and reduction of risk to population viability. In addition, we include new information from a study of the composition of bird communities in old-growth coniferous forests of southeastern Alaska. We then identify major areas of needed research, development, and application.

2. Background

An important outcome of the conservation assessments was awareness that there were substantial gaps in basic knowledge of the natural history and ecology of wildlife subspecies indigenous to southeastern Alaska. Information needs were prioritized, and several TLMP follow-up efforts were initiated, including studies of endemic small mammals, northern goshawk, and marbled murrelet. Additionally, a study was initiated to examine alternative systems of timber harvest (i.e., other than clearcutting) because of increasing interest in harvesting trees in a manner that approaches the natural disturbance regime of the region more closely.

Studies of endemic small mammals included two general topics: (1) documenting endemism in the mammal fauna, which included questions about taxonomy and phylogeography; and (2) ecology of endemic arboreal and forest-floor small mammals. The dynamic geological history and naturally fragmented nature of the southeastern Alaska archipelago has produced an environment where the potential for endemism is high. Yet, there was little knowledge of the distribution and diversity of mammals. There also had been no quantitative studies of habitat distribution or demography of old-growth-associated small mammals in southeastern Alaska.

An ongoing, interagency study of nesting ecology and movements of the northern goshawk was continued, and a study of diet composition during the breeding season was initiated. The Queen Charlotte goshawk (*A. g. laingi*) is an endemic subspecies of the region and was petitioned for listing as "endangered" under the Endangered Species Act. It was not listed as endangered, however, primarily because too little information existed to accurately assess population status. Concerns remained that continued broad-scale conversion of old-growth forest to young, even-aged stands would imperil goshawk populations on the Tongass (USDI Fish and Wildlife Service, 1995). The northern goshawk is a reputed old-growth forest associate with large home range requirements (Iverson et al., 1996). Goshawks are probably prey-limited in southeastern Alaska (Iverson et al., 1996); yet, there has been little quantitative information available about diet, key prey species, or attributes of foraging habitat during the breeding season. Suitable nesting and foraging areas are essential to sustaining viable populations (Iverson et al., 1996). Preliminary studies across the Tongass indicated low breeding densities and a preference for old-growth forests (Pendleton et al., 1998), with evidence of recent cumulative impacts from commercial logging (Iverson et al., 1996).

The marbled murrelet is unique among wildlife species in southeastern Alaska because it spends most of its time offshore but nests inland in late-seral coniferous forests (Piatt and Ford, 1993; Nelson, 1997). In California, Oregon, and Washington, marbled murrelets are listed as a "threatened" species under the Endangered Species Act because of the legacy of clearcut logging of coastal coniferous forests in the Pacific Northwest and the reputed dependence of marbled murrelets on late-seral forests for nesting (Nelson, 1997). Preliminary evidence indicated that marbled murrelets were not declining in southeastern Alaska (DeGange, 1996), but as with many other management indicator species, data regarding natural history and population dynamics are few. Crucial information needs for marbled murrelets relative to land-management planning on the Tongass included development of a sampling protocol to monitor inland populations (DeGange, 1996).

Several management indicator species were already the focus of ongoing studies and thus were not part of the TLMP follow-up effort. These included the American marten and Alexander Archipelago wolf. The American marten has large home range requirements and has been proposed as a species that requires landscape-level management (Bissonette et al., 1989). A reputed old-growth associate, martens apparently avoid clearcuts, and their abundance is correlated with habitat features that are typical of older forest; they also are believed to be sensitive to habitat fragmentation (Bissonette et al., 1989; Hargis et al., 1999). Ongoing research in southeastern Alaska indicates that American marten reproduction may be linked to vole (*Microtus* spp.) population levels (Flynn and Schumacher, 2001). Small mammals composed the largest portion of their diet in years when *Microtus* and *Peromyscus* populations were high, and they preferentially sought small mammals even when populations were low (Ben-David et al., 1997). An important question related to marten population viability in southeastern Alaska is whether riparian and beachfront buffers provide sufficient connectivity among old growth reserves in managed landscapes, a fundamental assumption of the 1997 TLMP conservation strategy (USDA Forest Service, 1997).

Concern about wolf population viability is linked directly to the cumulative impact of commercial logging on the habitat capability for black-tailed deer, the primary prey of the Alexander Archipelago wolf (Person et al., 1996). The legacy of five decades of commercial logging left a significant portion of forested landscapes (up to 50% of some Ranger Districts) in second-growth stands that have dense canopies and little understory, thus providing little forage for deer (Person et al., 1996). Understanding the implications of past clearcut logging on deer populations and developing silvicultural prescriptions that improve second-growth stands for deer are important for reducing future effects on wolf populations.

Finally, there has been growing interest in finding logging methods as alternatives to clearcut logging for harvesting wood from the forests of southeastern Alaska with minimum deleterious effects on wildlife habitat and other resources. Individual-tree selection, small group selection, and various levels of live-tree retention have been suggested as alternatives to clearcutting. Stand features resulting from such harvest systems differ especially in the size and distribution of canopy openings and the amount and spatial configuration of "edge" (Forman and Godron, 1986). The size of canopy openings and amount and distribution of edge are believed to have significant implications for wildlife habitat (Hayward et al., 1999), especially for forest landbirds (Gates and Gysel, 1978). An important consideration in managing forests with alternatives to clearcutting is the additional fragmentation and forest edge that may result from creating more canopy openings across a larger proportion of the landscape to obtain comparable levels of timber volumes. The composition and abundance of bird communities in old-growth forests and the role of forest edge in avian community structure in southeastern Alaska are important information that was virtually unknown at the time of the 1997 TLMP analysis.

3. Findings

3.1. Endemic small mammals

3.1.1. Evolutionary diversity and taxonomy

Conservation of biological diversity requires maintaining the evolutionary diversity of organisms indigenous to a region (Cook and MacDonald, 2001), as well as ecological components and processes (Smith, this issue). A solid evolutionary framework is fundamental to documenting endemism throughout southeastern Alaska (Cook et al., 2001). Early expeditions to southeastern Alaska surveyed about 1% ($n = 22$) of the named islands and documented 27 endemic mammal taxa with an additional 12 indigenous taxa having ranges largely restricted to the region (MacDonald and Cook, 1996; Smith, this issue). More recent studies added to the total number of surveyed islands ($n = 87$), documented that the structure of the mammal fauna in the Alexander Archipelago was nested, and used modern genetic techniques to review the taxonomy of previously described forms and conduct phylogeographic analyses (MacDonald and Cook, 1996; Conroy et al., 1999; Cook et al., 2001). Southeastern Alaska has 48 extant native, land mammal species with the highest number occurring in the Upper Lynn Canal Region and the highest number of endemic taxa occurring in the Mainland Subregion. Smith (this issue) summarizes the indigenous small (<10 kg) mammal taxa of southeastern Alaska. Whereas some reputed endemics showed nominal levels of genetic divergence among conspecific populations, there was more genetic differentiation in some taxa than was reflected in the current taxonomy (Cook et al., 2001). For example, the long-tailed vole (*Microtus longicaudus*), which includes two subspecies from the Alexander Archipelago, exhibited only a single distinctive genetic lineage. In contrast, some single subspecies (e.g., black bear; *Ursus americanus pugnax*) comprise multiple lineages (Cook et al., 2001) and, perhaps, should be multiple subspecies. Acute genetic variation was reported for five species that were composed of two or more clades.

