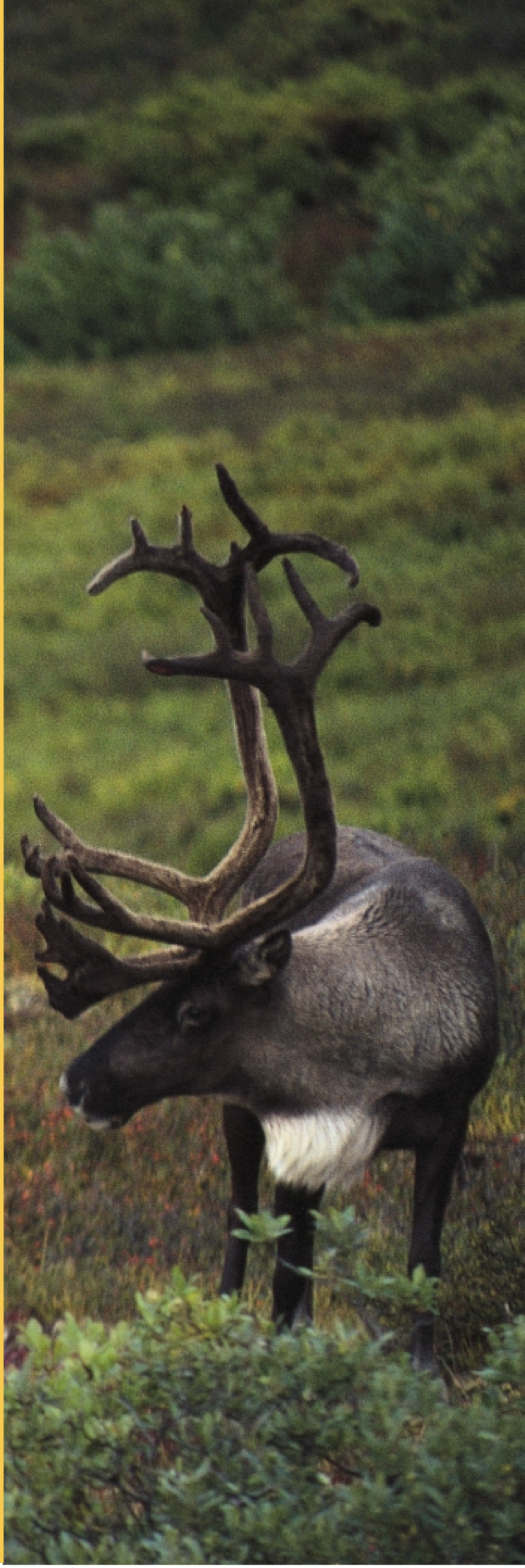
Alaska

Alaska is the largest state (1,477,270 square kilometers), more than twice as large as Texas and one-fifth the size of the lower 48 contiguous states. Alaska extends more than 20° in latitude, from Point Barrow at 71°23' to Amatignak Island in the Aleutians at 51°20'. It spans 42° in longitude, from 130° at the Portland Canal in the southeast to 172° at Attu Island in the western Aleutians (Fig. 1). The topography, climate, and communities of Alaska are characterized by their great diversity (Selkregg 1974–1976), including Mt. McKinley (Denali), the highest mountain in North America; more glaciers, ice fields, and active volcanoes than in the rest of the United States; several of the largest river systems in the country; a coastline of more than 54,700 kilometers that borders the North Pacific, Bering Sea, and Arctic Ocean; and extensive lowland boreal forest, wetlands, and coastal tundra.

Mean annual temperatures range from -2°C to 2°C along the southern coast, from -6°C to -2°C in the interior, and from -12°C to -10°C in the interior mountains and Arctic. The length of the frost-free period varies from more than 200 days in parts of southeastern Alaska and the Aleutian Islands to 40 days in the Arctic. In summer, the long day length in the interior and the 24 hours of sunlight in the Arctic partially compensate for the short growing season and account for relatively high plant productivity at these high latitudes. Precipitation can exceed 500 centimeters per year in parts of the Alexander Archipelago of southeastern Alaska, but it is generally less than 25 centimeters per year in the Arctic, which is an amount that would result in desert conditions at lower latitudes. Most of the precipitation in winter, however, remains on the land as snow until spring, and low summer evaporation rates and impeded drainage (because of permafrost) allow adequate moisture for plant growth. Permafrost is present throughout most of the Arctic and northwestern Alaska except beneath lakes, rivers, and adjacent riparian zones. South of the Brooks Range in the interior and in southwestern Alaska, permafrost is discontinuous and mostly occurs on north-facing slopes, at higher elevations, and in the lowlands.

During the Ice Ages of the Pleistocene Epoch, when the great continental ice sheets swept down across Canada into the northern tier of states, glaciation in Alaska was extensive only in the southern portion of the state from the Alaska Range, Wrangell and Saint Elias mountains, and Coast Range to the Gulf of Alaska (Hamilton et al. 1986). Portions of the Brooks Range and a few of the higher mountains in interior and western Alaska were also glaciated, but most of interior, western, and arctic Alaska was not glaciated. Because of the great volume of water tied up in the continental ice sheets, sea levels then were as much as 90 meters lower than today, and a continuous ice-free land area connected Alaska with eastern Siberia (that is, the Russian Far East) during the Tertiary and several times during the Quaternary, including the last exposure that occurred between about 30,000 and 11,000 years ago. The land bridge extended from just north of the Aleutian arc northward to the edge of the continental shelf in the Arctic Ocean (Hopkins et al. 1982). Plants, animals, and the first humans entered the New World by this route. This region connecting Asia and America—where a free exchange of species occurred until about 11,000 years ago when meltwaters again raised sea levels—is called Beringia. The area of Alaska and adjacent Asia that was



Courtesy T. Smith, USGS

Fig. 1. Outline map of Alaska showing the major rivers and mountain ranges.

not glaciated and adjacent parts of northwestern Canada constituted a vast refugium for plants and animals that were isolated from those south of the great continental ice sheets (Hopkins et al. 1982). As a result of Alaska's ice age history, much of its present flora and fauna are the same as or share genetic affinities with those of northern Asia and therefore provide a unique and diverse component of the total biological diversity of the United States.

The first humans in the Western Hemisphere are believed to have come across Beringia into Alaska 12,000 to 15,000 years ago. They were the Paleo-Indians who spread throughout North and South America and from whom most Native American cultures derived, including the Haida and Tlingit peoples of the southeastern coast of Alaska (Greenberg 1987). Later movements of people are believed to have been responsible for the Athabaskan cultures that are present throughout interior and south-central Alaska and in parts of northwestern Canada. The marine-oriented Eskimos of arctic, western, and southwestern Alaska (represented today by the Inupiat, Yupik, and Koniak cultures) arrived much later, apparently by boat across the Bering Strait. The Aleut culture of the Aleutian Islands and adjacent Alaska Peninsula has its closest affinity with early Eskimo cultures.

Today, the human population of Alaska is about 600,000. Most people live in and around Anchorage, Fairbanks, Juneau, and smaller southern coastal cities. Alaska Natives constitute about 16% of the population, mostly living in small communities throughout rural Alaska, where they are at least partially dependent on the fishes and wildlife of the land and waters for their subsistence (Selkregg 1974–1976).

Major Biogeographic Regions

Alaska's position between the cold Arctic Ocean and the relatively warm North Pacific Ocean, its extensive coastline and southern islands, its high mountain ranges and associated ice fields, and its large area are responsible for the state's ecological diversity. For this report, Alaska is divided into six major biogeographic regions (Fig. 2). Our classification of Alaska's ecoregions, which varies from classification schemes devised for other purposes (Selkregg 1974–1976; Fig. 3), groups areas of similar climatic and ecological features.

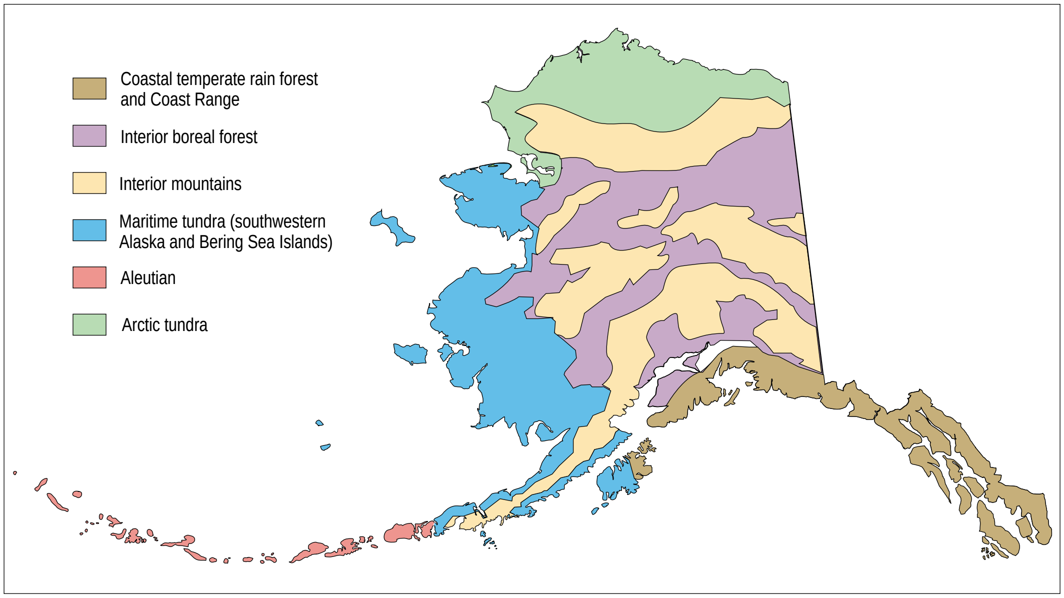


Fig. 2. The major biogeographic regions of Alaska.

Coastal Temperate Rain Forest and Coast Range

This ecoregion (Fig. 2) is shaped by the moderating maritime influence of the relatively warm ocean currents. It is a continuation of the temperate coniferous rain forest that extends from northern California along the northwestern coast of North America to northern Kodiak Island (Fig. 4). Although the number of tree species and the elevation of the treeline decline with increasing latitude, the extension of temperate rain forest to these high latitudes is globally unique. The abrupt terrain adjacent to the sea culminates in high mountains that capture moisture from the oceanic air as rain and snow. At higher elevations, extensive ice fields feed glaciers that often reach the sea at the heads of fjords in the deeply incised shoreline. Annual precipitation is heavy throughout the region but is highly variable locally because of irregular terrain. In winter, the frequency and accumulation of snow are also variable but increase with increasing latitude and altitude and also from the outer coast and islands to the mainland (Selkregg 1974–1976).

The entire region, except the mountain peaks within the ice fields (known as *nunataks*), was heavily glaciated during the last Ice Age. Ice receded from most of the region about 10,000 years ago, thus most plants and animals that characterize the region arrived from unglaciated areas. Plants dispersed primarily from the south by following a coastal route (Hultén 1937), whereas animals are representative of the fauna of the northern and southern Pleistocene refugia (Klein 1965).

The fauna and flora of the south dominate. The common garter snake, the only reptile in Alaska, has been reported in Revillagigedo Island in southernmost southeastern Alaska. Amphibians are represented by the western toad, three salamander species (the rough-skinned newt, northwestern salamander, and long-toed salamander), and two frog species (the Cascades spotted frog and the wood frog). All but the wood frog, which also occurs throughout the boreal forest, are restricted to southeastern Alaska. No studies have been made of the ecology of these amphibians in the rain forests of southeastern Alaska.

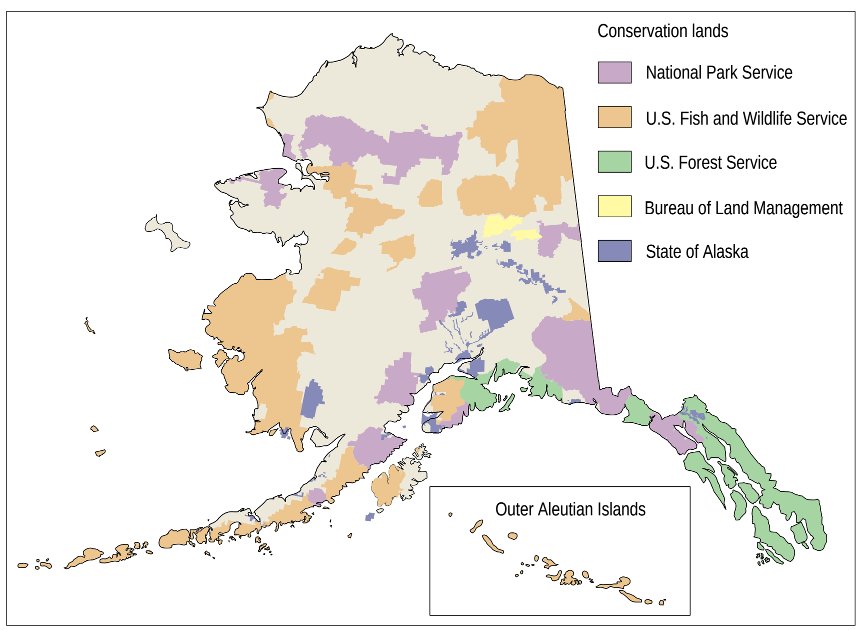


Fig. 3. State and national conservation lands in Alaska: some of the agencies listed also administer other land in Alaska. A large portion of the state's land is in protected status: national park lands in Alaska make up 75% of the nation's total, and 90% of national wildlife refuge lands are in Alaska.

Courtesy D. R. Klein, USGS

Fig. 4. The coastal temperate rain forest and Coast Range are a complex interface of mountains and sea.

Vegetation

Lowlands of this region are covered by complex forests of towering trees, by bogs where poor drainage and excessive groundwater preclude tree growth, and by the floodplains of streams and rivers. Lowlands and benches on mountain slopes are dotted with various types of bogs. Many are sphagnum bogs with low ericaceous (heath) shrub vegetation and scattered lodgepole pines (the only pine that occurs in Alaska), some Alaska-cedar, and mountain hemlock. Variability among bogs is great: some are rich in mosses, grasses, and sedges, and some have tussocks and hummocks, whereas others do not (Robuck 1985). Adjacent shallow seas support aquatic marine communities composed mainly of algae but also of surfgrass and eelgrass. In areas where sandy beaches form, the strands are scattered with salt-tolerant plants such as sea-beach sandwort, followed shoreward by beach ryegrass communities with codominants such as hairgrass, beach pea, beachstrawberry, Pacific silverweed, and beach lovage. Most shorelines, however, are narrow, and sea cliffs and rocky shores are common. Between beach and forest lies a dense zone of shrubs where Sitka alder and thorny devilsclub can be common and unforgettable to those who try to pass through.

The structure of the forest varies from south to north in the region. In the south, forests consist primarily of western hemlock and Sitka spruce with fewer western redcedar and Alaska-cedar. Pacific silver fir and Pacific yew reach the northern limits of their distribution in the southernmost portion of the coastal forest. To the north, the proportion of western hemlock increases and mountain hemlock becomes more conspicuous. The understory can be rich in various shrubs and herbaceous species such as grasses, forbs, and large ferns. Lichens and mosses are important on the forest floor and as epiphytes (Alaback 1982).

Species richness of the understory depends in large part on the tree canopy. A moss-dominated, shrub-poor understory is characteristic of young, even-aged stands with closed canopies, particularly in western hemlock forests (Alaback 1982). Frequent shrubs in this kind of understory are Sitka alder, devilsclub, salmonberry, Alaska blueberry and early blueberry, and menziesia.

Original forest stands of this region are ancient, with some trees older than 300 years. Often referred to as old-growth forests, these stands are nevertheless uneven-aged because as older trees die and fall, younger trees become established beneath breaks in the canopy. The resulting layered canopy has openings that let light penetrate to the forest floor, allowing shrubs, ferns, forbs, and tree seedlings to grow.

Local, large-scale natural disturbances are caused by blowdowns and (rarely) by fire. Even-aged forest stands that develop after blowdowns and clear-cutting lack the biological diversity of old-growth forests (Alaback 1982; Schoen et al. 1988). One limitation to diversity in even-aged forests is the closed canopy of second-growth stands, which does not allow sufficient light to reach the forest floor for growth of shrubs and other vascular plants. Also, although forests readily regenerate from seeds in the litter after removal of old-growth forests, species composition of the new growth is usually different from that of the original forests (Alaback 1982; Kirchhoff and Schoen 1987).

The subalpine zone occurs on mountain slopes at elevations of about 400 to 500 meters. Mountain hemlock forests with trees 38–50 centimeters diameter at breast height and a height as tall as 25 meters characteristically define this zone. Heavy snowpack accounts for late-lying snow in the subalpine region throughout the early to middle part of the growing season. In many areas, the subalpine region is a broad belt where small islets of stunted trees are confined to sheltered sites.

The transition to alpine tundra begins with lichen-rich mountain heath and dwarf shrub communities dominated by shrubs and subshrubs of heath and related families. At higher elevations, the landscape is increasingly broken by outcroppings of bedrock, and plant communities are correspondingly fragmented. In stable sites, such as snowbeds and snowflushes, prostrate, mat-forming woody species that occur on ridges are replaced by rich sedge–grass–forb meadows. In open communities these woody species are replaced by a variety of mat and cushion forbs and subshrubs. Ultimately, increasingly severe conditions at higher elevations restrict plants to ledges and crevices. At some localities—such as on Prince of Wales Island—abundant, seasonally dry, calcareous soils are locations of continental species disjunct in the archipelago from the interior (Jaques 1973).

