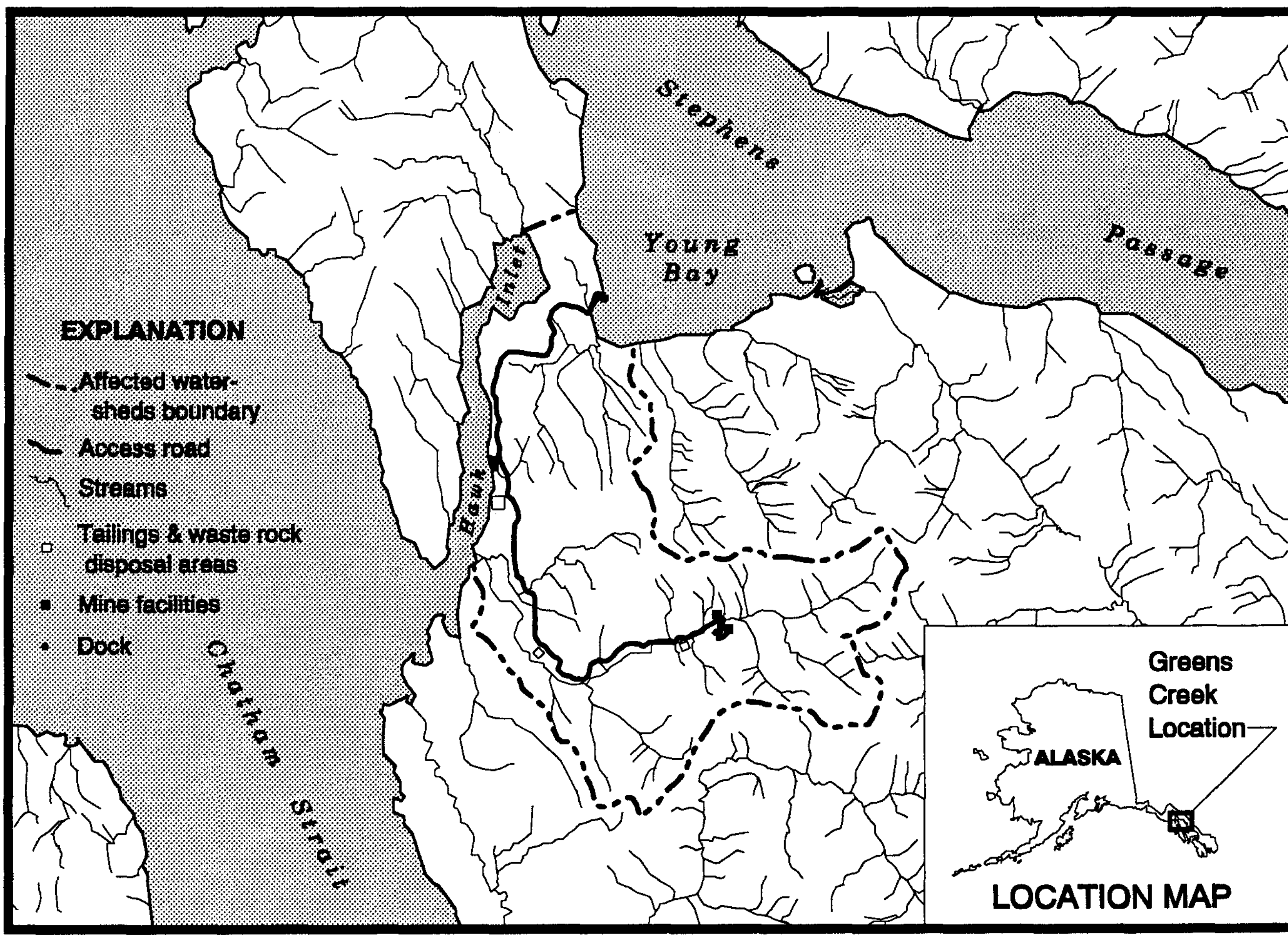
MODELING ECOSYSTEM IMPACTS of the GREENS CREEK MINE - A Preliminary Study -



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MODELING ECOSYSTEM IMPACTS OF THE GREENS CREEK MINE

- A Preliminary Study -

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ABSTRACT

The Bureau of Mines (BOM) has begun a project to increase the understanding of the relationships between ecosystem health and its functions, and minerals development. The BOM, Juneau Branch, Alaska Field Operations Center, is providing support for ecosystem based land-management decision-making and the development of ecosystem based regulations by documenting the effects of mining on ecosystems and demonstrating the tools used to assess and analyze those effects. This is done by reviewing the data available on ecosystems and the environment at a mining site, the Greens Creek Mine near Juneau, Alaska, and applying available Geographic Information System modeling tools to assess the impacts of the mine on components of the pristine ecosystem. Habitat Capability Models for wildlife indicator species are used in this examination. Wildlife indicator species are used as indicators of ecosystem health by the U.S. Forest Service and the Alaska Department of Fish and Game, who developed these models for southeast Alaska. Analysis techniques from the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) are also used in this report.

By applying available models and analytical techniques to the Greens Creek area, the benefits gained through mitigation of potential impacts become apparent. These or similar techniques are useful for cost/benefit analysis of mitigation alternatives. Also apparent from this analysis is that the degree to which potential impacts are observable will depend upon the ecosystem scale considered. This demonstrates the importance of defining the ecosystem and scale before performing impact and cost/benefit analysis. The watershed scale is found to be useful for assessing impacts to ecosystem components at the Greens Creek Mine. Much progress remains to be made in the modeling and prediction of impacts to ecosystems from mining activity.

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INTRODUCTION

The Bureau of Mines (BOM) has begun a project to increase the understanding of the relationships between ecosystem health and its functions, and minerals development. The Bureau plans to be an active participant, in concert with legislative authorities and land management and regulatory agencies, in defining and implementing the emerging concept of using an ecosystem-based regulatory approach to the protection of human health and the environment.

Ecosystem management is the method that is being developed to reconcile economic development with protection of the environment. Only by understanding the functions that ecosystems perform can economic development occur with as little negative impact as possible to the ecosystems on which we depend. In Alaska, this is especially important because of the relative lack of industrial activity and the pristine nature of the environment.

Ecosystem management strives to maintain the stability and integrity of the ecological system. It uses knowledge of the ecosystem and its interactions to produce products, services, and resource values in ways that sustain the diversity and productivity of the ecosystem. An understanding of ecosystem functions can greatly influence the conservation and management practices adopted by land-managers.

Ecosystem based land-management practices are becoming increasingly common within federal land-management agencies, and this trend is expected to continue. The BOM, Juneau Branch, Alaska Field Operations Center, is providing support for ecosystem based land-management decision-making and the development of ecosystem based regulations by documenting the effects of mining on ecosystems and demonstrating the tools used to assess and analyze those effects. This will be done in this report by reviewing the data available on ecosystems and the environment at a mining site, the Greens Creek Mine, and applying available modeling tools to assess the impacts of the mine on a pristine ecosystem.

In a previous report (8)[1], the BOM contacted numerous local, state, and federal agencies to determine the extent to which ecosystem based land-management is present in these agencies. It was found that in Alaska, the U.S. Forest Service (USFS) is taking the lead in promoting ecosystem based land-management concepts. The Bureau of Land Management (BLM) is also promoting ecosystem management policy. The U.S. Fish and Wildlife Service (FWS) is instituting ecosystem management principles at National Wildlife Refuges and at particular sites, while the U.S. Environmental Protection Agency and the Corps of Engineers are also becoming more involved in incorporating ecosystem management principles in their permitting practices.

An important ecosystem management issue identified in the previous report is that of ecosystem scale. Many scales can be considered when examining impacts to ecosystems, for example the Ecoregion of Alaska scale shown in Figure 1. This map is a joint effort of the U.S. Geological Survey, the U.S. Environmental Protection Agency and Colorado State University (5). Another scale is the Ecological Provinces scale used by the U.S. Forest Service for forest planning on the Tongass National Forest of southeast Alaska (Figure 2).

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[1]Underlined numbers in parentheses refer to citations listed in the "References" section of this report.

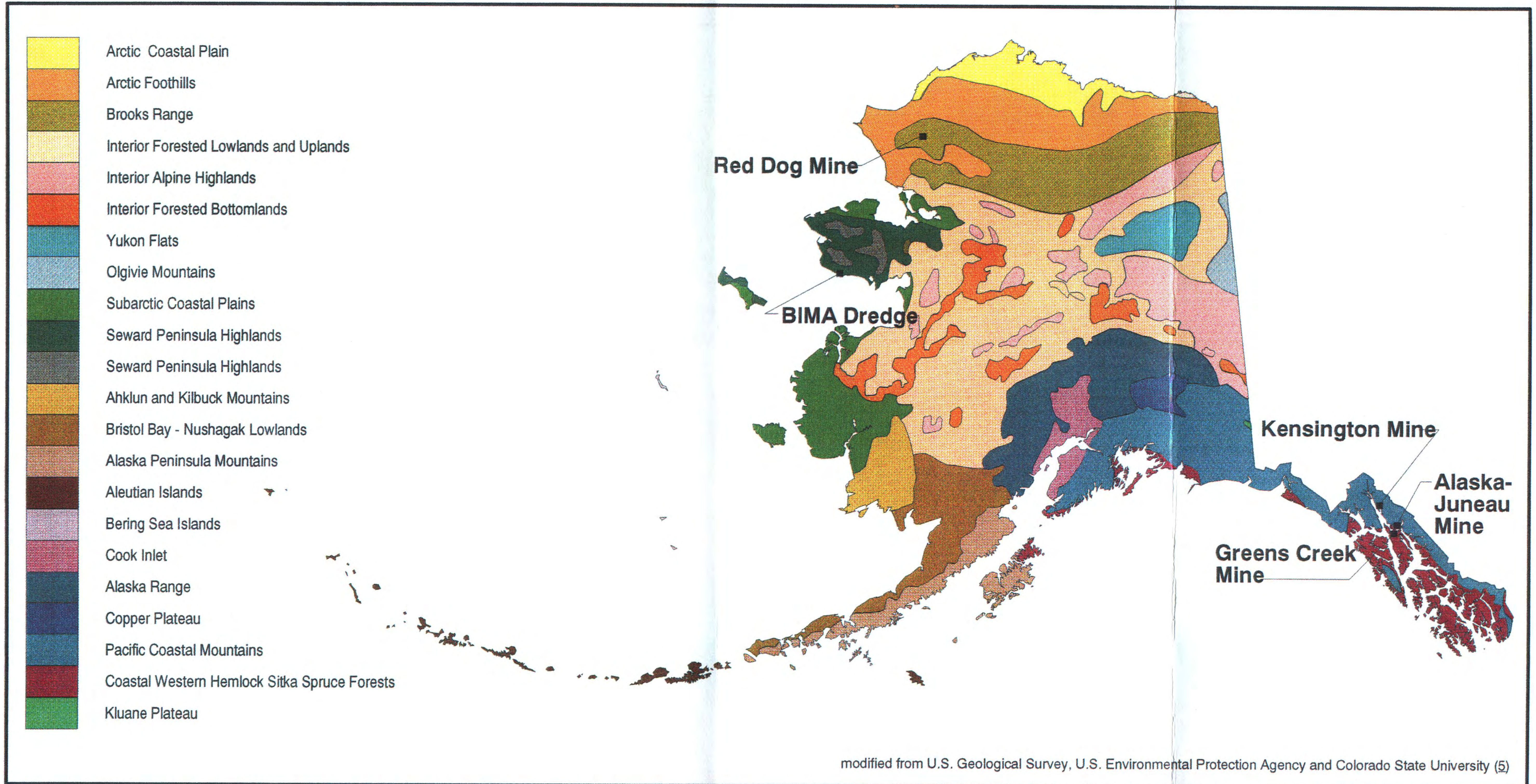
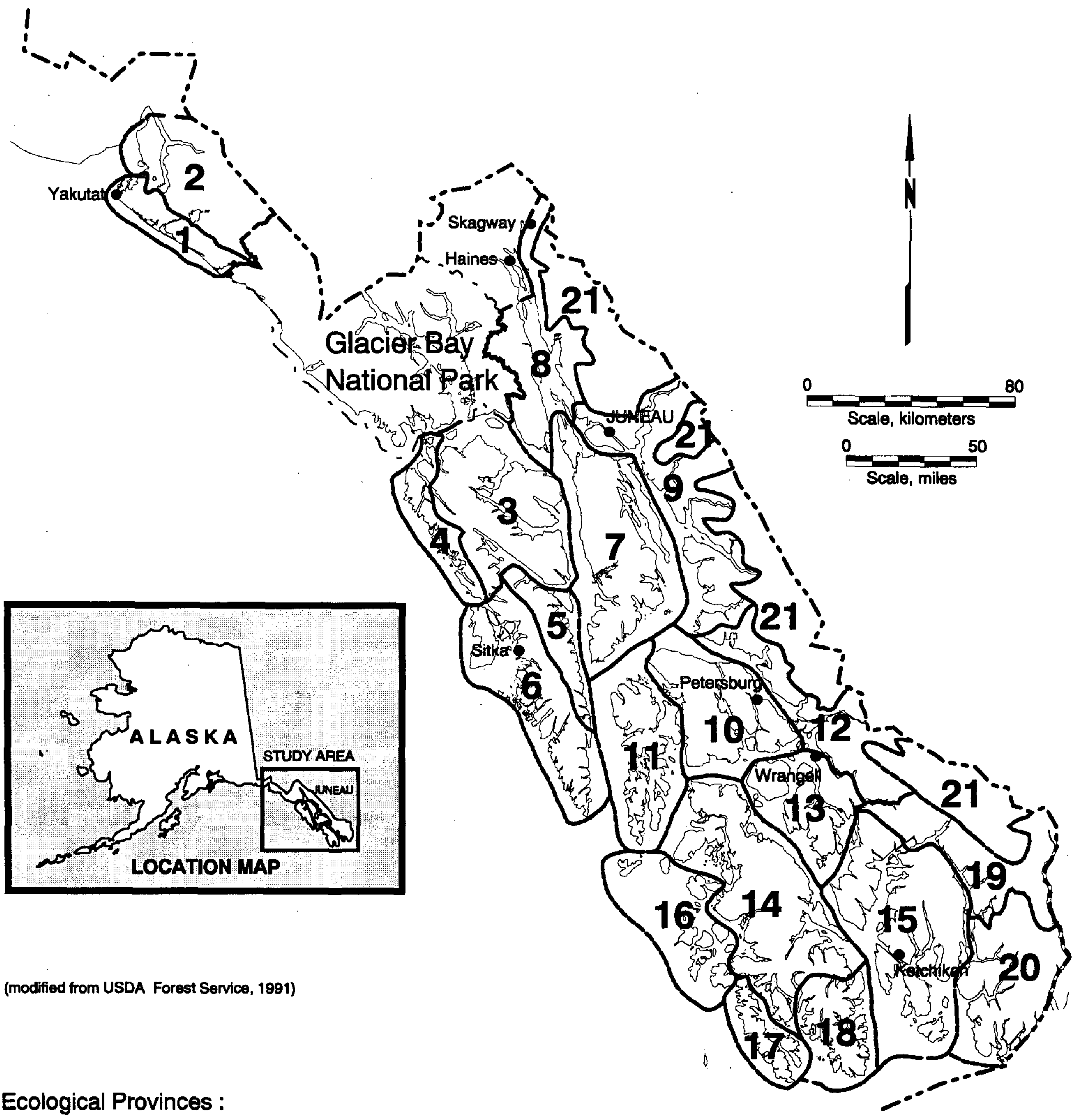