Northern flying squirrel and southern red-backed vole showed minimal levels of genetic divergence. Still, flying squirrels on the 11 islands of the Prince of Wales Island complex exhibited distinct mitochondrial lineage, low heterozygosity and allelic diversity, and severely reduced genetic variation (Bidlack and Cook, 2001, 2002). Genetic variation among southern red-backed vole populations was consistent with the current subspecific taxonomy. However, the current ranges depicted for red-backed voles (i.e., *C. gapperi* and *C. rultilus*) in southeastern Alaska (MacDonald and Cook, 1996) are in need of revision (Amy Runck, Alaska Department of Fish and Game, unpublished observations of occurrences outside the depicted ranges).

Recent evidence suggests that the mammal fauna of southeastern Alaska is composed of multiple elements with discontinuities and different histories representing distinct regional assemblages. It is much more complex than was suspected only a decade ago. Although Cook and MacDonald (2001) and their students have provided a wealth of new information in recent years, the evolutionary diversity and taxonomy of endemic small mammals of southeastern Alaska is just beginning to be understood.

3.1.2. Distribution and ecology of flying squirrels

Northern flying squirrels in southeastern Alaska are known to occur on the mainland east of Glacier Bay National Park and south of the Chilkat River (MacDonald and Cook, 1996). They have not been documented on Etolin or Woronkofski Island; the islands north of Sumner Strait (except Mitkof Island), and the islands south of Revillagigedo Island. The Prince of Wales flying squirrel (hereafter squirrel) is known from the Prince of Wales Island complex, a group of 11 islands including Prince of Wales and nearby islands along its western shore (MacDonald and Cook, 1996; Smith, this issue). A reputed associate of old-growth coniferous forests in the Pacific Northwest, this species occurred in upland old-growth western hemlock (*Tsuga heterophylla*)–Sitka spruce (*Picea sitchensis*) forests and largely noncommercial peatland/mixed-conifer forests of Prince of Wales Island (Smith and Nichols, 2003).

Squirrel densities vary depending on forest type, seral stage, and management history (Smith, this issue). In old-growth forests of the Tongass, densities were among the highest reported in northwestern North America (Smith, this issue; Smith and Nichols, 2003). Squirrel densities in mixed-conifer forests were less than in old growth, but were comparable to densities reported for some old-growth Douglas-fir (*Pseudotsuga menziesii*) stands in Washington (Carey et al., 1992). Age and sex composition, mean body weight, and juvenile recruitment of squirrels did not differ between habitats on Prince of Wales Island. However, summer survivorship and density of reproductive females were higher in old growth than in mixed-conifer forests (Smith and Nichols, 2003). Juvenile weights averaged 119 g on Prince of Wales Island, which is 20–40% higher than means reported for Oregon and Washington (Villa et al., 1999). Mean adult weights during spring (129 g) and autumn (123 g) (Smith and Nichols, 2003), however, seem to fall within the range of variation reported from Oregon and Washington for squirrels of similar age (Villa et al., 1999). Juvenile recruitment into the fall population was lower on Prince of Wales Island than in the Pacific Northwest (Villa et al., 1999), which may have been related to density-dependent influences on natality or survival on Prince of Wales (Smith and Nichols, 2003).

Possible factors contributing to demographic variation between Prince of Wales Island and the Pacific Northwest include predation, competitive release, and diet (Pyare et al., 2002; Smith and Nichols, 2003). In southeastern Alaska, there are no known predators that specialize on squirrels, such as the spotted owl (*Strix occidentalis*) does in the Pacific Northwest (Carey et al., 1992); and the small mammal community is relatively depauperate compared to the Pacific Northwest (Carey, 1991). Squirrel diets on Prince of Wales Island differed substantially from the Pacific Northwest (Pyare et al., 2002). Important habitat attributes associated with high densities of squirrels in the Pacific Northwest include complex forest canopy, tree decadence, large live and dead trees (standing and downed), and a well-developed understory of ericaceous shrubs (Carey et al., 1999). In southeastern Alaska, it is unclear what habitat features are important ecological correlates of abundance, but squirrel populations are apparently not limited to old-growth, spruce–hemlock forests. Peatland/mixed-conifer habitat likely contributes to breeding populations in managed landscapes and thus may reduce risks to population viability (Smith and Nichols, 2003). Nevertheless, important questions remain about dispersal and the influence of annual population fluctuations on habitat distribution and demography in managed landscapes.

3.1.3. Distribution and ecology of southern red-backed voles

The southern red-backed vole (hereafter vole) occurs as four endemic subspecies in southeastern Alaska: two subspecies reputedly occur on the mainland south of the Taku River (but see Smith et al., 2001), and two subspecies are island endemics of the nearshore islands Wrangell and Revillagigedo (MacDonald and Cook, 1996). This species is reputedly associated with old-growth coniferous forests (Nordyke and Buskirk, 1988; Aubry et al., 1991; Smith, this issue). Regardless of forest type, voles seem to favor mesic habitat and moist microenvironments (Odum, 1944), probably because of an unusually high physiological need of free water (Getz, 1962, 1968; McManus, 1974). In southeastern Alaska, voles occurred in old-growth forest, recently thinned young-growth stands (20–25 years old), and to a much lesser extent peatland/mixed-conifer forests (Smith and Nichols, 2004). Voles apparently prefer sites with abundant stumps, downed coarse woody debris (especially rotting logs), and exposed roots within a loose forest litter (Merritt, 1981; Moses and Boutin, 2001). Vole abundance has been linked to understory cover, which likely promotes a moist microclimate, provides important foods, and affords ample escape cover (Nordyke and Buskirk, 1991).

Vole densities reported for coniferous forests of the Pacific Northwest differ by an order of magnitude according to region, forest type, land use, and methodology (Smith, this issue). Unfortunately, densities from the Pacific Northwest were not computed with estimates of effective area sampled (Swift and Steinhorst, 1976), which can differ among habitats, and therefore are not directly comparable to estimates from southeastern Alaska (Smith and Nichols, 2004). In southeastern Alaska, voles consistently achieved their highest densities in old-growth forest, which was the highest ranked habitat according to several demographic parameters (Smith and Nichols, 2004). In contrast, vole density was very low in peatland/mixed-conifer forest, which invariably was the habitat ranked lowest in quality and probably was incapable of supporting breeding populations. Thinned young-growth stands supported breeding populations, at least in years when population levels were relatively high (Smith and Nichols, 2004). Moreover, mean body mass, minimum summer and overwinter survival, age and sex composition, and percentage of reproductive females did not differ between thinned young-growth and old-growth forests.

These results depart from the pattern reported for the Pacific Northwest (Aubry et al., 1991; Sullivan et al., 2000) and have significant implications for population viability in managed landscapes. It remains unclear what habitat attributes are necessary to sustain vole populations in southeastern Alaska, but it appears that breeding populations can exist in managed young, second-growth stands that have a relatively open canopy and developing understory (Smith and Nichols, 2004). Still, there remain several important areas that warrant further study: (1) influence of annual fluctuation in population levels on vole habitat distribution and demography in managed landscapes; (2) habitat capability of older second-growth (i.e., stem exclusion) stands; (3) benefits to vole habitat of precommercial and commercial thinning; and (4) stand and landscape features that limit dispersal.

3.2. Northern goshawk

An interagency study was initiated in 1991 with the goal of understanding the ecological relationships of nesting goshawks, including nesting area use, productivity, and movements on the Tongass National Forest, yet study results were not complete at the onset of the 1997 TLMP (Iverson et al., 1996; Flatten et al., 2001). Consequently, subsequent research was conducted to increase the database and study diet composition during the 1998 and 1999 nesting seasons (Lewis, 2001).

Observations revealed that areas of use (95% minimum convex polygons from radio-telemetry relocations) were large and varied among male and female goshawks (Flatten et al., 2001). Use areas during the breeding season (1 March–15 August) averaged 4153 and 4785 ha for females and males, respectively. During the nonbreeding season (16 August-28 February), use areas averaged 32,961 and 16,503 ha for females and males, respectively. "Nesting areas" included perch sites, roosts, and nest structures within a breeding-season use area. Based on the maximum movement of adults between nest structures in consecutive nesting years (range 0.5–3.2 km, $n = 24$), nesting areas were up to 3.2 km in diameter (804 ha).