The rare vascular plants of southeastern Alaska were recently surveyed by the Alaska Natural Heritage Program (University of Alaska, Anchorage, unpublished data). The most noteworthy of these are Calder's licorice-root, Alaska mistmaiden, netleaf willow, and cleftleaf groundsel.

Freshwater Fishes

Thirty-five fish species occur in the fresh waters of the coastal temperate rain forest and Coast Range region (Morrow 1980; Table). Species favored by humans are the chinook, chum, coho, pink, and sockeye salmon; the Dolly Varden; the rainbow and cutthroat trout; and the eulachon. The salmon species support a commercial fishery that in 1994 harvested more than 135 million salmon at a value of more than $200 million (Alaska Department of Fish and Game 1995). Salmon also provide subsistence food for Alaskans—in 1993 more than 107,000 salmon were caught for subsistence and personal use (Alaska Department of Fish and Game 1994a). In addition, salmon, Dolly Varden, rainbow trout, and cutthroat trout support a growing recreational fishery that now includes more than 1.5 million angler-days, or about 69% of the total sport effort in the state (Mills 1994).

The region's anadromous and freshwater resident fishes and their eggs provide food for a variety of mammals, birds, and other fishes. Willson and Halupka (1995) list 16 mammal, 31 bird, and 11 fish species in southeastern Alaska that feed on adult salmon and their eggs and young. In addition to the direct benefits these fishes provide to other

Table. Freshwater fishes in Alaska (modified from Morrow 1980).

Species	Region[a]
Lamprey family	
River lamprey	1
Western brook lamprey	1
Arctic lamprey	2, 4, 6
Pacific lamprey	1, 4, 5
Sturgeon family	
Green sturgeon	1, 5
White sturgeon	1
Shad family	
American shad	1
Salmon, trout, char, grayling, whitefish family	
Whitefish subfamily	
Sheefish, inconnu	2, 4
Humpback whitefish	2, 4, 6
Least cisco	2, 4, 6
Arctic cisco	6
Broad whitefish	2, 4, 6
Bering cisco	2, 3, 4, 6
Round whitefish	1, 2, 3, 4, 6
Pygmy whitefish	4
Grayling subfamily	
Arctic grayling	1, 2, 3, 4, 6
Trout, char, salmon subfamily	
Brook trout	1
Lake trout	1, 2, 3, 4, 6
Arctic char	3, 4, 5, 6
Dolly Varden	1, 2, 3, 4, 5, 6
Rainbow trout, steelhead	1, 2, 4
Cutthroat trout	1
Sockeye salmon, kokanee	1, 2, 3, 4, 5
Coho salmon	1, 2, 4, 5
Chinook salmon	1, 2, 4
Chum salmon	1, 2, 4, 5, 6
Pink salmon	1, 4, 5, 6
Smelt family	
Longfin smelt	1
Rainbow smelt	1, 4, 6
Eulachon	1, 5
Pond smelt	1, 4
Pike family	
Northern pike	1, 2, 4, 6
Blackfish family	
Alaska blackfish	2, 4, 6
Minnow family	
Lake chub	2
Sucker family	
Longnose sucker	1, 2, 3, 4, 6
Trout-perches family	
Trout-perch	2, 4
Cod family	
Burbot	1, 2, 3, 4, 6
Arctic cod	4, 6
Saffron cod	1, 4
Stickleback family	
Ninespine stickleback	1, 4, 6
Threespine stickleback	1, 4
Sculpin family	
Pacific staghorn sculpin	1
Fourhorn sculpin	4, 6
Prickly sculpin	1
Coastrange sculpin	1, 5
Slimy sculpin	1, 2, 3, 4, 6
Sharpnose sculpin	1, 5
Surfperch family	
Shiner perch	1
Flounder family	
Arctic flounder	4, 6
Starry flounder	1, 4, 6

[a] Regions: 1 = coastal temperate rain forest and Coast Range; 2 = interior boreal forest; 3 = interior mountains; 4 = maritime tundra of southwest and western Alaska; 5 = Aleutian Islands and adjacent Alaska Peninsula; 6 = arctic tundra.

vertebrates, nutrients from their carcasses he sustain productivity of streamside and lacustrine communities (Ritchey et al. 1975; Kline et al. 1990). The most obvious food chain relationships are the importance of salmon carcases and spawning eulachons in bald eagle diets (Hansen et al. 1984; Hansen 1987; Armstrong 1995) and of salmon carcasses in brown bear diets (Schoen and Beier 1990). Some systems—such as Anan Creek near Ketchikan, where black bears congregate, and Pack Creek on Admiralty Island, which attracts brown bears—are set up as special areas where the public can view bears (Quinlan et al. 1983). The less obvious food chain relationships involving the region's fishes are the consumption of staghorn sculpins by greater yellowlegs and the consumption of threespine sticklebacks by arctic terns, great blue herons, and river otters (O'Clair et al. 1992).

Stocks of salmon and eulachon attract the largest-known concentrations of bald eagles in North America. The most notable concentrations are those of more than 4,000 eagles attracted by spawning chum salmon in the Chilkat River near Haines and 1,500 eagles drawn by spawning eulachons in the Stikine River (Hughes 1982; Armstrong 1995). Spawning eulachons that congregate during early May each year in the Berners, Lace, and Antler rivers of Berners Bay in southeastern Alaska attract a world-class concentration of more than 50,000 gulls, hundreds of bald eagles, numerous harbor seals, sea lions, and even an occasional humpback whale (Armstrong and Gordon 1995).

Pacific Halibut in Glacier Bay National Park, Alaska

The Pacific halibut is a large (up to 3 meters long) predatory fish in the flatfish family. Glacier Bay National Park is the site of extensive and controversial commercial halibut fisheries that began before the park was established in 1925. These fisheries continue despite prohibitive regulations, including the Wilderness Act and National Park Service regulations. Today, more than 70 commercial boats (1991 and 1992 data) harvest between 136,200 and 181,600 kilograms of Pacific halibut per year within the park.

Commercial halibut fishing in Alaska began as a fishery open to all people and was managed by controlling its duration. The duration of the open fishing season has gradually been shortened, until in 1994 the openings were only a one- to two-day "derby." The large numbers of vessels fishing the waters of Glacier Bay National Park resulted in an additional conflict for the National Park Service, which severely limits the numbers of boats other than commercial fishing vessels permitted to enter Glacier Bay in order to reduce negative impacts on humpback whales and other park resources. In 1995 an individual fishing quota system replaced the derby-style fishery. This system was predicted to result in greater local resource use by fishing vessels, and preliminary data bear out this prediction. Because Glacier Bay is near many fishing communities and its waters are relatively protected, this new quota system may cause the bay to experience increases in fishing activity and more conflicts between visitors and fishing vessels. In addition, unlike the derby-style fishery, the individual fishing quota system permits fishing throughout the summer, which is when both whale abundance and visitor attendance also peak. The majority of previous studies on Pacific halibut have been directed toward maintaining maximum sustainable yield. In contrast, the National Park Service is directed to manage its resources in such a manner as to maintain their natural state and to provide for visitor enjoyment, which is why Glacier Bay Field Station's research efforts have been directed at such basic ecological questions as diet, home range, site fidelity, habitat selection, distribution patterns, and the relationships between halibut and other species.

To analyze the Pacific halibut's diet, we examined the stomach contents of 947 sport-caught fishes. Content analysis revealed a shift in diet as halibut mature, from small crustaceans consumed by young halibut to fish eaten by large, mature halibut. Two foraging modes by halibuts were revealed by analysis of stomachs with multiple prey items. Individual halibut often exhibited only prey items found during active foraging (for example, large numbers of juvenile crabs) or else only prey items associated with sit-and-wait predation (such as walleye pollock).


Courtesy USGS

Fig. 1. Sonic tag being internally implanted in a Pacific halibut.

Long-distance movements of Pacific halibut have been emphasized in previous studies (Skud 1977; St-Pierre 1984), and most population models developed for this species assume that movement is relatively unrestricted among areas (Quinn et al. 1985). In our own studies of movement patterns, we internally implanted long-life sonic tags in 97 halibut in Glacier Bay and individually wire-tagged more than 1,500 halibut (Fig. 1). Results from the sonic-tagging study indicate that home range patterns shift during the course of halibut development. Juvenile fish move widely but often still remain within the Glacier Bay area, whereas large, sexually mature individuals have much smaller home ranges—often less than 0.5 square kilometers—and many mature fish stay in the same area both during the course of a year and from one year to another with little simultaneous spatial overlap (Fig. 2). Larger fish occasionally alter their pattern of small home ranges to travel more widely before returning to a relatively sedentary pattern. A few larger fish, though, appear never to establish home ranges.

Wire-tagging data corroborate the apparent site fidelity of adult Pacific halibut. Of the halibut originally wire-tagged in Glacier Bay and then recaptured later, more than 95% were recaptured within Glacier Bay, with an additional 3% caught in the adjoining Icy Strait area. Individuals have been recaptured 5 years after tagging within a few hundred meters of their original capture and release location.

Sonic-tracking data also indicate that although some individuals leave during the winter, many appear to remain within Glacier Bay. Researchers have hypothesized that halibut may spawn only in certain areas off the outer coast during the winter (Skud 1977; St-Pierre 1984). The presence of reproductively mature individuals within Glacier Bay during winter may indicate either that Pacific halibut do not spawn every year or that spawning can also occur within the bay.

To study the species' habitat selection and distribution patterns in Glacier Bay, we have sampled Pacific halibut by setting 149 research long-lines with 400 hooks each throughout the bay (Fig. 3). *Long-lining* is a method of fishing that uses a piece of ground line (often kilometers in length) to which short (0.5 to 1 meter long) gangion lines with baited hooks are attached at intervals of 1 to 10 meters. Results of these studies and those from sonic-tracked individuals suggest halibut engage in two broad patterns of habitat choice and dispersion. The first pattern seems to depend on the developmental stage of the fish, with larger individuals distributed relatively uniformly in deeper water and smaller individuals preferring shallow water and areas of steep topographic relief in a much more aggregated distribution pattern. The second observed pattern, which reflects changes in distribution along the length of Glacier Bay's recently deglaciated fjord system, is characterized by decreased halibut abundance with greater proximity to glacial termini. Sampling of water conditions—salinity, temperature, and the amount of silt and phytoplankton (indicated by chlorophyll *a*)—indicates that this pattern is due to oceanographic conditions rather than the habitat's physical or biological successional processes. The presence of tidewater glaciers dramatically affects oceanographic conditions, and Glacier Bay, with its many tidewater glaciers, is a profound example of this. Tremendous amounts of cold, freshwater flow and as much as 6 centimeters of siltation a day come down into the bay from the tidewater glaciers. Comparisons between long-lining data and sonic-tag data indicate that many larger individuals are not caught by long-lines.

As a result of investigations into Pacific halibut ecological relationships, we hypothesize that the way halibut in Glacier Bay hunt depends on their life stage, and that these foraging modes determine their movement patterns, distribution, and catchability. Juveniles probably range widely, actively searching for areas of high prey abundance, where they are easily caught on long-lines. Many adults probably establish small, discrete home ranges where they wait for large fish or invertebrates; rarely does a long-line come close enough for these individuals to be captured.

We plan to continue our studies on long-term site fidelity, to test the hypotheses on foraging modes, and to further our understanding of the distribution and abundance of halibut predators and prey. If future regulatory fishing closures occur, we also hope to use them as experiments to examine the effects of local depletion or broader-scale ecological factors in fished and unfished areas.

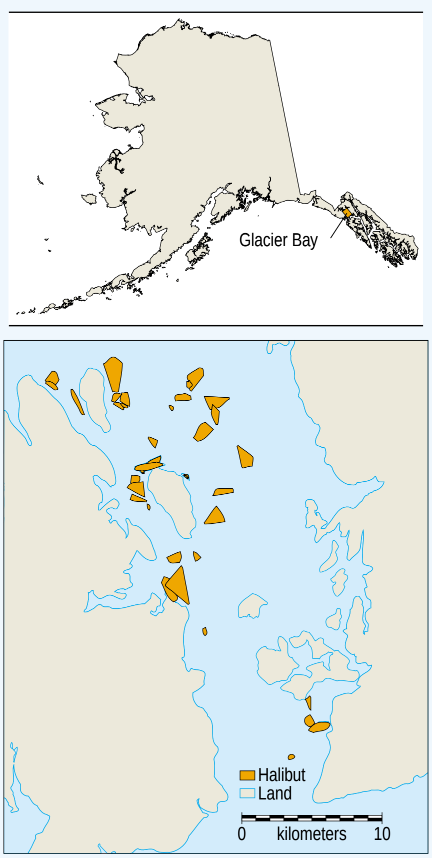


Fig. 2. Home ranges of a few larger halibut in Glacier Bay.

Courtesy P.N. Hooge, USGS

Fig. 3. Research long-lines being retrieved.

Our research results have management implications for the Pacific halibut. As stated, the studies at Glacier Bay indicate that halibut have much smaller home ranges and greater site fidelity than previously thought. These findings, coupled with the potential increase in local commercial fishing due to the individual fishing quota system and a rise in halibut sport fishing in southeast Alaska, indicate a potential for local resource depletion of this species. On the other hand, our hypotheses about differing foraging patterns and catchability in Pacific halibut suggest that this species' behaviors may help protect larger halibut from commercial long-line fishing but not from trawling with nets. This "behavioral refugium" could act to buffer the population from the collapses experienced by other fisheries that have been managed based on maximum sustainable yield models and catch-per-unit effort (Ludwig et al. 1993; Rosenberg et al. 1993).

See end of chapter for references

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Birds

The coastal temperate rain forest and the Coast Range region is the major migration route of Pacific Flyway birds during their seasonal transits between nesting areas in Alaska and adjacent Siberia and their southern wintering areas. The region also supports a rich diversity of nesting migratory species, and the number of resident species is greater in the coastal region than in the other biogeographic regions of Alaska.

Marbled murrelets nest in old-growth forests in south-central and southeastern Alaska and, less commonly, on the ground in south-central and southwestern Alaska (Quinlan and Hughes 1990). Although data from boat surveys of marbled and Kittlitz's murrelet populations have suggested a total combined population of about 600,000–900,000 murrelets in Alaska (Agler et al. 1995), it is difficult for researchers to determine the actual number of breeding marbled murrelets in the dense coastal forests (Ewins et al. 1993; Piatt and Ford 1993).

Waterfowl are common migrants that breed in wetlands in the coastal temperate rain forest, particularly in major river deltas (for example, the Copper River delta). Several subspecies of geese have limited breeding distributions in this region; for example, the Vancouver Canada goose breeds in southeastern Alaska forests, the dusky Canada goose in the Copper River delta, and the Tule white-fronted goose in the western Cook Inlet. Migrating sandhill cranes from the Pacific Flyway stop in the Copper River delta, at wetlands near Yakutat, and at several points in southeastern Alaska. The southern coastal area is also important for breeding trumpeter swans, whose population has increased since the middle of the century. However, suitable trumpeter swan habitat throughout this region may be saturated (Conant et al. 1993; Kessel and Gibson 1994) or adversely affected by human disturbance. Population sizes of Pacific loons and common loons, which nest in lakes in the southern coastal forest region, seem stable, although increasing human habitation and heavy recreational use of many lakes may potentially disrupt nesting (Ruggles 1994).

Raptors are common in prey-rich coastal areas. As mentioned previously, the largest U.S. populations of bald eagles occur in the coastal forests of southeastern and south-central Alaska (Schempf 1989); the bald eagle population in southeastern Alaska seems to be increasing (Kessel and Gibson 1994). Peale's peregrine falcon is a resident, but insufficient data are available to determine this subspecies' population trends (Ambrose et al. 1988; Schempf 1989).

Southern-coastal Alaska is important to the world's shorebirds because this region contains several large river deltas that serve as stopover sites for millions of migrating shorebirds (for example, the Copper River delta in south-central Alaska and, of somewhat lesser importance, the Stikine River delta in southeastern Alaska; Senner 1979; Bishop and Green 1994). During migration to their breeding grounds in western Alaska, several million western sandpipers and dunlins stop in the Copper River delta (Senner 1979); the western sandpipers make up a substantial proportion of the species' breeding population. Although gulls are common residents in coastal areas, the abundances of some gull populations (for example, glaucous-winged gulls) in Prince William Sound seem to have declined because of closure of some canneries and changes in methods of handling fish waste at other facilities (Ainley et al. 1994). Also, oil that leaked from the *Exxon Valdez* spill narrowly missed contaminating some of the major stopover sites for shorebirds in Prince William Sound.

The coastal temperate rain forest and mountains support abundant populations of resident and migrant passerines, forest-dwelling grouse, and alpine-inhabiting ptarmigan, but few data are available on the population trends of these species. Extensive clear-cutting of old-growth forests throughout the region is causing major habitat alteration for many of these species (Schoen et al. 1988); however, specific details of their habitat requirements are not well understood.

Mammals

The biogeography of mammals is more complex in this region than in the rest of Alaska, a consequence of the region's insularity. Mammals encounter many physical and temporal obstructions to moving, including water barriers, mountain ranges, ice fields, glaciers, and the relatively short geologic time that has passed since ice covered most of the region. More than 30 mammal taxa are endemic to the region, and more than 10 additional taxa are largely confined here (MacDonald and Cook 1994). The many natural barriers to the free movement of mammals into and within the region have acted as filters and affect mammal dispersal in different ways. For example, in the Alexander Archipelago of southeastern Alaska, among the larger mammals, Sitka black-tailed deer are present on all the larger islands, whereas their primary predator, the gray wolf, occurs only on the islands south of Frederick Sound. Bears are also uniquely distributed: brown bears are found only on the Admiralty, Baranof, and Chichagof islands of the northern complex, whereas black bears only occur on the southern island complex, which is also occupied by gray wolves. The distribution of small mammals also varies widely among the islands. Throughout the entire ecoregion, among the smaller mammals, species richness declines from the mainland to the outermost islands, whereas endemism is greatest on the outermost islands and decreases as one moves closer to the mainland (MacDonald and Cook 1994).