Figure 1. - Draft Ecoregions of Alaska Map.

Figure 2. - Ecological Provinces of Southeast Alaska.



(modified from USDA Forest Service, 1991)

Ecological Provinces :

1. Yakutat Forelands
2. Yakutat/Glacier Bay Upland
3. East Chichagof Island
4. West Chichagof Island
5. East Baranof Island
6. West Baranof Island
7. Admiralty Island
8. Lynn Canal
9. Northern Coast Range
10. Kupreanof/Mitkof Islands
11. Kuiu Island
12. Central Coast Range
13. Etolin Island and Vicinity
14. North Central Prince of Wales Island
15. Revilla Island/Cleveland Peninsula
16. Southern Outer Islands
17. Dall Island and Vicinity
18. Southern Prince of Wales Island
19. North Misty Fiords
20. South Misty Fiords
21. Ice Fields

The purpose of this study is to demonstrate the tools available to evaluate mining activity in an ecosystem context. The site chosen for preliminary analysis is the Greens Creek Mine on Admiralty Island near Juneau in southeast Alaska (Figure 3). The question of an appropriate scale when considering impacts to ecosystems from mining operations is examined. The report reviews the data available on ecosystems at a mining site in Alaska, and applies available modeling tools to assess the impacts of the mine on components of the pristine ecosystem.

Habitat Capability Models for wildlife indicator species are used in this examination. Wildlife indicator species are used as indicators of ecosystem health by the U.S. Forest Service and the Alaska Department of Fish and Game, who have developed these models for southeast Alaska. Analysis techniques from the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) are also used in this report (11).

Most state agencies, although not generally concerned with land management as directly as the USFS and the BLM, contribute to the understanding of the ecosystem through their monitoring activities. For example, tagging and monitoring of brown bear on Admiralty Island performed jointly by the Alaska Department of Fish and Game and the USFS, have been on-going for the last ten years. Reports on this work include models, known as Habitat Capability Models, developed primarily for predicting the effects of logging operations and other management alternatives on brown bear, marten, and other wildlife populations in the Tongass National Forest of southeast Alaska (12).

To better understand the impact of mining on ecosystems, it is important to consider how the NEPA Environmental Assessment process is presently predicting impacts of mining on the environment. To accomplish this, the environmental conditions of Admiralty Island before development of the Greens Creek Mine were reviewed based on data obtained from the Greens Creek Environmental Impact Statement (EIS) and two subsequent Environmental Assessments. Then, the major concerns raised by the Greens Creek EIS are reviewed.

Monitoring of groundwater, surface water, marine water, air quality, bio-accumulation of metals, wildlife populations, and other environmental and ecosystem parameters is on-going at Greens Creek. These environmental monitoring requirements, which are used to assess the impacts of the mine on the environment, are reviewed next.

It should be noted that these monitoring programs are designed to determine compliance with particular environmental permits. These permits in turn are designed to be protective of human health and the environment, but focus on a particular environmental media, such as marine water or air quality. An integrated and "macroscopic" approach to monitoring is desired with ecosystem management, and steps are being taken in this direction, but is not yet fully achieved.

The USFS has an extensive data base in a Geographic Information System (GIS) format containing information on indicators of the environmental health of the Tongass National Forest. One of these indicators is the Habitat Suitability (or Capability) Index (HSI), which is a measure of the suitability of an area to support particular wildlife species, and is determined using Habitat Capability Models. For the Tongass, there are thirteen species that are particularly sensitive indicators of the health of the ecosystem. Known as "management indicator species", these species are used to monitor and assess the overall health of an ecosystem. The thirteen management indicator species used by the USFS for the Tongass are:

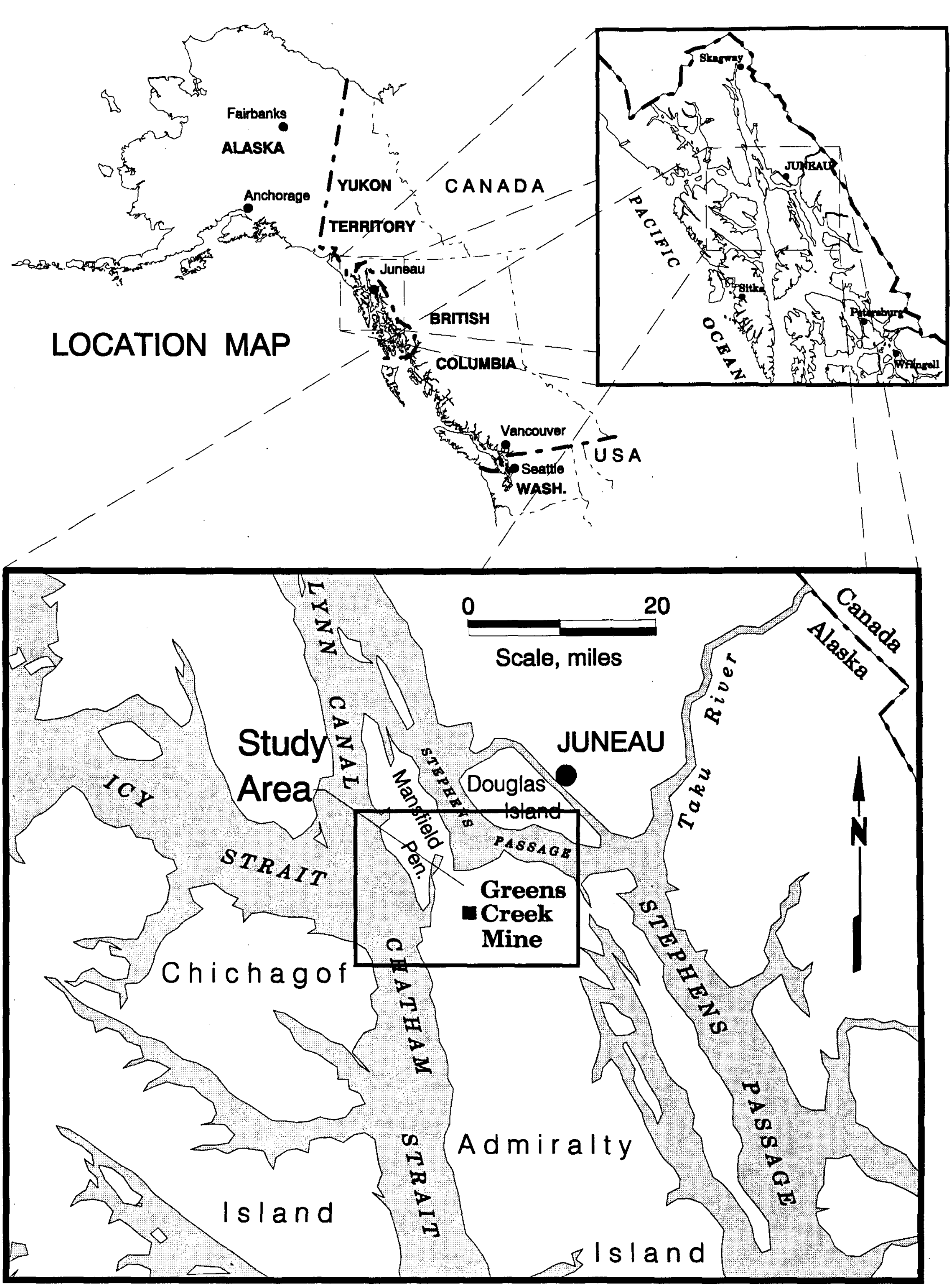


Figure 3. - Location Map of Greens Creek Mine.

Black-tailed Deer, Mountain Goat, Brown Bear, Black Bear, Wolf, Marten, Red Squirrel, River Otter, Bald Eagle, Hairy Woodpecker, Red-breasted Sapsucker, Brown Creeper, and Canada Goose.

Some of these indicator species are not present in the Greens Creek area and therefore do not have HSI coverages there. Coverages were obtained for five species in the Greens Creek area: black-tailed deer, brown bear, marten, river otter, and bald eagle.

Wildlife coverages containing HSI scores for these five management indicator species present in the Greens Creek area (i.e. the Juneau A2 and Juneau A3 20 by 15 minute quads) were transferred from the U.S. Forest Service GIS to the BOM system. The USFS also provided the Bureau with other coverages for the Greens Creek area, including those containing rivers, lakes, roads, and Admiralty Island National Monument boundaries. The BOM developed other coverages which are maintained in its ArcCAD based system.

In an attempt to make some progress toward the goal of assessing impacts to ecosystems, the potential impacts of the Greens Creek Mine were considered in terms of impacts to wildlife habitat as predicted by habitat capability models. These data are presented using Habitat Suitability Index maps of the Greens Creek area for the five wildlife species discussed above. Based on these data, the overall impacts of the Greens Creek Mine on the Admiralty Island ecosystem are estimated. It should be noted that these impacts are temporary and will diminish following closure of the mine, which is estimated to be after an additional ten to fifteen years of mining at an estimated rate of about 3,000 metric tons of ore per day.