Average occupancy of nesting areas by radio-tagged adults was 1.9 years for males and 1.6 years for females. Some nesting areas may have been used for

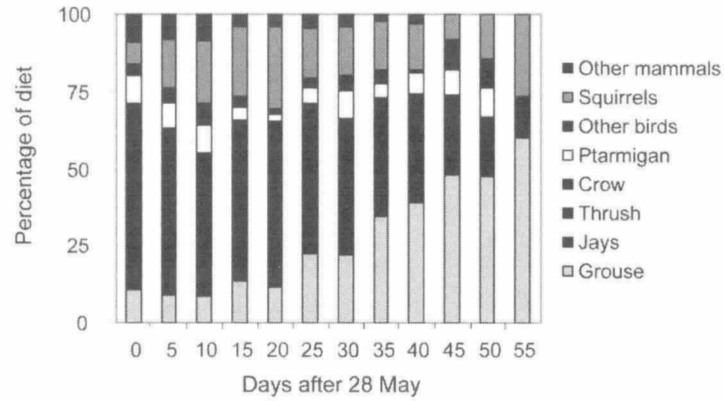

Fig. 1. Prey groups delivered over 5-day intervals throughout the nesting season (beginning at the start of first surveillance, 28 May) to all video-monitored northern goshawk nests in southeast Alaska, 1998–1999. Figure illustrates that regardless of date, there is much variability in the diet, and diet diversity may change over the nesting season, possibly reflecting either differences in availability or preference by adults (source: Lewis, 2001).

longer consecutive periods, but factors such as radio failure limited the number of years that a site was monitored. Nonetheless, occupation of a nesting area for more than 3 consecutive years was rare.

Goshawk productivity appeared to vary geographically across the Tongass (Flatten et al., 2001). An average of 28.4% of known nest sites were occupied annually during 1991–1999, but this differed across the region: 13% in northern, 20% in central, and 53% in southern study areas. Goshawks averaged 2.0 fledglings per active nest, which was comparable to goshawk populations elsewhere (Iverson et al., 1996).

Goshawk diets differed substantially among nests during the breeding season (Fig. 1), and within nests between years (Fig. 2; Lewis, 2001). Blue grouse (*Dendragapus obscurus*), spruce grouse (*Falcipennis canadensis*), ptarmigan (*Lagopus* spp.), red squirrels (*Tamiasciurus hudsonicus*), Steller's jays (*Cyanocitta stelleri*), varied thrushes (*Ixoreus naevius*), northwestern crows (*Corvus caurinus*), and small passerines (Passeriformes, Class: Aves) dominated the diet, although frequency of each prey species differed among nests, during the nesting season, and between years (Figs. 1 and 2; Lewis, 2001). Goshawks used a diversity of prey species, with birds representing a much greater percentage of prey than mammals, both in terms of number of deliveries to the nest and prey remains (78% versus 22% and 91% versus 9%, respectively). The variability in diet among nests could be attributable to differences in prey availability, nesting chronology (differences in prey vulnerability), or individual goshawk preferences (Lewis, 2001).

Current protective measures of goshawk habitat on the Tongass National Forest are "nest-based", i.e., a no-harvest buffer of 40.5 ha around known nest trees (USDA Forest Service, 1997). However, areas used by known goshawk breeding pairs are substantially larger than this buffer, especially when nests from multiple years are considered (Flatten et al., 2001). When radio-tagged goshawks nested in consecutive years in the same nesting territory, only 54% of alternate nests fell within the 40.5 ha buffer surrounding the initial nest site; a 314 ha buffer included 79% of the nests. Consequently, under current habitat management guidelines, potential nest sites may be subject to timber harvest, which ultimately may compromise the quality of the breeding territory. Goshawks tend not to use the same nest site in subsequent years, so availability of alternative nest sites in the breeding territory is an important habitat feature (Flatten et al., 2001). In addition, current guidelines may not adequately protect important foraging habitat either.

Management implications of the diet study are less clear than are those of the nesting study. Timber management affects community structure of many prey species, such as forest birds, by modifying vegetative structure and composition (Willson and Gende, 2000). Cumulative impacts of clearcut logging also influence populations of arboreal (DeSanto and Willson, 2001) and forest-floor mammals (Smith and Nichols,

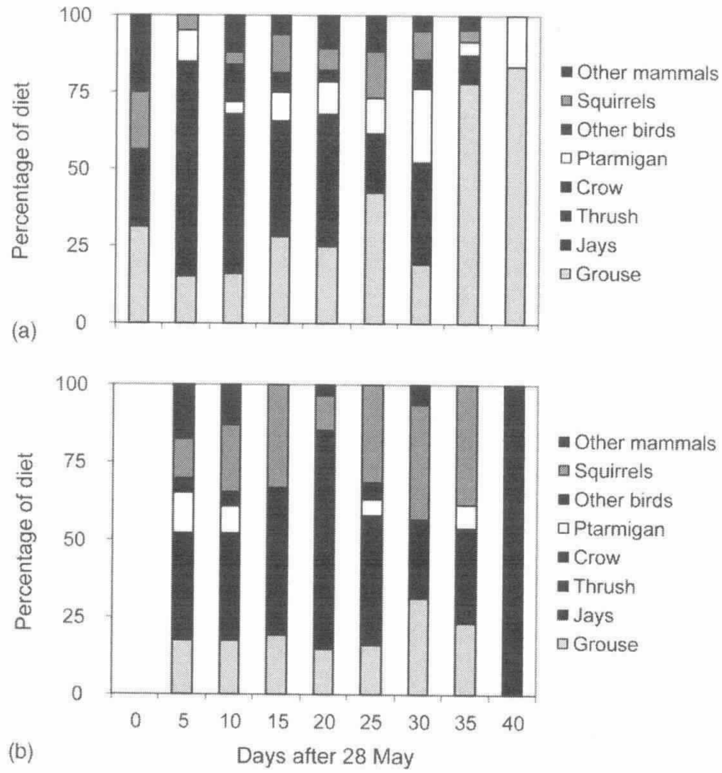

Fig. 2. Prey groups delivered over 5-day intervals throughout the nesting season (beginning at the start of first surveillance, 28 May) to northern goshawk nests near Fish Creek, Douglas Island, in 1998 (a) and 1999 (b). Figure illustrates the annual variability in goshawk diet in same geographic area (source: Lewis, 2001).

2004). Timber management, through influences on stand structure, also may affect the ability of goshawks to capture their prey (Iverson et al., 1996). Unfortunately, little is known about relations between forest structure and abundance of prey species or their vulnerability to predation. Furthermore, the degree to which goshawks on the Tongass depend on certain prey species for successful reproduction is unknown. Although evidence indicates that goshawks can use a wide diversity of prey (Lewis, 2001), it is unclear whether that has positive or negative implications for population viability. In areas of this species' range where it occurs at higher densities, goshawks concentrate on a few, large bird (e.g., grouse) or mammal (e.g., ground squirrel) prey species (Iverson et al., 1996). When a substantial portion of the prey delivered to nests are small, passerine nestlings (Lewis, 2001), the question is raised about whether a breeding pair can adequately provide food for their young (Iverson et al., 1996).

