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An overview of science contributions to the management of the Tongass National Forest, Alaska

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Abstract

After 6 years of intensive study, all the research studies designed to answer the information needs identified in appendix B of the Tongass land management plan have ended, with their results published or in press. The knowledge generated from these studies not only informs the ongoing process of regional natural resource management in southeast Alaska, but also helped to define future directions for research. Topics still needing additional study include issues related to wildlife, aquatic systems and salmon habitat, silvicultural options for forest management, wood products utilization, and social science. The role of science in supporting the development of options for natural resource management of the Tongass National Forest was carefully defined and implemented in order to maintain science objectivity and impartiality. The planning processes in southeast Alaska clearly exemplify a clear example of the recognition that natural resource plans need to be founded on the best available science. The complexity of ecosystems, including the scales at which they are organized and operate, require focused research to answer key questions in tandem with management decisions. Managers want the support of science institutions to bolster the effectiveness, predictability, and credibility of their decisions. The integration of science into the decision making process is far more prevalent today than it once was and will increase in the future as we move to refine management decisions based on a continually increasing body of science on which to base those decisions.

Keywords: Science; Sustainable management; Temperate rainforest; Alaska; Tongass National Forest

1. Introduction

The United States Department of Agriculture (USDA) Forest Service's strong commitment to science-based land management planning and decisions is clearly illustrated by the development of the Tongass National Forest land management plan (TLMP) of 1997 and the follow-on studies that were designed to fill information gaps that would assist managers in revising the plan in the future. The evolution of this commitment to science-based planning has a strong linkage to Forest Service history and culture. The contextual history of Forest Service management

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will help in understanding why science has taken a more prominent role in decision making in recent years. This history sets the stage for a description of how science involvement in the planning process began and why that involvement was so carefully defined in the 1997 Tongass National Forest (TNF) planning process. Scientist involvement, responsibilities, and the products produced were designed to set the basis for science-based decision making. This included an impressive body of assessments and syntheses of knowledge already finished prior to the development of TLMP and an extensive 6-year effort to answer many of the questions generated during the planning process that are needed for the plan revision. This paper summarizes the results of that 6-year follow-on effort.

2. A brief contextual history of Forest Service management

The USDA Forest Service's legal mandates for forest management have evolved from the original vision of its first Chief, Gifford Pinchot, as a significant provider of the nation's source of timber and wood products (Miller, 2001). In actual practice, the Forest Service functioned as a caretaker of the Nation's public forests until timber from private lands was in short supply after the end of World War II. The Forest Service, composed mainly of professionally trained foresters, responded to the national need by annually increasing the area harvested through the late 1960s. As the Forest Service rose to meet the challenge to increase timber production, negative public pressure grew in response to how resources were being extracted and the effects harvesting was having on other resources. National legislation passed in 1960, (Multiple-Use Sustained Yield Act, 1960; MUSY), was designed to evaluate fish and wildlife, recreation, watershed, and timber supply issues.

This heightened environmental consciousness resulted in new environmental laws such as the National Environmental Policy Act (1969) (NEPA) and the Endangered Species Act (1973) (ESA). These laws fundamentally changed the way the agency conducted business and required specialists from disciplines other than forestry to analyze the effects of timber harvesting on other resources. The analyses they prepared were both time-consuming and extremely costly. And, unlike earlier in the century, the knowledge needed to make good decisions at the end of the century exceeded the learning and experience of any one individual. Numerous laws and complex ecological information forced decision makers to rely on information prepared by teams of professionals and, where information was scarce, to rely on their team's technical and professional judgment concerning the risks involved in their decisions. Managers, who once were enabled to make decisions independently, found themselves defending their decisions with substantial professional support and analyses. Even decisions made with these detailed analyses were subject to administrative appeals and litigation.

Public pressure continued primarily in response to clearcutting practices and in 1974 the Forest and Rangeland Renewable Resources Planning Act (1974) (RPA) was passed by Congress, requiring periodic assessment of the status and opportunities for enhanced management of the Nation's publicly held natural resources. This was followed in 1976 with the passage of the National Forest Management Act (1976) (NFMA). The NFMA required each forest to have forest plans. Forest plans were essentially viewed as a contract with the nation detailing how the resources were to be managed, but at the same time they acknowledged the agency's professional flexibility to manage as it saw fit. Forest plans contained standards (rules that must be followed) and guidelines (suggested practices that should be followed) that specifically outlined how the forest would be managed. As the Forest Service managers pushed to meet what they believed was a national mandate to provide timber in ever increasing quantities, the environmental movement in the United States repeatedly challenged those practices. Other federal agencies were also trying to fulfill the country's timber demand, but the Forest Service was often the focus of environmental groups' concerns.