Development of models for predicting the potential effects of mining and other industrial activity on ecosystems is desired by land management agencies, including the USFS and the BLM. This report briefly discusses the state of the models available for the Greens Creek area, and applies them to quantify impacts to wildlife habitat under different mitigation scenarios. This can serve to demonstrate the types of data available to assess impacts of mining on the environment and the ecosystem to the extent possible with the data and modeling tools available.

DATA AVAILABLE ON MINE SITE

To better understand the environmental setting of the Greens Creek Mine, the ecosystem and the environmental conditions of Admiralty Island before development of the Greens Creek Mine is reviewed below, with particular emphasis on the watersheds directly affected by the mine. Data were obtained from the Environmental Impact Statement for the mine (25).

Admiralty Island is a pristine ecosystem which has had very limited industrial development of any kind, including logging. Most of the Island is within a National Monument and has high concentrations of numerous wildlife species, including brown bear, deer, and bald eagles. The location of Admiralty Island and the Greens Creek Mine is shown in Figure 3.

Old-growth forests are the dominant feature of southeast Alaska. The wet, maritime climate, has allowed forests to develop over centuries in the absence of wildfires (14), and this is true of the area around the Greens Creek Mine.

Baseline Data

Baseline studies were conducted prior to the development of the mine and these are summarized below. Environmental investigations were begun in the spring of 1978 to develop background information. This effort included incorporating information from state and federal agencies. The study areas for these investigations were primarily the Greens Creek, Zinc Creek, Fowler Creek, and Cannery Creek watersheds, as they are the drainages directly affected by the mine (see Figure 4).

Wildlife Species

Wildlife species present on Admiralty Island include:

Brown Bear
: Admiralty Island is reported to have the highest population density of brown bear in the world. Spawning salmon are a major summer food source for many bear.

Sitka Black-Tailed Deer
: Particularly important deer habitat is the vegetative understory of the south or west facing slopes of the low elevation old-growth forest.

Bald Eagle
: The highest documented density of breeding Bald Eagles in North America is on Admiralty Island.

Waterfowl/Shorebirds
: The estuary at the head of Hawk Inlet is of primary significance to waterfowl and shorebirds. Other areas of importance are the southern portion of Young Bay and the area at the mouth of Hawk Inlet.

Furbearers
: Marten, mink, river otter, and beaver are year-round residents of Hawk Inlet, Greens Creek, and Young Bay.

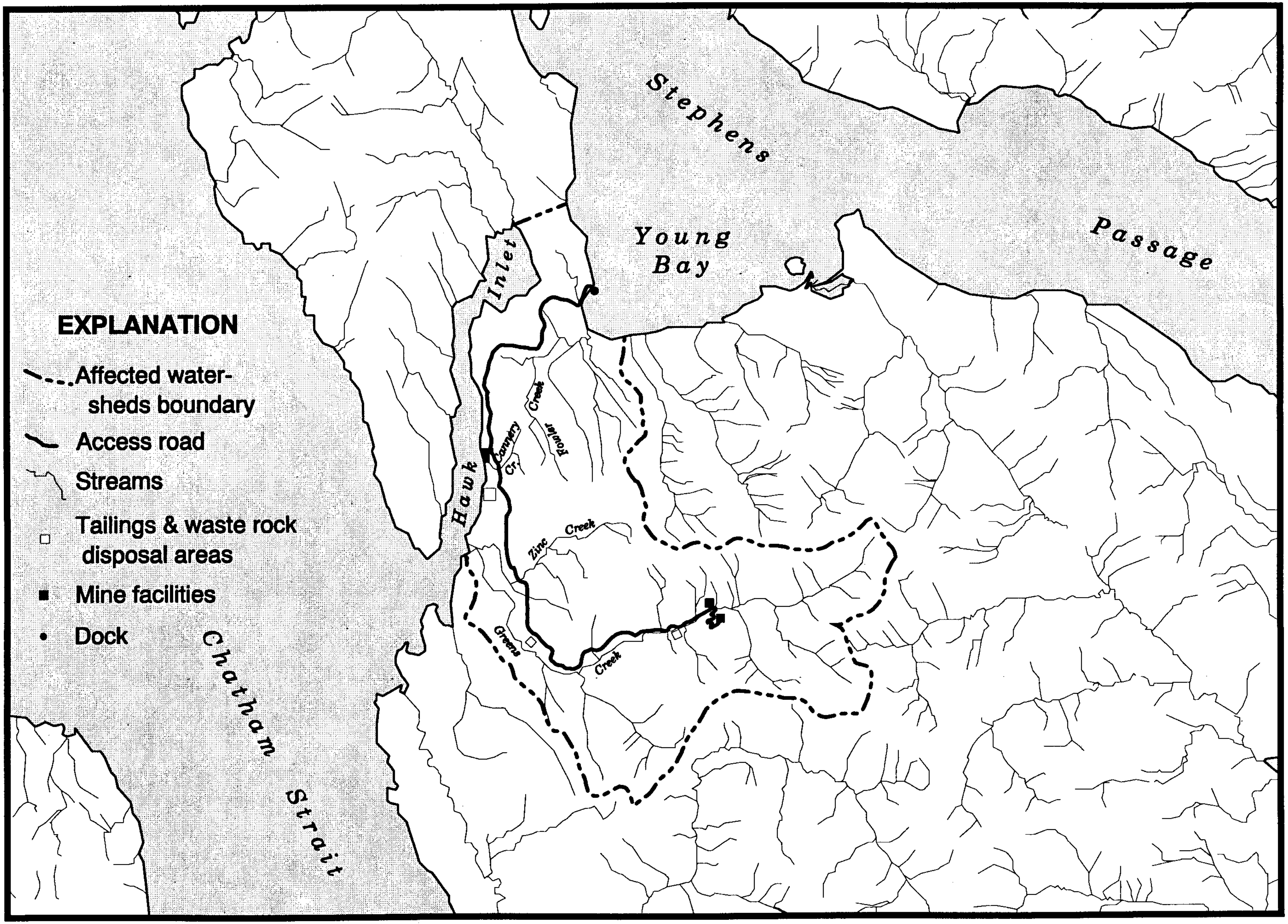


Figure 4. - Greens Creek Mine Site showing Affected Watersheds.

Marine Mammals

Harbor seals, fur seals, Stellar sea lions, three species of porpoises, sea otters, and several species of whales are encountered in the vicinity of Hawk Inlet.

Groundwater Hydrology and Quality

The naturally low pH of groundwater in much of southeast Alaska, combined with highly mineralized zones in the Greens Creek area, produces groundwater with relatively high concentrations of metals. For example, groundwater samples in the mine area have naturally high concentrations of total dissolved solids, sulfate, and some metals, with cadmium and zinc concentrations naturally exceeding Environmental Protection Agency (EPA) water quality criteria for aquatic life. Some groundwater samples taken before mine development from clay deposits in the coastal muskegs exceed EPA water quality recommendations for aquatic life for As, Cd, Cr, Cu, Fe, Pb, Ni, Ag, and Zn.

Freshwater Biology

Zinc, Greens, Fowler, and Cannery Creeks are inhabited by diverse fauna and flora, indicated by benthic invertebrate studies, characteristic of unpolluted waters. Greens, Zinc, and Fowler creeks are utilized by salmon for spawning and rearing and by char.

Freshwater Quality and Hydrology

Average annual flow for Greens Creek where it enters Hawk Inlet is 4.8 cubic meters per second (cms) (170 cubic feet per second (cfs)). Minimum average monthly flows vary from a low of 1.1 cms (40 cfs) during mid-winter and late summer to a high mean monthly flow peak of 7.1 cms (250 cfs) during October. Greens Creek water is of high quality but with a high sediment load. Some tributaries to Greens Creek (Upper Greens Creek and Big Sore Creek) have levels of Cd, Hg, and Ag which exceed EPA recommended criteria for aquatic life (25). However, Zinc and Greens Creeks have diverse flora and fauna indicative of unpolluted waters.

Marine Aquatic Biology

Sands, muddy sands, muds, and rock are the major subtidal benthic habitats. Hard-bottom subtidal areas are typical in species composition and relative abundance to similar habitats of the region and are dominated by anemones, large snails, sea urchins, starfishes, sea cucumbers, sponges, bryozoans, a wide variety of algae, edible shrimp, and edible crabs such as King, Tanner, and Dungeness. The soft-bottomed subtidal benthic habitats are similar in species composition to other similar habitats in being dominated by annelid worms, mussels, clams and, small crustaceans.

Marine Sediment Quality and Biota

In Hawk Inlet there are high natural concentrations of chromium, manganese, lead, copper, and zinc in sediments. With the exception of lead and chromium, the higher levels are comparable to other nearby unpolluted areas. The elevated lead and chromium levels are related to the mineral composition of the drainage basin around Hawk Inlet.

Within the inlet, marine benthic organisms (clams, mussels, and polychaetes) are differentially concentrating metals according to the particular species habitat preference. Coho salmon smolts test higher for metals concentrations than halibut which may be indicative of the salmons rearing time in freshwater around stream inlets as opposed to halibut mobility. The lack of heavy metals concentrations in halibut would seem to indicate that biomagnification through the food chain is probably not occurring in Hawk Inlet.

Marine Water Quality
Limited ongoing baseline water quality studies show that metal concentrations vary with location from below detection limits to near acute levels (for lead). However, tissue test data indicates low bioaccumulation and average levels of lead.

Environmental Monitoring

Monitoring of groundwater, surface water, marine water, air quality, bio-accumulation of metals, wildlife populations, and other environmental and ecosystem parameters is on-going at Greens Creek. These environmental monitoring requirements, which are used to assess specific impacts of the mine on the environment, are reviewed below (25; 2).

Wildlife
According to the EIS, bald eagle nest sites in Hawk Inlet were to be checked in April for nesting activity and in July for nesting success. Additional monitoring of nests, that are active near ongoing construction, was to be incorporated into the operating plan. The Young Bay and Hawk Inlet areas are flown annually to plot nest locations and determine nest use and breeding success.

The large population of brown bears on Admiralty Island is of special interest. Starting in 1981 baseline data were gathered on bear densities, movements, and habitat utilization and monitoring was to continue to measure the effects of project implementation. The project's possible effects on the brown bear population is in two major areas: bear/ human interactions resulting in brown bear mortality (relatively easy to quantify) and bears being displaced leading to bear mortalities away from human observance (relatively hard to quantify). The movement and denning habits of 68 bears in the mine site area are studied.

Fisheries
Significant impacts to anadromous salmonid production can result from fine sediment accumulation in spawning gravel beds. The data gathering on fine sediment additions reflected the seasons of the year, various locations along a stream, and the cross-section of the stream channel at the sample site. Testing is done yearly at six sites to assure that fine sediments are not settling in spawning areas. A change of 25% in pre-project conditions will trigger a search to determine the cause and whether it is related to any component of the mine's operation. If the mining operation is responsible, the company will be required to correct the situation.

Fisheries mitigation measures were to be monitored for three full years to determine the viability and effectiveness of the mitigation measures, which included removal of a natural barrier to salmon passage to allow access to additional spawning area to replace spawning area lost to tailings disposal. The fish pass constructed as a mitigation measure is surveyed annually to determine if salmon are successfully getting past the structure.

Freshwater Quality
During mine operation, there were monthly tests made of 14 surface water sites and 8 groundwater sites. The key indicator parameters are pH, zinc, nickel, lead, copper, total suspended solids, and chromium.

Freshwater Aquatic Biota
Fish species were tested annually for heavy metal tissue burden.

Marine Aquatic Biota
Annual testing, during construction and operation, was to be done on benthic communities at five locations and of indicator species of mussels, clams, and crabs at three locations. At five sites, marine aquatic organisms (sediment dwellers and filter feeders) are tested for bioaccumulation of heavy metals.

Marine Water Quality
The NPDES marine outfall site is sampled weekly. There are weekly tests of chemical and physical parameters, and quarterly bioassays for toxicity of effluent discharged into seawater. Seawater is tested semi-annually at five sites for metals and cyanide and sediments are tested semi-annually for metals.