Because of its large home range requirements and close association with old-growth forests, the northern goshawk was proposed as a management indicator species early in the TLMP process (Sidle and Suring, 1986). However, that was subsequently reconsidered because of a paucity of specific ecological information, and because preliminary data indicated that monitoring goshawk populations would be problematic (Iverson et al., 1996). Recently, a thorough analysis of data from the 10-year interagency study confirmed early predictions about the infeasibility of monitoring goshawk populations on the Tongass. Time and resources required for finding nest sites (with and without radio tags), large home ranges, movements of goshawks among nest sites within nesting areas, and logistics of accessing remote locations used by goshawks render monitoring of goshawk populations on the Tongass impractical (Flatten et al., 2001). Consequently, the northern goshawk will likely be eliminated from further consideration as a management indicator species for the Tongass National Forest in subsequent forest plans.

3.3. Marbled murrelet

The 1997 TLMP established a habitat conservation strategy for marbled murrelets (hereafter murrelets) that involved protection of near-shore, low-elevation, old-growth forests (USDA Forest Service, 1997). Long-term monitoring of inland population levels has been proposed as a means of testing the conservation strategy (Smith and Harke, 2001). Quantifying murrelet population trends is difficult because of murrelets' secretive and unpredictable behavior and the associated variability in dawn counts that results during inland surveys (Jodice and Collopy, 2000). Smith and Harke (2001) surveyed murrelets at fixed point-count stations during mid-July for 6 years with 10 min dawn surveys (Paton et al., 1990) to quantify this variation for the purpose of estimating sample size (number of survey stations) and duration (number of years) that would yield sufficient statistical power to detect a meaningful decline in detections. They reported that the number of fixed point-count stations necessary to detect significant variation among years, with 95% confidence, was 22 stations (Smith and Harke, 2001). Number of years required for detecting an annual decrease of 10% varied according to precision of estimates (Table 1). By visiting each station 12 times annually, it may be possible to detect a 10% annual decrease in 6 years, i.e., a cumulative decline of 50% (Smith and Harke, 2001).

Table 1
Number of point-count stations per year needed to discern significant annual variation, and number of consecutive years of sampling required to detect an annual 10% decline in murrelet detections at two levels of variation (CV), and associated probabilities of a Type I (α) and Type II (β) error when f (effect size index) is 0.4.

Stations/year	Consecutive years to detect an annual 10% decline		Type I (α)	Type II (β)
	CV = 0.507	CV = 1.523		
22	19	46	0.05	0.05
18	17	42	0.05	0.10
16	16	39	0.05	0.15
14	15	37	0.05	0.20
15	16	38	0.10	0.10
14	14	35	0.10	0.15
12	14	32	0.10	0.20
11	13	30	0.10	0.25
9	12	28	0.10	0.30

Source: Smith and Harke (2001).

In a pilot study to determine feasibility of using radio-telemetry to study nesting behavior and ecology, Nelson et al. (1999) captured nine murrelets near Juneau and followed their movements for an average of 67 days. Capture success (netting from an inflatable watercraft) was dependent on ambient light, as birds were captured only on dark, cloudy nights. Inland visits for each bird consistently occurred between 1:30 and 6:45 a.m., but the short duration of visits precluded following murrelets to potential nest sites (Nelson et al., 1999). Inland activity was concentrated along slopes and ridges of the Mendenhall River Valley. At-sea locations were concentrated in Auke Bay and Fritz Cove (near Juneau) until 19 June, after which murrelets were regularly located in Icy Strait near the mouth of Glacier Bay (Whitworth et al., 2000). Individual murrelets were identified at inland sites and at sea on the same day on 20 occasions, with some birds detected at sea up to 124 km from their inland locations (Whitworth et al., 2000). This study provided the first direct evidence that murrelets in southeastern Alaska consistently travel considerable distances between potential nesting and foraging areas. Radio-telemetry has promise as a method of obtaining detailed information on murrelet nest-site selection and success without affecting the behavior or survival of birds (Nelson et al., 1999).

3.4. American marten

New findings about American marten in southeastern Alaska since the 1997 TLMP come from two sources: (1) an M.S. thesis (Schumacher, 1999) and (2) the completion of a 10-year study of population dynamics and habitat use (Flynn and Schumacher, 2001). Habitat choice of dens and resting sites revealed that natal dens were in the boles of trees and snags or hard downed logs, and resting sites were beneath the roots of trees and snags (Schumacher, 1999). Martens used larger diameter and less decayed structures at dens than at resting sites, but other attributes of habitat were similar between dens and resting sites. Although martens showed little selection for other specific attributes of habitat at dens and resting sites, they clearly used the largest diameter trees, snags, or stumps available, most of which had evidence of decay and cavities. These findings indicate a high potential value of numerous and well-distributed old, large-diameter structures for marten recruitment.

Habitat selection of radio-collared marten (Schumacher, 1999) was used to evaluate the predictions of a spatially neutral habitat-capability model developed for the TLMP process (Lowell W. Suring, unpublished model on file in Alaska Regional Office, USDA Forest Service, Juneau) and two spatially explicit models developed subsequently (Winston P. Smith, unpublished model on file in Forestry Sciences Laboratory, USDA Forest Service, Juneau, AK). One spatially explicit model incorporated the effect of roads on mortality of marten, whereas the other ignored the effect of roads. Both spatially explicit models predicted substantially lower overall habitat capability than did the spatially neutral model. However, neither of the spatially explicit models improved the prediction of habitat selection of radio-collared martens over the spatially neutral model developed for the TLMP process (Flynn and Schumacher, 2001). Thus, current predictions of relative differences in capabilities of various habitats remain the same today as they were during the 1997 TLMP analyses.

Results from the 10-year study of marten population dynamics and habitat use indicated that populations fluctuated greatly between years, from an estimated low of about 12 to a high of 45 animals within the study area of northeastern Chichagof Island (Flynn and Schumacher, 2001). Marten abundance was invariably lower during winter than during the preceding autumn, reflecting seasonal losses through emigration and mortality. Sex ratios and age structure also varied substantially during the study. Body condition of females during summer and relative abundance of rodents explained 90% of the annual variation in marten fecundity, indicating the high importance of food resources in marten population productivity. Although the 1997 TLMP conservation strategy for marten appears to be sound within the study area of northeastern Chichagof Island thus far, further evaluation over time and in other study areas of the Tongass is needed (Flynn and Schumacher, 2001). However, the American marten is problematic as an indicator species for forest management. Trapping of marten for their fur is a potentially major factor affecting mortality and population dynamics, and trapping effort is driven by a wide range of human social–economic factors quite independent of habitat conditions. Thus, marten population dynamics are highly variable from year to year, and they are the product of variation in weather, food resources, habitat conditions, and trapping.

3.5. Alexander Archipelago Wolf

Wolf research since 1997 has focused on demography of wolves on the Prince of Wales Island complex and the interaction of wolf and black-tailed deer population dynamics. Results confirm much of what was reported by Person et al. (1996) and used in the 1997 TLMP analyses, but several new findings involving home range size and locations, dispersal, mortality, and population dynamics have emerged with implications for forest management.

A strong, inverse relation between home range size of wolves and the proportion of "critical winter habitat for deer" was found (Person, 2001), with larger home ranges in areas with little deer winter habitat, apparently reflecting a need for greater range when deer densities are low. Critical winter habitat for deer was defined as "productive old-growth forest, <250 m elevation, on southern exposures". Similarly, there was a strong positive relation between wolf pack size and proportion of deer winter habitat within home range (Person, 2001), apparently reflecting greater habitat capability for wolves where deer densities are high.

Wolves spent most of their time at low elevation, with over 90% of radiolocations below 300 m, regardless of season (Person, 2001). Consequently, migratory deer that move to alpine habitat in summer likely reduce their risk of predation relative to that experienced by nonmigratory deer that summer at low elevation (McNay and Voller, 1995; Person, 2001). Deer herds that have access to significant amounts of alpine habitat, therefore, might be somewhat buffered from effects of wolf predation relative to herds in ranges with little or no alpine habitat.

