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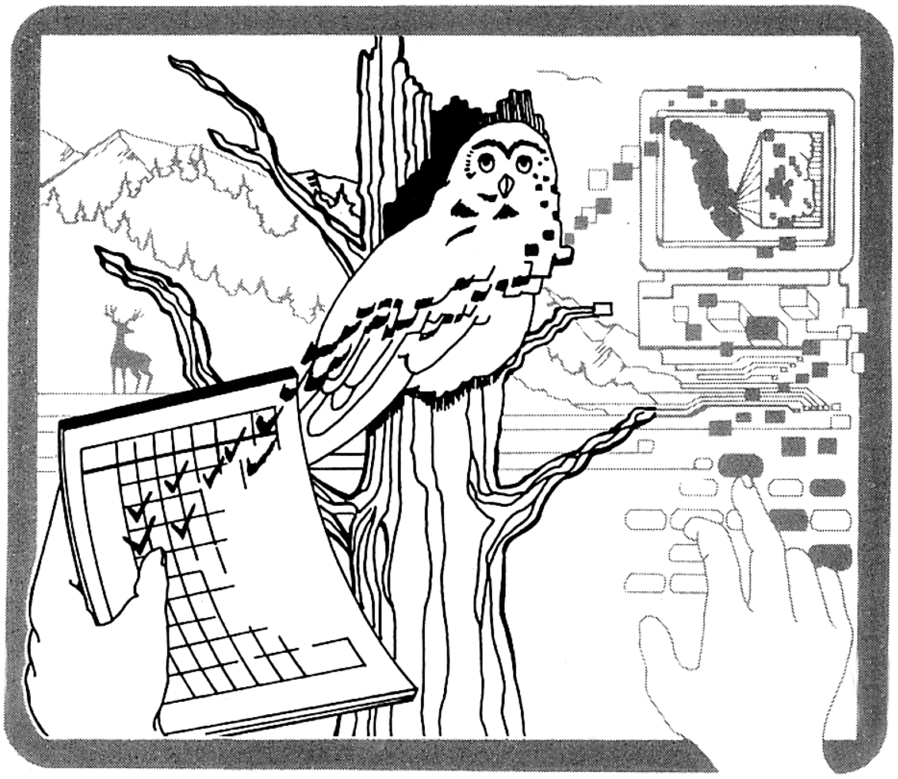

Applying Geographic Information Systems to Support Comprehensive Land Management Planning: Experiences of the Tongass National Forest, Alaska

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1 THE ISSUE

Management of the Tongass National Forest, which includes nearly 97% of the land in southeast Alaska, requires a comprehensive land management planning process to ensure all concerns are addressed in the formation of management strategies. The USDA Forest Service attempted to address issues involving the management of timber and wildlife on the Tongass National Forest through development of the original Tongass Land Management Plan (TLMP) from 1977 through 1979. In many cases, implementation of the plan did not resolve issues. The TLMP is currently undergoing a major revision. Addressing issues involving wildlife and timber management and incorporating them into the analysis and decision process again provides a major challenge to the USDA Forest Service.

The availability of comprehensive information describing the resources to be managed is probably the most critical element in the development of land management plans. Accurate information that can be accessed easily may be the determining point between a plan that is implemented consistently and efficiently or one that becomes a meaningless document. The first case will help to assure that resources are well managed in response to the public's desires. The second case will cause confusion and mistrust of the managing agency and may result in mismanagement of resources.

We will discuss how the USDA Forest Service has responded to this challenge in planning for the management of the Tongass National Forest. We will briefly present procedures and process for managing natural resource information during the original development and the implementation of the TLMP over the last 10 years. We will also describe the development and use of an automated Geographic Information System (GIS) used to support the current revision of the TLMP. This discussion provides some insights into the potential advantages and pitfalls that may be associated with implementing a GIS to support planning and management elsewhere.

2 THE SETTING

Southeast Alaska is characterized by numerous islands and peninsulas, with intervening saltwater channels, bays, and inlets with approximately 21 000 km of coastline. Vegetation communities in this area include upland old-growth forests of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) with scattered red cedar (*Thuja plicata*) and Alaska cedar (*Chamaecyparis nootkatensis*). These forests are interspersed with estuaries, riparian areas, muskeg openings with scattered shore pine (*Pinus contorta*), subalpine forests of mountain hemlock (*Tsuga mertensiana*), and alpine areas. These habitats support over 350 species of birds and mammals (Sidle and Suring 1986), including the densest breeding population of bald eagles (see Table 5 for scientific names of animals) and brown bears in the world. Several species which are endangered elsewhere in North America still flourish in southeast Alaska. Uses of wildlife include sport and subsistence hunting, trapping, and observation/photography. An expanding tourist industry has contributed to an increasing demand for opportunities to watch and photograph wildlife. This area also supports a substantial timber industry through timber harvest from private and federal lands.

The Tongass National Forest is the largest National Forest in the U.S. National Forest System, at 6 860 000 ha. The Tongass National Forest is managed under the multiple-use policy of the USDA Forest Service. This includes management to enhance use of the forest for recreation, wildlife, fisheries, and timber production. Management activities include development and maintenance of trails and cabins, implementation of fisheries enhancement projects, and timber harvest. Since the forest is so large, it is divided into three administrative areas, with Forest Supervisors offices in Ketchikan, Petersburg, and Sitka. Each supervisor's office has from two to four Ranger Districts under its administration.

In an attempt to encourage the establishment of a stable year-round industry in this area, long-term timber sale contracts were implemented in the 1950's. Two of these contracts are still in effect. The *Alaska National Interest Lands Conservation Act* requires the USDA Forest Service to make 10.6 million m^3 of timber available from the Tongass National Forest to the timber industry. On an annual basis, 703 000 m^3 is offered to companies holding the long-term contracts and 360 000 m^3 is offered under short-term sales (USDA Forest Service 1988*a*). The timber management program, with its associated road construction, is the most controversial management program in the Tongass National Forest. The controversy includes the impact of clearcut harvest practices on wildlife resources, the long-term nature of the timber sale contracts, and the costs associated with implementing the timber harvest program.

Most species of wildlife in southeast Alaska, including Sitka black-tailed deer, brown bear, bald eagle, Vancouver Canada goose, and hairy woodpecker have adapted to and rely on habitats provided by uneven-aged, old-growth forests (Lebeda and Ratti 1983; Schoen *et al.* 1984, Hughes 1985; Sidle *et al.* 1986; Peek *et al.* 1987). The conversion of old-growth forest to even-aged, second-growth forest through clearcutting dramatically changes ecological relationships and results in the reduction of habitat capability for most wildlife species (Schoen *et al.* 1988). The issue has been raised that timber harvesting, as currently practiced, will decrease the availability of wildlife resources for subsistence, sport, and commercial uses (USDA Forest Service 1989).

Issues regarding the long-term timber sale contracts have also been expressed. Some of the public believe there is a continued need for these contracts to ensure a steady, predictable, long-term timber supply upon which the timber industry can base its management decisions (USDA Forest Service 1989). Others feel that continuation of the long-term contracts does not give the USDA Forest Service enough latitude to address other resource issues and change management emphasis.

The costs associated with selling timber on the Tongass National Forest have recently exceeded revenue from the sales. This practice is supported by those people who believe that deficit sales are appropriate to maintain local economies. Others feel that timber that cannot be harvested economically should not be considered as part of the harvest base.