During the 1990s, Forest Service managers increased scientist involvement by asking for help with forest planning and the ensuing legal battles. Scientist assistance in the development of information in support of the TLMP effort was one of many examples of science collaboration with management that led to the development of options for sustainable natural resource management of the National Forests in the United States. Other noteworthy regional natural resource management plan examples include work of the Forest Ecosystem Management Assessment Team (FEMAT, 1993) for northern California, Oregon, and Washington, the Interior Columbia Basin Ecosystem Management Project (ICBEMP) for eastern Washington, Idaho, and western Montana (Quigley and Bigler-Cole, 1997) and the Sierra Nevada Ecosystem Project (SNEP, 1996). The development of TLMP was perhaps one of the most contentious in Forest Service history (Mills et al., 1998).

3. Science support for the Tongass National Forest

The TNF was the first forest to complete a management plan (1979). The TNF contains 80% of southeast Alaska's land base; accordingly, Forest Service policies have a potentially large impact on economic development. Two amendments were made to the plan (1986, 1991). The first draft environmental impact statement (DEIS) was issued in June 1990 to revise the forest plan as required by NFMA, but it was quickly followed by the Tongass Timber Reform Act (November 1990), necessitating the release of a supplemental DEIS (SDEIS) in August 1991.

The stage was set for science to become involved. Six categories of changes to the original forest plan were deemed necessary. These changes were in: multiple-use goals and objectives, management prescriptions, standards and guidelines, timber suitability, allowable sale quantity, and monitoring and evaluation. Ten issues were identified by the public for consideration in the forest plan revision in 1988: scenic quality, recreation, fish habitat, wildlife habitat, subsistence, timber harvest, roads, minerals, roadless areas, and local economy. In addition, 5 other issues were raised that were either new issues or extensions of the existing 10 public issues: wildlife viability (provision of sufficient habitat), fish habitat, karst and caves, alternatives to clearcutting, and socioeconomic considerations. The Final Environmental Impact Statement (FEIS) analyzed 11 alternatives. The Regional Forester ultimately chose to implement alternative 11, the preferred alternative (USDA Forest Service, 1997a, 1997b, 1997c).

In 1994, the Pacific Northwest Research Station Director was invited by the Alaska Regional Forester to participate in the Forest planning process. Six scientists were assigned as part of the planning team, but held roles separate from the National Forest System planners (Everest et al., 1997). The role that scientists would play was carefully considered to assure that value-neutral information was developed without reference to management decisions (Julin and Shaw, 1999). Three responsibilities were identified: conservation and resource assessments, evaluating risks to resources from management, and conducting a science consistency check to ensure the proper use of science (Szaro and Boyce, this issue).

The last responsibility was to assure that the scientific information was correctly interpreted. To do so required developing a *science consistency* process (Guldin et al., 2003a, 2003b). The process selected was an independent review of how science information was applied by managers in developing the final alternative. Results of the review were given to managers before the plan was finalized so that managers could make adjustments by using the best available information. A detailed description of the process is available but the criteria used to assess if the decisions were consistent with science are particularly relevant (Everest et al., 1997):

A. A management decision was considered to be *consistent* with available scientific information if the following three conditions were met:
   1. All relevant scientific information made available to managers was considered in the decision.
   2. Scientific information was understood and correctly interpreted.
   3. Resource risks associated with decisions were acknowledged and documented.
B. A management decision was considered to be *inconsistent* with available scientific information if any of the following circumstances occurred:
   1. Managers misrepresented or reinterpreted information in ways not supported by the original information.
   2. Managers selectively used information such that a different decision was reached than would have been made if all available information had been used.
   3. Decisions were stated and documented in such a way that implementation effects could not be predicted.

4. Projected consequences of management actions were not *consistent* with scientific information.

As the final selected alternative for the Forest plan was evolving, over 28 drafts were subjected to the formal science consistency check (Mills et al., 2001). The last science consistency check was for the record of decision implementing the forest plan, and it was published after scientific peer review (Everest et al., 1997).