Several mammal species that are typical of the temperate forest at lower latitudes reach the northern extensions of their Alaskan ranges in this ecoregion: Sitka black-tailed deer, four bat species (Keen's myotis, long-legged myotis, California myotis, and silver-haired bat), Keen's mice, southern red-backed voles, and most recently, fishers and mountain lions (MacDonald and Cook 1994). Several mainland species have not reached the islands; however, transplantations established mountain goats on Baranof and Revillagigedo islands. From 1916 through 1934, deer were introduced to the islands of Prince William Sound, from which they spread to the adjacent mainland, Kodiak Island, and the Yakutat Bay area, although they no longer are present in the Yakutat Bay area (MacDonald and Cook 1994). Moose were able to gain access to southeastern Alaska only in places where major rivers penetrated the Coast Range in the Stikine, Taku, and Chilkat river valleys; in the early 1900's moose also were able to enter the Yakutat forelands when a glacier that had blocked the Alsek River valley receded. Transplantations also established moose in the Copper River delta area and at Berners Bay north of Juneau (Burris and McKnight 1973).

Before Alaska's statehood in 1959, the Alaska Game Commission, often under the direction of the Territorial Legislature, engaged in wildlife transplantations to establish game species and furbearers and their prey on several of this region's islands where these species had not occurred. Consequently, the muskrat, beaver, marten, mink, snowshoe hare, and red squirrel were introduced to the Kodiak Island group; the marten to Baranof, Chichagof, and Prince of Wales islands in southeastern Alaska; the red squirrel to Baranof and Chichagof islands; the mink to Montague Island; the snowshoe hare to Admiralty, Prince of Wales, and the Shumigin islands; and the hoary marmot to Prince of Wales Island. Most but not all of these transplanted species established populations. Established nonindigenous species include elk on Afognak Island and on a few islands in the central Alexander Archipelago and European rabbits on Middleton Island in the Gulf of Alaska. Raccoons were introduced on the western coast of Prince of Wales Island, but the population subsequently died out (Burris and McKnight 1973).

With some exceptions, mammal populations throughout the ecoregion are at their historical levels and are characterized by natural fluctuations often tied to interannual weather variations. For example, the periodic heavy snow accumulation that occurs throughout the entire deer range causes heavy losses of deer in winter and subsequently depresses deer abundance for several years. In places where gray wolves and black bears are present, predation may further delay recovery. The number of wolves tracks the fluctuations in deer density but with lags of a few years (Klein 1995). Gray wolves have been most abundant in the southern islands of the Alexander Archipelago where deer densities are also high. These wolves are classified as an endemic subspecies.

Although hunters harvest all ungulate species for either subsistence or recreation, annual harvests in the region are constrained by seasons and bag limits. However, because of the vast areas, difficulty of access to many places, and the relatively small number of hunters, the actual kill (as many as 25,000 deer) is considered well below the annual population recruitment, except in areas close to human population centers (Alaska Department of Fish and Game 1994b).

Bears are hunted primarily by resident and nonresident trophy hunters, although some hunting of bears is for subsistence by Alaska Natives. The region's annual bear harvests may exceed 400 brown bears and 900 black bears (Alaska Department of Fish and Game 1994b); the state and federal agencies responsible for bear management consider these harvests sustainable throughout most of the region.

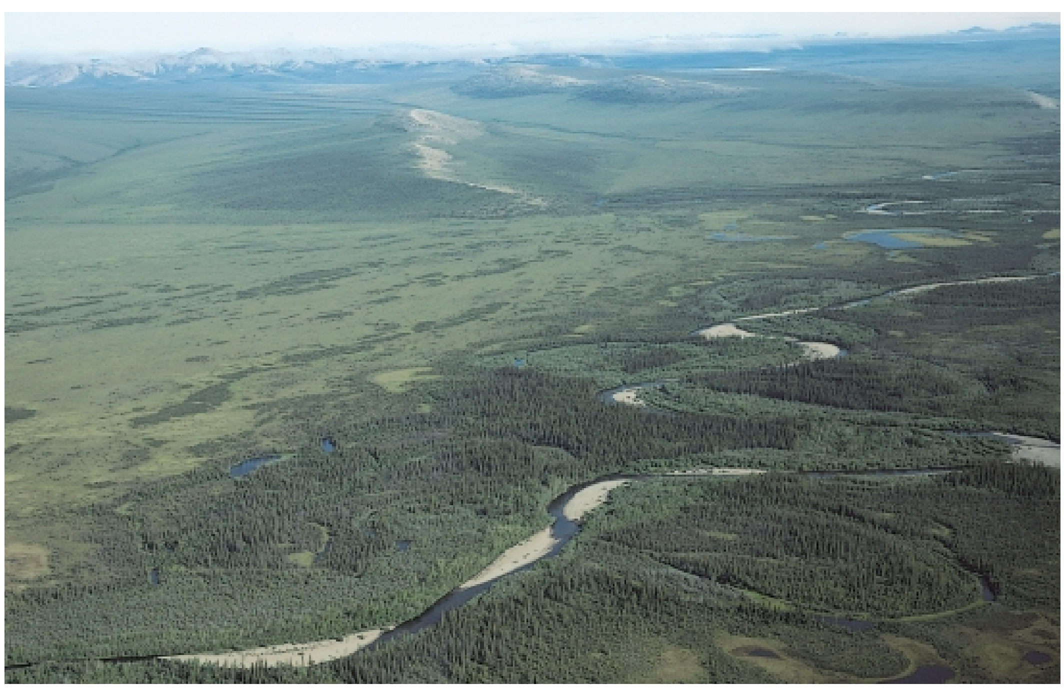
Interior Boreal Forest

High mountains in much of interior Alaska shelter the interior from the moist maritime air that occurs in the south and the cold arctic air characteristic of the north (Fig. 2). The climate is continental, with cold and long winters and short and warm summers. Seasonal climatic changes are rapid. Altitude strongly influences plant growth, the presence and composition of forests, and the presence and extent of permafrost. Fire, mostly caused by lightning, is a natural feature of the ecology of the interior boreal forest ecoregion. The vegetation of the interior boreal forest is a complex array of plant communities shaped by fire, soil temperature, drainage, and exposure (Fig. 5). Permafrost is mostly continuous in the northern portion of this region, except in riverbeds, beneath lakes, and on steep, south-facing bluffs. In the central and southern portions of the region, permafrost is discontinuous, absent on most southern exposures, and irregularly present adjacent to rivers and lakes. In the lowlands of the broad interior valleys, permafrost restricts drainage and accounts for the presence of extensive wetlands that form a complex of marshes, shrub thickets, small ponds, and forested islands (Selkregg 1974–1976).

Vegetation

The conifers of the boreal forest are white spruce on well-drained floodplain soils, on uplands, and on south-facing slopes where seasonal thaw is deep. Trees with diameters of 69–90 centimeters at breast height and heights of 30 meters generally occur on floodplain islands that have not been burned for a long time. Most white spruce stands in floodplains and on uplands consist of smaller, younger trees 12–15 meters tall. Black spruce grows in lowlands and on north-facing slopes where the annual thaw is shallow and permafrost is close to the surface. Black spruce stands are the most widespread of all stand types. The largest black spruce trees reach diameters of 18 centimeters at breast height and heights of 17 meters, but many are no larger than 10 centimeters in diameter at breast height and 9 meters tall.

A broad-leaved deciduous forest of quaking aspen, balsam poplar, and Alaska paper birch is prominent on well-drained uplands. The largest quaking aspens reach diameters of 25–36 centimeters and heights of 18 meters. In contrast, floodplain forests are composed of balsam poplar, white spruce, some paper birch mixed with mountain alder, and several species of willow. Balsam poplars can attain diameters of 40 centimeters and heights of 30 meters. Primary succession on the *point bars* (areas where rivers deposit silt, sand, and gravel on the inside of their curves) of large rivers passes through open-shrub willows and poplars and closed-shrub alder–poplar, two stages of dominant vegetation, before white spruce is well established (Van Cleve et al. 1991).



Courtesy D. R. Klein, USGS

Fig. 5. The interior boreal forest region is characterized by a diversity of vegetation types, including coniferous and deciduous forests broken by river floodplains and marshy wetlands.

Forest types are mixed, with species composition determined by steepness of slopes, *aspects* (the cardinal direction a slope faces), and fire histories. Natural wildfires, which are a critical component of the boreal forest environment, occur about every 50–70 years; stands older than 170 years are rare (Van Cleve et al. 1983). A complex fire history has created a patchwork landscape of stands of different species and ages. Fires occur often enough that the landscape is continually returned to successional forms, and true climax forest is seldom reached on uplands. Fires tend to remove white spruce, which is first replaced by paper birch and quaking aspen; eventually white spruce and then black spruce slowly return to these stands (Van Cleve et al. 1991). Although white spruce is fire-sensitive, the common broad-leaved quaking aspen and paper birch can quickly regenerate by root suckers, leading to pure stands of these species. Because of the ability of black spruce to reproduce vegetatively and because of its retention of seeds in persistent cones, this species is better adapted to withstand fire than white spruce. Postfire successional changes are more marked among understory shrubs and the moss and lichen ground cover than among trees in black spruce stands. The result of this fire history is an array of forest type combinations of white spruce and paper birch or quaking aspen. Extensive, nearly pure stands of paper birch form on floodplains; on warm, dry slopes, stands of quaking aspens persist for long periods without being replaced by spruce.

Forest understory varies greatly with stand density and the amount of moisture on the forest floor. Common tall shrubs found in various mixtures in white spruce forest are green alder and Bebb willow; low shrubs include Labrador tea, alpine blueberry, and especially lingonberry. In mixed stands on floodplains, horsetails carpet the forest floor, with feathermosses and foliose lichens prominent in the moist habitats. Shrubs are less important in quaking aspen forests, but highbush cranberry and prickly rose are common there. Mats of bunchberry, twinflower, and wintergreen are important shrubs, especially in mixed stands of paper birch and quaking aspen; in aspen stands in especially warm and dry settings, large patches of kinnikinnick develop.

Black spruce occurs with tamarack and even with paper birch, which more characteristically occurs on well-drained uplands. This forest type merges with bogs in which black spruce trees are scattered and stunted, forming a landscape called *muskeg*. The muskeg understory is characteristic of bogs—that is, rich in mosses, sedges (including tussock cottongrass), ericaceous shrub and subshrub taxa, and herbs such as roundleaf sundew. Treeless bogs, fens, and other wetlands are also common in this region.

Extensive deposits of sand and sand dunes were formed over some present-day interior boreal forest areas in the late glacial time. Many of these deposits were stabilized by forest cover, but others are exposed along river banks and deltas. The exceptional, extensive, active dune fields of the Great Kobuk Sand Dunes occur on the middle Kobuk River—where the oxytrope *Oxytropis kobukensis* is endemic—and on the Nogahabara Sand Dunes of the Koyukuk River, which is the sole Alaskan locality of *Carex sabulosa* (R. Lipkin, Alaska National Heritage Program, Anchorage, personal communication), a sedge of desert–steppe landscapes in Asia. This species is known from North America only from similar habitats in a few localities in the southwestern Yukon Territory, Canada (Porsild 1966). These unique landscapes and their plant complexes are protected because they are in national parks or national wildlife refuges.

Steppe vegetation, found on steep bluffs along the Yukon, Porcupine, Tanana, Matanuska, and Copper rivers, can be located and defined by its south-facing topographic aspect. The steepest portions of slopes are generally treeless, presumably because of drought and geomorphic instability. Stunted quaking aspens grow in a band on the more level ground that occurs at the crest of the slope between the upper edge of the steppe and the white spruce forest. Warmth-loving, drought-resistant grasses, sedges, forbs, and wormwoods are common steppe species (Murray et al. 1983).

Each steppe site can be thought of as a small island in a sea of forest. The steppe bluffs, especially in the upper Yukon River regions, are characterized by rare plant taxa and a restricted fauna of solitary bees (Armbruster and Guinn 1989). The vascular plants of these steppe bluffs—for example, the disjunct species American alyssum and the wormwood *Artemisia laciniatiformis*—occur only in the subarctic interior of Alaska and in the adjacent Yukon Territory. Other taxa of steppe sites in Alaska and in southwestern Yukon Territory are disjunct from taxa in dry grasslands in the western states, are subspecific variations of species that are more widespread farther to the south, or are narrowly restricted endemic species of eastern Alaska and the adjacent Yukon Territory and have no close relatives in Asia or elsewhere in North America. Researchers are exploring how these isolated plant communities became established on these bluffs and why they remain so restricted. The similarity of the modern bluff flora to pollen remains deposited at the peak of the last glacial maximum has led some researchers to postulate that the steppe vegetation type could be a relict of that time (Hopkins et al. 1982).

Freshwater Fishes

Twenty-two fish species occur in the fresh waters of the interior boreal forest region (Morrow 1980; Table). Humans favor the chinook, chum, and coho salmon; rainbow trout; sheefish; humpback and round whitefish; least cisco; arctic grayling; lake trout; northern pike; and burbot. These species support a growing recreational fishery of almost 500,000 angler-days on the region's fresh waters—about 19% of the total sport fishery in the state (Mills 1994). Commercial fisheries and subsistence and personal-use anglers harvest salmon (particularly chinook, coho, and chum) that are bound for major rivers of the interior boreal forest. Chum salmon are especially important to the Yukon River subsistence fishery, which harvested 188,825 fish in 1993 (Alaska Department of Fish and Game 1994a).

Throughout this region, almost all stocks of freshwater fishes targeted by sport anglers have declined, especially those stocks that are accessible by road. For example, lake trout and burbot stocks have been overharvested in most lakes that are accessible by road (Arvey 1993). Likewise, the density of arctic grayling has declined in the Tanana River drainage, especially in the Chena River, which once supported the largest sport fishery of arctic grayling in North America (Clark 1993). In the Susitna River drainage, the harvest of wild rainbow trout declined by 50% during the last 10 years despite a doubled harvesting effort (Rutz 1992). In recent years, chinook salmon returning to some interior rivers to spawn have failed to reach established population goals (Arvey 1993). Similarly, recent studies of northern pike populations in the Tanana River drainage indicate that exploitation rates of this species are higher than can be sustained by some populations (Arvey 1993). Harvests of whitefish species in the Tanana drainage increased steadily to a peak of 26,810 fish in 1986 but dropped drastically thereafter to a low of 739 in 1991. Fishing closures, reduced bag limits, and catch-and-release provisions were imposed on most of these fisheries in the hope of rebuilding or maintaining fish populations (Mills 1994).

Coho salmon *escapements* (that is, the successful return of fishes to their spawning grounds) have increased in some of the region's waters since 1985 (Bergstrom et al. 1992), probably because of commercial fishing restrictions in the lower Yukon River and because of the species' low natural mortality (Arvey 1993). Burbot populations in the Tanana River also seem healthy and do not seem to be overharvested, although the species is growing more popular with anglers (Arvey 1993; Evenson 1993a,b).

Waters in this region are stocked with fishes that include rainbow trout, arctic grayling, lake trout, arctic char, and coho, chinook, and sockeye salmon (Engel and Vincent-Lang 1992; Arvey 1993). Stocking, which currently provides about 65% of the fish harvested from the Tanana River drainage (Arvey 1993), is designed to ease harvest pressure on wild stocks and to diversify angling opportunities. Only species of direct importance to sport and subsistence fisheries of the region are monitored and then usually only in select systems, thus the status and trends of most other freshwater fish species are unknown.

The interior valleys of this region contain many rivers that originate from different water sources. Arctic grayling, which evolved and adapted to these different rivers, take advantage of the varied freshwater habitats, even though some rivers freeze solid in winter. According to Tack (1980), arctic grayling use glacier-fed systems mainly for overwintering or as migratory routes to other systems, spring-fed systems mainly for feeding but not for spawning or overwintering, bog-fed systems for spawning and feeding but not for overwintering, and large unsilted runoff systems for spawning, feeding, and overwintering. Arctic grayling are able to adapt to such a wide variety of aquatic habitats because they spawn in spring and early summer and because their eggs and larvae develop relatively quickly. This early and rapid development enables the young to leave the streams before the water becomes frozen and uninhabitable in winter.

The adaptations of fish species to different systems or to different parts of the same system have sometimes caused complex migrations to overwintering, spawning, and feeding sites (Armstrong 1986). Spring-fed systems like the Clearwater River delta provide ice-free spawning habitats for coho salmon, which typically spawn late in the year from mid-September to early November (Parker 1991). Such systems also provide ice-free habitats for young coho salmon, which remain as long as 3 years in the Clearwater River delta before going to sea as smolts.

The Alaska blackfish, an unusual fish in this region, occurs only in Alaska and eastern Siberia. Blackfishes are unique because they have a modified esophagus capable of gas absorption, which allows them to breathe air. This ability allows the fishes to live in small, stagnant tundra pools that are almost devoid of oxygen in summer and to survive in moist tundra mosses during extended dry periods until rain again fills the tundra pools (Armstrong

1988). Their great abundance and ease of capture make the Alaska blackfish an excellent subsistence fish for Alaska Natives, especially when other food is in short supply. One native name for the fish—*oonyeeyh*—literally means *to sustain life*.