Road construction and maintenance activities in southeast Alaska are closely associated with timber harvest. Under some circumstances, these roads have increased the opportunities for the management of other resources and subsistence and recreational use of wildlife and fish. Other roads have resulted in concentration of use and increased competition for recreation, wildlife, and fish resources. In response to these varying results, some people favor additional roads and connection of existing roads; others oppose additional roads and feel existing roads should be closed to protect remaining wildlife populations and maintain the primitive character of Alaska.

3 DEVELOPMENT OF THE TONGASS LAND MANAGEMENT PLAN, 1977 TO 1979

Limited information was available to describe the resources in the Tongass National Forest in 1977. Five task forces were assembled to evaluate information available to them and determine how that information could be used to assist in the analysis of management options. The five task forces were land type/timber, minerals, wildlife, fisheries, and recreation/wilderness (Environmental Systems Research Institute 1984).

The forest was divided into 867 Value Comparison Units (VCU's) to provide common areas for the inventory and analysis of resources. These units are distinct geographic areas whose boundaries, in most cases, follow watershed divides. Occasionally, an island or group of islands constituted a VCU. The VCU's average 7300 ha, ranging from a few thousand hectares to hundreds of thousands. They were designed to provide a basis for describing and interpreting all resources.

3.1 Timber

A systematic point sampling technique was implemented to describe each VCU's potential yield of timber (USDA Forest Service 1978*a*). Approximately 210 000 sample points were selected and manually located on aerial photographs of the forest, using a grid. Each individually numbered point represented about 32 ha of land. About 0.5 ha around each sample point was analyzed through photo interpretation techniques for several variables (Table 1) and verified with existing information. These site descriptions were then assigned to the entire 32-ha plot. Information assigned to the plots concerning visual sensitivity and wildlife habitat that may have affected timber harvest were provided by the recreation/wilderness and wildlife task forces. All information was entered manually on data forms.

The resource information associated with each sample point was entered into a remote hierarchical database and summaries generated by VCU. This information was then used to evaluate the timber supply and availability for each VCU relative to the others. A 0 to 5 ranking scale was used.

This effort led to the development of the most complete inventory of land type and timber data to that date. It was the first time that uniform data were available for the total forest. However, accuracy was limited by lack of field verification and by the potential lack of uniformity in interpretation of information from aerial photography.

3.2 Wildlife

The wildlife task force did not use the sample point inventory compiled by the landtype/timber task force to evaluate the habitat in each VCU. The wildlife task force selected 11 species and species groups upon which to base the assessment (USDA Forest Service 1978*b*). Information on the habitat relationships and range of each species was compiled from existing literature, survey data, personal experience, and professional judgment (Table 2). This information was recorded on maps of the forest. Overlays with VCU boundaries were placed over these maps and a value was assigned to each VCU for each species or species group and their habitat. These values were summed by VCU and the totals used to assign a rating of 1 to 5 for each VCU. The highest ratings tended to reflect the VCU's with the highest species and habitat diversity. Estimates were also made, by VCU, of the proportions of old growth needed to maintain viable populations of wildlife.

The reliability of this information varied with the remoteness of the area. The more remote sites were visited less often, so less survey and personal information was available. The best information was available for the major islands and major mainland river systems; the weakest information was for upland mainland areas.

3.3 Application of Information

The information generated to describe the timber and wildlife resources on the Tongass National Forest through this process was integrated throughout the planning process and in planning documents associated with development of the land management plan (USDA Forest Service 1979). The affected environment was described using the information generated (e.g., distribution of wildlife and wildlife habitat, proportion of VCU's with high and low value rankings for wildlife, area of commercial forest land [CFL], and proportion of CFL in each operating class).

Planning was facilitated by developing four Land Use Designations (LUDs) that specified management for wilderness (LUD I), primitive environment (LUD II), combination of commodity and amenity values (LUD III), and intensive development of commodity resources (LUD IV). Management alternatives were developed by evaluating the rankings of the VCU's for timber, wildlife, and other resources and then assigning high and low value VCU's to each of the LUD's in different combinations. Alternatives were evaluated in the effects analysis using inventory information for wildlife and timber (e.g., area of specific wildlife habitats by LUD; proportion of VCU's, by wildlife rankings, in each LUD; area of CFL in each LUD; and proportion of VCU's, by timber ranking, in each LUD).

TABLE 1. Description of variables used to describe data points during resource inventory for development of the Tongass Land Management Plan (USDA Forest Service 1978*a*)

Variable	**Descriptors**
Land type	Private land
	Censused freshwater (>16 ha)
	Non-censused freshwater (>16 ha)
	Estuary
	Muskeg
	Alluvial
	Valley bottoms and lowlands
	Glaciated valley walls
	Alpine
	Native land selection
	Other withdrawals
Timber land class	Commercial forest land (CFL)
	Noncommercial forest land
	Nonforest
Forest type (CFL)	Hemlock-spruce
	Cedar
	Red alder
	Black cottonwood
Stand size class	Unstocked
	Seedlings and saplings (diameter at breast height [DBH] ≤13 cm)
	Pole timber, (DBH >13 cm, ≤28 cm)
	Young growth sawtimber (DBH >28cm, ≤150 years old)
	Old growth (>150 years old)
Volume class	< 47 m^3/ha
	47–117 m^3/ha
	117–175 m^3/ha
	175–292 m^3/ha
	>292 m^3/ha
Site index	Low (55–85)
	Medium (85–115)
	High (115–150)
Slope class	0–40%
	40–66%
	66–75%
	>75%
Soil hazard	None
	Moderate
	Extreme
Harvest operability	Normal log operation (high-lead, tractor, skidder, single-span skyline, A-frame, deck and cable swing)
	Non-standard (multi-span skyline, helicopter, balloon, slackline)
	Inoperable
High/medium visual sensitivity	Marine highway
	Other boats
	Roads and trails
	Other recreation sites
	Areas associated with communities
	Administrative sites
Special areas	Research natural areas
	Historic and archeological areas
	Research area
	Wilderness study area
	Proposed wilderness study area
	Islands <20 ha
	Islands 20–120 ha
Wildlife habitat	Brown/black bear
	Beach fringe (300 m)
	Estuarine/upland grasslands (300 m buffer)
	Riparian (150 m buffer)
	Subalpine
	Gray wolf
	Denning/rendezvous areas (400 m buffer)
	Sitka black-tailed deer
	Intermediate winter range
	Winter range

TABLE 1. (Cont'd.)