Other Monitoring
Other studies include meteorological, total suspended air particulate, road sediment, and tailings and waste rock acidification.

Pre-mining Impact Analysis

The major concerns raised by the Greens Creek EIS are briefly reviewed below.

Quality of Wildlife Habitat
In the EIS, particular concerns were expressed about possible impacts to brown bear, bald eagles, Sitka black-tailed deer, waterfowl/shorebirds, furbearers, and marine mammals. Specific concerns were physical change resulting in habitat loss, increased human activity resulting in species displacement (indirect habitat loss), and water quality degradation resulting in contamination of the biological community.

Quality of Fishery Habitat
Among other laws, the Alaska National Interest Lands Conservation Act of 1980 (ANILCA) sec.505(a) highlights the concern "...to maintain habitats, to the maximum extent feasible, of anadromous fish and other food fish, and to maintain the present and continued productivity of such habitat..." (25). The species of concern, as defined in the original EIS are pink, chum, and coho salmon along with Dolly Varden char and cutthroat trout.

Freshwater concerns expressed in the document are increased sediment loads from disturbed areas, alteration of streamflow rates, and chemical contamination or alteration of surface and/or groundwater from acid mine drainage (pH change), heavy metal and trace element leachates, and the addition of reagent chemicals. Marine water concerns are with effluent discharge and shipping effects on fisheries. The species of concern are salmon and halibut.

MODELING IMPACTS OF MINE DEVELOPMENT

Habitat Capability Models

Habitat Capability Models, developed primarily by the U.S. Forest Service and the Alaska Department of Fish and Game, were used to characterize components of the ecosystem at the Greens Creek Mine site. Habitat Suitability Index maps were generated using Habitat Capability Models developed for the Tongass Land Management Plan (TLMP) revision presently in review phase by the USFS. These models provide a planning tool to estimate the relative effects of land management activities on habitat capabilities for indicator species (23).

The models developed for the Tongass National Forest combined efforts of the U.S. Forest Service which traditionally develops Habitat Capability Models for areas within its jurisdiction, and the Alaska Department of Fish and Game, with assistance from the U.S. Fish and Wildlife Service which traditionally develops Habitat Suitability Models, discussed below (19). The Habitat Suitability Models used by the FWS have generally been more site specific in nature, utilizing more detailed field investigations in the database, while Habitat Capability Models have generally been developed for the landscape or watershed scale, employing data on forest stand type and other data which could be obtained through remote sensing and did not require field data collection. In this report, habitat suitability and habitat capability are used interchangeably because the cooperative effort on the Tongass National Forest included a significant amount of field data collection (such as brown bear monitoring) and diminished many of the distinctions normally present in the two types of models (4).

The models used in this report require a computer Geographic Information System description of the environment to estimate habitat suitability or habitat quality, but do not necessarily predict actual populations. Actual populations may be above or below habitat model predictions, population estimates can change significantly with minor changes in the model. For these reasons, Habitat Suitability Index scores should be used for comparing effects of alternatives rather than predicting absolute numbers of animals (3).

Habitat capability is defined as the long-term potential of an area to support animals, rather than an estimate of actual numbers present at any given time. Numbers of animals present can vary over time according to influences other than habitat, such as hunting and predation pressures and short-term climatic conditions. However, it is known that without suitable habitats, populations will be depressed or totally absent (13).

The habitat capability models are designed for forest planning and environmental assessments. They quantify habitat quality and can serve as a set of biological rules that permit wildlife resources to be considered with other aspects such as timber harvests and mining (13).

To construct the models, a task group with expertise in each of the wildlife management indicator species was formed to establish the habitat relationships for the species. The relationships and assumptions used in the model were documented and a computer program was developed which accessed the data bases which contain the information necessary to predict a Habitat Suitability Index. Habitat variables used in the models included forest overstory type, vegetation landscape (including upland, riparian, beach fringe, and estuary fringe), timber volume class and successional stage. Other factors not related to vegetation were also used, including elevation, aspect, presence of predators and/or prey, and snow conditions (13).

Model development proceeded in distinct phases, specifically: construction of the model; draft of documentation; development of computer program; verification of computer program; verification of model; expert review; final documentation; and evaluation.

Verification is the process of determining if habitat model predictions conform to accepted biological theory. Models were verified and calibrated by applying them to areas where population data exists and adjusting the models to reflect the actual populations. The models were refined by this iterative process. They were then reviewed by experts on the various species who were not associated with the development of the models, and final documentation of the models were prepared. As the final step in their development, field evaluation of the relationships and assumptions incorporated into the models has been initiated for most of the species habitat models used in this report (13).

The models for brown bear and black-tailed deer have proceeded through expert review and have received final documentation. The models for marten, river otter, and bald eagle have been verified (12).

The Habitat Capability Models were run for the five species available at commencement of the study, using data from the Tongass Land Management Plan Office of the U.S. Forest Service in Juneau. For convenience, the models were run so as to characterize twenty acre blocks with a single HSI score, although almost any scale could be chosen provided the available data are detailed enough to match it. Use of polygons rather than blocks is preferred, provided the data can be manipulated easily. The twenty acre blocks were used in this study due to hardware limitations. Each of the models used is discussed briefly below.

Bald Eagles

The objective of this model is to estimate the capability of habitats in southeast Alaska to support populations of nesting bald eagles. The model provides an evaluation of habitat quality which is assumed to be related to long-term carrying capacity for nesting bald eagles. Only nesting habitat is evaluated in this model. The model cannot assess impacts from mining activity, other than those associated with removal of trees.

Almost all bald eagle nests in southeast Alaska occur in old-growth stands located within well-forested landscapes. Clearcuts without sufficient numbers of remnant old growth trees are avoided by bald eagles. The majority of bald eagles in southeast Alaska nest in coniferous forest habitats along the coastline and associated saltwater inlets. These locations provide the best opportunities for foraging over open water and on tidal flats. Nests are generally located in large, old trees averaging about 30 meters (100 feet) in height, 1.1 meters (3.6 feet) in diameter, and at least 400 to 500 years old (16).

Figure 5 shows the HSI scores for bald eagles in the Greens Creek area with no consideration for mining impacts. Actual nesting sites of bald eagles is shown in Figure 6, which corresponds well with the HSI coverage in Figure 5, although it is clear that not all potential nesting sites are actually utilized.

Brown Bear

Brown bears were once widely distributed across western North America, but few exist in the contiguous 48 states today, and those that do are primarily in Glacier and Yellowstone National Parks. Brown Bears were declared threatened in 1975 in the United States south of Canada.

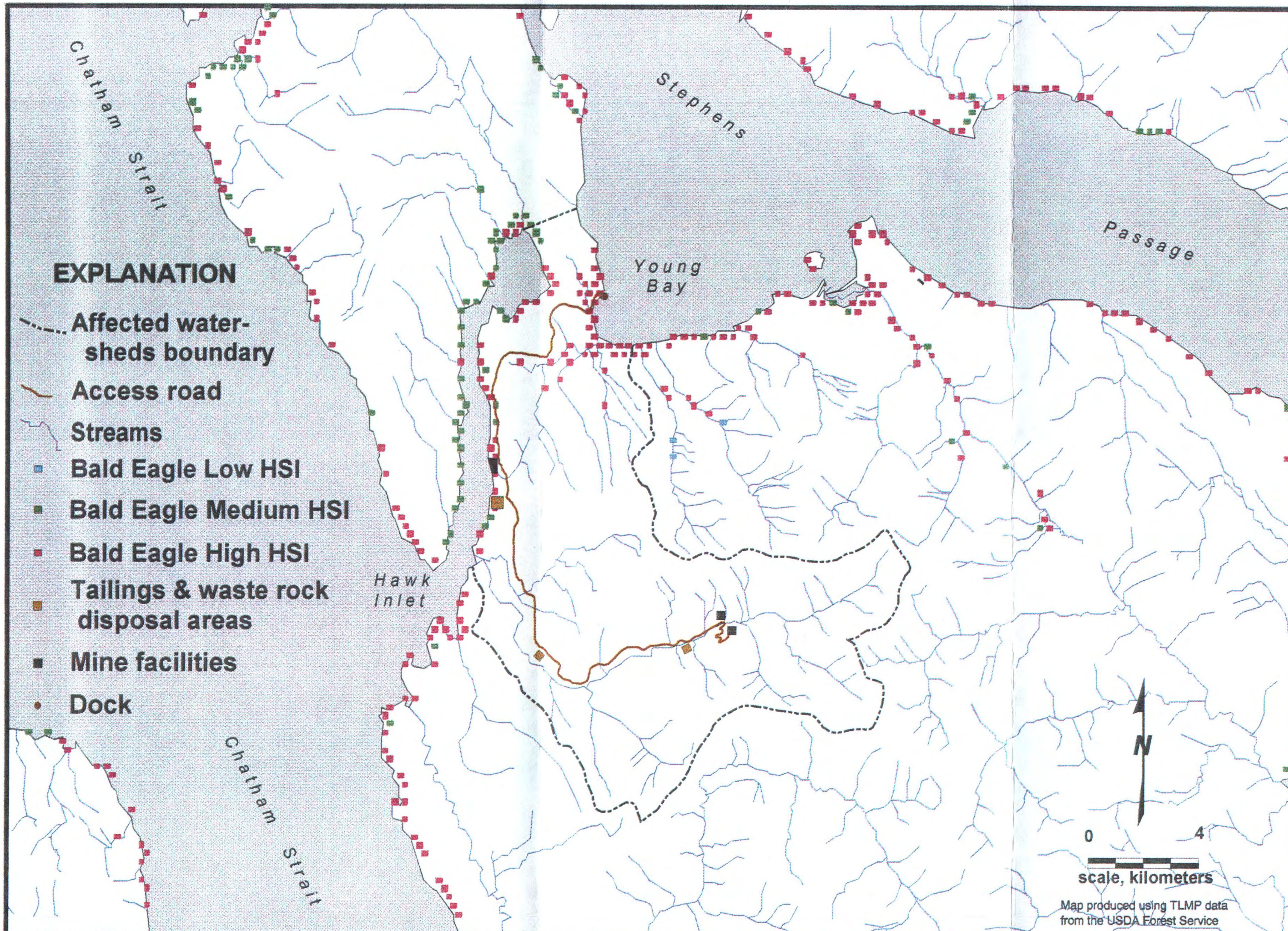


Figure 5. - Bald Eagle Habitat Suitability Index.