4. Science targeted at filling information needs

An important science product resulting from the work of the scientists on the risk assessment panels resulted in an understanding of where major gaps in information existed for important resource issues. From their work, 10 major information needs along with numerous minor information needs were identified where priority research could be directed to acquire knowledge that would substantially inform decision makers for future forest plan amendments or revisions (see Table 1 in Szaro and Boyce, this issue). Acquisition of the information provided the genesis of a new working relationship between the Alaska Region and the Pacific Northwest Research Station of the USDA Forest Service. That collaboration resulted in what has been termed the TLMP follow-on studies. Filling each of the 10 information needs involved a substantially increased scientific effort over a 6-year period. Below is a general overview of what was learned (see Table 1 in Szaro and Boyce, this issue):

4.1. Timber productivity and response to harvest of forested wetlands in southeast Alaska

Because excluding trees growing on poor soils in wetland areas increases the cost of designing and implementing timber sales, it was important to learn if those trees are capable of meeting minimum commercial standards. D'Amore and Lynn (2002) improved the characterization and classification of organic forested soils in southeast Alaska. Julin and D'Amore (2003) then learned that stands naturally regenerated in forested wetlands were densely stocked and would produce wood volume nearly double the USDA Forest Service minimum standard for commercial timber. The Alaska variant of the Forest Vegetation Simulator (SEAPROG; Dixon et al., 1992) predicted that wet soils would allow for tree growth to exceed the minimum standard for commercial timber, but empirical data were lacking. Based on their data (Julin and D'Amore, 2003), the culmination of mean annual increment is modeled to occur at 110 years with a quadratic mean diameter of 20 cm. Based on these results, the Tongass National Forest Supervisor permitted these wetland areas to be included in the suitable timber base. Lombardo (2002) evaluated the use of science by the Forest Supervisor, in reaching the decision to include trees in these wetland areas within the land base suitable for timber harvest, and found the decision was consistent with the available science.

4.2. Determine the relationship between socioeconomic conditions in rural communities and resource allocations on the Tongass National Forest

With the release of the 1997 Forest Plan, the amount of timber made available for commercial harvest was substantially reduced from previous allowable levels. Communities were concerned about the economic effect that this decision might have on them. Robertson (1999) investigated this issue in communities where recent harvest declines were occurring in the western United States. The overriding concern was the perceived economic shock that communities would experience, including associated social issues that might arise, when there was a major reduction in timber exports. Robertson (1999) examined 14 small communities in southeast Alaska and found that reductions in timber harvest export activity did not cause changes in economic activity in other sectors at the community level. The perceived shock was buffered by dynamic adjustments within the community and stabilizing growth in other sectors including government employment, fishing, tourism and private business (Robertson, 2003). Crone (this issue) used socioeconomic data from the 2000 U.S. census and found that the small southeast Alaska communities with a higher dependence on timber harvests were no worse off than the other small communities in the region. Residents continue to be concerned over impacts of tourism growth, one of the fastest growing components of Alaska's economy that has averaged a 10% increase per year over the past 15 years, on local communities (Cerveny, 2004; Kruger, this issue). Robertson (2003) points out that growth in certain economic sectors (tourism) offsets declines in other sectors.

Crone (this issue) reported that Alaska is at a competitive disadvantage in national and international timber markets partly because of high labor costs and other market factors (transportation costs). For example, owing to decreased demand, the world and national markets have experienced a 50% reduction in dissolving pulp production over the last 30 years, forcing both of southeast Alaska's pulp mills to close in the 1990s. Alaska is sensitive to international and national market swings and it often is the first to feel the effects of market changes. For instance, Chilean pen-reared salmon are now prepared as fillets and are far cheaper than their Alaska wild caught counterparts, creating large economic and competitive pressure on the Alaskan native salmon industry. The comparative advantage of southeast Alaska is its access to world-class outdoor recreation opportunities, freedom from congestion, commuting, pollution, and relief from other detractions associated with urban life.