Variable	Descriptors
Wildlife habitat	Moose
	Prime habitat/concentration areas
	Mountain goat
	Concentration areas,summer range, winter range
	Furbearers
	Forest habitat
	Beach fringe (180 m)
	Land birds
	Present
	Water birds
	Nesting, feeding, moulting, and concentration areas
	Bald eagle
	One nest every 3220 m or more
	One nest every 1610 to 3220 m
	One nest every 1610 m or less

TABLE 2. Description of variables used to rate Value Comparison Units for wildlife values for development of the Tongass Land Management Plan (USDA Forest Service 1978*b*)

Variable	Rating - Descriptors
Brown bear/black bear	0 - Absent
	1 - Present
	2 - Beach fringe
	3 - Estuarine/upland grass flats
	-Streamsides
	-Subalpine
	-Inland grasslands
Gray wolf	0 - Absent
	1 - Present
	2 - Salmon streams, large tidal flats, travel routes, big game concentration areas
Sitka black-tailed deer	0 - Absent
	1 - Present
	2 - Intermediate winter range
	3 - Winter range
Moose	0 - Absent
	1 - Occasional use areas
	2 - Viable population areas
	3 - Prime habitat and concentration areas
Mountain goat	0 - Absent
	1 - Occasional use areas
	2 - Viable population ranges
	3 - Concentration areas, summer range, and winter range
Furbearers	0 - Absent
	1 - Occasional use areas
	2 - Forest habitat except beach fringe
	3 - Beach fringe
	- Islands (< 20 ha)
	- Major rivers
	- Lakes
Marine mammals	0 - Absent
	1 - Occasional use areas
	2 - General shoreline
	3 - Concentration areas
	- Rookeries
	- Hauling grounds
	- Feeding and resting areas
Land birds	0 - Absent
	1 - Uniform habitat types
	2 - Mixed upland habitat
	3 - Mixed habitat adjacent to marine waters, inland waters, or alpine
Water birds	0 - Absent
	1 - Occasional use areas
	2 - General shoreline

TABLE 2. (Cont'd.)

Variable	Rating - Descriptors
Water birds	3 - Nesting, feeding, moulting, and concentration areas
Bald eagle	0 - Absent 1 - One nest every 3220 m or more 2 - One nest every 1610 to 3220 m 3 - One nest every 1610 m or less

4 IMPLEMENTATION OF THE TONGASS LAND MANAGEMENT PLAN, 1979 TO 1989

Contiguous VCU's were grouped into 141 separate management areas to provide management direction to specific geographic areas (USDA Forest Service 1984). Management areas contained one or more VCU's allocated to a single LUD or to a combination of LUD's III and IV. Management areas ranged in size from a few thousand hectares to nearly a million hectares. Analysis of the management areas at the prescription level was to result in standards and guidelines that would refine the management direction specified in the TLMP. Project planning and design which incorporated these standards and guidelines was to occur at the implementation level.

However, forest-wide direction for Management Area Analysis (MAA) was not implemented. This resulted in MAA efforts on the three administrative areas that were inconsistent in approach and sporadic in action. Validation and updating of information used in development of the TLMP was to have taken place during MAA. This has not been accomplished, mainly because the sample point inventory and other information were not designed for use in project planning and were rarely used. Generally, during MAA and project planning, resource specialists manually prepared a series of maps that reflected timber types, specific habitats, timber operability, and prescriptions. These were then overlayed and evaluated to determine the best implementation of project activities to meet public expectations.

Although this approach was occasionally successful, it was recognized that well-structured and sound data were required for meaningful development and analysis of management actions (Environmental Systems Research Institute 1984). There was a lack of direction about what data should be collected and how they should be analyzed and presented. Protocols for data storage, presentation and documentation were inconsistent, undeveloped, or unenforced. Duplicate sets of data were maintained because of long delays and lack of confidence associated with data storage in the remote computer center. These problems demonstrated that standardized procedures for data collection, defined methods and formats for data storage, and a well-designed process for data access, sharing, and retrieval were needed. Specific to planning, enhanced capabilities were needed to perform overlays of resource maps and to produce area calculations, tabular reports, and final map products.

5 REVISIONS OF THE TONGASS LAND MANAGEMENT PLAN, 1989

Current legislation and the focus of attention on the management of National Forests, especially the Tongass National Forest, require that the USDA Forest Service effectively use available information to ensure that management issues are adequately addressed in the revision of the TLMP. Comprehensive inventories of soils and vegetation had been completed since the initial development of the TLMP. These inventories provided the opportunity for a comprehensive evaluation of resources on the forest if they could be effectively incorporated into the planning process.

5.1 Evaluation of Data Management Strategies

The need for an effective system for managing information to support the revision of the TLMP led the USDA Forest Service in the Alaska Region to implement a Natural Resource Management Information Needs Study conducted by Environmental Systems Research Institute (ESRI). The purpose of the study was to evaluate the information structure of the Tongass National Forest in order to recommend methods to efficiently manage information generated and used by the USDA Forest Service.

The ESRI study led to three basic alternatives relative to database design and use on the Tongass National Forest (Environmental Systems Research Institute 1985). Those alternatives were:

1. maintain existing data resources
2. provide improved manual databases, and
3. Provide automated databases.

An important benefit of maintaining existing data resources was that new costs would not be incurred. Also, the current data structure did respond, to varying degrees, to current tasks. However, large investments of time were needed to carry out even simple analytical procedures. Costs associated with these procedures would stay the same or most likely increase as the need for more comprehensive planning increased. There were also several procedural limitations associated with Alternative 1. Aggregation of mapping and tabular data to the Supervisor’s Office, Regional Office, and Washington Office for reporting purposes was very difficult. Maps and associated tabular data were difficult to link for analysis purposes. There was also little correlation or integration of related resource boundaries (e.g., timber types and soils) in manual maps. This often led to problems in the preparation and analysis of interpretive maps and in the implementation of plans on the ground.

The second alternative would have used existing manual data to build a series of consistent base maps. A set of maps making up a manual database would have been produced. Design of maps and associated data tables would have been very similar to those developed in association with Alternative 3. Substantial costs would have been incurred for preparing the standardized manual maps and associated tabular data. Cost for updates would have been high too, although they would vary depending on frequency of update. Considerable cost would also have been associated with use of the manual system in planning activities, as in Alternative 1.

Alternative 3 involved the manual preparation of improved maps and associated tabular data, which were then automated for analysis and production use. In other words, it called for implementation of an automated GIS. The range of capabilities associated with such an automated system corresponded closely to the needs identified during implementation of the TLMP.

This alternative resulted in the highest initial costs for developing databases and loading data into the automated system (Figure 1). However, the cost of using a GIS for data analysis and presentation was much reduced from that of a manual system (Prather 1989). Time-consuming, labor-intensive, and duplicative efforts such as map redrafting, area calculations, and buffer generation are all performed automatically, resulting in a 2.5 benefit/cost ratio.

It was essential, however, that development of a new approach to data management and use be carefully planned to ensure its success (Antenucci 1987). Prior to selection and full-scale implementation of a GIS on the Tongass National Forest, ESRI conducted a pilot test in 1985 on the Cleveland Peninsula in southern southeast Alaska, in association with an ongoing MAA. The pilot test was designed to examine and evaluate the proposed database design and to demonstrate and test the use of a GIS in a planning setting. The study area was composed of five VCU's on the Cleveland Peninsula. Eight map overlays of various natural resource information were incorporated into the system. Following successful completion of the pilot test, the Alaska Region requested approval from the Washington Office to acquire the ARC/INFO GIS to complete planning on Cleveland Peninsula. This request was approved. Based on those experiences, the Tongass National Forest was included in the National Controlled Evaluation of GIS as a pilot forest in 1987. This led to implementation and use of ARC/INFO GIS in the revision of the TLMP.