Radio-collared wolves have been found to move freely among the islands of the Prince of Wales Island complex, despite separation by ocean distances of up to 4 km (Person, 2001). Person (2001) suspects that the wolves of the Prince of Wales Island complex constitute a single breeding population or, possibly, a metapopulation. Thus, wolves might shift their ranges significantly over time as habitat conditions change, and the absolute number of wolves in a given area may be very difficult to determine.

Humans were the major source of mortality for wolves on the Prince of Wales Island complex, accounting for 89% of mortality of radio-collared wolves between 1993 and 2000 (Person, 2001). The presence of roads had a significant effect on the harvest of wolves. Person (2001) estimated the threshold density of roads that likely would result in over-harvest of wolves (harvest greater than the productive capacity of the wolves) on Prince of Wales Island. They reported that threshold to be >0.53 km/km^2 in areas connected to the main road system of the island and >1.04 km/km^2 in areas not connected to the main road system. Human harvest consisted of both legal and illegal harvest (about equal amounts of each), so road access may remain a significant factor affecting wolf mortality even if legal hunting is closed (Person, 2001).

Person (2001) predicted that the wolf population of the Prince of Wales Island complex would decline as much as 25% between 1995 and 2045 because of the combined effects of past timber harvest and future forest management outlined in the 1997 TLMP. He predicted that the population of deer would decline by 28% during that time, and argued that wolves and deer are subject to "succession debt", wherein the pattern of forest succession initiated by past timber harvest will have long-term effects on the predator–prey system by significantly reducing both the productivity and population size of deer. He argued that currently productive populations of deer and wolves are misleading indicators of future conditions, when young clearcuts will advance into closed-canopy, even-aged stands. Silvicultural management of second-growth forests, therefore, would play a major role in future population dynamics of wolves.

3.6. Alternatives to clearcutting

3.6.1. Bird communities of old-growth forests

Forest birds were surveyed at three sites (blocks) as part of pretreatment measurements in a multidisciplinary study of alternatives to clearcutting (McClellan et al., 2000). Sites included Hanus Bay on Baranof Island (Sitka Ranger District) as the northernmost block, Portage Bay on Kupreanof Island (Petersburg Ranger District) in central southeast Alaska, and Lancaster Cove on southern Prince of Wales Island (Craig Ranger District) as the southernmost block. Within each block, nine different treatments of logging alternatives were planned (McClellan et al., 2000). The pretreatment data provided descriptions of bird community structure and density in old-growth forests on the Tongass (Table 2). Although censused in different years (and thus not directly comparable between sites), there were consistent patterns of bird species density in old growth. For example, chestnut-backed chickadee (scientific names for birds are in Table 2), golden-crowned kinglet, hermit thrush, Pacific slope flycatcher, Townsend's warbler, varied thrush, and winter wren were consistently found in high densities, regardless of site or year. Similar results were found in a survey of research natural areas (RNA) by using similar methods (Smith et al., 2001). Results from the RNA surveys are not directly comparable to the McClellan et al. blocks, because the RNA surveys involved a mosaic of habitats, including forest edge and muskeg, and were censused only once in a season. Nonetheless, community composition was relatively similar in both studies (Table 2).

3.6.2. Habitat fragmentation and edge

Distribution of passerine nest predators and predation rates on artificial nests were quantified along natural and anthropogenic edges to examine whether clearcuts or the edge between recent clearcuts and old-growth forests might influence nesting success of forest passerines (DeSanto and Willson, 2001). Nest predation rates did not differ between clearcut edges and natural, wetland edges. Predation rates in clearcut edges exceeded those of interior forest, however, when clearcuts were near urban areas of Juneau. Elevated predation rates near human habitation reflected elevated densities of nest predators (e.g., crow, raven, Steller's jay). Predation rates on artificial nests were correlated with densities of common nest predators in another study in southeastern Alaska as well (Sieving and Willson, 1998). Predation rates in clearcuts were high and, similarly, were high in old-growth forest adjacent to the clearcuts (DeSanto and Willson, 2001), most likely because of high densities of red squirrels in both clearcuts and adjacent forests. Red squirrels are a common avian nest predator in southeastern Alaska (Sieving and Willson, 1998).

These results indicate that consequences of forest edge for nest predation depend primarily on predator density in surrounding habitat and that a wide range

Table 2
Bird species and their relative densities (number per hectare, $\bar{x} \pm$ S.E.) at three old-growth forest sites and average of seven research natural areas (RNA)[a]

Species	Hanus Bay[b]	Portage Bay[b]	Lancaster Cove[b]	RNA[c]
American robin (*Turdus migratorius*)	0.05 ± 0.05	0 ± 0	0.01 ± 0.01	0.09 ± 0.04
Blue grouse (*Dendragapus obscurus*)	–[d]	–	–	0.06 ± 0.03
Brown creeper (*Certhia americana*)	0.04 ± 0.03	0.48 ± 0.09	0.18 ± 0.09	0.41 ± 0.11
Canada goose (*Branta canadensis*)	–	–	–	0.42 ± 0.18
Chestnut-backed chickadee (*Parus rufescens*)	1.35 ± 0.25	2.01 ± 0.15	1.07 ± 0.22	1.06 ± 0.14
Common raven (*Corvus corax*)	0.04 ± 0.03	0 ± 0	0.08 ± 0.04	0.25 ± 0.08
Dark-eyed junco (*Junco hyemalis*)	0.17 ± 0.09	0.14 ± 0.08	0.01 ± 0.01	0.39 ± 0.10
Downy woodpecker (*Picoides pubescens*)	0 ± 0	0.01 ± 0.01	0 ± 0	–
Golden-crowned kinglet (*Regulus satrapa*)	0.27 ± 0.10	0.83 ± 0.15	1.06 ± 0.13	1.34 ± 0.18
Hairy woodpecker (*Picoides villosus*)	0 ± 0	0.09 ± 0.06	0.09 ± 0.05	0.09 ± 0.04
Hermit thrush (*Catharus guttatus*)	0.45 ± 0.08	0.85 ± 0.17	0.51 ± 0.06	1.68 ± 0.17
Lincoln's sparrow (*Melospiza lincolnii*)	–	–	–	0.18 ± 0.08
Northern flicker(*Colaptes auratus*)	0 ± 0	0.01 ± 0.01	0 ± 0	0.03 ± 0.03
Northwestern crow (*Corvus caurinus*)	–	–	–	0.47 ± 0.20
Northern waterthrush (*Seiurus noveboracensis*)	–	–	–	0.06 ± 0.03
Orange-crowned warbler (*Vermivora celata*)	0.14 ± 0.08	0.01 ± 0.01	0 ± 0	0.29 ± 0.08
Pacific-slope flycatcher (*Empidonax difficilis*)	0.73 ± 0.11	1.89 ± 0.18	2.04 ± 0.1	2.48 ± 0.15
Pine grosbeak (*Pinicola enucleator*)	0.04 ± 0.03	0 ± 0	0 ± 0	–
Red-breasted nuthatch (*Sitta canadensis*)	0 ± 0	0.01 ± 0.01	0.06 ± 0.04	–
Red-breasted sapsucker (*Sphyrapicus ruber*)	0.04 ± 0.04	0.18 ± 0.06	0 ± 0	0.03 ± 0.03
Ruby-crowned kinglet (*Regulus calendula*)	0.36 ± 0.13	0 ± 0	0 ± 0	0.06 ± 0.03
Rufous hummingbird (*Selasphorus rufus*)	0.09 ± 0.05	0.01 ± 0.01	0.01 ± 0.01	0.04 ± 0.02
Steller's jay (*Cyanocitta stelleri*)	0 ± 0	0.08 ± 0.05	0.01 ± 0.01	0.11 ± 0.04
Swainson's thrush (*Catharus ustulatus*)	0 ± 0	0 ± 0	0.54 ± 0.20	0.17 ± 0.06
Townsend's warbler (*Dendrocia townsendi*)	1.15 ± 0.18	1.5 ± 0.25	1.18 ± 0.13	0.63 ± 0.09
Varied thrush (*Ixoreus naevius*)	0.71 ± 0.13	0.82 ± 0.15	0.96 ± 0.17	0.96 ± 0.12
Winter wren (*Troglodytes troglodytes*)	1.29 ± 0.13	1.73 ± 0.24	1.16 ± 0.20	1.04 ± 0.11

Old-growth forest sites include Hanus Bay, Portage Bay, and Lancaster Cove.