4.3. Determine subsistence resource patterns in southeast Alaska

The State of Alaska allows residents to harvest natural resources to help them live and subsist in a state where the cost of living is high. Subsistence is the collection of natural resources for personal use and not for commercial use. Resources can be shared but not sold. Subsistence is a federally protected right for Alaskans as legally defined in the Alaska National Interest Lands Conservation Act (ANILCA) (1980). ANILCA gives harvest priority to people living in rural areas (communities of 2500 people or less). Should a resource become restricted, commercial and sport harvests would be restricted before subsistence use would.

Kruger (this issue) reports over 85% of rural households use wild game and 95% use fish. Mazza (2003) reports the average annual harvest of subsistence food is 170 kg per person in rural areas. Early research conducted by Bob Schroeder (see Kruger, this issue) found: (1) subsistence use nearly met the national average of total use for meat, fish, and poultry; (2) harvest levels remained consistent since 1980 in the larger communities; (3) harvest levels varied across the region; (4) high-harvesting households (75% of total community harvest) distributed their surplus to the community via kinship networks, barter and trade. Schroeder also found that about 80% of the subsistence harvest, as measured in food weight, was from marine resources.

The two important and intertwined issues are subsistence management/sport hunting management and vegetation management: (1) Are there enough resources (particularly Sitka black-tailed deer [*Odocoileus hemionus sitkensis*]) available to satisfy the needs of both the recreational user and subsistence user? (2) Does the forest vegetation management strategy provide adequate habitat to support deer populations? To begin to answer these questions meant acquiring knowledge of subsistence use patterns. The data on subsistence use patterns were collected and made available by the State of Alaska's Department of Fish and Game Web Site as the State Community Profile Database (CPDB): (http://www.state.ak.us/local/akpages/FISH.GAME/subsist/geninfo/publctns/cpdb.htm.

To address the adequacy of the resource supply question, Mazza (2003) examined hunter demand for deer on Prince of Wales (POW) Island and analyzed the factors influencing the demand. She also looked at deer pellet count data to see if deer had decreased. She found that subsistence use of deer is for economic security rather than sport or accumulation of goods. In good economic times, fewer deer are used. When there is an economic downturn, then per capita use of deer increases (Mazza, 2003). Eighteen percent of total subsistence harvest by weight is deer in southeast Alaska (Alaskan Department of Fish and Game 2001 as cited in Mazza, 2003). Unreported deer harvest was thought to equal the reported harvest, suggesting current harvest regulations are too limiting. Nonresident hunter numbers increased as did per capita harvest in five communities on POW Island. Deer counts were within the historical 14-year average, but it remains unknown if supply can continue to satisfy demand as demand continues to increase.

The forest vegetation management question is important because of the belief that timber harvest activities negatively affect deer habitat; essentially converting preferred old-growth timber habitat to young-growth forest. Deer do not use forests where high canopy closure (i.e., dense conifer regeneration) suppresses or eliminates the understory plants upon which they depend. There is a concern that the reduction in preferred deer habitat has already negatively influenced subsistence use by lowering the number of deer available and making it more difficult for people to get the deer they need. To confound the problem, the number of hunters on Prince of Wales Island has increased 9% in the last 6 years increasing competition between residents and visitors for a common resource (Mazza, 2003). Although over the short term the deer population may appear stable, there is agreement that as old-growth winter habitat is harvested and lost, deer populations will decline; "It is predicted that the forest will lose 50–60% of its deer-carrying capacity by the end of the logging rotation in 2054" (Mazza, 2003, p. 16). Increased hunter demand contrasted with a projected 50% decrease in future deer-carrying capacity suggests an impending management conflict.

4.4. Identify and measure the interactions between aquatic/riparian habitat and perturbations in upland areas and the response of anadromous and resident salmonids

Two major issues were (1) Are upland riparian areas, which contain no fish, linked to downstream aquatic habitat for salmon? (2) Can stream habitat variables be linked to salmon density for use in evaluating the effects of land management activities in high-gradient watersheds on downstream aquatic habitat? Wipfli (this issue) evaluated invertebrates and coarse organic detritus originating from forested headwaters and traveling to downstream systems that potentially contain fish. He found substantial transport of both invertebrates and detritus in quantities that would support coho salmon (*Oncorhynchus kisutch*) fry in virtually every kilometer of stream. Headwaters linked upland ecosystems with habitats downstream. Partial canopy removal is expected to influence solar penetration, but full removal would likely reduce invertebrate abundance and litter in streams.