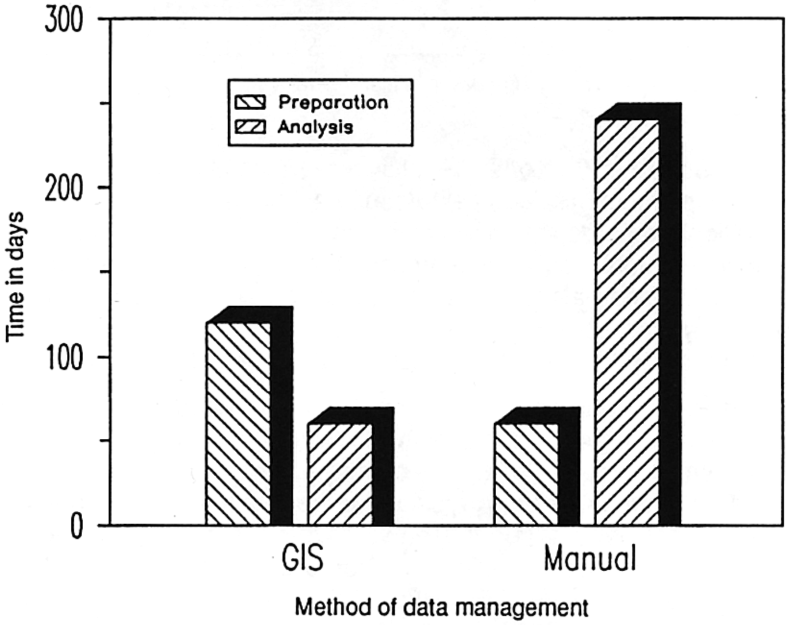

FIGURE 1. Comparison of time required for preparation of data and analysis for manual and automated information systems (from Prather 1989).

5.2 Implementation of GIS

Efficient data management is essential in the successful application of a GIS in natural resource planning (Johnston 1987). This was especially true in the Tongass National Forest, where the database is made up of approximately 2100 maps, making it one of the largest in the world incorporated into a GIS.

Thirty-nine kinds of data were identified as needed to manage the Tongass National Forest during the development of the regional database structure for GIS. A data dictionary was developed to describe individual variables and file formats associated with these 39 kinds of data (USDA Forest Service 1988*b*). All of this information was not needed in the process of TLMP revision. Computer resources may also have been severely affected if all of these resource layers had been included in the planning database. Of the 39 map layers, 11 were identified as needed for the revision effort (Table 3). Development and implementation of this GIS required the development of database management procedures that were unknown in the USDA Forest Service. A brief review follows that describes some of the problems encountered in establishing a GIS database of this magnitude and the solutions that were developed.

5.3 Management of Data in GIS

5.3.1 Sliver polygons

One of the basic features and functions of a GIS is the ability to overlay two or more resource maps to develop a separate map incorporating the desired map information. This process was implemented in a effort to develop an individual response unit or polygon that would be used by all resources for inventory and analysis.

TABLE 3. Mapped information required for the revision of the Tongass Land Management Plan[a]

Primary base series information for shoreline, administrative areas, and ownership
Vegetation
Roadless areas
Quadrangle map boundaries
Existing and planned roads
Value Comparison Units (1978 TLMP)
Elevation ranges derived from digital elevation model
Soil polygons
Stream channel type
Third-order watersheds
Recreation and visual polygons

[a] DeGayner, E.J. GIS database design for the Tongass land management plan revision. USDA For. Serv., Tongass Natl. For., Juneau, Alaska. In prep.

The overlay process in a GIS often results in the formation of small polygons called sliver polygons. Sliver polygons have the potential to cause a severe impact on computer processing time because of the additional records that need to be handled. Slivers are often caused by: 1) lack of standard lines for stable features, such as shoreline, that occur on several maps; 2) differences in the location of polygon boundaries along ecological transition zones; and 3) legitimate subdivision of polygons. We will briefly discuss our experiences dealing with a specific case of the second cause, although the principles apply for the management of all sliver polygons.

Timber type and soil polygon boundaries are highly correlated on the Tongass National Forest. The same photography was used to create both, and vegetation characteristics were used to locate boundaries for both. When these two maps are overlayed, many sliver polygons are formed because the boundaries cross numerous times. A typical quadrangle map contains about 3000 timber type polygons and 2500 soil polygons. When these two covers are overlayed, a map containing approximately 15000 polygons is produced; 10000 of these are less than 0.5 ha. The maximum polygon density for efficient processing in the ARC/INFO system is from 3000 to 5000 polygons per quadrangle map. This problem must be addressed if data are to be managed efficiently.

A two-step process was used to solve this problem. The timber-type inventory has about 75 different descriptors for vegetation. The resource models that use timber-type information require only 16 of those descriptions. It was also possible to aggregate the nearly 600 soil mapping units to about 100 categories that were needed for planning purposes. Dissolving 75 timber type classes into 16 classes and 600 soil units into 100 had the effect of reducing the number of polygons by about 50%. The quality of the data needed for the analysis proposed was maintained throughout this process. However, new groupings of the original inventory data were not possible once polygon lines were dissolved.

The second step to solving the sliver polygon problem was to eliminate the slivers formed after maps were overlayed. Small polygons were merged with larger neighboring polygons. After timber type and soils maps underwent the dissolve process described previously and were overlayed, about 70% of the polygons were still less than 5 ha. However, these polygons represented an area of less than 5% of the total map. Therefore, if all polygons less than 5 ha were eliminated, processing requirements would be reduced by approximately 70%, while only 5% of the information on the map would be affected.

The effect of eliminating 0.5-, 2.0-, 4.0-, 8.0-, and 20.0-ha polygons on data integrity and efficiency was determined through a series of trial runs. Elimination of polygons of increasing size was performed on overlays of the timber type and soil maps for three quadrangles. If all polygons less than 4 ha were eliminated, a 40% reduction in number of polygons, computer storage space needed, and processing efficiency can be expected (Table 4). As the number of polygons decreased through elimination of larger and larger polygons, the average size of polygon increased, but the total area of the resource of interest stayed about the same (Figure 2).

TABLE 4. The effect of eliminating polygons on the number of remaining polygons per quadrangle map

Size of polygon eliminated (ha)	Number of polygons remaining
0.0	15 000
0.5	6000
2.0	3600
4.0	2300
8.0	1500
20.0	900

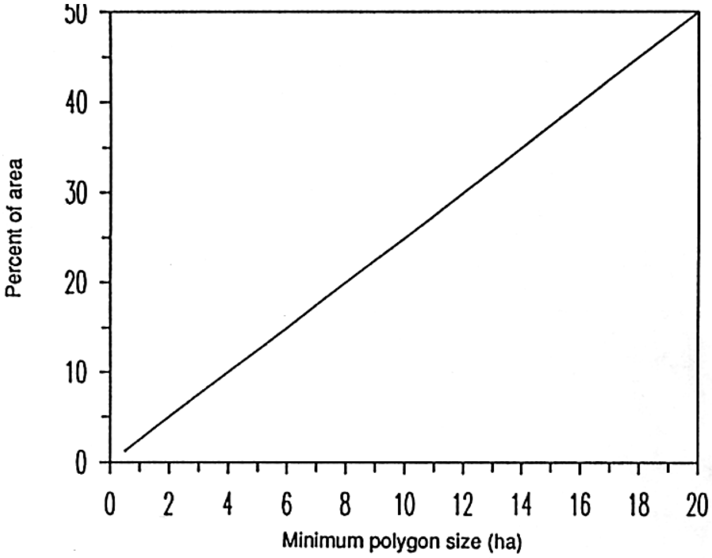

FIGURE 2. The effect of eliminating polygons ranging in size from 0.5 to 20 ha on average polygon size, number of polygons, and total area (from DeGayner, in prep.).