[a] Not included are raptors (e.g., bald eagle, *Haliaeetus leucocephalus*), irruptive species (e.g., crossbills, *Loxia* spp.; siskins, *Spinus* spp.), waterbirds (e.g., oystercatchers, *Haematopus bachmani*; murrelets, *Brachyramphus* and *Synthliboramphus* spp.), or species typically associated with deciduous forests (common yellowthroat, *Geothlypis trichas*; Wilson's warbler, *Wilsonia pusilla*; fox sparrow, *Passerella iliaca*).

[b] Pretreatment data from study of alternatives to clearcutting (McClellan et al., 2000) obtained by 50 m-radius point-count estimates (three times per sample): $N = 24$ at Hanus Bay, surveyed in 1995; $N = 27$ at Portage Bay, surveyed in 1996; $N = 27$ at Lancaster Cove, surveyed in 1997 (source: Toni L. DeSanto, USDA Forest Service, Pacific Northwest Research Station, Juneau, AK, unpublished data).

[c] Research Natural Areas encompassed a range of habitats, including muskeg and forest edge, that varied greatly in vegetation cover and forest structure. Sampling was by 50 m radius point-count estimates (one time per sample); number of samples differed among the seven areas. All research natural areas were surveyed in 1997 (source: Smith et al., 2001).

[d] Dashed line indicates none were found.

of predators may respond to forest edge. Thus, passerine community response to alternatives to clearcutting will depend not only on changes in food and nesting resources but also on nest predation rates in relation to changes in the broader wildlife community itself.

4. The future management environment

The management environment of the Tongass National Forest is very different today than it was when the Tongass Land Management Plan was being written in 1995–1997, and it is likely to change even further in the near-term future. First and foremost, there has been a huge decline in both the demand and harvest of timber. Both pulp mills in Sitka and Ketchikan have ceased operation and no longer exist. The annual cut from the Tongass has decreased dramatically. Native corporations, too, are harvesting less timber, as most of their best land has already been harvested, and world demand for their round-log exports has slackened.

Second, the "roadless rule" promulgated in the final days of the Clinton Administration could have major consequences for the geographic pattern of timber harvest in the future, if it is indeed implemented on the Tongass. If so, then future timber harvest will be limited to existing road systems, with two major consequences for wildlife habitat: (1) much more of the Tongass will remain protected from timber harvest, and issues concerning maintenance of viable populations of endemic species will diminish. Issues of annual allowable cut, forest fragmentation, second-growth management, and old-growth reserves will not be applicable in areas where new roads are prohibited. (2) The areas currently accessible by road will be the only significant areas for timber harvest and, therefore, likely could be subject to much more intensive management than in past or current situations. Issues of intensive silviculture of even-aged stands and their landscape pattern will play major roles in blending timber and wildlife habitat objectives there.

Finally, the past decade has brought a huge increase in tourism to southeastern Alaska, and all projections are for that trend to continue (Crone et al., this issue). Although most tourists travel by cruise ship, shore-based tour industries are increasing. The most popular tours are flight-seeing by floatplane or helicopter and boat tours of marine and near-shore wildlife. In addition to organized tours, however, the use of the Tongass for recreation in general is increasing each year and is expected to increase indefinitely. Popular recreational pursuits are hiking, camping, wildlife viewing, fishing, hunting, and photography. The net result of the increase in tourism is much greater and more widespread use of the Tongass by a much more diverse public than has ever been the case in the past.

The changing economy of southeastern Alaska, from a timber-dominated use of the Tongass to a recreation-dominated use, poses many new challenges for forest managers. The five greatest challenges for wildlife habitat are the following: (1) increasing management emphasis on second-growth forests, (2) designing conservation strategies regarding old-growth forests, (3) finding timber-harvest alternatives to clearcutting, (4) managing forest habitats for "subsistence" harvest of black-tailed deer, and (5) minimizing effects of tourism on sensitive species of wildlife.

The future in southeastern Alaska holds an increasing emphasis on second-growth, even-aged forests. More than 160,000 ha of even-aged forests already exist on the Tongass alone, with another 85,000 ha on Alaska Native corporation lands (Eugene DeGayner et al., USDA Forest Service Alaska Region, unpublished report based on data in Forest Service files). Most of that land is the most highly productive land for timber in southeastern Alaska. Silviculture treatments are needed to improve even-aged stands for a variety of resources—timber, wildlife habitat, and other values (e.g., fish habitat, recreation) simultaneously. Additionally, some high-priority, multiple-use areas such as riparian and beach-fringe forests will likely be a focus of intensive management for nontimber values. New approaches to even-aged management involving thinning of older, "commercial"-aged stands and including red alder (*Alnus rubra*) in new clearcuts are potentially on the horizon (Hanley, this issue). However, they currently offer only *potential*, and they need much more research before they might be implemented with any certainty of results.

The current conservation strategy regarding old-growth forests involves reserves (hundreds to thousands of hectares), streamside buffers, and beach-fringe buffers. New challenges lie in evaluating the effectiveness of such reserves and buffers in relation to their size, landscape pattern, and geographic distribution. If road construction is prohibited from currently roadless areas of the Tongass, the importance of large reserves will be lessened (because much more of the Tongass will become large reserves ipso facto). However, the importance of old-growth buffers along streams and beach fringe would be intensified with the more intensive management that will come to the currently roaded areas. If road construction into currently roadless areas continues on the Tongass, then the questions of size and geographic distribution of large reserves will remain an important part of the conservation strategy for maintaining well-distributed and viable populations of all wildlife species. The 1997 TLMP also relies on long timber rotations (e.g., 200 years) for providing forests with old-growth characteristics in some areas. However, we currently know very little about even-aged stands of such age, even though they already are naturally widespread throughout the Tongass (Nowacki and Kramer, 1998; Kramer et al., 2001).

Although clearcutting will remain a method of timber harvest in the future, especially on private lands, there will be increasing interest in alternatives to clearcutting—from both wildlife habitat and aesthetic (viewshed) perspectives. Individual-tree selective harvest with helicopter logging may be one alternative. New approaches to stand management (e.g., "shelterwood" cuts, small clearcut patches within stands, small residual "leave" patches within clearcuts, etc.) (McClellan et al., 2000) might be other alternatives. Currently, however, all such alternatives to clearcutting are in early stages of research, and effects remain mostly unknown.

Black-tailed deer are the major wildlife species harvested by both recreational hunters and subsistence users in southeastern Alaska, so deer will continue to be a focal species of much interest. Current models for habitat evaluation and planning are applicable at the scale of individual timber stands but are weak or not applicable for large-scale, landscape-level analysis involving landscape pattern (sizes and locations of timber stands). A major challenge for intensive management of the Tongass will be evaluating and managing forest habitat for deer at large spatial scales (e.g., importance of alpine habitat in combination with low-elevation forests). Coincidentally, the forest service and other federal agencies will face increasing needs for data and analysis of population dynamics of black-tailed deer. The federal role has increased in the management of subsistence harvest on federal lands in Alaska, and concerns continue about population viability of the Alexander Archipelago wolf.