Birds

Large numbers of breeding waterfowl summer on wetlands of the interior boreal forest, and thousands more pass through this region during migration. The number of trumpeter swans has increased since the early 1980's; similarly, tundra swans have expanded their breeding range into some parts of the boreal forest (Conant et al. 1991, 1993; Wilk 1993; Kessel and Gibson 1994). The interior boreal forest region is important for canvasbacks that winter on the Atlantic coast and for greater white-fronted geese that winter in the central United States.

Trends in sizes of duck populations are variable, however. The abundances of dabbling duck species (such as the northern pintail) and diving duck species (such as the scaups) have increased since 1977, although scoters (also a diving duck) are declining in abundance (Conant and Groves 1994). Wintering populations of waterfowl are small and restricted to a few duck species that inhabit the warmer, open waters used for cooling of utility plants (Christmas Bird Count data) or that inhabit spring-fed areas in rivers that retain some open water in winter (Ritchie and Ambrose 1992).

Although rock ptarmigan, willow ptarmigan, ruffed grouse, spruce grouse, and sharp-tailed grouse are hunted during fall and winter in the interior boreal forest, recent data on population-size trends of these resident species are incomplete. Reports from local residents of the region in 1994, however, indicated that the numbers of ptarmigan were low, whereas grouse numbers were moderate and increasing. Winter counts of ptarmigan and grouse in Fairbanks indicated that the sizes of local populations vary, generally on a several-year cycle that is possibly associated with the snowshoe hare cycle (Christmas Bird Count data) because the species share common food resources and because they are preyed upon by lynx. Thus, when the hare cycle is at a peak, lynx are abundant and prefer to eat hares, thereby reducing predatory pressure on ptarmigan, which then also reach peak levels.

Birds of prey have been closely monitored. Bald eagles that breed along major river systems have maintained relatively stable populations. Along the Tanana River, the population may even be growing (R. J. Ritchie, Alaska Biological Research, Inc., Fairbanks, personal communication). Breeding peregrine falcons on the Yukon River have recovered from their low population sizes during the 1970's and continue to increase in numbers, although populations on the Tanana River have not completely recovered, perhaps because of the growing presence of humans there (Ambrose et al. 1988; White 1994). The American peregrine falcon remains listed as endangered but may soon be moved to threatened status. No data are available on population-size trends of resident northern goshawks, a species recommended for listing in other parts of its range and currently a species of concern (U.S. Fish and Wildlife Service 1996). Population-size trends are also unknown for small birds of prey such as the sharp-shinned hawk, American kestrel, and merlin. Sizes of owl populations seem to fluctuate with prey availability, but trend data are not available.

Population-size trends are largely unknown for shorebirds and gulls, which are present in the interior boreal forest only during summer (May–September). Breeding shorebirds such as the common snipe and the yellowlegs nest in forested bogs, and the spotted sandpiper nests on gravel bars of large rivers. Few data are available on breeding populations of gulls, whose numbers seem to be greater near human settlements.

Passerine populations in the interior boreal forest primarily include migrant breeders and a few residents. Data for evaluating long-term population-size trends for passerines are generally lacking, except in the Fairbanks area. The abundances of Swainson's thrushes, yellow warblers, orange-crowned warblers, and white-crowned sparrows in the Fairbanks area seem to have declined since about 1977 (Kessel and Gibson 1994). Four other species are of special concern because of their declining population trends throughout North America: the olive-sided flycatcher, gray-cheeked thrush, Townsend's warbler, and blackpoll warbler (Alaska Department of Fish and Game 1994c). Researchers believe that the declines of these Neotropical migrants are a consequence of the loss of their wintering habitats in Central America and South America (Greenberg 1992). Wintering populations of resident passerines have been monitored since 1964 in the annual Christmas Bird Count in Fairbanks. The common raven, gray jay, boreal chickadee, black-capped chickadee, and redpolls (common and hoary) are the most common species in winter and show no distinct population-size trends.

Mammals

During the last Ice Age, most of interior Alaska north and west of the Alaska Range and south of the Brooks Range was not glaciated. Interior Alaska and similar, unglaciated areas in the adjacent Yukon Territory and north of the Brooks Range were part of the Beringian Refugium (Hopkins et al. 1982). The unglaciated area included a broad land connection with Asia and adjacent parts of northeastern Siberia that allowed for the presence of many Asian species. The steppelike environment of Beringia supported large numbers of grazing mammals, such as the woolly mammoth, steppe bison, and Lambe's horse, as well as their predators, including the lion, dire wolf, and short-faced bear. Most of these species went extinct when the climate and vegetation changed as glaciers receded about 10,000 years ago (Pielou 1991), with only the badger and black-footed ferret surviving in the Great Plains area of the United States.

As the cold climate ameliorated and the ice sheets melted, winds that had been generated by the adjacent ice sheets subsided, precipitation increased, and the present boreal forest became established throughout the region (Pielou 1991). In interior Alaska, the present boreal forest is an extension of the northern boreal forest that occurs from the Atlantic coast of Canada across the northern portion of the continent into Alaska. With few exceptions, mammals characteristic of this major biome are similar throughout its extent across Canada and the northern tier of states to Alaska (Pielou 1991).

The interior boreal forest is interrupted by several mountain complexes that support typical montane mammal species, some of which (for example, the caribou, grizzly bear, and wolverine) occupy the adjacent forest ecoregion during part of each year. The mammalian faunas of the boreal forest and the alpine habitat of the interior mountain complexes overlap in the transition zones between the two regions, where mammalian biological diversity and productivity of these faunas are consequently particularly high. Denali National Park and Preserve, which is internationally known for the diversity and abundance of its mammalian species, is an example of the ecotonal interface of boreal forest and montane habitats (Selkregg 1974–1976).

The abundances of mammals in the largely intact interior boreal forest community fluctuate primarily in response to variations in snow depth in winter and to plant succession after wildfires. Occasional winters with deep snows are detrimental to moose survival, especially to young-of-the-year animals, but are beneficial to small mammals that live beneath the insulating snow cover (Pruitt 1967). As a result, predators and scavengers are also affected by the weather-induced fluctuations of prey abundances and availability. Most mammal populations in the interior boreal forest region are healthy, and their reproduction rates are at moderately high levels. The abundance of snowshoe hares, whose population levels fluctuate over a cycle of about 10 years, is increasing slowly from the low of its present cycle. The abundance of the lynx, a specialized predator of the hare, is also low.

The extent of trapping of all furbearers remains low because of low fur prices. Past localized reductions of some furbearers resulted from intensive trapping stimulated by high fur prices.

Interior Mountains

The interior mountain biogeographical region (Fig. 2) is a complex of mountain ranges characterized by extreme physiographic variability. Wide differences in elevation, slope steepness, and exposure exist locally and between major mountain masses. The composition of vegetation throughout the region, although primarily dominated by alpine forms, reflects the variability of the terrain, and at lower elevations includes elements from the boreal forest (Fig. 6). The sizes of plant communities and habitats for animals are small, which means that the home ranges of a lot of animals include many habitat types.

The climate of this region is also variable. The seaward sides of the mountain ranges receive rain or snow from moist oceanic air masses, whereas the interior sides are arid. Plant growth occurs earlier in the year on south-facing slopes and at lower elevations than it does on north-facing slopes and at higher elevations. This variability in the timing of plant growth creates a complex pattern of vegetation in different annual growth stages and of different quality and quantity throughout the year. Consequently, large herbivores in search of food may move extensively over such a landscape.

The treeline varies throughout the region from about 900 meters in the Talkeetna Mountains to about 300 meters in the southern drainages of the Brooks Range, north of the Arctic Circle. Few plants and animals occur above about 2,000 meters in elevation. In this highest region, the high rate of erosion and the glacial recession that characterize the rugged mountains expose mineral soil to pioneering plant species that initiate a succession of plants and animals (Viereck 1979).

Vegetation

Alpine tundra generally occurs on land above 750 meters in elevation. The transition from forest to tundra varies from abrupt, where the terrain is steep, to a gradual shift from closed forest to open woodland and then tundra

Courtesy D. R. Klein, USGS

Fig. 6. The interior mountains support complex and diverse habitats resulting from variation in elevation, substrate, slope, and exposure.

in places where changes in elevation are more gentle. The greatest penetration of forest into tundra occurs in sheltered riparian stands in the narrow headwater valleys. Throughout most of interior Alaska, the predominant tree species at treeline is white spruce (Viereck 1979). Balsam poplars, though, also reach the treeline and even occur as isolated groves well beyond treeline (Viereck and Foote 1972). Vegetation at the transition from forest to tundra is frequently a zone of alder and willow or birch and willow shrubs. In the birch–willow zone, dwarf birch dominates. Outliers of paper birch contain numerous hybrids between tree and shrub birches.

Alpine tundra is a complex of low shrubs, grasses, sedges, and forbs that develops in response to topographic relief, slope, aspect, and surface stability, which in turn determine snow accumulation, soil temperature, depth of thaw, amount of moisture, and soil texture and nutrients. Perhaps the most widespread tundra type in this region is formed around species of mountain avens, plants that occur with sedges or ericaceous prostrate shrubs in extensive closed communities and with lichens and a variety of forbs in open communities.

Uplands with sufficient relief for treeless slopes and summits occur in huge areas of the interior, with some uplands extending beyond this region west to the Bering Sea. The Yukon–Tanana upland extends roughly east–west from the eastern boundary of Alaska and Yukon Territory (Canada) westward to the Koyukuk River. The upland is a complex of ranges that includes the White Mountains, Ray Mountains, and Kokrines Hills. Isolated mountain groups rise above the upland surface, reaching 1,200 meters or higher. Similarly, the Nulato Hills, a belt of mountains between 800 and 1,200 meters, flank Norton Sound and the Kuskokwim Mountains and extend southwest from the interior to the coast at Bristol Bay. Except for local areas of glaciation, these ancient surfaces remained ice-free throughout the last glacial maximum (Hamilton et al. 1986). The well-formed cirques at the head of many valleys were formed during earlier glaciations. *Solifluction* (that is, soil creep caused by forest action) terraces and lobes are common on many slopes, and stone circles and nets are common on many summits and saddles. (Stone circles and nets are the patterning of the ground surface by frost sorting, which results in stones or coarser materials being moved into lines around finer materials, resulting in circle or net-like patterns.) These geomorphic features contain surface irregularities that greatly enrich the diversity of the resident plant communities; such features exist only in places where cold-climate geomorphic processes have persisted undisturbed for long periods

The bedrock of mountains and uplands is too complex for generalization, but rock types have had an important effect on the region's flora. The Brooks Range and White Mountains of the Yukon–Tanana upland, for example, have limestone backbones and consequently are rich, calcareous habitats. Certain plants in these habitats are absent from the more acid environments of granitic rocks that are widespread in the Chugach Mountains, Wrangell Mountains, and parts of the Alaska Range.

Freshwater Fishes

Several lakes in the interior mountains of Alaska support a small but unique assemblage of freshwater fishes with a known total of ten species (Morrow 1980; Table). Of these, the arctic grayling, lake trout, and burbot are the most sought after by anglers (Mills 1994). About 30,000 angler-days were spent at these interior lakes during 1993 (Mills 1994); this is too many angler-days for waters of such small size with relatively low fish abundances and reflects the excessive fish harvest in some lakes.

Slimy sculpin and round whitefish are extremely important food sources for the predatory lake trout and burbot, whose numbers have declined in lakes with road access (for example, Lake Louise, Lake Paxson, and Summit Lake in the Glennallen area and the Tangle Lakes in the upper Tanana drainage; Lafferty et al. 1992; Szarzi 1992). Lake trout typically occur in deep mountain lakes, where fishes grow slowly; in Alaska lake trout may live longer than 50 years (Burr 1987). These fish usually spawn for the first time when they are 7–14 years old and may not spawn every year. This species' spawning behavior and its allure to anglers make it vulnerable to excessive harvest (Szarzi 1992). The catch and release of lake trout probably increases the mortality of the species because certain types of hooking gear have raised mortalities of lake trout to 71% (Loftus et al. 1988).

Many lakes and streams in the interior mountains freeze severely in winter, often to the bottom. Consequently, habitat becomes extremely limited in winter, and fishes may become concentrated in small areas of rivers and at the bottom of lake basins (Burr 1987). Fishes of this region are in a delicate balance with other species and their habitats. Successfully maintaining these fish populations requires a thorough understanding of their biology.

Birds

Mountain lakes support small numbers of breeding waterfowl (primarily ducks) during summer. Harlequin ducks nest along fast-moving mountain streams and rivers. Although no data on population-size trends are available for this species in the interior mountains, it is a species of concern (U.S. Fish and Wildlife Service 1996), primarily because of concerns over population declines in the coastal regions, particularly Prince William Sound. Pacific loons, common loons, and red-throated loons also breed in mountain lake systems with abundant prey (invertebrates and fishes) for these species.

White-tailed ptarmigan are common local breeders in the Alaska Range and in mountains to the south, and willow and rock ptarmigan are residents of the mountain ranges throughout the interior. The latter two species migrate vertically in winter from higher slopes to lower slopes, where willows are abundant. Little is known about population-size trends in these species.

Golden eagles commonly breed in the interior mountain region, especially on south-facing slopes in the Alaska Range (C. McIntyre, National Park Service, Anchorage, Alaska, personal communication). Gyrfalcons and peregrine falcons nest in some mountains, particularly where suitable cliff-nesting habitats are available. Merlins are also common breeders in the interior mountains (Ritchie and Ambrose 1992).

Upland-nesting shorebirds that are locally common breeders in some interior mountains include surfbirds, American golden-plovers, whimbrels, wandering tattlers, Baird's sandpipers, and least sandpipers. Upland sandpipers are a less common shorebird in the region, but evidence suggests that they breed in small numbers in some interior mountains (Ritchie and Ambrose 1992); this species was classified as a species of ecological concern by the Alaska Natural Heritage Program (West 1991). However, data on population-size trends of all shorebird species are lacking.

Gulls generally are uncommon in the interior mountains, except where substantial wetlands are present that support nesting mew gulls and sometimes nesting herring gulls. Small numbers of long-tailed jaegers also breed in the interior mountains (Gabrielson and Lincoln 1959).

Similarly, limited data are available on the population status or on population-size trends of passerines, which commonly breed in interior mountains in summer (Cooper 1984). Almost all passerines are present only to breed during summer because winter in the mountains is too harsh. American dippers, however, are residents of mountain streams with open water throughout winter. Some species that breed in alpine regions of the interior mountains, such as the snow bunting and Lapland longspur, also breed farther north in the arctic tundra. However, other species (for example, the golden-crowned sparrow, water pipit, and horned lark) breed primarily in the interior mountains. At least two species of Asiatic origin, the northern wheatear and arctic warbler, breed in Alaska's interior mountains.

Mammals

Several mammals of the interior mountain region, including the Dall sheep, collared pika, arctic ground squirrel, and singing vole, do not occur in other states. These species survived the last glaciation in the interior Alaska refugium and are adapted to the short summers and long winters of their mountain habitats. Their ranges do not extend southeastward beyond the interior of northwestern Canada. Dall sheep occur in the Brooks Range mountains of the Arctic National Wildlife Refuge to nearly 70° north, where the sun remains below the horizon for 3 months in the arctic winter. Other common arctic–alpine species in this region include the caribou (Fig. 7), hoary marmot, wolverine, grizzly bear, tundra vole, and brown lemming. The more ubiquitous species that are important components of this mountain ecosystem include the gray wolf, red fox, snowshoe hare, lynx, coyote, moose, northern red-backed vole, ermine, least weasel, and shrews (Hall and Kelson 1959).

An interesting relationship exists between the three canid species of the interior mountains—the coyote, red fox, and gray wolf. The coyote, which is a more recent species in Alaska, suppresses the abundance of the red fox, but wolves in turn suppress coyote populations. In interior Alaska, coyotes are most common close to human settlements and major road and railroad transportation corridors where gray wolves are less frequently present. In areas that are remote from human settlements, wolves are more common and seem to suppress the abundance of coyotes.

The high diversity of ungulate species and the high productivity of other vertebrate wildlife throughout the interior mountains provide a large prey base for gray wolves (Alaska Department of Fish and Game 1994c). The number of wolves is moderate to high in this region, and populations are productive. Control of wolves by the Alaska Department of Fish and Game in 1994 reduced the number of wolves in the northern portions of the central Alaska Range by an estimated 40% to 50% (P. Valkenburg, Alaska Department of Fish and Game, Fairbanks, personal communication). This reduction should be temporary and of little consequence to the long-term status of wolves in the area.

Mammal species and their habitats in the interior mountains biogeographic region have been, for the most part, far removed from the effects of most human development. Widely scattered exceptions are regions with small-scale gold mining, the highways and the Alaska Railroad that transect the Alaska Range, the highways that penetrate the Tanana Hills, and the Dalton Highway that runs through the Brooks Range (Foster 1985). Large representative habitat components of the region are protected in the federal reserve lands of the National Park Service, U.S. Fish and Wildlife Service, and the Bureau of Land Management. Hunting is restricted to traditional subsistence users in some of the national parks in Alaska (Foster 1985).


Courtesy D. R. Klein, USGS

Fig. 7. The interior mountains offer productive habitats for mountain sheep, moose, and caribou, shown here in late winter.