This approach facilitated the combination and conversion of mapped information to tabular information. The process resulted in little loss of the integrity of data associated with area parameters. However, the geographic information tends to be distorted as small polygons are combined and lose their integrity. As the polygon size eliminated increased, the percentage of the map that lost its original inventory classification increased (Figure 3). Also, small features such as buffers on riparian areas tend to be significantly reduced, unless the polygon elimination process is carefully applied.

5.3.2 Grid cells

Even with reduction of the number of polygons, substantial amounts of computer time were needed to implement inventory and analysis procedures on the Tongass National Forest database. An alternative approach to the traditional use of polygons with the GIS was implemented in the revision process to decrease the computer resources needed and to avoid spatial distortion.

A grid was electronically laid over each resource map. The attributes associated with the center point of the cell in the grid were then automatically assigned to the cell. The resulting cumulative grid cell information was processed very efficiently by the ARC/INFO GIS. The grid cell method of building a working database is processed 7 times faster than the polygon overlay method.[1] The process of assigning area and attribute values to a point from a polygon is rather simple and straightforward, and is not influenced by the complexity of the polygon map. Resource maps can be maintained in their original format and do not have to be simplified to be used.

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[1] DeGayner, E.J. GIS database design for the Tongass land management plan revision. USDA For. Serv., Tongass Natl. For., Juneau, Alaska. In prep.

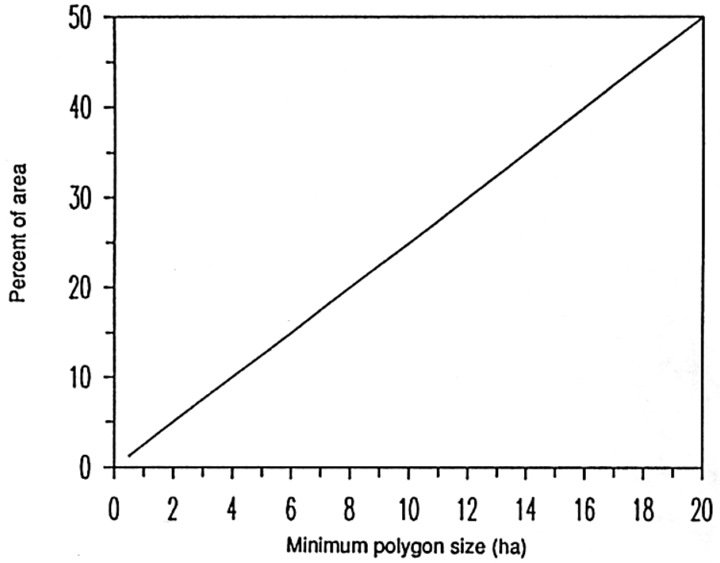

FIGURE 3. The effect of eliminating polygons ranging in size from 0.5 to 20 ha on proportion of inventoried area that is reclassified.

To determine the accuracy of area estimates associated with grid cells, six randomly generated 6-ha grids and five randomly generated 20-ha grids were applied to the timber-type map for three quadrangles. These applications generated area estimates for a number of attributes, including the 175-292 m^3/ha timber volume class.[2] This process was repeated 120 times for the 6-ha grid and 100 times for the 20-ha grid. Total land area calculated from the grid cells was within 1% of that calculated from the polygon maps. The accuracy of estimates for particular attributes varied with size of the grid cells and the average size of the associated polygon. The standard deviations of the mean difference between area estimates from grid cells and polygon maps were 5% for the 6-ha grid and 7% for the 20-ha grid.

The grid cell approach appeared to adequately represent mapped resources on the forest to the level required by planning associated with revision of the TLMP. However, the structure of the grid cells is not conducive to creating and drawing base maps. More computer time is needed to create the maps from grid cells than with polygon files, and fine features — such as riparian areas — are not mapped as well. Therefore, the polygon files were used for developing planning maps whenever possible, while the grid cell information was used to generate and analyze tabular data.

The number of grid cells and computer storage space required increases exponentially as grid size decreases (Figures 4 and 5). One point per 6 ha would result in approximately 1.13 million points in the forest. One point per 20 ha would result in 338 000 points (the original TLMP had a 32-ha grid). A 6-ha grid would create a file requiring about 500 hours of computer time to build data files for analysis; a 20-ha grid would require 300 hours (Figure 6). An 8-ha grid was chosen to process revision data because it was considered to have sufficient resolution and reasonable processing time, and to be within hardware limitations.

5.4 Application of GIS

5.4.1 Wildlife

Once the inventory data files were established in the GIS, analysis of the data began in an effort to describe the resources in the forest and to evaluate the effects of proposed management alternatives on those resources. Thirteen wildlife species were selected as Management Indicator Species (MIS)

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[2] Ibid.

to provide a basis for evaluation during the revision process (Table 5). Population changes of MIS are believed to reflect the effects of land management activities. The total number of species occurring within a planning area can be reduced through this concept to a number that promotes meaningful evaluation. The evaluation of the effects of management practices on MIS and their habitats provides an additional basis for ensuring the maintenance of biological diversity.

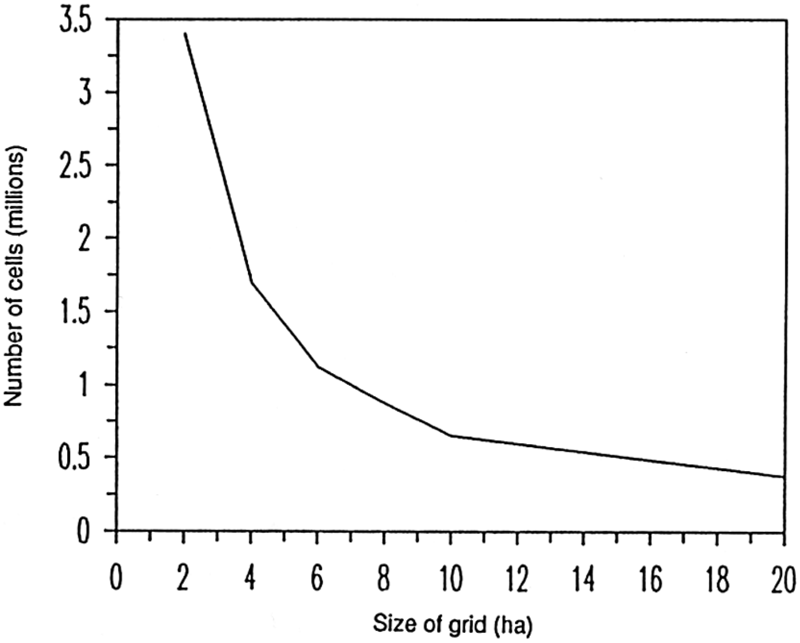

FIGURE 4. The effect of grid density on number of grid cells.