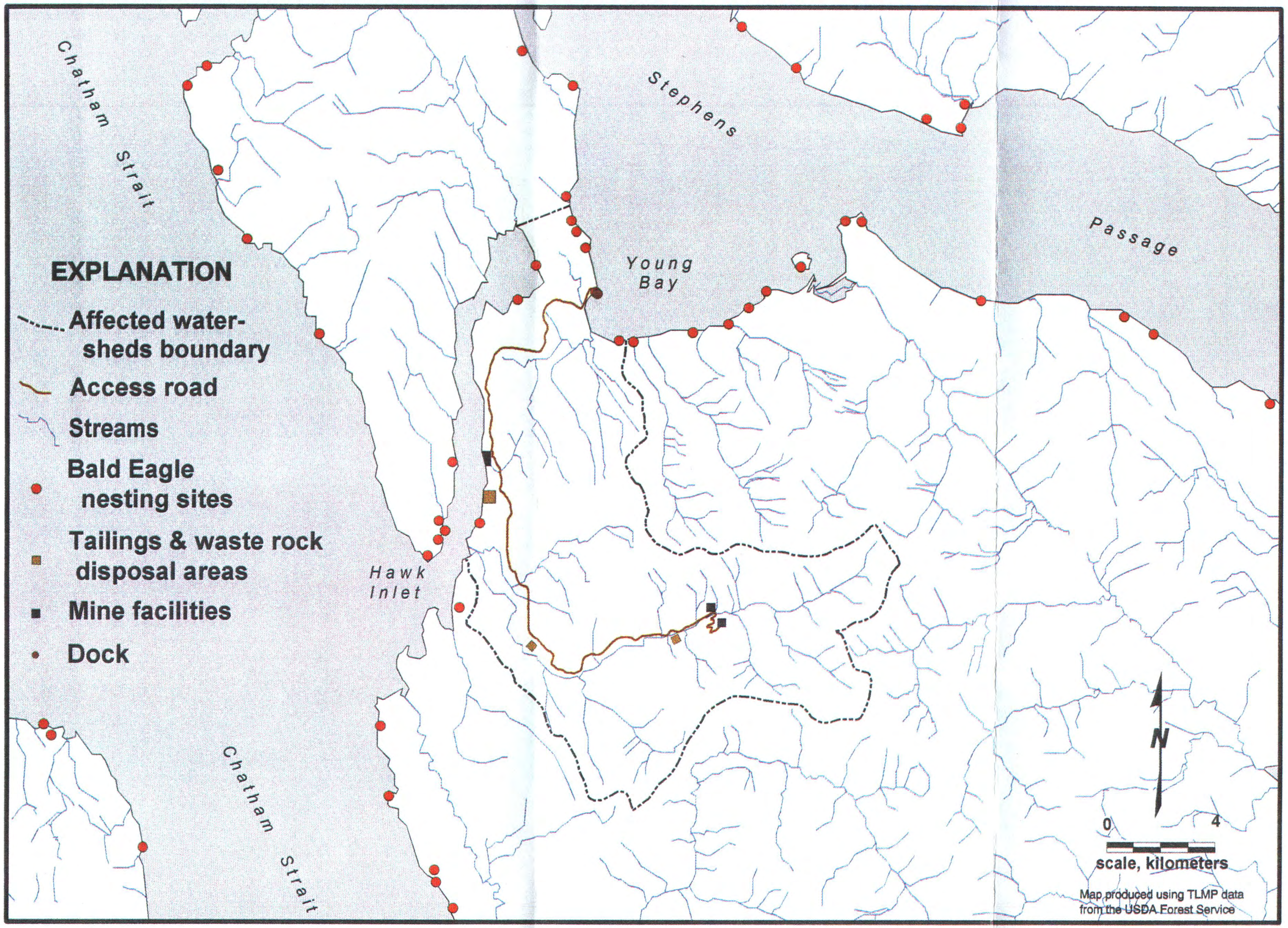


Figure 6. - Bald Eagle Nesting Sites.

In Alaska there are an estimated 30,000 to 40,000 brown bears (9).

The brown bear habitat capability model was designed to evaluate bear habitat on a single or multiple-watershed scale. Habitat use data from 95 radio-collared brown bears on Admiralty and Chichagof Islands (see Figure 3) were used to develop this habitat capability model. Habitat types were assigned a habitat capability value and the effects of some human activity and resource development (primarily roads) on habitat capability were considered in the model (9). HSI coverages were generated for brown bear in the Greens Creek area before impacts from mining activity are considered.

Sitka Black-tailed Deer

Sitka black-tailed deer are found throughout southeast Alaska and are the major big game species, providing meat and recreation through annual harvests of over 15,000 animals. They also provide recreational opportunity for those who enjoy viewing wildlife (14). HSI coverages were generated for deer in the Greens Creek area.

Marten

The marten is generally an inhabitant of climax forest communities throughout North America. Therefore, the majority of marten populations in the U.S. are in the extensive old growth forests in the Pacific states, and have been eliminated throughout the southern and eastern portions of their original range. Marten populations are "reasonably dense" throughout southeast Alaska (17). HSI coverages were generated for marten in the Greens Creek area before impacts of mining activity are considered.

River Otter

The historic range of the river otter includes the majority of the North American continent. River otters still occur in 44 states and populations in Alaska are stable (18). HSI coverages were generated for river otter in the Greens Creek area.

Habitat Suitability Models

The U.S. Fish and Wildlife Service has begun an effort to apply its Habitat Evaluation Procedures (HEP) at the Alaska-Juneau Project near Juneau. The HEP system utilizes Habitat Suitability Index models to evaluate effects of land-management decisions on wildlife habitat. These procedures have been under continuous development since the early 1970's, and are taught through the FWS, now the National Biological Survey, National Ecology Research Center in Fort Collins, Colorado (11).

With HEP, the basic accounting unit used to measure habitat is the Habitat Unit (HU), which is determined by multiplying the HSI score by the area that is associated with it. If performance standards relating HSI scores to actual populations are known, the HU score can give an estimate of the number of animals which the habitat of the area can support in a long-term, sustainable manner. These data have been generated for brown pear and marten in southeast Alaska through long-term field studies.

HEP generally applies HSI models which require some on-site field evaluations. An important step of this process is identifying the species and ecosystem to be used to analyze impacts. Further information on HEP is available (11,26), and a detailed description is beyond the scope of this report. To date, this system has been applied to a limited extent in Alaska. However, the

FWS is expected to make greater use of these evaluation procedures in Alaska in the future (6).

Other Models

Other models which attempt to assess impacts from industrial activity to the environment exist. One example of a commercially available model for assessing potential impacts to the environment from industrial activity is SPEARS® (SPatial Environmental Assessment and Review System). It is an environmental screening tool which contains an expert system (called SCREENER®) for evaluating impacts of proposed projects on the environment. It interacts with a Geographic Information System which describes the environment, and therefore requires that a GIS exist for the area under consideration.

The model determines the potential for impacts to wildlife and the environment from human activity using expert system rules (approximately 2,500) and information on the project activities and the environmental components that are present. Spatial models and rules are used to determine the zone of influence for the impact mechanisms. The model analyzes the interactions between environmental components and the zones of influence for the impact mechanisms and generates a report on the overall impact of the project (27).

The current version of SPEARS® is set up as a fairly general purpose system that contains broad information on many types of industrial and development activity. The model would require modification to address the particular impacts and industrial processes used at mining sites (27). This model is primarily used to assess impacts immediately prior to and during project development, rather than as a tool for general, large scale land-management.

One ecosystem modeling method for large scale land-management is gap analysis. It is a GIS based technique developed by the U.S. Fish and Wildlife Service for mapping species diversity and analyzing "gaps" in protected wildlife habitat, and is being tried by land-managers throughout the western states. This method does not presently assess potential impacts to habitat from human activity, however (7).

The BOM is using STELLA® modeling software to develop models which assess impacts of mining activity on ecosystems. These models were not ready for application to the Greens Creek Mine when work on this report commenced, however.

Modeled Impacts

Using the available habitat capability models, an analysis of the habitat impacts of the Greens Creek Mine was performed. The initial analysis of impacts to wildlife habitat was limited to the areas directly covered by mine facilities, including the mill site, tailings and waste rock disposal areas, and roadways. Table 1 is a compilation of the area of each type of wildlife habitat directly impacted by mine facilities, i.e. the area of disturbed ground for each type of wildlife habitat.

It should be noted that disturbing the ground will in most cases remove or destroy the habitat value of the land due to such activity as road building, paving, tailings disposal, etc. However in some cases habitat value may be partially retained. For example, the road shoulder and fringe may serve as foraging habitat for deer. This will increase summer habitat and may result in some redistribution of deer, but winter habitat is limiting for deer populations in southeast Alaska (14), and a small decrease in this habitat occurs due to direct removal (see Table 1).

Table 1. Direct Impact to Wildlife Habitat within Affected Watersheds and within Admiralty Island from Greens Creek Mine.

	Acres within Admiralty Island	Acres within affected watersheds	Acres of disturbed ground	**Percent of Admiralty Island disturbed**	**Percent of affected watersheds disturbed**
Total	1,078,000	26,700	356	**0.03**	**1.3**
Deer					
Low HSI	237,000	7,400	130	**0.05**	**1.8**
Med HSI	283,000	5,260	152	**0.05**	**2.9**
High HSI	29,000	820	74	**0.26**	**9.0**
Brown Bear					
Low HSI	63,700	1,960	4	**0.01**	**0.2**
Med HSI	856,000	21,100	348	**0.04**	**1.6**
High HSI	8,090	280	4	**0.05**	**1.4**
Bald Eagle					
Low HSI	2,100	0	0	**0.00**	**--**
Med HSI	16,200	200	9	**0.06**	**4.5**
High HSI	27,000	1,140	26	**0.10**	**2.3**
Marten					
Low HSI	157,000	1,760	64	**0.04**	**3.6**
Med HSI	270,000	7,000	110	**0.04**	**1.6**
High HSI	200,000	5,560	182	**0.09**	**3.3**
River Otter					
Low HSI	7,550	100	4	**0.05**	**4.0**
Med HSI	6,040	80	0	**0.00**	**0.0**
High HSI	48,400	1,400	31	**0.06**	**2.2**

In addition to the direct impacts shown in Table 1, the wildlife capability models for brown bear and marten are able to quantify impacts on HSI scores from human activity associated with a road in the Greens Creek area. These models do not address other potential mining impacts, however. The impacts of roads are addressed in the model by the use of a reduction factor within a "zone of influence" of the road.

Figure 7 shows the HSI coverage for brown bear after the mine and including impacts from a "local" road typical of southeast Alaska. Impacts associated with the road are from increased hunting pressure, noise, human presence, etc. As can be seen from this figure, the impacts from the road has resulted in a lowering of HSI scores from "high" and "medium" to "low" within the zone of influence around the road. Therefore, the acres of high and medium level habitat were decreased from the original values (before the mine), while acres of low level habitat were increased. This data is shown in tabular form in Tables 2 and 3.

Figure 8 shows the HSI coverage for marten after the mine, with impacts from a local road typical of southeast Alaska. The impacts associated with the road were primarily from increased trapping pressure and resulted in a lowering of HSI scores from high and medium values to low with the zone of influence around the road. Therefore, the acres of high and medium level habitat present before the mine were decreased while acres of low level habitat were increased. This data is also summarized in tabular form in Tables 2 and 3.

At the Greens Creek Mine, however, for both brown bear and marten, many potential impacts from the road were mitigated due to special measures requested by the Forest Service and undertaken by the mining company during development and operation of the mine. These mitigating measures included limiting access and use of the road to mining related functions, therefore decreasing impacts associated with increased access for hunting and trapping.

Figure 9 and 10 are HSI coverages for brown bear and marten, respectively, and show HSI coverages for the Greens Creek area when the mitigated effects of the roads are considered. Tables 4 and 5 show this data in tabular form. They show that for brown bear, the decrease in medium level habitat (the predominant habitat) reduction to low level was 58% in the affected watershed for road impacts with no mitigation, while only 19% of the medium level habitat was reduced to low level for mitigated road impacts.

For marten, there is a more equal distribution of the three levels of habitat (see acres of habitat in Table 1). For road impacts with no mitigation, 54% of the high level habitat was reduced to low level within the affected watershed, while 40% of the medium habitat was reduced to low level. With mitigation, only 3.2% of the high level marten habitat was reduced in value, and only 1.6% of the medium habitat was reduced in value.

From the data presented in the tables it can be seen that mitigation of the potential impacts of the road associated with hunting decreased the impacts to wildlife habitat by a considerable amount. It is also apparent that the extent of potential impacts will be dependent on the scale that is being considered. For the entire Admiralty Island ecosystem, the changes in the total area of wildlife habitat will be very minor. As the area of consideration is decreased, the extent of potential impacts to wildlife habitat increases.