Most hunting in the interior mountains is for subsistence, sport, and trophies. Regulations that govern hunting on state and federal lands are conservative (Alaska Board of Game 1994; U.S. Fish and Wildlife Service 1994a). For example, most sport and trophy hunters are restricted to hunting only males of mountain sheep and moose, and female bears accompanied by young are protected. Registration, permit hunts, and the length of hunting seasons are regulated to restrict harvests to quotas based on surveys of population status and levels. Because of these hunting restrictions and the favorable condition of habitats in the region, most resident mammal populations are considered healthy and at moderate to high population levels. Exceptions are small caribou herds in the northern foothills and mountains of the Alaska Range that experienced low recruitment for several years. Their estimated population sizes in 1994 were 2,050 in the Denali herd, 4,350 in the Delta herd, 800 in the Chrisana herd, 1,346 in the Tonsona herd, and 750 in the Mentasta herd (Valkenburg, personal communication). Recent low recruitment in the much larger (about 22,000 animals in 1994) Fortymile herd in the Tanana Hills slowed this population's increase from a population low of 6,000 animals in 1977 (Valkenburg, personal communication).

Maritime Tundra of Southwestern and Western Alaska

The maritime tundra that dominates throughout southwestern and western Alaska (Fig. 2) is the product of the cool climate generated by the cold Bering Sea waters. There is a gradient, however, from the more humid and milder conditions that prevail in Bristol Bay and the coastal Alaska Peninsula next to the Aleutian region, to the Seward Peninsula where the adjacent seas may remain ice-covered for 8 months of the year. A gradual transition from maritime to arctic tundra occurs in the region of Kotzebue Sound, and a transition from maritime to alpine tundra occurs in places where mountains extend into the region. The extensive coastal wetlands throughout the region dominate the broad expanse of the ancient delta of the Yukon and Kuskokwim rivers (Selkregg 1974–1976; Fig. 8).


Courtesy D. R. Klein, USGS

Fig. 8. The wetlands of the Yukon and Kuskokwim River deltas provide some of the most important nesting areas for waterfowl and shorebirds in North America.

Vegetation

The climate and plant life of this region are transitional between the arctic tundra and the subarctic or maritime tundras of the Alaska Peninsula and Aleutian Islands. Furthermore, islands of the Bering Sea are not floristically similar. The vegetation of Saint Matthew and Saint Lawrence islands has affinities with arctic tundra vegetation on the mainland to the north (Young 1971), whereas the vegetation of the Pribilof Islands is clearly distinct and allied more closely with vegetation of the Aleutian Islands (Hultén 1968).

The Asian character of much of Alaska's flora is most evident in the Bering Sea region. This influence becomes less conspicuous eastward in Canada, and many species common in Alaska do not occur east of the Mackenzie delta (Hultén 1968). The Asian component in Alaska's flora is, of course, a consequence of the state's proximity to Asia (as little as 75 kilometers separate Cape Prince of Wales, Alaska, from Cape Dezhnev, Chukotka) and the geologic history of the region, which included a land bridge between Asia and America.

The distribution of so many vascular plants that are restricted to Alaska and Chukotka prompted Eric Hultén (1937) to propose the concept of Beringia. During glacial maxima when the Bering Land Bridge was exposed, Alaska was essentially the easternmost extension of Asia because ice sheets blocked access to the rest of North America. The emergent Bering Sea floor and the largely unglaciated lands east and west were a glacial refugium. Beringia—the refuge area during glacial maxima when the Bering Land Bridge was exposed—was a route of dispersal for plants. Consequently, it was the place where speciation occurred and where regional endemics developed. Among endemic Beringian taxa are a sagebrush (*Artemisia senjavinensis*), Wright's alkaligrass, Chukchi primrose, and Krange's sorrel (Murray and Lipkin 1987). Two other rather narrowly restricted endemics of Alaska, boreal primrose and Bering douglasia, are mostly confined to the maritime tundra region. In postglacial time, Beringia was an important source of plants for revegetation of the Arctic as ice sheets and glaciers receded and exposed the land to recolonization (Hultén 1937).

The Seward Peninsula is topographically diverse; rugged ranges there have peaks that rise to 1,460 meters from their base at or near sea level. Acidic volcanic rock in some areas and limestone in others support separate and distinctive flora and vegetation. Shrublands of willow, alder, and dwarf birch are well developed on low rolling hills in the southern portions of the uplands. To the north, the same terrain is covered for many kilometers by tussock tundra, which is broken only by low ridges and water tracks. Tussock cotton-grass is the dominant plant on the Seward Peninsula, but in some areas the Bigelow sedge is abundant and also can form tussocks. In spaces between tussocks, the combination of permafrost close to the surface and fine-grained soils accounts for high soil moisture and the frequent appearance of frost scars. Low shrubs such as dwarf birch, Labrador tea, blueberry, and lingonberry are common in tussock–heath phases.

On the Seward Peninsula, lava fields of recent origin provide unusual sites for plants. Groves of balsam poplar and other boreal forbs and ferns, which are common in the boreal forest farther east and south but unusual here, occur in the immediate vicinity of hot springs, presumably because soils are suffused with warm mineral waters. Clusters of pingos and thermokarst lakes (sites of erosion and subsidence by thawing of permafrost) occur in the interior lowlands, which were formed by large rivers, and may also occur in association with isolated groves of balsam poplar where other trees are absent. A Coastal Plain with wet meadows and beaches forms the perimeter of the peninsula, especially in the area of Cape Espenberg.

The central portion of the Bering Sea region is remarkable for its huge extent of low-lying coastal tundra over combined deltas and estuaries of the Yukon and Kuskokwim rivers. The diurnal tidal range in this area is about 2 meters, and the landscape rises so little in elevation from the coast that the influence of tides extends up the rivers to 55 kilometers inland. Storm surges of 1 meter or more in spring and fall allow saline water to penetrate rich wetlands as far as 16 kilometers inland (Kincheloe and Stehn 1991).

Important taxa in the sedge–graminoid meadows where flooding occurs are the Ramenski sedge, loose-flowered alpine sedge, Lyngby sedge, reedgrass, and the forbs silverweed cinquefoil and low chickweed. Pingos 3–30 meters tall in lakes and wet meadows provide a sharp contrast in topography and vegetation to the surrounding terrain (Burns 1964). Bluejoint and the low shrub *Beauverd spiraea* can be codominants. This microrelief provides nesting and denning habitat for several bird and mammal species.

Sandy beaches are common in the maritime region, some of which are associated with dune fields, as on Nunivak Island where dune vegetation is heavily grazed by introduced muskoxen. Mudflats support open communities of halophytic grasses, sedges, and forbs (for example, creeping alkaligrass, Hoppner sedge, seabeach sandwort, and oysterleaf) that are typical of the strand zone in this and other regions to the south and north. The sandy beaches are dominated by beach ryegrass and forbs such as beach pea and seaside ragwort. In places where dunes formed, strong floristic differences exist between plants on prominences and those in depressions, and between plants on dunes and those on backslopes. The taxa are derived from the tundra immediately inland. South of the Yukon–Kuskokwim delta, coastal headlands and uplands of the Kuskokwim Mountains reach the coast. These uplands are covered with tundra and have many of the same characteristics as interior uplands, including topographic, geologic, and floristic similarities.

Freshwater Fishes

Thirty-four fish species occur in the fresh waters of the maritime tundra region (Morrow 1980; Table). The species most used by humans are the sheefish, whitefishes, arctic grayling, arctic char, Dolly Varden, rainbow trout, northern pike, Alaska blackfish, and five salmon species—sockeye, coho, chinook, chum, and pink. All salmon species support a commercial fishery in the region's marine waters that in 1994 yielded more than 39 million fishes at a value of about $152 million (Alaska Department of Fish and Game 1995). Salmon and other freshwater fish species also provide subsistence for the region's residents. In 1993 about 770,000 salmon were taken, making up more than 80% of the total subsistence catch for the state (Lean et al. 1993; Alaska Department of Fish and Game 1994a). In addition, the region supports a growing sport fishery that now consists of more than 150,000 angler-days, or about 6% of the state's total sport fishery effort (Mills 1994).

In the northwestern part of the maritime tundra region, fresh waters are subject to severe freezing in winter. Here, springs are important to the overwinter survival of freshwater fishes (DeCicco 1993a). The region's anadromous and freshwater resident fishes and their eggs provide food for a diversity of mammals, birds, and other fishes. The arctic chars of the Wood River Lakes, for example, depend at times on sockeye salmon smolts for food (McBride 1980). Similarly, in Bristol Bay the eggs of sockeye salmon provide a food source for young rainbow trout, and decaying salmon carcasses provide nutrients for aquatic invertebrates that are, in turn, food for trout. Russell (1977) presented evidence that the condition factor (length–weight relation) of rainbow trout was significantly lower in years of low sockeye salmon escapement than in years of high salmon escapement. Chemical nutrients derived from sockeye salmon carcasses are critical for the productivity of these ecosystems and perhaps even for subsequent generations of sockeye salmon (Kline et al. 1993). The famous opportunities for viewing brown bears at the Brooks and McNeil rivers are only possible because of the seasonal concentrations of bears feeding on spawning salmon (Quinlan et al. 1983). The escapements of salmon to fresh waters of this region have been strong, and most stocks seem to be maintaining their densities. However, in the Norton Sound area stocks of chum salmon declined from 1987 to 1993, which is a cause for concern (Alaska Department of Fish and Game 1994a).

In 1990 the Alaska Board of Fisheries imposed catch-and-release regulations for fly fishing in several waters of this region. Since then, the abundance of rainbow trout in these waters seems to have remained stable (Dunaway 1993). In the Kobuk and Selawik rivers, sheefish are harvested for commercial purposes, subsistence, and sport. These fishes are often harvested throughout the year and are possibly overharvested (Arvey 1993). On the Seward Peninsula, northern pike support a subsistence fishery, but sport fishing of this species has also increased (Burkholder 1993). Arctic grayling populations on the Seward Peninsula may be declining. More restrictive bag limits on arctic graylings were imposed in 1988, and in 1992 the Nome River was closed to fishing of arctic grayling to allow the recovery of this population (DeCicco 1993b).

The status and trends of most other freshwater fish species are not known. Only species of direct importance to commercial, subsistence, and sport fisheries of the region are monitored and then usually only in select systems. The residents of most villages in this region depend on anadromous and freshwater fishes for subsistence: this region accounts for more than 70% of the total subsistence harvest of salmon in Alaska (Alaska Department of Fish and Game 1994a), and more sheefish and Dolly Varden are taken here for subsistence than in any other region.

Runs of sockeye salmon into the Bristol Bay area are the single most valuable stocks of salmon in Alaska. In 1994 the catch of sockeye salmon in Bristol Bay was valued at more than \$136 million, or about 30% of the entire value of the harvested salmon in Alaska in that year (Alaska Department of Fish and Game 1995). Sockeye salmon contribute significantly to the biological diversity in this area; the species is probably indirectly responsible for the famous wild rainbow trout stocks that also occur here because young rainbow trout feed heavily on sockeye salmon eggs, which likely improves the growth rate of the rainbow trout. The rainbow trout support an annual multimillion-dollar recreational industry (Dunaway 1993). The region is well known for producing trophy-sized arctic grayling, sheefish, northern pike, rainbow trout, and Dolly Varden. The largest Dolly Varden (nearly 9 kilograms) in the state was caught in this region in the Noatak River (Arvey 1993). The sheefish in this region are as large as 27 kilograms (Alt 1987). Dolly Varden of the Seward Peninsula and northwestern Alaska have migrated between unconnected freshwater drainages via the adjacent sea. Some marked Dolly Varden migrated more than 1,600 kilometers, even from Alaska to Russia (DeCicco 1992).

Birds

The maritime tundra of the Yukon–Kuskokwim River delta of western Alaska is one of the nation's most important nesting areas for geese; it supports large populations of brant, cackling Canada geese, emperor geese, and greater white-fronted geese (Kessel and Gibson 1994). The populations of all of these species underwent significant declines from the mid-1960's through the mid-1980's as a consequence of subsistence hunting in spring on the breeding grounds and, except for emperor geese, of hunting on the wintering grounds. Late snowmelt and heavy predation by foxes during nesting and rearing of young have also contributed to the decline and continued suppression of populations (J. Sedinger, University of Alaska, Fairbanks, personal communication). Recently, populations of Canada geese and white-fronted geese rebounded significantly (Platte and Butler 1993; Kessel and Gibson 1994; Schmutz et al. 1994). Most of the Pacific Flyway brant population stages in the fall on the Izembek Lagoon on the Alaska Peninsula before making a transoceanic migration to wintering grounds in Mexico (Reed et al. 1989). (Staging birds are migratory species that gather in certain areas and usually feed there to gain weight and energy before moving on to the next migratory segment.) Large numbers of ducks, tundra swans, and sandhill cranes also nest on the coastal tundra of western Alaska, particularly on the Yukon–Kuskokwim River delta. The number of spectacled eiders that breed in this area was large but has declined dramatically during the past 20 years (Kertell 1991; Stehn et al. 1993). The spectacled eider has been listed as threatened since 1993, and Steller's eider, which formerly occurred in much smaller numbers, was federally listed as threatened in 1997 (U.S. Fish and Wildlife Service 1996).

Birds of prey are relatively rare in this area, although the *pealei* subspecies of peregrine falcons is common around seabird colonies. Population-size trends of all birds of prey are poorly known but are thought to be stable (Schempf 1989). The number of bald eagles is smaller in western Alaska than in areas to the east (Kessel and Gibson 1994).

The large numbers of shorebirds that breed on coastal maritime tundra in western Alaska include the entire world's population of black turnstones and most of the world's population of bristle-thighed curlews (West 1991; Handel and Gill 1992). The bristle-thighed curlew is classified as a species of concern by the U.S. Fish and Wildlife Service (1996). In spite of the abundance of shorebirds in this region, population-size trends for most of these species are unknown. Gulls and jaegers also breed on coastal tundra but, as for most shorebirds, estimates of their population sizes and trends are unavailable.

Passerines breed on the coastal tundra and on the Bering Sea islands, but species richness on the Bering Sea islands is low. McKay's bunting is endemic on several Bering Sea islands, commonly breeds on Saint Matthew and Hall islands, rarely breeds on Saint Lawrence and the Pribilof islands, and winters on all the islands just listed and in coastal western Alaska (Kessel and Gibson 1978). The species is not endangered, but its limited distribution makes it a species of ecological concern (West 1991). Some species of Asiatic origin (for example, the arctic warbler, red-throated pipit, and yellow wagtail) also breed during summer in western Alaska.

Mammals

The mammalian fauna of this region is composed of shared elements from the boreal forest (the muskrat, northern red-backed vole, tundra vole, and red fox) and from the arctic tundra (the Greenland collared lemming, arctic ground squirrel, and arctic fox). The number of arctic foxes fluctuates widely in response to prey abundance. In turn, predation by arctic foxes on eggs and young of brant in the Yukon–Kuskokwim delta is considered a major factor in the alarming decline of brant in the late 1980's and in the species' subsequent slow recovery (Sedinger, personal communication).

Species that have been absent from much of the area in the recent past include the moose, caribou, snowshoe hare, lynx, beaver, coyote, and gray wolf. Moose, however, became established in recent decades on the Seward Peninsula and are extending their distribution in riparian habitats downstream along the Yukon and Kuskokwim drainages. Human residents in these areas are cooperating with wildlife management authorities by restraining subsistence hunting of this species until viable populations are established. Like moose, beavers and snowshoe hares are also expanding their ranges onto the Seward Peninsula and the Yukon–Kuskokwim delta, apparently in response to the increased growth of willows (Hopkins 1972), a primary winter food for all three species.

Caribou, which disappeared from the Seward Peninsula in the 1800's and have not been present in the Yukon–Kuskokwim delta region for more than a century (Murie 1935), recently began to return to these areas. The number of caribou in the adjacent Western Arctic herd is the highest ever recorded. In recent winters, the Western Arctic herd moved onto the Seward Peninsula, and in 1994 it moved south of the Yukon River (J. Coady, Alaska Department of Fish and Game, Fairbanks, personal communication). The Mulchatna caribou herd, which is also at an all-time high (180,000 animals) also expanded its distribution in winter into the maritime tundra adjacent to Bristol Bay.

By 1994 many native villages in the maritime tundra region had access to caribou for subsistence hunting for the first time in more than a century. In the past, the low numbers of caribou throughout much of this region were at least partly associated with the expansion of reindeer (domestic caribou) husbandry in western Alaska during the first part of this century (Klein 1980). Reindeer herds expanded throughout this entire region; their abundance reached a peak in the late 1920's but then drastically declined. Reindeer herds have persisted only on the Seward Peninsula and Bering Sea islands. The expanding caribou herd on the Seward Peninsula has created serious problems for the native reindeer herders because their reindeer mingle with the caribou and tend to leave with the caribou when they migrate to their calving grounds in the Arctic. However, there is renewed interest in reindeer husbandry in the region.

Wolves are beginning to return to the Seward Peninsula because of the establishment of moose, an incursion of caribou in winter, and the discontinuance of government-sponsored control of wolves around reindeer herds. As ungulates expand their distributions into other portions of the region, wolves are expected to follow.

The tundra hare is endemic to the region, occurring from the tip of the Alaska Peninsula to the Kotzebue Sound drainages. This species was formerly found in the western Alaskan Arctic (Bee and Hall 1956), but its range decreased southward and its numbers seem to have declined throughout its remaining range. Researchers have not yet identified the causes of the decreased distribution and declining numbers of tundra hare but believe they may be related to vegetational changes caused by the advance of trees and shrubs into the region; this new habitat type is favored by snowshoe hares, whose numbers are increasing (D. R. Klein, U.S. Geological Survey, personal observation).

High densities of minks and river otters in the Yukon–Kuskokwim delta depend on the abundant resident and anadromous fishes for prey (Burns 1964). This rich resource base has also long supported the highest density of indigenous people in all of Alaska.