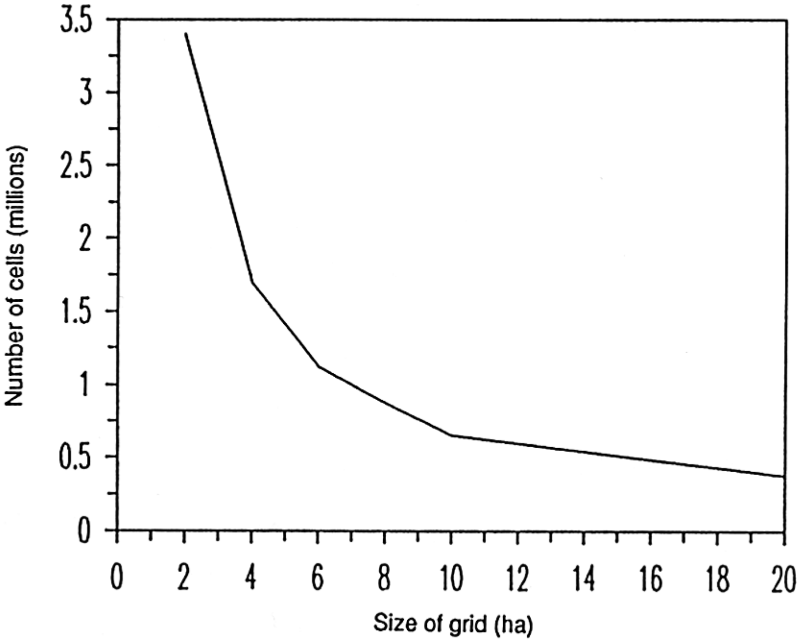

FIGURE 5. The effect of grid density on computer space required for storage. Horizontal line is upper limit of maximum computer file size.

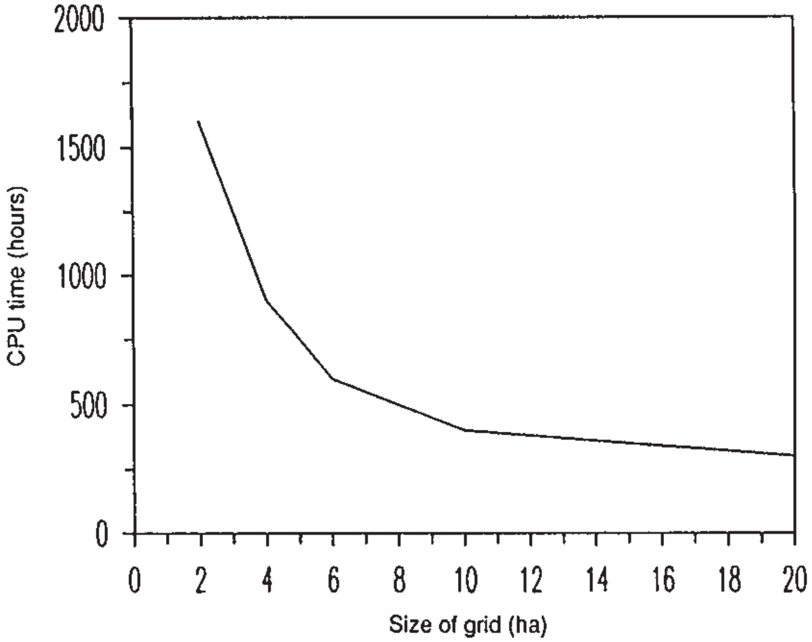

FIGURE 6. Computer processing required to develop data files for analysis purposes.

TABLE 5. Wildlife management indicator species being used in the revision of the Tongass Land Management Plan

Common name	Scientific name
Gray wolf	*Canis lupus*
Black bear	*Ursus americanus*
Brown bear	*Ursus arctos*
Marten	*Martes americana*
River otter	*Lutra canadensis*
Sitka black-tailed deer	*Odocoileus hemionus sitkensis*
Mountain goat	*Oreamnos americanus*
Red squirrel	*Tamiasciurus hudsonicus*
Vancouver Canada goose	*Branta canadensis fulva*
Bald eagle	*Haliaeetus leucocephalus*
Hairy woodpecker	*Picoides villosus*
Red-breasted sapsucker	*Sphyrapicus ruber*
Brown creeper	*Certhia americana*

A system was established to incorporate the MIS into the planning process (Figure 7). Interagency task groups developed habitat capability models for each of the MIS. Models were specifically designed for implementation on the GIS. These models required information on 10 habitat variables and other information (e.g., buffers) available from the GIS (Table 6). The models were verified by being run on portions of the Tongass National Forest where population data have been collected for the individual MIS or where task force members have personal knowledge of population levels. Estimates of habitat capability produced by the models were compared with available data or other estimates. This activity served as a verification procedure for both the models and habitat information in the GIS. Interactive revision of the models and the database will proceed as necessary.

By linking habitat capability models to the GIS, summaries may be generated for any combination of habitat variables, along with associated estimates of habitat capability for the species in question. A high degree of spatial resolution is possible for these habitat summaries and habitat capability estimates.