Woodsmith et al. (this issue) developed a set of physical habitat measurements to assess stream channel condition. Bryant (2000) developed a methodology to estimate coho salmon populations in second- to fourth-order streams and used this data with that collected by Woodsmith et al. (this issue) to examine relationships between fish populations and stream channel condition as a monitoring tool in southeastern Alaska. Channel morphology, pool size and density (spatial), channel bed surface grain size, and fish populations were assessed in the hopes of finding a set of predictive variables. Because of the complexity of aquatic systems, strong relationships between channel condition and salmon densities were not evident except that coho salmon fry density and two measures of pool frequency showed a significant and positive relationship. There was also a positive trend between salmon density and large wood in the streams. Many sources of variation affect salmon density, including influences that occur at sea before the fish even return to the river systems.

4.5. Determine the geographic and habitat distribution of endemic mammals on the Tongass National Forest

The Tongass National Forest is an island archipelago with thousands of islands ranging in size from less than 1 ha to over several thousand km^2. Prince of Wales Island is the third largest island in the United States at 6675 km^2. Eight of the top 10 largest islands in the United States are located in Alaska, many in southeast Alaska (Admiralty, Baranof, Chichagof). The resident mammalian fauna are subjected to island biogeographic forces and varying correlated probabilities of extinction. Several recognized mammalian taxa have limited historical ranges, and there was a need to continue to document geographic extent and habitat distribution within and across islands and the mainland portion of the Tongass National Forest. The long-term prognosis for two old-growth associated species and the knowledge base required to inform management decisions for wildlife also needed evaluation.

Smith (this issue) reported that the indigenous biota unique to southeast Alaska's island archipelagos, especially endemic species, may be susceptible to higher rates of extinction. Twenty-seven endemic mammalian taxa have been identified, including charismatic fauna such as the Alexander Archipelago wolf (*Canis lupus ligoni*) (Person et al., 1996). Recent genetic research (mitochondrial DNA sequencing, etc.) has clarified earlier taxonomic work, including revealing the phylogenetic, phylogeographic and biogeographic patterns in some species that suggest multiple colonization events (northern flying squirrel, Demboski et al., 1998; Arbogast, 1999; Bidlack and Cook, 2001, 2002; long-tailed vole, Conroy and Cook, 2000a, 2000b; American pine martin and dusky shrew, Demboski et al., 1999; Demboski and Cook, 2001; *Microtus* sp., Conroy and Cook, 2000a, 2000b; shrews, martin, mink, bear, Cook et al., 2001; Stone and Cook, 2000). Two reputed old-growth associated species, northern flying squirrel (*Glaucomys sabrinus*) and red-backed vole (*Clethrionomys gapperi*), may be able to persist in southeast Alaska with continued timber harvesting activities as they are also present in forests designated as noncommercial timber (*G. sabrinus*) and they have been found in managed second-growth stands (*C. gapperi*).

The Tongass National Forest Plan included habitat conservation areas designed to protect the population viability of wildlife species. Hanley et al. (this issue) recognized that the steep drop in timber harvest on the Tongass National Forest reduced concerns about the effectiveness of the habitat conservation areas. Additionally, the roadless rule passed in 2001 protected roadless areas from having roads built in them and altering wildlife habitat. Hanley et al. (this issue) identified five continuing challenges for managing wildlife habitat (1) increasing management emphasis on second-growth forests, (2) designing conservation strategies for old-growth forests, (3) developing timber harvest alternatives to clear-cutting, (4) managing black-tailed deer habitat for subsistence use, and (5) managing the effects of tourism on sensitive species of wildlife.

These issues will persist well into the future as long as humans continue to use the forests of southeast Alaska.

4.6. Evaluate the future timber productivity of young-growth stands on the Tongass National Forest

Much of the timber on the Tongass National Forest is composed of old trees. As old trees are harvested, it is important to understand how to manage young-growth stands for future timber productivity including distribution of site indexes, modeling (SEAPROG) routines, stem quality, intermediate treatments, harvesting standards, and alternative harvest systems. Knowledge about these factors is necessary to evaluate future timber production projections and to evaluate the influence of these factors on the restoration and enhancement of deer and other wildlife habitat.