Muskoxen were introduced to Nunivak Island in 1935 and 1936 to reestablish the species in its historical Alaskan Arctic range. To prevent overgrazing of the limited coastal habitat in winter, muskoxen from Nunivak Island were transplanted elsewhere yearly from

1967 to 1970 and in 1977 and 1981 (Klein 1988). Additional muskox populations derived from these transplanted animals were established on Nelson Island in the Yukon–Kuskokwim delta and on the Seward Peninsula. The populations on Nunivak and Nelson islands have been hunted under a limited permit system for several years. The first hunt of the rapidly expanding population on the Seward Peninsula was scheduled in 1995 (Coady, personal communication), but no hunt had occurred by late 1997. With the growth of the Seward Peninsula muskox population, some reindeer herders there are concerned about potential competition for forage between the muskoxen and reindeer or the displacement of reindeer from their preferred grazing areas by the muskoxen.

The Bering Sea islands of Saint Lawrence, Saint Matthew, Hall, and the Pribilofs were part of Beringia during the last glacial period and support relict populations of small mammals. These include the arctic ground squirrel, northern collared lemming, red-backed voles, tundra vole, and shrews; researchers believe that shrews are an endemic species on Saint Lawrence Island. Other species believed to be endemic in the Bering Sea islands are a shrew on the Saint Paul Islands (Manville and Young 1965), a vole on the Saint Matthew Island group (Rausch and Rausch 1968), and the brown lemming on Saint George Island (Rausch 1953). The only record of a population of polar bears that were resident on land throughout the summer is from the Saint Matthew Island complex, where several hundred polar bears were present until the late 1800's (Elliott 1882), when the population was apparently eliminated by fur trappers. Although polar bears occasionally reach Saint Matthew Island over the pack ice in winter, they have not reestablished themselves there (Rausch and Rausch 1968).

Aleutian Region

The Aleutian Islands and adjacent Alaska Peninsula are the interface between the North Pacific Ocean and the Bering Sea and include the southernmost land area of Alaska (Fig. 2). The Aleutians extend nearly 1,900 kilometers from the tip of the eastern Alaskan Peninsula to the western tip of Attu Island. The island arc is the product of the convergence of the Earth's crustal plates, formed when the massive Pacific plate was forced downward beneath the Bering Sea plate (Gard 1977). This rupturing of the Earth's crust is characterized by extreme tectonic activity, frequent earthquakes, and extensive volcanism. Of the 76 volcanoes throughout the Aleutians, about 40 have been active in the last 250 years.

The Aleutians are geologically young; scientists believe they originated in the early to mid-Tertiary period (Gard 1977). During the last Ice Age, these islands were mostly covered by glacial ice (Hamilton et al. 1986), although extensive lava flows continued building islands throughout the Pleistocene (Péwé et al. 1965).

Persistent cloudy weather, fog, mist, drizzle, and rain borne on powerful driving winds characterize the climate of the Aleutians (Armstrong 1977). Cold ocean currents keep land temperatures consistently cool, even during the warmest summer weather. The mean daily temperature of 3.9°C has an annual range of only ±9.4°C.

The Aleutian Islands are geologically and biogeographically unique in the United States. These islands have acted as a filter for life forms, most of which have island-hopped from the Alaska mainland. As a consequence, the diversity of plant and animal life declines progressively across the nearly 2,000 kilometers from the Alaska Peninsula to the outermost islands. The stormy nature of the North Pacific Ocean and the Bering Sea and the often wide gaps among island groups in the Aleutians have also fostered some endemic plant and animal species.

Although the sea acted as an obstacle to the movement of terrestrial life to the Aleutian Islands, it provided access for sailing ships. The Danish explorer Vitus Bering reached the islands in 1741 during his voyage of discovery from the Siberian coast. More than a century of exploitation of sea otters and other resources of the region rapidly followed, accompanied by major disruption of the lifestyle and culture of the native Aleut people. Animals were also affected: populations of ground-nesting birds were drastically reduced by introductions of the arctic fox to many of the islands by Russians and later by Americans and by the accidental escape of Norway rats from ships to several islands, especially during World War II (Murie 1959).

Vegetation

The Aleutian Islands are an arc of submerged mountains with their visible summits making up the island chain. Some (like Amchitka) have flat summits, whereas others, (like Buldir) have steep summits. The islands are a maritime, treeless zone that is often classified as a distinct subarctic or maritime tundra (Hultén 1968; Fig. 9) because the origin, history, and floristic composition of their vegetation differ from mainland northern tundras. Many islands are bordered by cliffs and bluffs, which can be as high as 60 meters, and by boulder beaches and small dune fields, some of which are on the tops of coastal bluffs. The strand and cliff plants differ little from those in the coastal

Fig. 9. Active volcanoes and treeless maritime tundra are characteristic of the Aleutian Island chain.

forest and in the Bering Sea regions. Eelgrass beds in shallow waters of the Alaska Peninsula and the Aleutians account in part for the huge flocks of migratory birds that stop at Izembek Lagoon each year.

Uplands of the Aleutian Islands have deep, peaty soils with thick mats of heath tundra in which crowberry and sedges such as Alaska long-awn sedge are prominent. Rich meadows consist of Pacific reedgrass, sedges, and numerous large forbs such as Aleutian wormwood, umbellifers such as angelica and cow parsnip, and ferns. Trees are absent (except where they were planted in recent times), and even erect shrubs are rare (Shacklette et al. 1969; Amundsen and Clebsch 1971). Snowbed communities are common in sheltered areas at high elevations. The forb and prostrate shrub component of alpine vegetation has many species that are not present farther north or in the interior, including Alaska arnica, Siberian spring beauty, caltha-leaved avens, western buttercup, Kamchatka rhododendron, and club-moss mountain-heather (Hultén 1968).

Although plant cover in the Aleutian Islands is sparse, the mountainous backbone of the islands and the fell-fields on the exposed slopes and ridge crests (even near sea level) provide habitats for some plants that are endemic to the Aleutians: Aleutian draba, Aleutian chickweed, Aleutian wormwood, Aleutian shield-fern, and Aleutian saxifrage (compare Hultén 1968). Aleutian wormwood is known from only two islands, and the Aleutian shield fern is known only from Adak and is federally listed as an endangered species. Personnel at the Alaska Maritime National Wildlife Refuge, which administers the area, are attempting to find additional Aleutian shield fern populations and to protect the species from damage by introduced caribou. Research is under way to develop techniques for propagating this species in the greenhouse. Several other regional plant species that originate in Japan, Korea, and China are found in the western Aleutians but were not part of the Asiatic element that arrived in Alaska via Beringia. These species are found nowhere else in North America (Hultén 1968).

Freshwater Fishes

Eleven fish species occur in the fresh waters of this region (Morrow 1980; Table). The species most used by humans are the Dolly Varden and sockeye, pink, coho, and chum salmon. All communities use the salmon for subsistence when available, and the total annual harvest is usually between 4,000 and 5,000 fish (Alaska Department of Fish and Game 1994a). The 1994 commercial fishery harvested about 18 million salmon at a value of nearly $45 million in the marine waters of the Alaska Peninsula–Aleutian Islands (Alaska Department of Fish and Game 1995). A small amount of sport fishing is done by local residents near villages in the eastern part of the chain, by military personnel and their families adjacent to the bases, and by commercial fishing crews that occasionally come ashore to angle (U.S. Fish and Wildlife Service 1988). The number of streams in which salmon spawn is greater in the Aleutian Islands unit of the Alaska Maritime National Wildlife Refuge than in any other refuge in the United States. In the comprehensive conservation plan for this refuge, 360 such streams are listed (U.S. Fish and Wildlife Service 1988). The status and trends of freshwater fishes in this region are poorly known.

Locally produced salmon, especially their young, may be important forage for the millions of seabirds and numerous marine mammals that frequent the Aleutian Islands. The islands provide nesting habitat for about 10 million seabirds, which all feed heavily on fishes in the marine environment and may eat locally spawned young salmon. In turn, the seabirds enrich the ocean environment with thousands of tons of their droppings, which contain phosphates and nitrates that foster the growth of phytoplanktons (U.S. Fish and Wildlife Service 1990), which then provide food for the zooplankton eaten by the young salmon in the fresh waters of the region.

Birds

Because of the rugged maritime nature of this region, the diversity of breeding waterfowl is limited, though several unique species breed here. The Aleutian Canada goose recovered from near-extirpation caused from predation by foxes introduced on the islands for fur farming (Banks and Springer 1994; Kessel and Gibson 1994). After the foxes were eradicated, the geese were protected on their wintering grounds and were reintroduced to some islands. Now, nesting populations of Aleutian Canada geese are established on three islands, which in 1991 allowed them to be downlisted from endangered to threatened status (Banks and Springer 1994). The emperor goose, which breeds in western Alaska, winters almost exclusively on the rocky coasts of the Aleutian Islands and the Alaska Peninsula (Eisenhauer and Kirkpatrick 1977). This species marginally recovered from a major decline, the causes of which are still unclear (Schmutz et al. 1994), during the 1970’s to the mid-1980’s. The Steller’s eider breeds mainly in Russia, but a small number formerly nested on the maritime tundra of western Alaska. This species winters along the Alaska Peninsula and in the eastern Aleutian Islands (Kertell 1991).

Two raptors are residents in the Aleutian Islands. Approximately 300 pairs of the *pealei* subspecies of the peregrine falcon nest in the Aleutians; this subspecies seems to be maintaining a stable population (Ambrose et al. 1988; Schempf 1989). Although bald eagles have been abundant around military installations on Adak, even nesting there, downscaling of the base may reduce the size of eagle populations if natural prey does not replace human garbage as food. At present, bald eagles nest in the Aleutians only east of the Rat Islands, although in the past they nested on the Rat Islands as well (Kessel and Gibson 1994). The proximity of the Aleutian Islands to Asia allows the occasional occurrence of white-tailed eagles and Steller’s sea eagles, particularly on Attu Island.

The isolated nature of the Aleutian Islands gave rise to several endemic subspecies of the rock ptarmigan (Murie 1959). The Evermann’s rock ptarmigan, which is restricted to Attu Island, and the Yunaska rock ptarmigan, which is restricted to Yunaska Island, are species of concern (U.S. Fish and Wildlife Service 1996). Few data have been collected on the population size or status of many of the other rock ptarmigan subspecies, but research is ongoing (Holder 1994).

Small numbers of shorebirds breed on some islands but not at the same level as in mainland tundra areas (Kessel and Gibson 1994). Rock sandpipers and black oystercatchers are the most common shorebirds in the Aleutians. Although some Asiatic shorebird species occur in the Aleutians during spring migration, none regularly remain there to breed. Gulls, particularly glaucous-winged gulls and kittiwakes, breed throughout the region. Glaucous-winged gulls probably benefit from commercial fishing offal at sea and in major ports with canneries, such as Dutch Harbor (Kessel and Gibson 1994).

Passerines are resident in the region, although only six species nest west of the eastern Aleutians. The isolated nature of the island chain resulted in the development of several subspecies of resident passerines that are exclusive to one or more islands (Murie 1959). The classic example of this island effect is the largest-bodied subspecies of the song sparrow in North America, which is resident in the central and western Aleutians. One song sparrow subspecies on Amak Island is a species of concern (U.S. Fish and Wildlife Service 1996). Asiatic passerines occur regularly during migration, when they are pushed ashore by winds and storms in the North Pacific or when they stray from their usual migration route. Gibson (1981) and Byrd and Day (1986) suggested that the westernmost islands of the Aleutians are in the regular migration routes of these Palearctic migrants, which accounts for the species’ regular occurrence there.

Mammals

The ranges of 19 terrestrial mammals that occur in North America reach the tip of the Alaska Peninsula where the tundra habitat closely resembles that of Unimak Island, which is the closest of the chain to the peninsula. Fourteen of these species, including the brown bear, caribou, and gray wolf, also occur on Unimak Island; only three species occur on Unalaska and only two, the northern collared lemming and red fox, on Umnak Island (Murie 1959). The remaining islands to the west, which extend more than three-quarters of the length of the island chain, are without native terrestrial mammals.

Many mammal species have been introduced to the Aleutian Islands; for example, the arctic fox of the blue phase and the red fox were introduced on most of the larger islands of the outer Aleutians for the harvest of their furs (Murie 1959). The nonindigenous arctic ground squirrel was released on Unalaska Island in the 1890's and on Kavalga Island in 1920 and has become established. European rabbits became established after they were released on Umnak Island and on small islands near Umnak and Unalaska islands (Burris and McKnight 1973). Feral populations of reindeer were established on Umnak and Atka islands after introductions in 1913 and 1914; their numbers fluctuate widely, though in recent decades researchers believed their numbers remain in the range of 1,000–2,000 animals. Reindeer are occasionally hunted for food by local Aleuts.

Caribou were introduced to Adak Island in 1958 and 1959 to provide an emergency source of food as well as recreational hunting for Naval personnel and their dependents at the Adak Naval Air Base (Boone 1993). Management of this population—established jointly by the Alaska Department of Fish and Game, the Navy, and the U.S. Fish and Wildlife Service—has been by harvest quotas for hunters to hold the herd, in the absence of natural predators, to about 200–250 animals. In recent years, however, the population greatly exceeded this number (more than 800 in 1994), and downscaling of the Navy base after the Cold War subsided left too few people to meet the prescribed annual harvest quotas. To prevent overgrazing and consequent erosion from a growing caribou herd and to end the threat to the endangered Aleutian shield fern found only on Adak Island, the U.S. Fish and Wildlife Service (1994b) proposed the elimination of caribou from the island. Removing the caribou from the island by a method that is publicly acceptable will be difficult, however. The proposal for the removal (U.S. Fish and Wildlife Service 1994b), has been made available for public comment.

Arctic Tundra

The rapid rise in elevation of the Brooks Range mountains, which are part of the interior mountain biogeographic region, account for the abrupt demarcation between the boreal forest and the arctic tundra (Fig. 2; Fig. 10). This is unlike the very gradual transition from boreal forest to tundra in northern Canada. The arctic tundra of Alaska extends northward from the higher and drier ground at its southern limit to the broad and wet Coastal Plain that continues to the Arctic Ocean. The tundra of the Coastal Plain is interspersed with thousands of shallow lakes and is the only arctic biogeographic province in the United States.

In winter, the arctic tundra region experiences strong northeasterly winds that are generated by the arctic high pressure system over the frozen Arctic Ocean (Selkregg 1974–1976). The little snow that falls throughout the long winter is redistributed by winds and accumulates in concavities of the microrelief of the tundra and as drifts on the leeside of stream and river bluffs in the Coastal Plain. In the upland tundra and foothills, riparian shrubs and the leeside of hills accumulate large drifts. The snow-free summer is brief, but the daily 24 hours of sunlight during much of summer accelerate plant growth without the cost of respiration during the darkness of night. The life forms in this

Courtesy D. R. Klein, USGS

Fig. 10. The arctic tundra region extends from the northern foothills of the Brooks Range to the Arctic Ocean. It is the calving grounds and summer habitat for hundreds of thousands of caribou.

region are extremely productive in spite of climatic extremes, the short plant growth season, low mean annual temperature, and cold soils underlain by permafrost. This is particularly true of caribou and most migratory birds that are present in the area only during summer.

The Alaskan Arctic obviously is no longer remote from the influences of the industrialized world to the south. The energy and mineral resources of the Alaskan Arctic are already under intensive exploitation, and scientists are finding that the Arctic basin is a sink for pollutants transported by global air movements from industrial centers to the south (Barrie 1986). These pollutants are entering Arctic marine and terrestrial food chains and are being concentrated in the tissues of animals at upper trophic levels, including the human residents of the Arctic (Muir et al. 1988). In addition, the thinning ozone layer in the atmosphere over the poles increases the ultraviolet radiation that reaches the plants and animals of the Arctic, the consequences of which are not fully known. Global climate change from increasing carbon dioxide and other greenhouse gases in the atmosphere is expected to generate the greatest warming in Arctic regions, especially in the Alaskan Arctic, the ecological consequences of which are also unknown (Committee on Earth and Environmental Sciences 1994).

Vegetation

Arctic tundra lies beyond the latitudinal treeline. The area from the summit of the Brooks Range northward to the Arctic Ocean has been known as the *Arctic Slope* and, since development of oil fields there, also as the *North Slope*. The North Slope consists of mountains, foothills, and the Coastal Plain. The higher mountains were glaciated during the last glacial maximum, with revegetation beginning about 12,000 years ago (Hopkins 1972). Portions of the arctic foothills escaped glacial advances; these areas were not glaciated throughout the 1.5 million years of the Quaternary and therefore served as plant refugia (Hamilton et al. 1986). Likewise, the Coastal Plain was not glaciated, but because marine transgressions during higher sea levels as recently as 0.7–1.9 million years ago reached far inland, the contemporary vegetation postdates that event (Hopkins 1967).

Alaska's environmental and climatic conditions are the result of the state's far northern location. As a direct consequence of the region's geographic position at a high latitude, the Alaska Arctic experiences less intense solar radiation and more pronounced variation in seasons. The region is characterized by a short growing season but long days; continuous permafrost close beneath the land surface; and low summer temperatures that are exacerbated by frequent coastal fog and drizzle, although the overall annual precipitation of the region is low (compare Murray 1987, 1992).

A vascular plant flora is largely shared by each landform; only a few of about 500 species in the total flora are unique to any one landform. Among endemics, however, a sagebrush, *Artemisia artica* ssp. *comata*, is restricted to the Coastal Plain province, Alaska bluegrass and Drummond's bluebells to the transition from plain to foothills, Muir's fleabane to the foothills, and Kokrine's locoweed to the far western mountains.