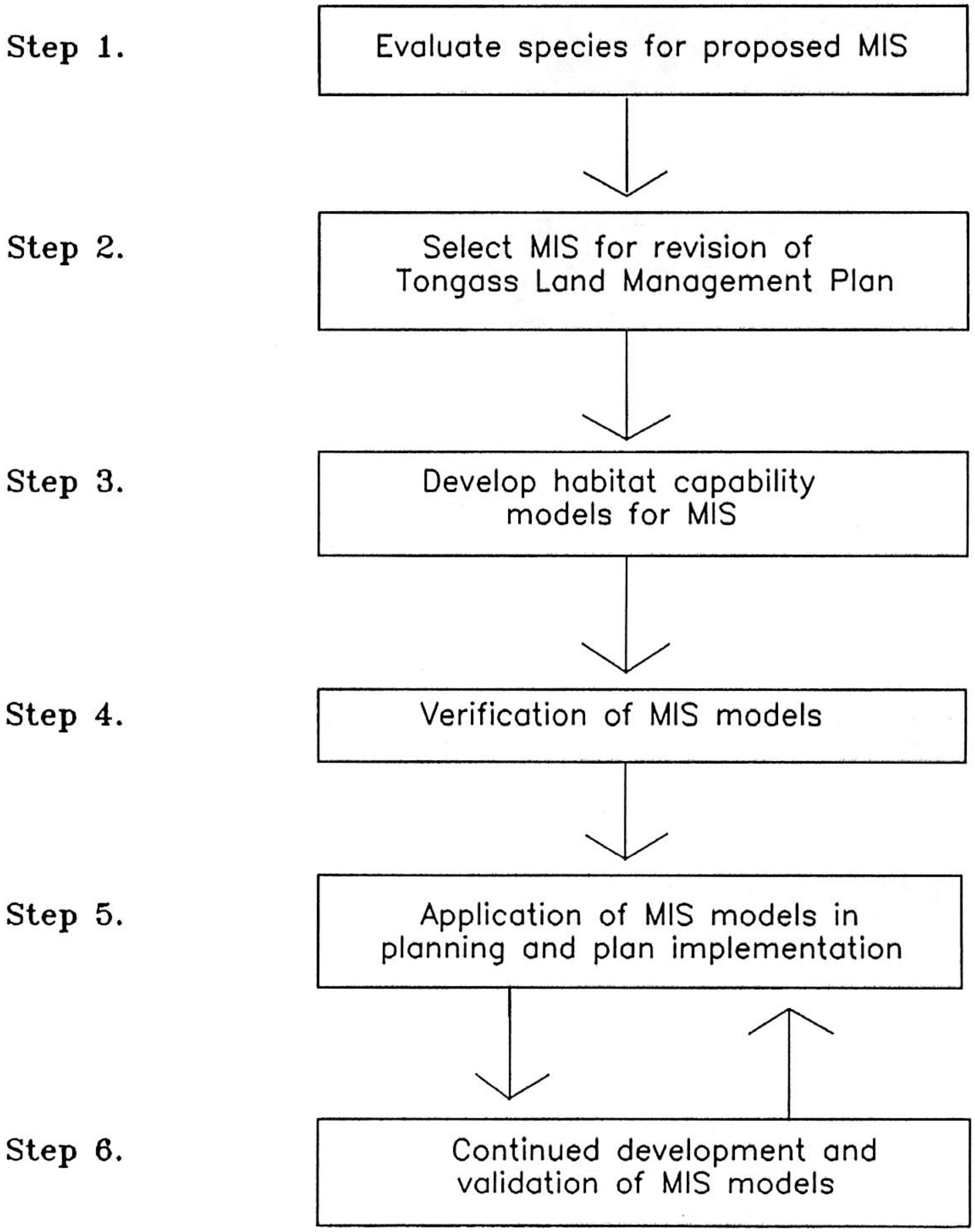

FIGURE 7. Process for incorporating management indicator species and associated habitat capability models into the planning process.

TABLE 6. Variables included in the GIS used to model habitat capability for the management indicator species for revision of the Tongass Land Management Plan

Management indicator species	**Variables**
Gray wolf	None (based on number of prey animals - black-tailed deer and mountain goat)
Black bear	Forest overstory type Upland Riparian Beach fringe Estuary Timber volume class Successional stage Stream class
Brown bear	Forest overstory type Upland Riparian Beach fringe Estuary Successional stage Stream class Disturbance/mortality
Marten	Forest overstory type Upland Beach fringe/riparian Timber volume class Successional stage Elevation
River otter	Forest Upland Riparian Beach fringe Timber volume class Successional stage Elevation Stream class Lake size
Sitka black-tailed deer	Forest overstory type Upland Riparian Timber volume class Successional stage Elevation Aspect Winter severity Predators Patch size
Mountain goat	Forest overstory type Timber volume class Successional stage Aspect Presence of cliffs
Red squirrel	Forest overstory type Successional stage
Vancouver Canada goose	Forest overstory type Beach fringe Riparian Timber volume class Successional stage Elevation
Bald eagle	Forest overstory type Upland Riparian Beach fringe Timber volume class Successional stage Elevation Stream class Lake size

TABLE 6. (Cont'd.)

Management indicator species	Variables
Hairy woodpecker	Forest overstory type Timber volume class Successional stage
Red-breasted sapsucker	Forest overstory type Timber volume class Successional stage
Brown creeper	Forest overstory type Timber volume class Successional stage

SITKA BLACK-TAILED DEER

The habitat capability model for Sitka black-tailed deer required information from: 1) the vegetation map layer (i.e., overstory tree species, forest productivity, and successional stage); 2) the stream channel type layer (i.e., riparian areas); 3) the soil layer (i.e., riparian areas); 4) the topographic map layer (i.e., aspect and elevation); and 5) the VCU layer (winter severity and presence of predators).[3]

Polygons of forested vegetation in the GIS database were assigned to: 1) timber volume classes ranging from forests without commercial value to high volume forests, depending on the average net volume of wood in the polygon; 2) one of five successional stages ranging from clearcut to old growth; and 3) one of eight forest types based on the dominant canopy tree species. These variables were used to represent the relationship between deer and vegetation in southeast Alaska. A preference has been demonstrated by deer during winter in this area for stands of old-growth western hemlock and Sitka spruce with high volumes of timber (Rose 1984; Schoen *et al.* 1985). Decreasing use by deer was noted in more open stands with lower timber volumes, and in clearcuts and second-growth forests.

Information on stream channel types and riparian soils in the GIS was used to describe and delineate riparian areas in southeast Alaska. The resulting information on location of riparian areas and information from the vegetation layer were used in the model to refine further the relationship between deer and their habitat in the model. Old-growth Sitka spruce riparian forests do not receive significant use by deer during the winter because forage production is limited and such forests tend to occur in cold-air drainages (Schoen *et al.* 1981).

A digital elevation model was used in conjunction with the GIS to assign each vegetation polygon to one of six aspect classes. This was useful in describing habitat for deer because slopes with southerly aspects are more valuable to deer in the fall, winter, and spring than slopes with northerly aspects (Hanley 1984). The digital elevation model was also used to assign one of six elevation classes to each vegetation polygon. Forested winter range at lower elevations is more valuable to deer than similar habitats at higher elevations where snow makes forage unavailable and movement difficult (Schoen and Kirchhoff 1985).

Winter severity in association with habitat conditions may have a significant influence on the health of a deer herd (Verme 1968). Annual snowfall was found to be the best indicator of winter severity in southeast Alaska as related to habitat capability for Sitka black-tailed deer (R. Flynn and M. Kirchhoff, Alaska Dep. Fish and Game, unpubl. data). The VCU's throughout southeast Alaska were rated in terms of four classes of typical winter severity as estimated by snow depth. The resulting map of winter severity in southeast Alaska was accessed through the GIS to provide this information to the model.

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[3] Suring, L.H. E.J. DeGayner, R.W. Flynn, M.D. Kirchhoff, J.W. Schoen, and L.C. Shea. 1992. Habitat capability model for Sitka black-tailed deer in southeast Alaska: winter habitat. USDA For. Serv., Alaska Reg., Juneau, Alaska. Draft document.

Predation can act as a significant controlling factor on deer populations (Keith 1974). This is especially true in those areas of southeast Alaska where gray wolves are present (Van Ballenberghe and Hanley 1984). The presence or absence of gray wolves in each of the 867 VCU's on the forest was determined and incorporated into the GIS database. We were then able to modify the habitat capability for deer by a predation factor wherever gray wolves occurred.

This habitat capability model was applied to the Kadashan Quadrangle in central southeast Alaska to provide an example of the information that may be generated (Table 7). These and other summaries provide the land manager with site-specific information on the amount, location, and quality of habitat available in a planning area and an estimate of the potential of that habitat to support wildlife populations. This information may be used to establish management objectives for wildlife and wildlife habitat. Similar information for other resources (e.g., timber, recreation, minerals) may be combined with the wildlife information to determine areas of potential conflict and tradeoffs associated with various management strategies.

TABLE 7. Application of the habitat capability model for Sitka black-tailed deer on the Kadashan Quadrangle in southeast Alaska (habitat and elevation examples)

Habitat/location	**Area**		**Mean index**	**Habitat capability for deer**		
	hectares	**%**		**Total number**	**Number per ha**	**%**
Old growth						
Low productivity	9238	19	0.18	811	0.09	26
Medium productivity	9084	19	0.31	1375	0.15	43
High productivity	2063	4	0.45	451	0.22	14
Unproductive forest and early to mid-succession	11366	24	0.10	542	0.05	17
Nonforest	16316	34	0.00	0	0.00	0
Total	**48067**	**100**	**0.14**	**3179**	**0.07**	**100**
Elevation						
Less than 245 m	20717	43	0.24	2414	0.12	76
245 m to 365 m	7572	16	0.14	529	0.07	17
365 m to 460 m	3462	7	0.14	236	0.07	7
Greater than 460 m	16316	34	0.00	0	0.00	0
Total	**48067**	**100**	**0.14**	**3179**	**0.07**	**100**

5.4.2 Land suitable for timber harvest

A model was also developed to estimate the amount of land in the forest that was tentatively suitable for timber harvest in response to provisions of the *National Forest Management Act* regulations (USDA Forest Service 1988*c*). Lands suitable for timber harvest constituted the land base in the planning process for determining the allowable sale quantity of timber and for planning all vegetation management practices associated with timber production.