In 1999, over 30 representatives of forest products industry, environmental groups, the state of Alaska, Alaska Native corporations, and local governments met to identify future alternatives for southeast Alaska timber industry (Zaborske et al., 2000). An important outcome of the meeting was agreement that clear, strong, large-diameter wood provides the widest range of future resource use options. Deal et al. (2003) investigated the development of epicormic sprouts in Stika spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) trees that were thinned and pruned (2.4, 3.7, 5.2 m) between 23 and 29 years old. Six to 9 years later, sprouts were very numerous for the different pruning treatments. Sitka spruce appears to be a poor choice for pruning if the goal is to produce clear high-valued wood. Wang et al. (2000, 2001a, 2001b) evaluated a nondestructive wood strength and stiffness test (stress wave technique) for standing young-growth Sitka spruce and western hemlock trees and found that the evaluation of wood properties was relatively accurate and reliable, and that it simplified tracking property changes as trees grow. Users of the southeast Alaska forest vegetation growth simulator model (SEAPROG) felt the model produced unrealistic output. McClellan and Biles (2003) evaluated the model by using empirical data and found that several parameters (quadratic mean diameter, basal area, height, and volume) were underestimated, underscoring the need to refine the model.

Managers have been concerned that commercial thinning results in inadequate understory vegetation for black-tailed Sitka deer owing to dense conifer regeneration (Walmo and Schoen, 1980). Zaborske et al. (2002) evaluated commercial thinning treatments at five demonstration areas. They discovered that individual tree selection yielded better forage for deer than the other treatments including the untreated control. Importantly, individual tree selection thinning produced deer summer habitat similar to old-growth forest deer habitat (see Hanley [this issue] for black-tailed deer response to habitat heterogeneity).

4.7. Evaluate alternatives to clearcut timber harvest on the Tongass National Forest

Walmo and Schoen (1980) reported that even-aged management (clearcut) of coniferous forests resulted in a significant decrease in deer carrying capacity. Shortly thereafter, Alaback (1982) reported that clearcutting may change plant communities by excluding understory growth, particularly forbs and shrubs needed by black-tailed deer for survival. Walmo and Schoen's (1980) findings created an immediate management concern as even-aged forest management was used extensively throughout southeast Alaska. Alaska residents became particularly alarmed since stable black-tailed deer populations provide an important source of their annual protein requirement (subsistence harvest) and deer are valued by sport hunters, and needed to sustain wolf populations. In addition to the immediate effect to deer, it was later learned predation rates for bird nests were highest near suburban areas and clearcuts regardless of whether nests were in open areas, along edges, or in adjacent forest interior (De Santo and Willson, 2001). Increased scientific resources were directed to understanding and developing alternatives to clearcutting with important results noted below.

The social acceptance of clearcutting, residual effects to the remaining vegetation, and effects to wildlife became important issues to understand and resolve. Clausen and Schroeder (2004) prepared a literature review and discussion of social acceptability of alternatives to clearcutting emphasizing southeast Alaska. They found a growing public dissatisfaction with clearcutting and a shift in societal values away from economic benefits of forests toward the spiritual, recreational, and aesthetic values forests provide. The long-held belief of abundant resources being available for the taking, has given way to the realization that there is a finite supply of natural resources that must be managed in a sustainable way. Previous expert-decision making styles have been replaced with public involvement in decision making.

In a local study of residents values in Hanus Bay, Alaska, Burchfield et al. (2003) found that timber harvest treatments that left 75% of the basal area were more acceptable than other treatments because they allowed for moderate harvest and minimal disturbance to other resources. McClellan et al. (2000) noted that partial cutting and helicopter logging emerged as technically feasible alternatives, but the expense of helicopter logging when treating for 75% basal area retention was three times more costly than clearcutting. Burchfield et al. (2003) believe residents make complex assessments when considering community and personal values regarding complicated forest management issues.

Understanding residual effects of alternatives to clearcutting was studied by retrospective examination of 18 stands that were partially cut 12–96 years earlier (Deal, 1999a, 1999b, 2000, 2001; Deal and Tappeiner, 2000; Deal et al., 2002; McClellan, 2004). Concerns about effects on tree growth, species composition, tree vigor, and Sitka spruce regeneration were unsubstantiated. Understory plant abundance, stand structural diversity, and species richness were all greater in partially cut stands than in clearcuts with young growth. Deal found, however, that when more than 50% of the basal area was removed, a significantly different plant community structure developed. Also, the 25% retention treatment showed more damage to the residual trees than the 75% retention treatment (McClellan and Deal, 2001). Yount (1998) studied 17 selectively logged stands (logged between 1900 and 1984 and not managed since) and reported no Sitka spruce regeneration in unlogged plots in his study, suggesting that soil disturbance promotes Sitka spruce regeneration.