Except along the Chukchi Sea coast where cliffs are extensive, coastal communities consist of eroding bluffs, mudflats and sandy beaches, and dune fields at the mouths of major rivers along the Beaufort Sea. Along the Beaufort Sea coast, deposition has formed spits, barrier islands, and lagoons. Plants of the strand include some of the same salt-tolerant taxa of southern regions but differ by the absence of distinctly southern species and the addition of arctic grasses and forbs, such as Anderson alkaligrass, purplish braya, and few-flowered whitlowgrass, which are taxa more common in the high Arctic of Russia, Canada, and Greenland. Although the tidal range is minor, storm tides in fall have carried driftwood as far as 3 meters above sea level and 5 kilometers inland (Reimnitz and Maurer 1979); the position of driftwood indicates how far inland the influence of the sea can penetrate.

Wet meadows are extensive in the Coastal Plain, where continuously distributed permafrost maintains a water table close to the surface. Despite low annual precipitation, lakes and ponds are abundant, and their margins in certain seasons are red with arctic pendantgrass. Wet meadows are dominated by pure and mixed stands of water sedge, cottongrass, and tundra grass. The plants in several localities were comprehensively described during the past two decades, yet the early paper by Britton (1967) remains the best generalization of conditions on the Coastal Plain.

Habitat diversity on the Coastal Plain is primarily a result of the region's raised beaches and drained lakes of thermokarst origin. Beach ridges and some lake margins are dry and exposed and thus are the floristic equivalent of alpine ridges. Exposed lake bottoms offer bare soil for colonization by plants. Networks of high-center and low-center ice-wedge polygons offer sharp, repeated contrasts of well- and poorly drained sites (Fig. 11). Slopes of pingos are also alpinelike. Floodplains of large rivers are a complex of terraces of various ages and a patchwork of sands and gravels in various stages of temporary stabilization.

Outside the reach of the modifying effects of the ocean, rises in temperature and changes in plants are significant. Tussock tundra is absent near the Arctic coast but is the dominant vegetation type in much of the interior Coastal Plain and arctic foothills. Only prostrate shrubs occur near the coast, but the abundance of willows increases inland, especially in riparian settings. Dwarf birch, which is prostrate in places where it is exposed but as tall as 1 meter in sheltered areas, forms thickets on the southern uplands. Balsam poplar stands persist well north of the treeline in the headwaters of several arctic rivers where well-watered gravels (that is, gravels through which groundwater passes) are sheltered by benches and bluffs (Murray 1980; Edwards and Dunwiddie 1985). The tundra on mountain slopes is alpine in many respects and shares the floristic and basic features of the physical environment with the interior uplands. Closed communities are replaced on summits and ridge crests by massive unstable screes and widely scattered plants.

Freshwater Fishes

Twenty-three fish species occur in the fresh waters of this region (Morrow 1980; Table). Species most used by humans are the arctic cisco, least cisco, humpback whitefish, arctic grayling, and Dolly Varden. A commercial fishery on the Colville River takes about 20,000 whitefishes every year (Bergstrom et al. 1992). Whitefishes and the Dolly Varden provide subsistence along the entire North Slope where they may be taken throughout the year for human consumption and for dog food. Craig (1987) reports that Dolly Varden and arctic cisco are the principal anadromous species harvested from the Colville River east to the Canadian border, and pink salmon, chum salmon, broad whitefish, humpback whitefish, round whitefish, and least cisco are the principal species harvested west of the Colville River. Anglers spent 5,600 angler-days in 1993 in the arctic tundra and harvested an estimated 1,632 arctic grayling and 1,092 Dolly Varden (Mills 1994). The abundance of whitefishes in this region provides a forage base for other species such as the Dolly Varden (Arvey 1993).

Angling in this region is relatively light, and most stocks of freshwater fishes are probably stable. Arvey (1991) reviewed the stock status of Dolly Varden on the North Slope and found no evidence of depletion. The status of many of the freshwater fish species in this area seems poorly known, however. Springs in the rivers of the North Slope provide critical habitat for spawning and overwintering of Dolly Varden because the sections of streams without springs usually freeze solid (Craig and McCart 1974; McCart 1980). Fishes that overwinter at sea in this area have evolved antifreeze compounds in their blood—temperatures of seawater may drop to below that at which a fish's blood would otherwise freeze. Because species such as the Dolly Varden and the arctic grayling have not evolved these antifreeze compounds, they must overwinter in fresh water.

Courtesy D. R. Klein, USGS

Fig. 11. The permafrost that underlies the Coastal Plain of the Alaskan Arctic and the seasonal frost action at the land's surface have generated the polygonally patterned ground that is common throughout much of the area.

Birds

Waterfowl breed across most of the arctic tundra of Alaska, although their total numbers there do not approach those on the maritime tundra of western Alaska. In recent years, tundra swans that breed in the region (and winter on the Atlantic coast) experienced increasing populations, which now seem to have stabilized (Earnst 1991; Stickney et al. 1993, 1994; Brackney and King 1994; Anderson et al. 1995). The population of the greater white-fronted goose, the most common breeding goose, seems to be stable or increasing (Brackney and King 1994). Scattered, small breeding colonies of brant have been monitored closely only in the Colville River delta and in the North Slope oil fields; their numbers seem to be stable (Stickney et al. 1993, 1994; Smith et al. 1994; Anderson et al. 1995). Large numbers of brant from breeding populations in Alaska, western Canada, and Siberia, as well as Canada geese and greater white-fronted geese, also molt in the Teshekpuk Lake area southeast of Barrow (Derksen et al. 1982).

In the United States, snow geese currently nest only in a few small colonies in Arctic Alaska (Johnson 1991; Ritchie, unpublished data). The largest colony (about 400 pairs in 1990) is on Howe Island near Prudhoe Bay (Burgess et al. 1994). Although this colony had been increasing since its inception in the mid-1970's (Johnson 1991; Burgess et al. 1994), its long-term viability is uncertain because of the nearly complete lack of reproduction during 1991–1994 when late springs deterred nesting and when arctic foxes gained access to the colony island and preyed upon the eggs (Burgess and Rose 1993; S. Johnson, LGL Ltd., Sidney, British Columbia, personal communication). In autumn these small breeding populations and a major portion (as many as 325,000 birds) of the western Arctic population of snow geese from Canada stage in the Arctic National Wildlife Refuge in northeastern Alaska (Brackney and Hupp 1993).

The threatened spectacled eider also breeds on the Arctic Coastal Plain, but its current population status is still under investigation; the size of this population may have been declining (Warnock and Troy 1992; Troy Ecological Research Associates 1993a; Anderson and Cooper 1994; Larned and Balogh 1994; Anderson et al. 1995). Oldsquaws and northern pintails are the most abundant ducks in the region, and king eiders are common breeders in this westernmost part of their range (Brackney and King 1994). During droughts in the mid-continental United States, the region serves as habitat for large numbers of nonbreeding northern pintails (Derksen et al. 1979). From Wainright to the Colville River, the North Slope also hosts small numbers of breeding yellow-billed loons.

Five species of raptors regularly breed in the arctic tundra region: peregrine falcon, gyrfalcon, rough-legged hawk, short-eared owl, and snowy owl. The arctic peregrine falcon, which became endangered because of pesticide contamination, has sufficiently recovered to be removed from the endangered species list (U.S. Fish and Wildlife Service 1996). Few data are available on population trends of breeding rough-legged hawks and snowy owls; monitoring of snowy owls is especially difficult because of their annual variability in breeding locations, which seem to coincide with locations of high abundances of lemmings, one of their preferred foods.

Willow and rock ptarmigan breed on the arctic coastal tundra, but their population sizes and trends are unknown. Rock ptarmigan make short migrations to winter in the foothills of the south slopes of the Brooks Range where willows are more abundant (Johnson and Herter 1989). Willow ptarmigan also move inland to the foothills, although some birds move south of the Brooks Range into more forested habitats. During spring, thousands of ptarmigan move north across the foothills to reach their breeding areas on the tundra.

The arctic tundra is one of the most productive and abundant habitats for shorebirds in Alaska and supports a diversity of breeding species (Connors et al. 1979; Page and Gill 1994). Monitoring of shorebirds across the Arctic coast has been sporadic and usually of limited duration. Results from the longest study (more than 10 years), which is still ongoing in the Prudhoe Bay area, indicate that large annual variations in nesting densities and nesting success (because of harsh weather and predation) of most species make determinations of long-term trends difficult (Troy and Wickliffe 1990; Troy Ecological Research Associates 1993b).

Only a few passerine species breed on the arctic tundra; as with shorebirds, their population sizes seem to fluctuate in response to weather conditions and predation levels. The snow bunting may have benefited from the recent increase in artificial structures in their habitat (for example, oil-field buildings and pipelines) by using them as new nest sites. As in western Alaska, some species of Asiatic origin breed on the arctic tundra (for example, bluethroat and yellow wagtail).

Mammals

Mammals of the arctic tundra of Alaska are the caribou, muskox, northern collared lemming, brown lemming, singing vole, arctic ground squirrel, arctic fox, and the barren-ground grizzly, a subspecies of the brown bear. Other mammals in the arctic tundra region—such as the arctic ground squirrel, tundra vole, and the wolverine—are also typical in alpine habitats of the interior mountains, whereas the red fox, wolf, ermine, and least weasel are more widespread in places where prey species are also present. The snowshoe hare and moose are typical boreal forest dwellers that have expanded their distribution into riparian shrub communities along several of the major stream drainages north of the Brooks Range (Bee and Hall 1956; LeResche et al. 1974).

Strategies vary among species for dealing with the long, severe arctic winters and low food availability. Shrews, voles, lemmings, and weasels live in a *subnivian* (beneath the snow) environment where temperatures are mediated by the insulating snow. All of these mammals are active throughout winter. In contrast, arctic ground squirrels and grizzly bears hibernate during most of the winter, foregoing the need to feed. They must, however, accumulate adequate body reserves during the arctic summer to accomplish this; thus, the large body size of the arctic ground squirrel in contrast to that of its conspecifics farther south, seems to be an adaptation to help ensure sufficient fat storage (Barnes 1989).

Muskoxen and caribou are adapted to the climatic extremes of the Arctic and remain active throughout winter, finding plant food by digging through the snow or by seeking areas where winds blow snow from vegetation. Caribou in the large migratory herds cannot remain at high densities in the Arctic in winter when suitable forage biomass is low. Consequently, most caribou migrate long distances through the Brooks Range to winter on the northern fringes of the boreal forest in open woodlands with lichens.

Wolf densities are low in the arctic tundra because of the region's relatively low availability of ungulates and other prey throughout winter. The highest densities of wolves in this region are in the northern foothills of the Brooks Range, where caribou that winter on the North Slope tend to concentrate and where prey such as moose, mountain sheep, and snowshoe hares are available. Wolverines and foxes are wide-ranging during winter and supplement prey with food they cached during summer (Magoun 1985).

Because ecological communities and food chains are less complex and involve fewer mammals in the Arctic than at lower latitudes, such communities are more easily disrupted by human activities. Mammals of the arctic tundra are vulnerable to human activities, but the level of each species' vulnerability depends in part on its body size. The smaller mammals are more secure in the low vegetation of the tundra, which offers them adequate escape cover. Among the large ungulate species, the muskox, which was extirpated from Alaska in the late nineteenth century but has since been reestablished, is particularly vulnerable to uncontrolled hunting and displacement from its habitats by disturbance (Barr 1991). In summer and early winter, muskoxen make heavy use of riparian habitats, also the primary habitats of moose. Humans in the Arctic also favor riparian zones for their use as transportation corridors for road and pipeline construction and associated gravel extraction, or for recreational boating and hiking. In the 1970's humans displaced moose from riparian habitats during the construction of the Trans-Alaska Pipeline and the adjacent Dalton Highway (Klein 1979).

A relationship between the effects of the expanding moose and muskoxen populations and the shrub communities that provide a major food source for these ungulates has not been documented, although riparian shrub growth may possibly be increasing because of climatic change. Even though long-term oscillation between and among these herbivore populations and the extent and biomass of the willows on which they feed is expected, research is required.

The larger carnivores may be directly harmed by human development. The wide-ranging habits of bears, foxes, wolverines, and gray wolves and their propensity for being attracted to any food often bring them in contact with humans in the Arctic. Bears and foxes become nuisances around oil fields, construction camps, and villages where food wastes are available. Bears in these situations lose fear of humans and may damage buildings or threaten humans and are usually shot. Foxes also readily habituate to the availability of human food wastes and to being deliberately fed by construction workers. Consequently, these animals often become tame and, because foxes in the Arctic may become rabid, they then pose a potential threat to humans (Klein 1979).

Increased access to the Alaskan Arctic has become possible by the all-season Dalton Highway, which extends 563 kilometers from the highway system in interior Alaska to Prudhoe Bay. This highway, originally built for commercial use to service the oil fields, was officially opened to the public in 1994. Coupled with the improved designs and reliability of snowmobiles, the Dalton Highway may increase hunting and trapping of carnivores in the Arctic. In the Arctic's open terrain, carnivores can be readily tracked with snowmobiles in late winter when light and snow conditions are favorable. Such ease of hunting may, however, be countered by low fur prices.

The effects of petroleum development on caribou have received major attention in the media. The ecological complexity of this species, which differs greatly from other northern ungulates, makes it difficult to assess the response of caribou to anthropogenic development. Unlike moose, deer, and muskoxen, most caribou are seasonally migratory and thus expand their relationships to food and predators across two or more ecosystems. The winter diet of caribou is dominated by lichens, which unlike vascular plants are unrooted, extremely slow-growing plants that are vulnerable to destruction from overgrazing and fire. Caribou tend to avoid humans in the same manner in which they avoid predators. They give birth in specific, traditionally used areas that favor survival of their young. Caribou are particularly vulnerable to harassment by insects and the parasites associated with insects and in summer require free access to habitat that offers relief from insects (Klein 1991).

Development and operation of the Prudhoe Bay, Kuparuk, and satellite oil fields coincided with a period of increases in the sizes of caribou herds across northern North America, and thus complicated an assessment of the effects of development on the Central Arctic caribou herd that uses the oil-field area. Because other caribou herds were also experiencing population increases, presumably because of favorable environmental conditions, possible detrimental effects of oil-field development may have been overridden. In recent years, reduced reproduction in the Central Arctic herd has been recorded (Klein, unpublished information). A reliable assessment of the effects of this development will require several decades rather than merely a few years. Some anthropogenic developments are obviously detrimental, including the ones that displace caribou from calving and post-calving habitat or obstruct their movements to and from the coastal habitats that offer them relief from insects. Reduced reproduction in caribou seems to reflect the effects of such developments (Cameron et al. 1992, 1995; Cameron 1994).

Caribou herds undergo long-term population fluctuations in response to such environmental constraints as limited forage, extreme weather conditions, predation, and hunting by humans. The estimated size of the Western Arctic herd is close to 500,000 (Valkenburg, personal communication), which greatly exceeds all previous population estimates. A population decline seems imminent in view of previous declines from peak numbers. Although food is expected to limit the herd, assessments of forage resources and the effect of caribou on them have not been made. The Western Arctic caribou herd is extremely important to the subsistence of native peoples in more than 25 villages—more than 5,000 households—in northwestern Alaska (Klein 1989). The Porcupine caribou herd of northeastern Alaska and adjacent Canada, which consisted of an estimated 160,000 animals in 1994 (Valkenburg, personal communication), has been the primary subsistence food source for Gwichin people in Alaska and Canada for millennia. Caribou from this herd are also harvested by the Inupiat and Inuit Eskimos of Alaska and Canada.

Major Issues and Research Needs

Humans have had a much smaller effect on natural communities in Alaska than elsewhere in the United States. Development of land for agriculture and the extent of alterations of land for mining and petroleum development have been minimal. Most human settlement is concentrated along the coast. More than 40% of Alaska is in national conservation lands of the National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Bureau of Land Management (Foster 1985). The most extensive alteration of natural communities has been the widespread clear-cutting of old-growth forests in southeastern Alaska.

Coastal Temperate Rain Forest and Coast Range

Extensive clear-cutting on national forest, state, and native-owned lands throughout much of this region is causing a reduction in the biological diversity of the regenerating forests as the uneven-aged old-growth forests are replaced by even-aged second-growth forests. Long-term studies of changes in forest structure after logging and the consequences of these changes for the ecological nature of the region are necessary to formulate effective future land-use policies.

Salmon populations throughout the coastal temperate rain forest and Coast Range are considered healthy. Recent commercial catches of all salmon species in this region have been among the highest on record, and escapements to most spawning streams are considered adequate (Geiger and Savikko 1990; Burger and Wertheimer 1995). However, some rather severe declines in the abundances of steelhead, cutthroat trout, Dolly Varden, and perhaps eulachon stocks have occurred throughout the region, especially in freshwater systems with many recreational anglers. Similarly, steelhead stocks have declined significantly in the Karta River (Harding and Jones 1993), the Situk River (Glynn and Elliott 1993), Peterson Creek (Harding and Jones 1992), and several systems on the Kenai Peninsula (Larson 1990). Harvests of cutthroat trout by anglers have declined throughout southeastern Alaska to about half of what they were 16 years ago; at the same time angling effort has doubled (Mills 1994). The abundance of Dolly Varden also declined in many systems, including in the Juneau area (Armstrong 1979) and on the Kenai Peninsula (Larson 1990). These declines prompted the Alaska Board of Fisheries to reduce bag limits of steelhead, cutthroat trout, and Dolly Varden, to completely close some systems to harvest, and to establish catch-and-release-only fisheries on other streams (Larson 1991; Harding and Jones 1992, 1993). A greater number of anglers are releasing the fish they catch; however, excessive mortality from hooking and releasing fishes remains a concern.