Criteria included in the model, which defined biologically and administratively unsuitable lands, included: 1) land that is not forest land; 2) technology unavailable to ensure that timber harvest will not result in irreversible damage to productivity of soils or condition of watershed; 3) inadequate information to estimate responses of the land to timber management activities; 4) lack of reasonable assurance that adequate restocking will occur; and 5) land that has been administratively removed from timber production. The model was based on a stepwise process to evaluate National Forest lands (Figure 8). This model required information from four different inventories available through the GIS (Table 8). The 6.86 million ha of the forest were classified through the GIS to determine the land base available for potential timber production (Table 9). After proceeding through the six-step process, 1392598 ha were determined to be suitable for timber production (USDA Forest Service 1990).

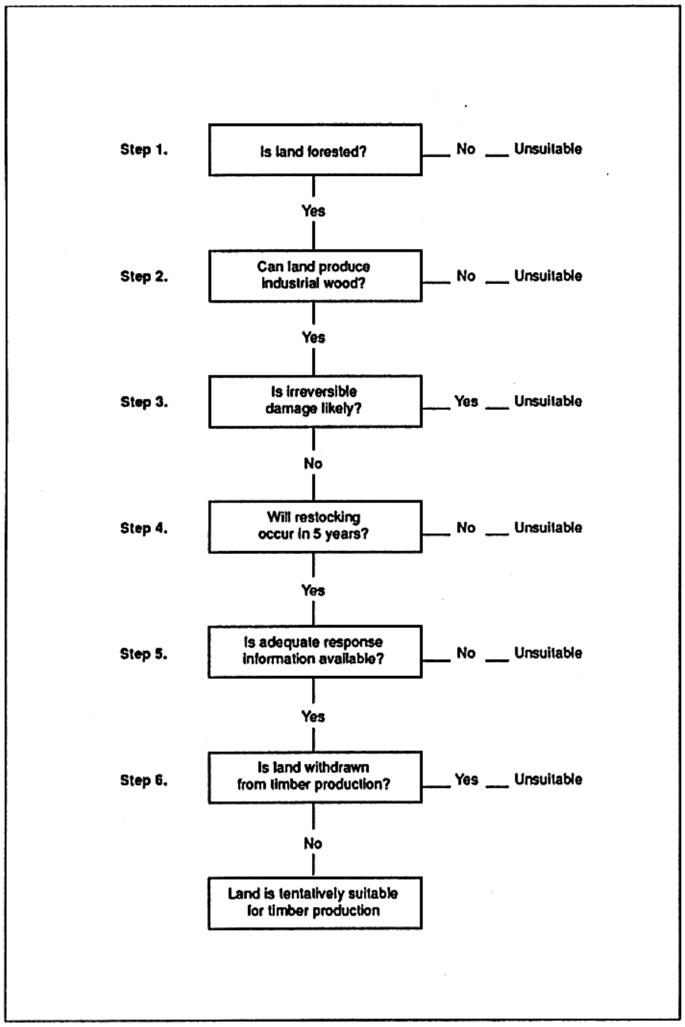

FIGURE 8. Process for identifying lands suitable for timber production in the Tongass National Forest of southeast Alaska.

TABLE 8. Inventories available in the GIS that were used to define lands tentatively suitable for timber production in the Tongass National Forest of southeast Alaska

Inventories	**Criterion used**
Forested land	Vegetation Soils Administrative Roads
Forested land capable of producing industrial wood	Vegetation
No irreversible damage	Soils
Restocking in 5 years	Soils
Vegetation response information	Vegetation Soils
Administratively available	Administrative boundaries

TABLE 9. Classification of lands suitable for timber production in the Tongass National Forest of southeast Alaska (from USDA Forest Service 1990)

Classification step		Area (ha)
Total National Forest area		6 861 834
Step 1. Is land forested?		
Fresh water		108 314
Non-forest lands		2 816 138
Developed for purposes other than timber production		5 848
	Remainder	**3 931 534**
Step 2. Can land produce industrial wood?		
Not capable of growing industrial wood products		19 628
	Remainder	**3 911 906**
Step 3. Is irreversible damage to the landscape likely?		
Irreversible damage is likely to occur		344 257
	Remainder	**3 567 649**
Step 4. Will restocking occur in 5 years?		
Regeneration will be difficult		39 261
	Remainder	**3 528 388**
Step 5. Is adequate response information available?		
Response information is inadequate		1 226 160
	Remainder	**2 302 228**
Step 6. Is land withdrawn from timber production?		
Existing wilderness		895 432
Existing Research Natural Areas		8 464
Existing Experimental Forest		5 734
Lands tentatively suitable for timber production		1 392 598

6 CONCLUSIONS

The development and verification of the GIS database, and the resource models associated with it, have provided users with unprecedented access to the resource inventories available for the Tongass National Forest. The ability to describe wildlife habitat and timber resources for a particular analysis area (forest-wide planning) or site (plan implementation) was greatly enhanced because numerous vegetation and landscape attributes may be used to describe that area or site. Areas where the potential exists for resource conflict can be graphically illustrated for numerous management alternatives. Such maps, along with tabular summaries of information, provide the resource manager and the public with a clearer understanding of management benefits and consequences. The design and structure of the database being used in the revision of the TLMP, and the availability of a GIS, will result in a more implementable plan than was produced originally. Access to the database and the analysis techniques is greatly enhanced and will allow validation to be incorporated into implementation of the plan.

It is anticipated that the GIS database and associated resource models will be made readily available to users through menu-driven systems. This will vastly increase our ability to access inventory information and will improve the quality of our analyses. However, the job of the resource specialist in management planning and implementation will not necessarily be made easier because of the presence of a GIS. The increasing complexity of the issues associated with managing National Forests will require increasingly complex analyses. The resource specialist will need to have a complete understanding of the strengths and weaknesses of the inventories being used. The specialists will have to understand the functions and assumptions incorporated into the models being used so that the models are applied properly. Additional analysis techniques will need to be developed because menu systems cannot anticipate all the ‘‘what ifs’’ that may arise in the planning process. The biologist or forester will need to know the limitations of the software and hardware being used, to ensure analyses and inquiries will be successful.

The experiences of the Tongass National Forest in the design and implementation of a GIS have lessons for others considering the use of a GIS in management of forest resources. Other than in size, the Tongass National Forest is not unique in its use of a GIS. Other management areas may be smaller in area, but they often have more complex inventories, more management options, and more variable landscapes. It is important not to expect too much from a GIS. Our ability to use and present information from resource inventories is greatly enhanced through the use of a GIS. However, the size of our database and associated software and hardware limitations restricted our ability to use the full capability of the GIS. Design and implementation must be approached cautiously and be done thoroughly to ensure that the system will do what is needed and expected.

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