The brown bear and marten coverages in this report were limited to analysis of the impacts of the road because this is the only mining related impact that has been modeled at present. However,

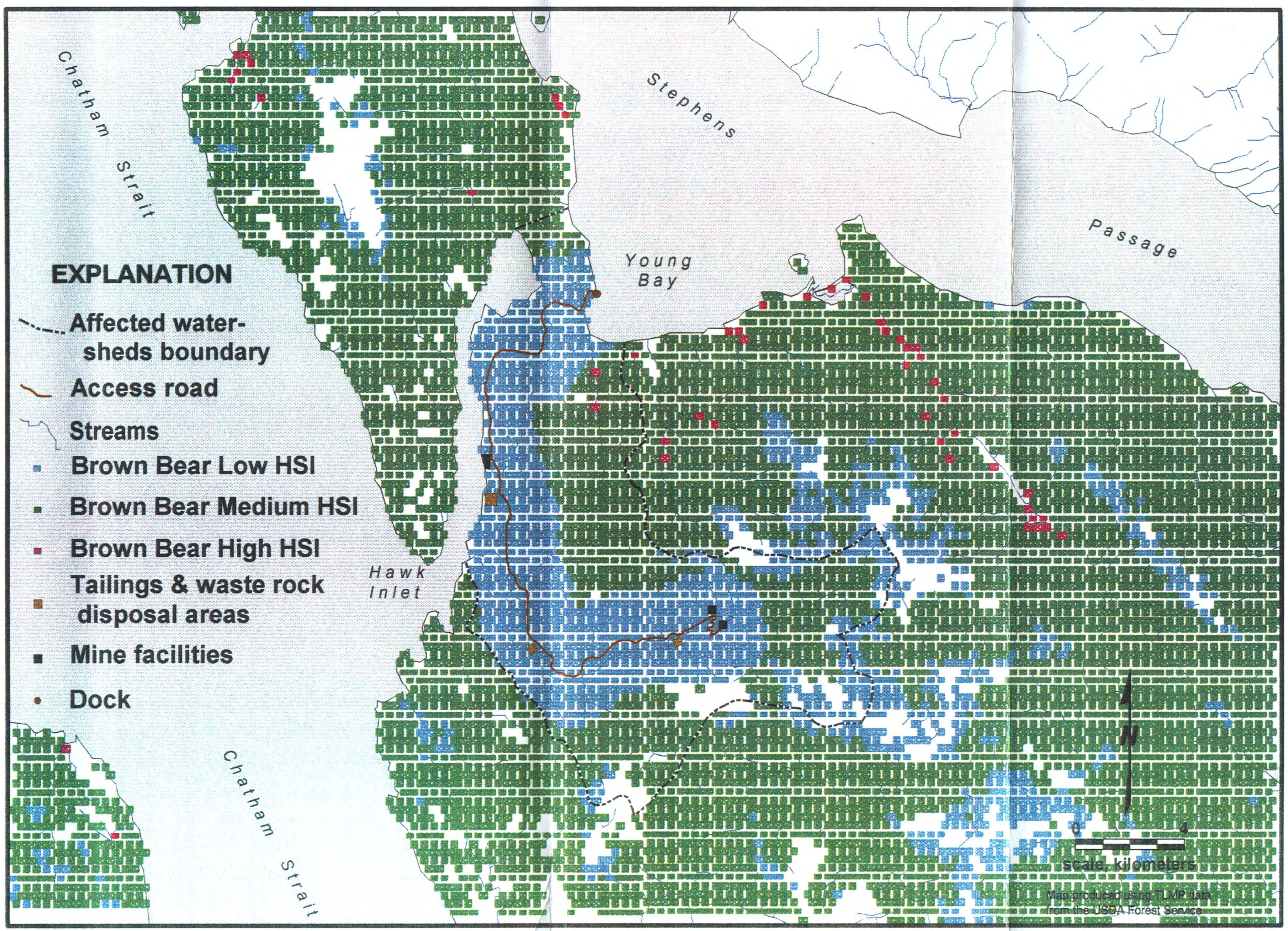


Figure 7. - Brown Bear Habitat Suitability Index with No Mitigation of Road Impacts.

Table 2. **Estimated Acres of Brown Bear and Marten Habitat Before and After Greens Creek Mine with No Mitigation of Road Impacts.**

	Acres within Admiralty Island before	Acres within Admiralty Island after	Acres within Juneau A2 and A3 before	Acres within Juneau A2 and A3 after	Acres within affected watershed before	Acres within affected watershed after
Brown Bear						
Low HSI	63,700	75,700	12,500	24,500	1,960	14,000
Med HSI	856,000	844,000	125,000	113,000	21,100	8,950
High HSI	8,090	7,890	1,180	978	280	76
Marten						
Low HSI	157,000	162,000	23,400	28,900	1,760	7,240
Med HSI	270,000	267,000	33,500	30,700	7,000	4,190
High HSI	200,000	197,000	27,200	24,200	5,560	2,540

Table 3. **Percent Change of HSI Acres After Greens Creek Mine with No Mitigation of Road Impacts.**

	Change within Admiralty Island	Change within Juneau A2 and A3	Change within affected watersheds
Brown Bear			
Low HSI	+19%	+96%	+610%
Med HSI	-1.4%	-9.6%	-58%
High HSI	-2.5%	-17%	-72%
Marten			
Low HSI	+3.2%	+24%	+310%
Med HSI	-1.1%	-8.4%	-40%
High HSI	-1.5%	-11%	-54%

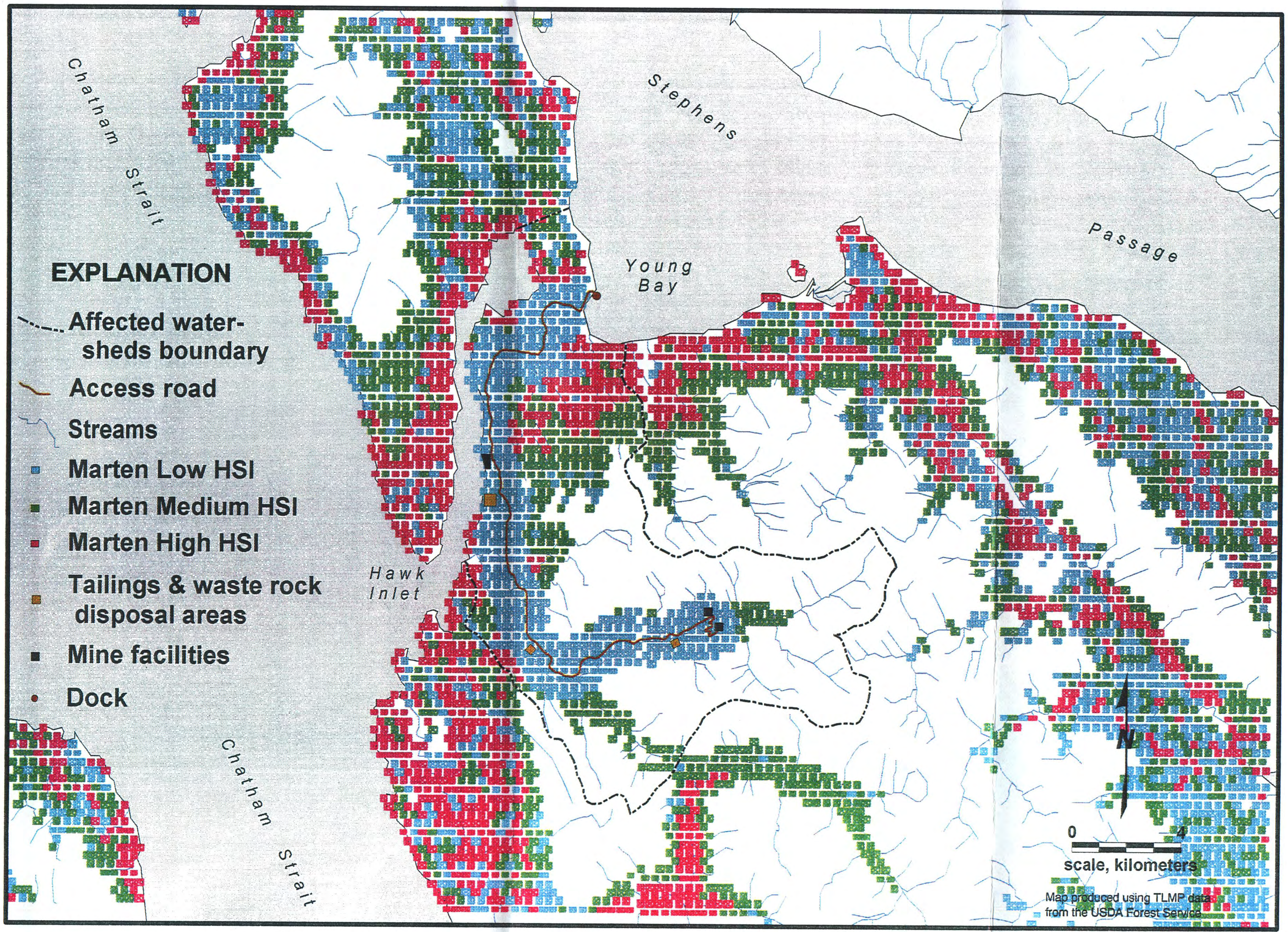


Figure 8. - Marten Habitat Suitability Index with No Mitigation of Road Impacts.

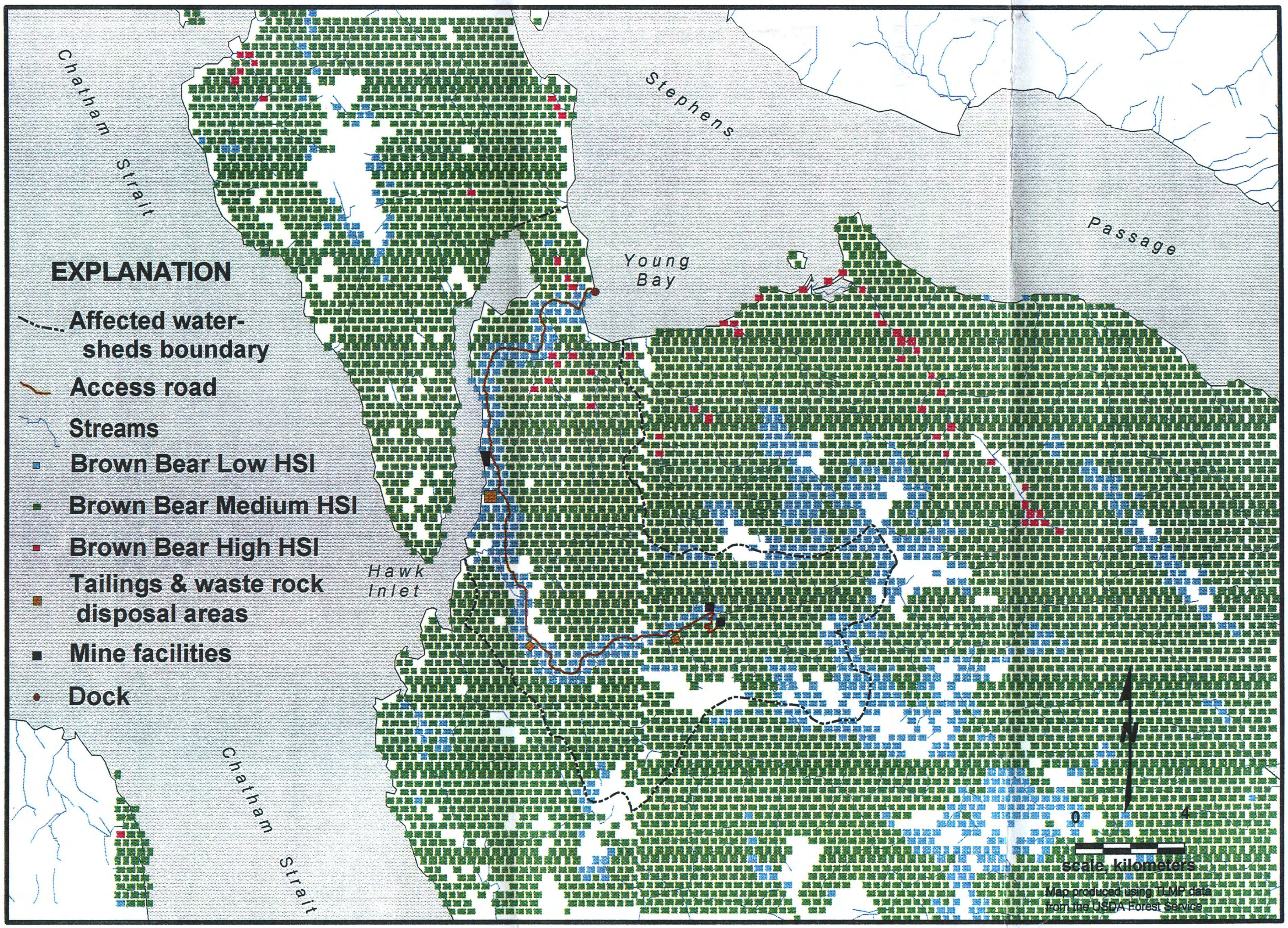


Figure 9. - Brown Bear Habitat Suitability Index with Mitigation of Road Impacts.