Finally, greater number of people coupled with greater means of access to remote areas will result in increasing conflicts between the growing tourism industry and the wildlife habitat it exploits. Most immediate concern on the Tongass will likely center on issues involving perceived effects of helicopter tours on mountain goats (*Oreamnos americanus*) and increased conflicts between brown bears and humans. Concerns about helicopters largely center on ice field and glacier tours that occur near prime mountain goat habitat. Concerns about brown bears largely center on disturbance of bears around streams during salmon runs (increased demand for wildlife viewing areas) and on increased "defense of life or property" killing of bears as human use becomes more widespread and common.

5. Future research, development, and application

The 1997 TLMP wildlife conservation strategy focused on management indicator species and old-growth reserves (conservation areas, riparian and beach-fringe buffers). Since the plan was written, however, there has been growing apprehension about the management-indicator-species concept at the national level (new forest service planning rules—USDA Forest Service, 2000) as well as on the Tongass. In fact, several of the Tongass management indicator species exemplify problems with the concept. Some species have been found to have unique problems in either being very difficult to monitor (e.g., rare species like goshawk; Flatten et al., 2001) or not being as restricted to limited habitat as was expected (e.g., flying squirrel; Smith and Nichols, 2003). Others are no longer believed to be "representative" of more than their own habitat requirements (e.g., brown bear; Titus and Beier, 1999). Generally speaking, there are theoretical and practical difficulties in using any single species to predict the response of other species to forest management at either the stand or landscape levels (Mannan et al., 1984; Szaro, 1986; McGarigal and McComb, 1995).

Interest in the habitat and population status of many of the current management indicator species will continue well beyond the plan itself, however, because people care about particular species for various reasons. Current thinking expressed within the new Forest Service planning rules is that such species should be more appropriately termed "focal species" rather than "indicator species". The difference reflects an interest in a species in its own right, rather than as an indicator of something more than itself.

While acknowledging that interest in particular, focal species will continue, we suggest that future research, development, and application focus on plant and animal communities, as well, and on management of vegetation to achieve specific objectives for wildlife habitat. We suggest that such efforts emphasize second-growth forests, old-growth reserves, and alternatives to clearcutting. Improved models for evaluating black-tailed deer habitat and populations also are needed, and some work probably needs to be directed at interactions between tourism and selected wildlife species.

5.1. Second-growth forests

Much research is needed in second-growth forests, both for understory vegetation and for wildlife communities. The principal problem regarding understory vegetation is that of promoting a diverse and productive understory, especially the herb component. To date, most silviculture of even-aged stands in southeastern Alaska has been limited to precommercial thinning, and results for wildlife habitat have been either undocumented (at best) or discouraging. New approaches involving thinning of older ("commercial"-aged) stands and including red alder in the secondary successional sequence might provide significant benefits for wildlife habitat (Hanley, this issue). However, much research needs to be conducted on both those approaches. Specifically, we need research on the autecology of major understory species, especially in relation to light and soil environments, and the roles of thinning and red alder in modifying the light, soil, and nutrient environments of the understory (ibid). We need silviculture prescriptions (e.g., thinning, pruning, soil disturbance) for modifying even-aged conifer stands to create desired understory environments and for incorporating red alder into even-aged stands. In application, we need large-scale, adaptive management studies and demonstration projects conducted in partnership between the Tongass National Forest and the Pacific Northwest Research Station (ibid).

Very little is currently known about wildlife communities in even-aged forests of southeastern Alaska. Studies of small mammal and bird communities in relation to stand structure (overstory and understory variables) would be an important beginning. Such studies would be descriptive and correlative but would provide patterns of wildlife community structure in relation to habitat structure, which could be a first step toward predicting consequences of silviculture treatments. We also should seek to understand relationships between stand structure and the relative abundance of specific habitat features already known as especially important for the current management indicator species (flying squirrel, American marten, black-tailed deer, Alexander Archipelago wolf, brown bear, northern goshawk, and marbled murrelet) and any other wildlife species of special interest. Do such habitat features specific to any of the current indicator or focal species also correlate with small mammal or bird community structure?

We need quantitative models for evaluating habitat quality of even-aged stands for both wildlife communities and for individual focal species (e.g., potential threatened or endangered species and subsistence species), and we need identification of specific habitat features desirable for maintaining diverse small mammal and bird communities. Such models and knowledge would provide the basis for designing silviculture prescriptions for wildlife objectives. The application and success of silviculture prescriptions should be tested primarily at the scale of timber-management stands, primarily through adaptive management studies.

5.2. Old-growth forests

Understory vegetation of southeastern Alaskan old-growth forests has received much more attention than has that of second-growth forests. Community patterns and environmental relations are fairly well known (e.g., Ver Hoef et al., 1988; Alaback and Juday, 1989; Hanley and Hoel, 1996; Hanley and Brady, 1997). However, most of that work has focused on all-aged stands, where the predominant disturbance regime is one of high-frequency, low-magnitude events driven mostly by windthrow of individual trees or small groups of trees and resulting "gap phase" succession at a small scale of tens of meters (Brady and Hanley, 1984). Recent work on landscape pattern of naturally occurring old-growth forests in southeastern Alaska, however, has shown that old, multi-cohort stands, responding to large-scale (landscape level) windstorms are very common in the region, with multi-cohort stands predominating on wind-exposed slopes and all-aged stands predominating on wind-protected slopes (Nowacki and Kramer, 1998; Kramer et al., 2001). We currently know very little about the community patterns, environmental relations, and temporal dynamics of old, multi-cohort stands. Such knowledge, however, is very important for planning and managing old-growth reserves. Understanding the community structure and temporal dynamics of those stands also could provide much insight into the validity of assumptions inherent in the use of long rotations (e.g., 200 years) for providing old-growth forests in the 1997 TLMP. We need new models of late even-aged, early "old-growth" succession, especially in multi-cohort stands (which might be similar to managed stands subjected to periodic thinnings). We need to understand better the shift from even-aged to all-aged stands in order to design optimal silviculture prescriptions for older stands.

The greatest needs for wildlife community research within old-growth forests relate to the importance of size and landscape distribution of old-growth reserves. Barriers to dispersal and potential isolation of populations in small, few, or widely scattered reserves still pose the same threat to population viability of endemic small mammals as when the 1997 TLMP was written. The greatest needs for knowledge about any particular species probably concern the flying squirrel in heavily logged areas of Prince of Wales Island in areas where past logging has been extensive. Moreover, our knowledge of the occurrence and distribution of endemic small mammals on islands of the Alexander Archipelago still is small. We especially need greater information of small mammal distribution on small islands potentially subject to intensive logging in the future (>500 and <20,000 ha). Such information needs to be developed into guidelines for forest managers.

5.3. Alternatives to clearcutting

Alternatives to clearcutting, for timber harvest, might become increasingly important in the future if the current trends of decreasing timber economy and increasing tourism economy continue. Recent, retrospective studies of individual-tree selection cutting have shown that partial removal of overstory might have minimal deleterious impacts on the forest understory (Kirchhoff and Thompson, 1998; Deal, 2001). A long-term experiment comparing various partial-cutting patterns also is currently underway (McClellan et al., 2000), although it is currently too early for results. The wildlife portion of that study focuses on bird communities and is anticipated to yield comparisons between treatments and correlations between stand structure and bird community structure.