Hennon and McClellan (1999) designed an experimental study to identify and categorize the disturbances causing tree mortality. Wind disturbance is considered a major source of tree mortality in southeast Alaska, but other disturbances that break sound trees are snow and ice loading (Hennon and McClellan, 2003). Hennon and McClellan (1999) discovered that most trees die standing and that standing dead trees were most frequently encountered, followed by trees with broken boles (wind events, or wind coupled with disease), and then uprooted trees (wind event with saturated soils). Heart rot is suspected to predispose trees in old-age stands to weakening through decay, eventual death standing, or earlier death from bole breakage facilitated by wind. Hennon et al. (2002) found that western hemlock lacked the specialized heartwood compounds that prevented saprophytic decay making them particularly susceptible to breakage, whereas yellow cedar (*Chamaecyparis nootkatensis*), containing the heartwood compounds that prevent decay, persisted as intact snags (containing tops) for 80 years or more (Hennon et al., 2002).

Wipfli and Gregovich (2002) examined 52 small streams to evaluate the export of invertebrates and coarse organic detritus from fishless headwaters, which are numerous in southeast Alaska, to larger streams containing other food webs lower in the valleys. They discovered that substantial numbers of invertebrates, which are valuable food for coho salmon fry, are delivered to distant aquatic food webs. Partial canopy removal is expected to influence solar penetration and increase headwater productivity, and full removal would likely reduce invertebrate abundance and litter in streams. Wipfli and Gregovich (2002, p. 966) caution that timber harvesting may also increase soil erosion and sedimentation (Waters, 1995), obliterating the biological response. Musslewhite and Wipfli (2004) sampled 17 headwater streams in timber harvest units before and after treatments and found no clear relationship in drift densities of invertebrates or organic detritus to type of timber harvest treatments applied. They observed a trend in increased proportion of true flies (*Diptera*) and a decrease in mayflies (*Ephemeroptera*) in more intensive treatments. Generally, the drift densities were comparable to natural variation in drift densities.

4.8. Determine Alaska timber prices and market arbitrage in the Pacific Northwest

The question was whether the markets for Alaska lumber and logs were integrated with those of Canada and the U.S. Pacific Northwest. The degree of integration of markets provides opportunities to describe factors common to both markets that might be useful in forecasting Alaska prices from values available in the other markets.

Stevens and Brooks (2003) investigated the Alaska softwood market price arbitrage and concluded that Alaskan western hemlock and Sitka spruce logs shared an integrated market with similar products from Canada and the U.S. Pacific Northwest. The relationship for lumber was less certain. Given the shared market conditions, Alaskan exports of forest products will be sensitive to international market conditions.

4.9. Determine prices and costs in Alaska timber production and product supply

Factors that influence Alaska's competitiveness in the Pacific Northwest forest products market are export supply, response to changing market forces, labor costs, and transportation costs. Robertson and Brooks (2001) report that southeast Alaska is a high-cost, softwood producer operating at the margin of profitability owing to high labor costs and low productivity for labor for both logging and sawmill sectors. Pacific Northwest labor is 35% more efficient than Alaska labor, while Alaskan labor costs are 65% higher. Both factors combine to make Alaska marginally competitive. The Pacific Northwest competitiveness is due to high mechanization, production of standardized dimension lumber, efficiencies and economies of large scale, newer equipment, and operating at capacity versus Alaska mills working well below capacity. The cost of transporting logs or lumber south to markets is a disadvantage. Alaska's advantage of high-grade Sitka spruce and yellow-cedar is offset by the high cost of transporting logs or lumber to southern markets.