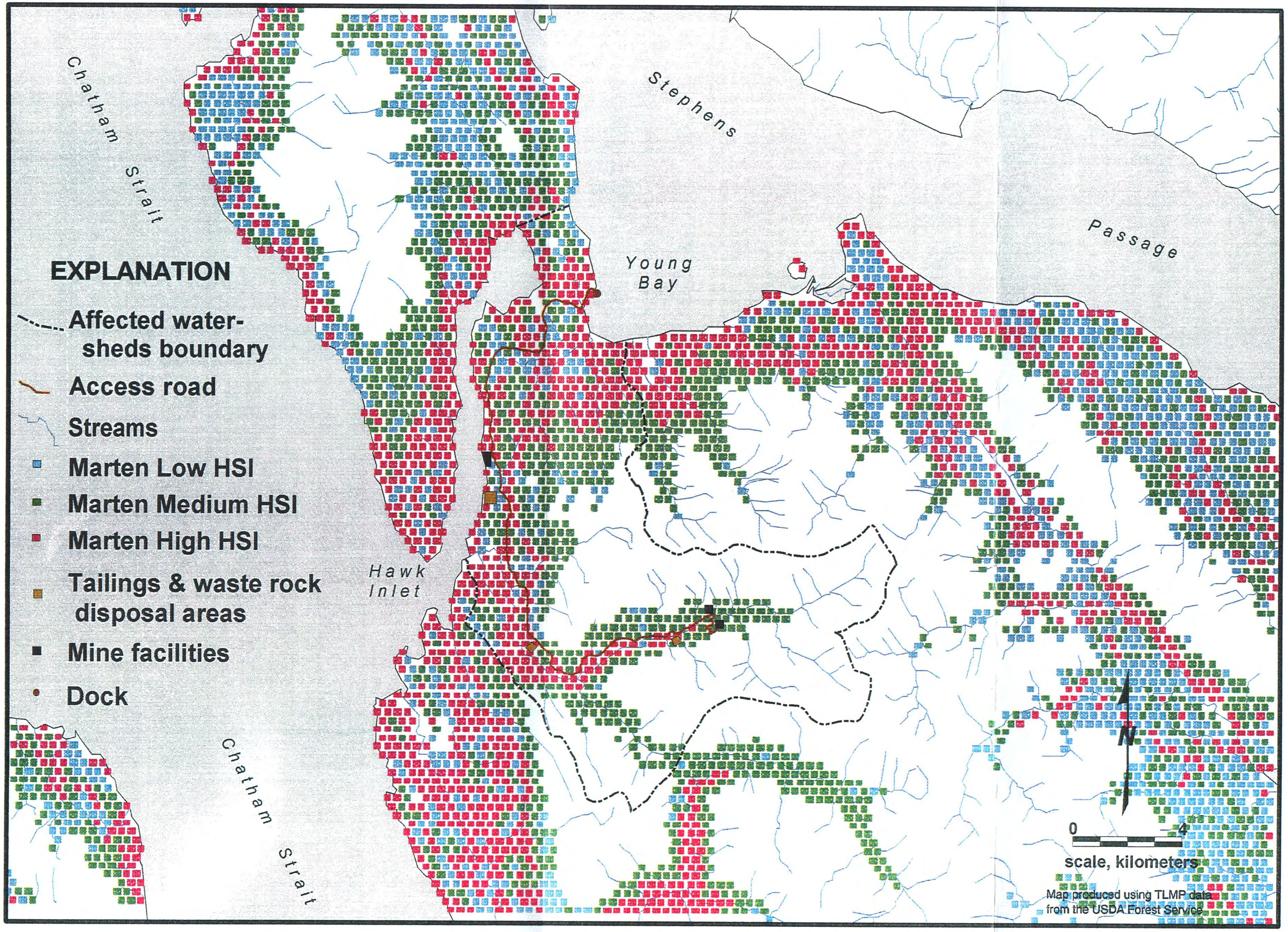


Figure 10. - Marten Habitat Suitability Index with Mitigation of Road Impacts.

Table 4. **Estimated Acres of Brown Bear and Marten Habitat Before and After Greens Creek Mine with Mitigation of Road Impacts.**

	Acres within Admiralty Island before	Acres within Admiralty Island after	Acres within Juneau A2 and A3 before	Acres within Juneau A2 and A3 after	Acres within affected watershed before	Acres within affected watershed after
Brown Bear						
Low HSI	63,700	67,500	12,500	16,300	1,960	5,720
Med HSI	856,000	852,000	125,000	121,000	21,100	17,000
High HSI	8,090	8,090	1,180	1,180	280	276
Marten						
Low HSI	157,000	157,000	23,400	23,300	1,760	1,700
Med HSI	270,000	270,000	33,500	33,400	7,000	6,890
High HSI	200,000	200,000	27,200	27,000	5,560	5,380

Table 5. **Percentage Change of HSI Acres After Greens Creek Mine with Mitigation of Road Impacts.**

	Change within Admiralty Island	Change within Juneau A2 and A3	Change within affected watersheds
Brown Bear			
Low HSI	+6.0%	+30%	+190%
Med HSI	-0.5%	-3.2%	-19%
High HSI	0%	0%	-1.4%
Marten			
Low HSI	0%	-0.43%	-3.4%
Med HSI	0%	-0.30%	-1.6%
High HSI	0%	-0.74%	-3.2%

impacts associated with the road and other directly disturbed areas are expected to contribute the most to overall habitat impacts. Other potential impacts to brown bear from mining activity could include, for example, increased turbidity and siltation in the streams leading to decreased salmon carrying capacity, resulting in decreased values of brown bear habitat (19). The models used in this report, however, are not currently able to assess these and other potential impacts to wildlife habitat from mining and other human activity.

A procedure similar to the U.S. Fish and Wildlife Service Habitat Evaluation Procedure (11,26) was used to better quantify some of the potential impacts to wildlife habitat predicted using the HSI models. This was done by calculating Habitat Units (HU) both with and without mitigation.

Shown in Tables 6, 7, and 8 are the Habitat Units for brown bear and marten at three ecosystem scales for the Greens Creek area. The values in these tables can be considered an estimate of the number of animals that each area could potentially support long-term, both with and without mitigation of road impacts to wildlife habitat due to increased hunting and trapping. Mitigation involved restricting the road to allow use only for mine-related activities. Table 9 shows the percentage reduction in loss of original habitat units using this mitigation rather than not using it.

Another consideration is that the mine will have a limited operational life, therefore the impacts associated with the mine will also be limited in time. The Greens Creek Mine is estimated to have an additional ten to fifteen years of reserves at a mining rate of about 3,000 metric tons of ore per day. This time component should be considered, especially for cost/benefit analysis.

To illustrate the time component, Figures 11 and 12 show an estimate of Habitat Units for brown bear and marten in the affected watersheds, both with and without mitigation of road impacts, over the predicted remaining life of the mine. This is compared with the baseline case of HU without the mine, and assumes that reclamation and other activities will be completed soon after mine closure to allow habit values to quickly approach original levels.

The net impact of the project on wildlife habitat can be estimated by calculating the Average Annual Habitat Units (AAHU) for the different mitigation options. This is done by dividing the area under the HU versus time curve (Figures 11 and 12) by the lifetime of the project (years of operation) for each mitigation option and wildlife indicator species. These values are shown in Table 10, and are useful for comparing alternatives which operate over different lengths of time.

Cost/Benefit Analysis

If the cost of mitigation alternatives can be estimated, then cost/benefit analysis, as shown in Table 11, can be performed. For illustration, if it costs $1,000 per year to administer the road closure, then a cost per average annual habitat unit saved can be estimated. The cost per average annual habitat unit saved can then be compared for various mitigation alternatives, and the most cost-effective alternative can be identified.

As discussed earlier, mitigation consisted of restricting road access to allow only mining related activities, thereby reducing or eliminating hunting, trapping, and other impacts related to increased road access. As can be seen from Tables 8, 9, and 10, and Figures 11 and 12, limiting road access greatly reduced the potential impacts of the mine wildlife habitat for the two species analyzed, yet cost almost nothing to implement. Therefore, the cost/benefit ratio of this mitigation effort would be very low, supporting the action for these species.

Table 6. **Habitat Units for Brown Bear and Marten on Admiralty Island Before Mine, with Mitigation, and without Mitigation.**

	HU for Admiralty Island before mine	HU for Admiralty Island after mine without mitigation	HU for Admiralty Island after mine with mitigation
Brown Bear	1,713	1,697	1,708
Marten	1,392	1,379	1,391

Table 7. **Habitat Units for Brown Bear and Marten within Juneau A2 and A3 Before Mine, with Mitigation, and without Mitigation.**

	HU for Juneau A2 and A3 before mine	HU for Juneau A2 and A3 after mine without mitigation	HU for Juneau A2 and A3 after mine with mitigation
Brown Bear	252	236	247
Marten	184	171	183

Table 8. **Habitat Units for Brown Bear and Marten within Affected Watersheds Before Mine, with Mitigation, and without Mitigation.**

	HU for Affected Watersheds before mine	HU for Affected Watersheds after mine without mitigation	HU for Affected Watersheds after mine with mitigation
Brown Bear	43	27	37
Marten	36	23	35

Table 9. **Percent Reduction in Loss of Original Habitat Units using Mitigation.**

	Percent reduction in loss of original Admiralty Island HU using mitigation	Percent reduction in loss of original Juneau A2 & A3 HU using mitigation	Percentage reduction in loss of affected watersheds HU using mitigation
Brown Bear	0.64%	4.4%	23%
Marten	0.86%	6.5%	33%

Figure 11. - Habitat Units for Brown Bear in Affected Watersheds.

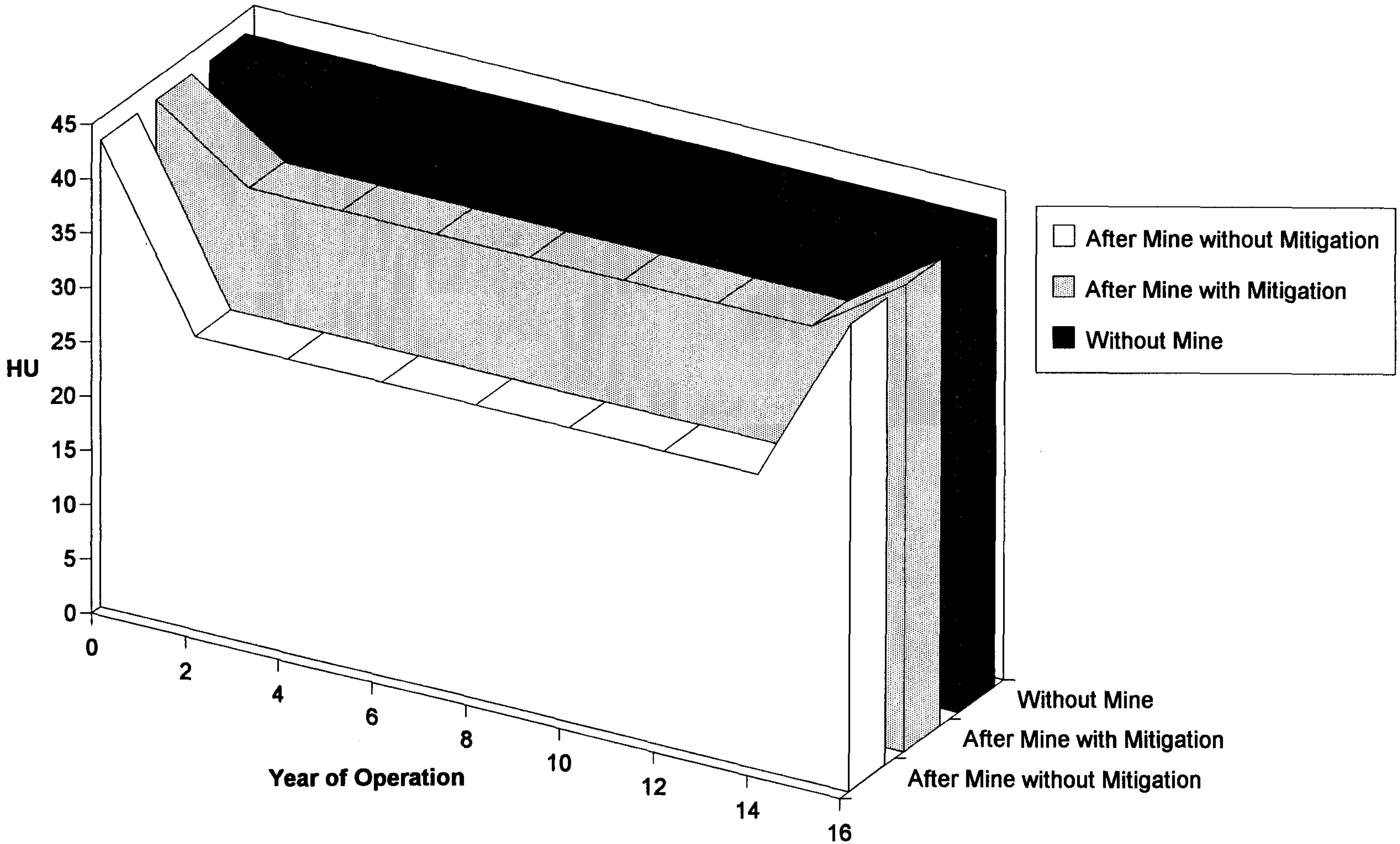


Figure 12. - Habitat Units for Marten in Affected Watersheds.