Research into alternatives to clearcutting should focus on the processes involved in community response to cutting pattern, especially the role of patch size in vegetation and animal response. For example, Kirchhoff and Thompson (1998) and Deal (2001) have shown that removal of individual trees by logging probably is very similar to the gap phase successional pattern of vegetation response to small-scale wind disturbance in old-growth forests. DeSanto and Willson (2001) found that forest edges might be associated with elevated predation rates of songbird nests in southeastern Alaska, depending on predator density. Thus, from both understory vegetation and songbird nesting perspectives, it appears that very small gaps (on the scale of meters or tens of meters at most, as occur naturally in old-growth forests) might be highly desirable, whereas larger gaps might be deleterious. Other processes of interest include dispersal by small mammals, role of scale in habitat heterogeneity for animal community structure, fruit production in relation to sunlight (and size of canopy opening), and snow interception as a function of canopy structure. These are only examples; the point is that future research focusing on ecological processes affected by gap size and forest edge is key to better understanding and management. Implications of those processes can provide the basis for predicting specific results in the McClellan et al. (2000) field study and other such studies conducted as adaptive management experiments. With time and effort, we can begin designing new guidelines and prescriptions for uneven-age stand management and other alternatives to clearcutting.

5.4. Black-tailed deer and subsistence harvest

Black-tailed deer and their habitat have been the focus of much research in southeastern Alaska (Hanley et al., 1989; Kirchhoff, 1995; Parker et al., 1999). They are the principal game species for recreation and subsistence hunters and are the principal prey species for the Alexander Archipelago wolf (Person et al., 1996). Current models for evaluating habitat capability for black-tailed deer (Hanley and Rogers, 1989; Lowell W. Suring, unpublished model on file in Alaska Regional Office, USDA Forest Service, Juneau) were designed for the scale of individual timber stands, however, and are of very limited applicability to large-scale, landscape-level analysis where the combination of habitats, their juxtaposition, and topographic distribution are important factors. The large home ranges and seasonal migratory behavior of black-tailed deer add to their indicator value in forest planning (Hanley, 1993, 1996) but require landscape-level analysis. Current models must be expanded to include the additional factors associated with large spatial scale and time, as Forest Service responsibilities have broadened to include population management as well as habitat management for deer. Likewise, analytical techniques and models for evaluating population status and trends must be developed. Long-term goals should include linkages between habitat and population models and should include explicit consideration of hunting harvest and wolf predation. That research would ideally be coordinated with the Alaska Department of Fish and Game, which historically has had the principal responsibility for population management and currently has active research programs in both black-tailed deer and wolf ecology.

5.5. *Effects of tourism*

Public concerns about flight-seeing impacts on mountain goats have intensified significantly as the tourism industry has increased in Alaska. However, actual effects, if any, are unknown. The most likely impact would be that of scaring mountain goats away from favorite habitats, especially those of steep cliffy terrain (Fox et al., 1989), thereby decreasing their foraging efficiency and increasing their susceptibility to accidents or predation by wolves. The consequences (currently entirely speculative) would most likely affect the probability of success in raising lambs to adulthood and, therefore, decrease the recruitment rate of the population. Testing such hypothetical relations through research, however, would be a difficult task as the questions do not lend themselves well to experimentation. Mountain goat populations are small, restricted in distribution, and not easily accessible. Statistical problems involving small sample sizes, replication, and accurate measurement of treatment effects would be substantial. Nevertheless, the need for such research might become sufficient to require it. In such case, we suggest that mountain goat research be conducted in coordination with the Alaska Department of Fish and Game and other interested agencies.

Similarly, concerns about tourism impacts on brown bears are difficult to test experimentally. Salmon play a major role in the nutrition, body size, reproductive rate, and population density of brown bears (Hilderbrand et al., 1999a, 1999b), and disruption of bears from favorite salmon-fishing areas could have significant consequences. However, measuring the effects of disturbance (bear shifts in habitat use and dietary intake) in biologically meaningful terms of nutritional consequences requires substantial costs and effort, especially in the dense forests of southeastern Alaska. Moreover, with increased familiarity with humans at wildlife viewing areas, bears become accustomed to humans, and consequences of tourism may become nil, with some individual bears shying away from close contact with humans and other, less shy bears being unaffected (Fagen and Fagen, 1994; Olson et al., 1997). Increased familiarity with humans, however, also tends to increase the probability of "defense of life or property" killing of bears that get into mischief in less closely regulated areas of human–bear contact. Increased mortality through such killing of bears must be analyzed in the context of population dynamics. This, too, is an area of research that would benefit greatly from close collaboration with the Alaska Department of Fish and Game.

The goals of both mountain goat and bear research concerning tourism would be guidelines for habitat management and development.

6. Conclusions

We have learned that southeastern Alaska has a high potential for endemism, with a substantial amount of evolutionary diversity already documented in its mammal fauna from sampling a small proportion of islands and total land area. Many endemic mammal taxa are associated with old-growth forest habitat, but some species, notably northern flying squirrels, are apparently capable of sustaining breeding populations in low-timber-volume, noncommercial, old-growth forests. Also, forest-floor species, like the southern red-backed vole, may not be as sensitive to overstory removal in southeastern Alaska as has been reported elsewhere. Moreover, vole populations of intensively managed landscapes likely will benefit from active stand management (i.e., precommercial and commercial thinning) of second growth because of the benefits to the understory in younger stands and the shorter stem-exclusion phase of older stands. Challenges of maintaining habitat to sustain viable and well-distributed endemic small mammal populations will continue regardless of future logging, however, because of the legacy of five decades of industrial clearcut logging. The cumulative impact of clearcut logging on dispersal and isolation of endemic small mammal populations has not been examined, nor have we completely documented mammalian taxonomic diversity. Many of the small islands and remote portions of large islands have not been adequately surveyed.

Managing forest habitat to sustain viable and well-distributed small mammal populations also has implications for the northern goshawk and American marten, both of which are likely prey-limited in southeastern Alaska. Voles and flying squirrels may represent a relatively large portion of the diet of northern goshawk in southeastern Alaska because of the scarcity of larger prey species. Reproduction in marten populations is linked directly to rodent abundance. Because American marten and northern goshawk are old-growth associates, a challenge will be managing forest habitat to sustain prey populations that are available to each. Active second-growth management probably will benefit both marten and goshawk through an increase in small mammal populations and by speeding the succession of older second-growth stands toward old-growth condition.

Regardless of the future management environment, there is an urgent need to develop sampling protocols for inventory and monitoring of wildlife populations. Without procedures to gather reliable information about the abundance and distribution of wildlife populations over time, we will not be able to adequately document biological diversity, assess population responses to specific management prescriptions, evaluate conservation strategies, and conduct effectiveness monitoring.

New challenges lie ahead, particularly involving intensive even-age forest management, old-growth forest reserves, alternatives to clearcutting, black-tailed deer habitat/population management, and tourism impacts on sensitive wildlife species. There is need for much research into ecological patterns in plant and animal community organization, cause-and-effect mechanisms underlying the patterns, and predictive theory and analytical modeling. Applications of new knowledge will be most evident in new guidelines for forest management, including new silviculture prescriptions for multiple-resource objectives and quantitative tools for evaluating consequences of habitat change. We encourage forest managers and scientists to work together in testing the application of science through large-scale adaptive management studies in partnership between the Tongass National Forest and the Pacific Northwest Research Station. Other federal and state agencies, as well as private industry (such as Alaska Native corporations), also have much to contribute in collaborative work.

The challenges facing the Tongass National Forest are significant and important throughout southeastern Alaska. They are broad, interdisciplinary, and cross-jurisdictional. The economy of southeastern Alaska and the role of the Tongass in that economy are changing rapidly. The Tongass will continue to play a vital part in the socioeconomic fabric of the region, from recreation to employment to subsistence lifestyles. As society increasingly turns to science to guide decision making, the role of research becomes ever more important. Collaboration between interested parties is needed for the application of science to forest management. We look forward to the challenges and opportunities that lie ahead.

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