4.10. Study lumber recovery of second-growth timber from southeast Alaska

Increasing Alaska's competitiveness in the timber volume and quality market required a baseline lumber recovery study on second-growth western hemlock and Sitka spruce from southeast Alaska. Such a study produces estimates of timber volume, lumber volume by grade, and lumber value recovery by diameter class and species. Christensen et al. (2002) reported mean recovery from all sawn logs (western hemlock and Sitka spruce) was 44.9%. Lumber was graded no. 2 or better (at least 90% of time), 5% was clear, and 10% select neutral. All grades matched or exceeded bending values for their species. Volume recovery and grade were not different for Sitka spruce obtained from thinned or unthinned stands. Volume recovery and grade were higher for western hemlock harvested from unthinned stands.

Barbour et al. (this issue) determined the effect of thinning management strategies on the resulting value of trees to produce future revenue by examining three thinning options for volume production and revenue generation at rotation ages of 70, 110, and 150 years. The commercial thinnings were (1) precommercial 3.66 m × 3.66 m spacing at 20 years, (2) precommercial thinning 5.49 m × 5.49 m spaçing at 20 years, (3) commercial thinning 6.10 m × 6.10 m spacing at 60 years, and (4) a passive management prescription with no thinning. Precommercial thinning (5.49 m × 5.49 m spacing) produced the greatest volume at 70 years. The passive management prescription equaled the precommercial thinning (5.49 m × 5.49 m spacing) prescriptions at 50 years on both high- and low-quality sites. The wood from precommercial thinning (5.49 m × 5.49 m spacing) prescriptions is believed to be more restrictive in terms of product potential than either the passive management or commercial thinning prescriptions. The high-value products derived from passive management and commercial thinning prescriptions translate to greater revenue per thousand board feet over precommercial thinning (3.66 m × 3.66 m spacing) prescriptions at 110 and 150 years.

5. Conclusion

After 6 years of intensive research, the major information needs appearing in appendix B of the Tongass National Forest plan (1997) have been addressed. As the studies progressed, some changes were made to the original objectives outlined in the forest plan as new information was gathered or as issues changed or new issues emerged. The final products reflect the requested refinements or revisions to the original questions and successfully finish the commitments made to the Tongass National Forest. The knowledge generated from these studies helped define future research direction and regional management in southeast Alaska. These include research questions centered on issues related to wildlife, aquatic systems and salmon spawning habitat, silviculture, wood products utilization, and social science research (Table 1). These broad questions remain focused on sustaining the forest ecosystem into the future while at the same time providing for resource use by the local communities and economies dependent on the forest for their survival.

The role of science in supporting the development of planning options for natural resource management of the Tongass National Forest was carefully considered to maintain science objectivity and impartiality. The Tongass planning process is a clear example of the recognition that natural resource management plans need to be founded on the best available science. The complexity of ecosystems and the scales at which they are organized and operate require focused research to answer key questions in tandem with impending management decisions. The social and economic pressure in high-profile locations, such as the Tongass National Forest, challenges managers to provide solutions to complex sustainable forestry issues. Managers want the support of science institutions to bolster the effectiveness, predictability, and credibility of their decisions. The integration of science into the decision making process is more prevalent today than it once was and will increase in the future as we move to refine management decisions based on a continually increasing body of science on which to base those decisions. We have an optimistic view of the future as managers of the world's natural resources are making increasing strides to integrate science information into the decision making process.

Table 1
Representative examples of future research issues for southeast Alaska by major research area

Research areas	Research issues
Social science	The tourism industry has been growing at a steady rate of 9% per year for the last 15 years in southeast Alaska. It is projected that 800,000 visitors will arrive in tour boats in 2004. The impacts of tourism on existing natural resources remain unknown. The effect of this increase in visitor numbers upon the value systems of residents also remains largely unknown. Models are needed that project demand and facilitate infrastructure development
Economics	As international and national markets continue to change it is important to understand the competitive standing of southeast Alaska in terms of primary wood production and secondary wood products market
Silviculture	Effective management of second-growth forests for multiple benefits continues to be a major challenge for managers. Sectors of society have competing value systems that often clash over proposed uses of the forest. Alaska has a competitive advantage in its high-quality timber. Managing second growth to take advantage of that competitive advantage is an important area of research
Wildlife and fish	Wildlife response to increased visitor use patterns and habitat alterations continue to be of particular interest in the highly fragmented island archipelago of southeast Alaska
Aquatics	Understanding the flow of water below the land surface is critical knowledge that helps managers examine the effects on salmon fry

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