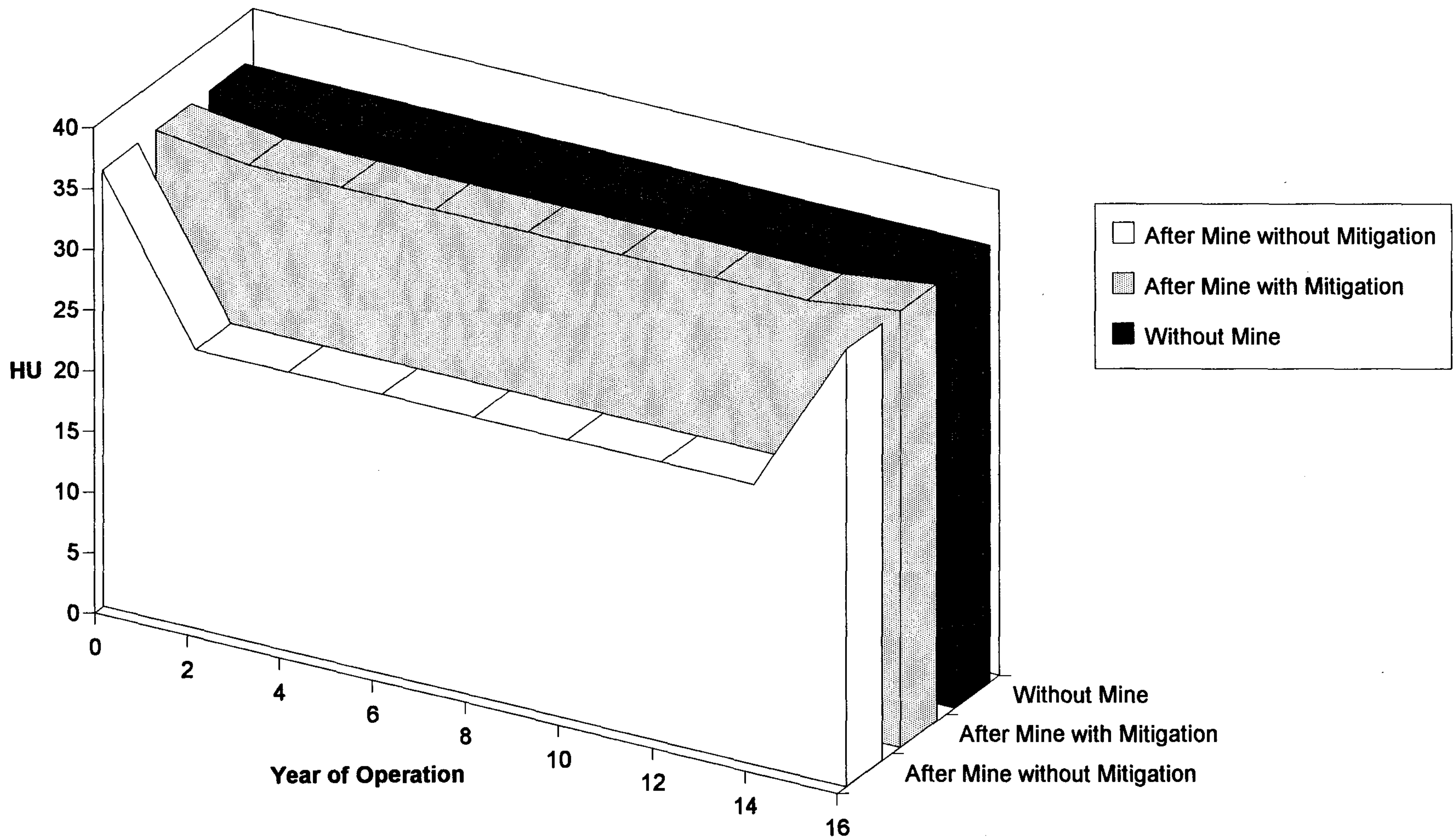


Table 10. **Average Annual Habitat Units for Brown Bear and Marten within Affected Watersheds Before Mine, with Mitigation, and without Mitigation over Life of Mine.**

	AAHU for Affected Watersheds before mine	AAHU for Affected Watersheds after mine without mitigation	AAHU for Affected Watersheds after mine with mitigation
Brown Bear	43.0	29.0	37.8
Marten	36.0	24.6	35.1

Table 11. **Cost per Average Annual Habitat Unit Saved for Brown Bear and Marten within Affected Watersheds.**

	AAHU for Affected Watersheds saved with mitigation of road impacts	Estimated Annual Cost for mitigation of road impacts	Cost per AAHU Saved for Affected Watersheds with mitigation
Brown Bear	8.8	$1,000	$110/AAHU
Marten	10.5	$1,000	$95/AAHU

This type of analysis could be applied to other mitigation alternatives being considered. For example, from Figure 10 it can be seen that if the road from the Young Bay dock to the mine site had been laid on a nearly straight line between the two ends of the road, much of the marten habitat that the present alignment impacts along the creek would have been avoided. The brown bear habitat (see Figure 9) impacted would be about the same in either case.

This new alignment may be much more costly (and perhaps technically infeasible), and as has been shown, the road with mitigation (Figure 10) had only direct impacts on marten (direct removal of habitat), so only a small amount of marten habitat would be saved by choosing the new road alignment. Brown bear habitat, although impacted more by the road even with mitigation (due to indirect impacts, Figure 9), would also be impacted along the new road alignment. Therefore only a small amount of brown bear habitat would be saved by using the new alignment.

The cost/benefit ratio of the newly proposed road alignment would likely be very high for both marten and brown bear habitat (high cost, low benefit), and may not be a reasonable mitigation alternative for these species. This illustrates the type of analysis that can be performed using these tools.

In another example of mitigation at the Greens Creek Mine, replacement of lost salmon spawning habitat in the tailings disposal area was required. To accomplish this, a natural barrier to fish migration on Greens Creek was removed, at considerable expense to the mining company. Some involved in the project felt that the money spent on the fish barrier removal could have been better spent on other mitigation efforts which may have been more cost-effective (1). These types of issues are good candidates for cost/benefit analysis as discussed above.

Concern has also been expressed that with removal of the fish barrier, salmon which could now spawn on upper Greens Creek near the mill site might attract bears to the area. The increased potential for human-bear contact could be problematic (19). These issues illustrate that although cost/benefit analysis of mitigation efforts can provide useful information, there may be other factors (e.g., technical feasibility, impacts of mitigation) that may be difficult to quantify except through professional judgement. Cost/benefit analysis, then, is only one of many considerations.

Finally, the scale being used is central to defining ecosystems. In this report, impacts to habitat were considered primarily at the watershed scale, with some analysis being done on larger scales, including the USGS 20 by 15 minute quadrangle and Admiralty Island scales. It is apparent from this analysis that the degree to which potential impacts are observable will depend upon the ecosystem scale considered. This demonstrates the importance of defining the ecosystem and scale before performing impact and cost/benefit analysis. In this analysis, the watershed scale was found to be useful for assessing impacts at the Greens Creek mining site. At larger scales, impacts may be difficult to observe, while at smaller scales, impacts may be more costly to assess than benefits warrant. However, for forest management or other management perspectives, other scales may be more useful.

DISCUSSION AND CONCLUSIONS

Extensive monitoring of permitted outfalls, disposal areas, and the environment is ongoing at the Greens Creek Mine. This monitoring is required for compliance with environmental permits and is used to assess impacts to particular components of the environment in particular areas. The monitoring program was briefly reviewed in this report. However, these programs are designed to be permit-specific rather than to assess overall impacts to ecosystems.

Methods are desired for assessing potential mining impacts to ecosystems and the environment in a comprehensive and holistic manner, for use in land planning by the USFS, the BLM, and other land-management agencies. At present, few models or other organized methods exist for doing this, especially for generalized, large-scale management; and there are no universally accepted procedures for assessing mining impacts to ecosystems. The methods available to assess the potential impact of the Greens Creek Mine on the Admiralty Island ecosystem were reviewed in this report.

Potential impacts of the mine to selected components of the ecosystem (wildlife habitats) were considered through the use of Habitat Capability Models developed jointly by the U.S. Forest Service, the Alaska Department of Fish and Game, and the U.S. Fish and Wildlife Service. These models hold promise for assessing the potential for mining and other industrial impacts, but at present are generally able to address only human impacts to wildlife habitat associated with roads (other than logging impacts). The impacts of mining roads on wildlife habitat for two management indicator species (brown bear and marten) were modeled and the results displayed through habitat suitability index maps and in tabular and graphic form. Applying available models and impact assessment techniques to the Greens Creek area, the benefits gained through mitigation of road impacts became apparent.

The U.S. Fish and Wildlife Service uses models to assess impacts from industrial activity, and this procedure, known as HEP, generally requires site specific models and field evaluation. In Alaska, the FWS has begun an effort to apply its Habitat Evaluation Procedures at the Alaska-Juneau Mine Project near Juneau. The HEP system utilizes Habitat Suitability Models to evaluate effects of land-management decisions on wildlife habitat. These procedures have been used primarily in the contiguous states; however, the FWS is expected to make greater use of these evaluation procedures in Alaska in the future (6).

By applying preliminary methods similar to HEP to the HSI data available for the Greens Creek area, the impacts of the mine to indicator species habitat under different mitigation scenarios were better quantified and were presented in tabular and graphic form. From the data presented in these tables and graphs, it can be seen that mitigation of the potential impacts of mine roads decreased the impacts to wildlife habitat considerably. The cost of this mitigation was minimal, resulting in a very small cost/benefit ratio.

By applying available habitat models and analytical techniques to the Greens Creek area, the benefits gained through mitigation of potential impacts became apparent. These or similar techniques were found to be useful for cost/benefit analysis of mitigation alternatives at mine sites. They allow an assessment of impacts to wildlife habitat in an organized manner and can be used by land-managers when considering mitigation options. They may be employed with increasing frequency as impacts to entire ecosystems are considered and cost/benefit analysis of mitigation options is performed more routinely.

It is also apparent from this analysis that the degree to which potential impacts are observable will depend upon the ecosystem scale considered. In this analysis, the watershed scale was found to be useful for assessing impacts at the Greens Creek mining site. However, for forest management or other management perspectives, other scales may be more useful. This demonstrates the importance of defining the ecosystems, species, and scales of concern before performing impact and cost/benefit analyses. The indicator species used will also influence the ecosystem impacts that are observed from this type of analysis, and defining these species is a key part of the assessment process.

Much progress remains to be made in our ability to predict the impacts of mining on ecosystems. More comprehensive models, which can address impacts from mining activity other than roads, are needed. This will require a more holistic approach to modeling ecosystems, modeling that considers various mining related activity, wildlife species, ecosystem functions, and their interactions.

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