The release of many salmon from the region's hatcheries into the marine environment is not without potential problems. An increased harvest of wild salmon stocks could take place during harvest of returning hatchery fish (Pahlke 1992). Also, the drastic reduction in the body sizes (weight by age group) of salmon (as much as 27%) across the North Pacific may be due to excessive grazing of the ocean by too many hatchery fishes (J. Helle, National Marine Fisheries Service, Juneau, Alaska, personal communication). Releases of hatchery-reared coho and chinook salmon have contributed substantially to sport fisheries in some areas; elsewhere, such enhancement has proved costly and largely unsuccessful (Suchanek and Bingham 1992).

Alaska's anadromous and freshwater resident fishes are managed primarily for human use. Little or no consideration is given to their value and use by other vertebrates or to their value to the natural community as a whole. For example, fishery managers commonly refer to salmon runs as the escapement needed to perpetuate a fishery but rarely consider the value of salmon needed as food for other vertebrates or for the well being of the environment (Willson and Halupka 1995). Notable exceptions are studies that include the importance of salmon to bald eagles (Hansen 1987; Hansen et al. 1984) and to brown bears (Schoen et al. 1994), and studies of the value of salmon carcasses to a stream's ecosystem (Kline et al. 1990, 1993). Investigations of the use of these fishes often focused on the role of other vertebrates as predators of salmon species. In some instances, results of such studies led to misguided predator-control efforts to protect salmon species; these efforts resulted in the killing of many animals, including more than 6 million Dolly Varden between 1921 and 1946 and more than 100,000 bald eagles between 1917 and 1952 to protect Alaska's salmon fisheries (O'Clair et al. 1992). More recently, thousands of arctic chars were captured and held in pens until sockeye salmon smolts had safely passed (McBride 1980).

The abundance of marbled murrelets in Prince William Sound has been declining (Hatch 1993), and data suggest that this trend is also occurring in other parts of the species' range in Alaska (Hatch 1993; Piatt and Ford 1993; West 1993; Ralph 1994). The marbled murrelet in Alaska is a species of concern that could suffer from the loss of nesting habitat resulting from clear-cutting of old-growth forests. Even less is known about trends in the population sizes of Kittlitz's murrelets, which nest on alpine slopes in the coastal mountain ranges. The abundance of this species is also declining (Hatch 1993); it is a species of concern in Alaska. Declining abundances of the dusky Canada goose on the Copper River delta seem to be associated with the 1964 earthquake and its resulting habitat changes that favored predation of eggs and young in nests (West 1993). Habitat loss and fragmentation from logging jeopardize resident northern goshawks on forested islands in southeastern Alaska (West 1993) and have led to the classification of this population as a species of special concern by the state of Alaska.

In winters with deep snows, deer are confined to old-growth forests at low elevations where snow is intercepted by the crowns of large trees. Clear-cutting of these old-growth forests with their high timber volume has greatly reduced the availability of winter refuge areas to deer. New clear-cuts produce an abundance of deer forage but accumulate deep snows that make forage unavailable to deer in winter (Wallmo and Schoen 1980; Schoen et al. 1988). Eventually, the closed canopy of the even-aged second-growth forests does not allow sufficient light to reach the forest floor for forage growth.

In the absence of wolves, the numbers of introduced deer on Kodiak Island and on islands in Prince William Sound have increased to such high densities that deer are altering the vegetation and reducing other animals' food resources. The abundance of plant species preferred by deer, especially shrubs that are heavily browsed in winter, is declining. Many of these plants, such as alpine blueberry, Pacific red elderberry, and Sitka mountain-ash, produce berries and fruit that are important in the diets of brown bears and other mammals and birds.

Increased road access from logging, especially on Chichagof and Prince of Wales islands, is generating concern that easier human access will result in an excessive harvest of brown and black bears on these islands. Wolves may also be threatened by continued clear-cutting on Prince of Wales Island and on other islands in the region. The loss of old-growth forest habitat lowers densities of deer, the primary prey of wolves, and the extensive road systems built during logging opened up much of the region to intensive trapping of wolves by local residents (Person et al. 1996). Consequently, the wolf was considered for listing as a threatened genotype under the Endangered Species Act of 1973. Although the listing was found unwarranted, the species was subsequently (1995) designated as a candidate for federal listing as an endangered species. Following a review period, this proposed listing was also denied in September 1997.

Ecological relationships and population statuses of many mammal species of this region are not understood sufficiently to accurately assess the consequences of extensive clear-cutting on populations. In addition to deer, bears, and wolves, other species that may be affected by logging are the marten, river otter, mink, mountain goat, northern flying squirrel, and bats.

Interior Boreal Forest and Interior Mountains

The role that all species of freshwater fishes play in the natural communities of Alaska is poorly understood. Because of the concerns of funding sources and the need to respond to immediate public interest, research is usually done only on important sport, subsistence, and commercial species of freshwater fishes. Activities that threaten fish populations throughout the interior boreal forest and interior mountain region include proposed timber harvest in the western drainages of the Susitna River; such harvesting may harm the recreational use of the area as well as the fishes and wildlife (Engel and Vincent-Lang 1992). In addition, new public boat-launching areas may increase fishing from boats in areas that are already too congested or may result in further restrictions on the use of motorized boats (Engel and Vincent-Lang 1992). Fish habitat and water quality in the Chuitna River drainage may be reduced because of the development of the Diamond Chuitna coal project. Mine workers at the new site may also increase fishing pressure on all fisheries in the Tyonek–Beluga area (Engel and Vincent-Lang 1992).

Placer mining is also a problem for freshwater fishes in Alaska; it often elevates stream turbidity, which causes gill abrasion and prevents feeding by sight feeders such as arctic grayling. Increased turbidity also limits the growth of aquatic plants and invertebrates that are important for the overall health of natural communities (Weber 1986). Additionally, placer mining can increase the levels of toxic metals such as arsenic and mercury (Alaska Department of Environmental Conservation 1986) and change the physical characteristics of stream channels and riparian habitat (Arvey 1993). In recent years, more than 3,000 new mining claims per year were recorded in the region (Bundtzen et al. 1991).

The number of commercial-use permits on rivers classified for recreation by the Alaska legislature and an increase in the number of wilderness lodges in this region have become issues of environmental concern (DeCicco and Barnes 1992; Engle and Vincent-Lang 1992). These types of activities can increase pressure on certain fish stocks, particularly those in more remote, roadless areas. Vast areas without roads exist, and little is known about the fish populations in many lakes and rivers. For example, more than 40,000 lakes and ponds occur in the area of the Yukon Flats National Wildlife Refuge (U.S. Fish and Wildlife Service 1987), yet little information is available on resident fishes that use these vast wetlands (Arvey 1993).

In Alaska, the boreal forest has been little influenced by human activities, except in habitat adjacent to major settlements where forests were cleared for residences, limited industrial development, and small-scale agriculture. Logging and cutting of firewood have also been localized, primarily in areas with road access. Proposals for large-scale commercial logging in the Tanana Valley generated concern for the potential effect of clear-cutting of the forests on wildlife habitats and their long-term productivity. Because information about the long-term effects of extensive logging in this region does not exist, research is needed on the ecological features of the interior Alaska boreal forests and the long-term response of the vegetation and animals to clear-cutting there.

In the boreal forest and the interior mountain regions, local issues may influence mammal populations or their habitats. In winters of heavy snows, the number of moose killed when struck by trains on the Alaska Railroad and to a lesser extent by autos on the highways reaches into the hundreds (Alaska Department of Fish and Game 1994b). Although this loss of moose and the associated property damage and injury (or occasional death) of humans are regrettable, the overall effect on moose populations is not long lasting.

The control of wolves by the Alaska Board of Game, supported by the Alaska legislature, met with public opposition from both inside and outside Alaska. The objective of the control was to reduce the number of gray wolves by about 70% in specific areas where management goals are to increase the sustainable annual harvest of moose and caribou by hunters. Effectiveness of the control of the gray wolf was limited because of external influences—the chosen methods of control were restricted as a consequence of public opposition and, in late 1994, the governor of Alaska placed a moratorium on further wolf control until previous control efforts had been evaluated. A wolf bounty bill has been introduced in recent Alaska legislative sessions but has failed to become law. Supporters were expected to propose similar legislation in 1996.

The relationship among the distributions and habitats of small mammals throughout the region is poorly understood. Intensive surveys are required to assess the biological diversity and ecosystem relations of the small mammal fauna.

Maritime Tundra

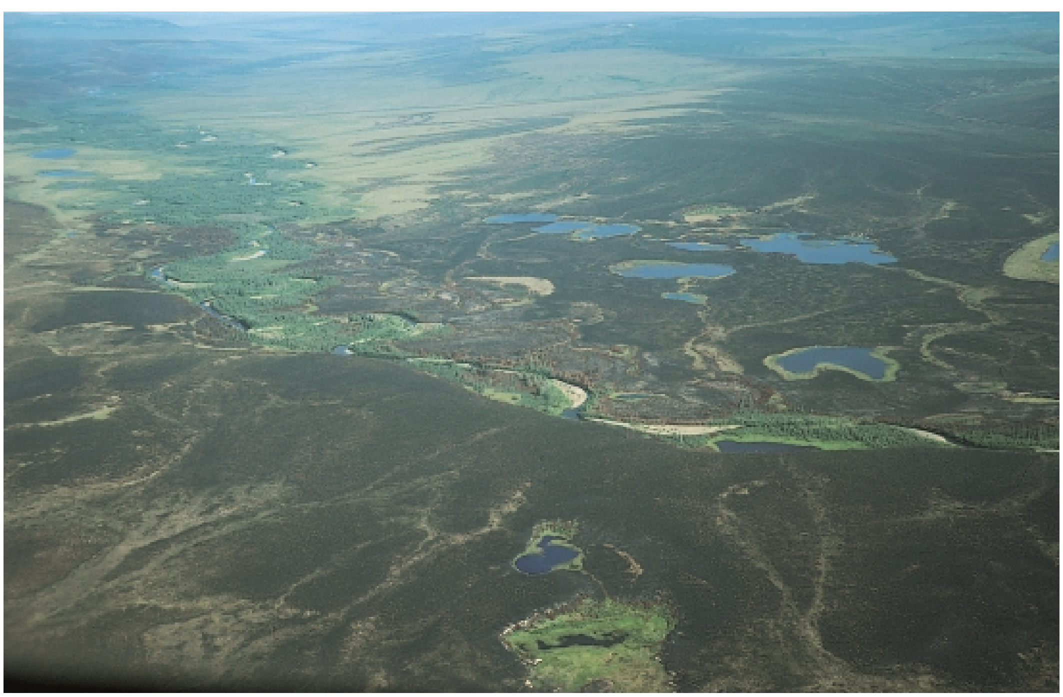
The maritime tundra region (southwestern Alaska and the Bering Sea Islands) supports populations of freshwater fishes that are so unique that they have intrinsic ecological values that reach beyond Alaska. These populations have not been genetically altered by releases of fishes from hatcheries and represent some of the only truly wild populations left in the world. Any type of proposed development, such as oil exploration, deserves careful consideration of the possible ramification for these fish stocks. Likewise, the growing popularity of recreational fishing in this region must be carefully monitored. Considering the value of many of these freshwater stocks for subsistence use, additional harvests may lead to overexploitation.

Mining is also of environmental concern in the maritime tundra region. The Cominco Alaska Corporation, for example, annually mines more than 2 million tons of zinc–lead–silver concentrate from the Red Dog deposit north of Kotzebue (Bundtzen et al. 1991). A potential threat of this operation is heavy-metal contamination of the Red Dog and Ikalukrok creeks from natural leaching of the ore body as it is stripped for ore production and from discharge of impounded waters from which contaminants are not removed (Arvey 1993). Such contamination may affect both resident and migrating fishes, such as Dolly Varden, in the Wulik River. Regulatory surveillances by the Alaska Department of Environmental Conservation are intended to minimize this hazard (Arvey 1993).

Overall, human effects on natural habitats have been minimal throughout most of the maritime region, although overgrazing was widespread during a population peak of reindeer in the 1920's and after the introduction of reindeer on the Pribilof, Saint Matthew, Nunivak, and Hagemeister islands (Scheffer 1951; Klein 1968; Lay 1994). Lightning-caused tundra fires in the drainages of the Kotzebue Sound in infrequent dry summers destroyed lichens, the primary food for caribou and reindeer on their winter ranges (Fig. 12). Fire also favors shrub growth, which supports an increased number of moose. The numbers of shrubs and trees in the tundra are expected to increase even more because global climate warming from the greenhouse effect is expected to be among the greatest in the Alaskan Arctic and subarctic. This could have a cascading effect throughout the region. For example, during the nineteenth century, when caribou disappeared from the Seward Peninsula and much of the maritime tundra adjacent to the Bering Sea, gray wolves, bears, and scavengers such as wolverines and foxes also declined. In turn, however, the recent and ongoing return of caribou to much of this region also could have a cascading effect on other species that could help restore the former complexity of the region's natural communities and of its biological diversity.

Aleutian Region

Many areas of concern in the Aleutian region will require future consideration and research effort. For example, the short drainage systems of the Aleutians have small runs of salmon and Dolly Varden, making these populations vulnerable to excessive harvest by subsistence, commercial, and sport fisheries. Another concern is that the relationships among seabirds, marine mammals, and salmon in this region are not well understood and should be a focus of study. Except for the effect of the intensive commercial fisheries of the region on seabirds that nest in the Aleutians, the major influence of human activities has been the introduction of nonindigenous mammals, particularly foxes and rats, and perhaps reindeer, caribou, and



Courtesy D.R. Klein, USGS

Fig. 12. Wildfires contribute to the patterning of vegetation in this drainage to Kotzebue Sound and have both short- and long-term effects on caribou and moose. The burned areas in the photo are the result of a fire on the Selawaik National Wildlife Refuge in the summer of 1988.

domestic livestock (Burris and McKnight 1973). Although foxes were eradicated from several islands where the abundances of nesting birds subsequently increased, they remain a problem on many other islands. Rats are not as widely distributed as foxes and are believed to have fewer effects on nesting birds (Bailey 1993). However, further investigation of the effect of rats on the bird community is needed, and effective eradication techniques have not been developed. Similarly, the effects of reindeer, caribou, and livestock grazing on nesting habitat and nesting success have not been evaluated.

Grazing by fenced and free-ranging sheep, cattle, horses, and pigs has been practiced on Unalaska and Umnak islands since at least the early 1930's. These activities, which have been of limited economic success, have sometimes resulted in the establishment of feral or semiferal populations of livestock. Little is known, however, about the effects of this grazing on the native flora and fauna, although decreased plant species diversity was observed on fenced ranges grazed by sheep on Umnak Island (Klein, personal observation).

The widespread introduction of foxes throughout the Aleutian Islands from 1750 to 1932 for fur production had a devastating effect on the abundant bird life there (Bailey 1993). Ground-nesting waterfowl, shorebirds, ptarmigan, and burrow-nesting seabirds were most detrimentally affected. Only a few hundred breeding pairs of the endangered Aleutian Canada goose survived on three islands where foxes had never been introduced. In 1949, the U.S. Fish and Wildlife Service began eliminating foxes from specific islands by shooting, trapping, biological controls, and approved toxicants. By 1992, the foxes were believed to have been exterminated from 21 islands (Bailey 1993), and the recovery of breeding birds on these islands has been spectacular. The removal of introduced foxes is continuing on the remaining islands and is expected to further restore the biological diversity of the avifauna of this highly productive biogeographical region.

Arctic Tundra

Transportation corridors (such as the Dalton Highway and the Trans-Alaska Pipeline) and the extraction of gravel for roads, pipeline, and construction pads for buildings, drill rigs, and other oil-field facilities on the North Slope have disturbed fish habitat in the arctic tundra (Arvey 1993). Evidence suggests that the construction of Prudhoe Bay's West Dock Causeway has disrupted the migration and recruitment of the arctic cisco in the Colville and Sagavanirktok rivers (Moulton et al. 1986; Gallaway et al. 1987). Continued monitoring of the subsistence fishery for whitefishes may be useful for determining the extent of changes in stock status of species from the construction of the West Dock Causeway. Documentation of oil spills and their adverse effects on fish populations from contamination on the North Slope is lacking (Arvey 1993).

Shorebirds and waterfowl in the oil fields are potentially threatened by their possible access to contaminants. Although contaminants have been found in the tissues of eiders collected in western Alaska (Henny et al. 1995), no evidence of uptake of contaminants by eiders in the oil fields has yet been noted. Close monitoring of contaminant levels in the oil fields and investigation of their possible influence on birds that nest in the tundra are needed.

Generally, mammals of the arctic tundra are at moderate to high population levels. With the exception of the Prudhoe Bay oil-field complex and the associated Trans-Alaska Pipeline and Dalton Highway, loss of habitat from human activities has not been significant. The increasing demand for fossil fuels and other minerals by world markets may, however, bring about a major expansion of petroleum exploration and development, large-scale mining of coal reserves, mineral extraction, and the construction of roads and other infrastructures in the Alaskan Arctic. Integration of these large-scale developments and their associated transportation corridors with natural arctic communities will not be possible without substantial effect on the mammals of the Alaskan Arctic.

Major issues confronting the biological environment of Alaska are few and widely dispersed in contrast to other biogeographic regions. Nevertheless, the consequences of clear-cut logging in the southern coastal areas, oil exploration in the Arctic, small- and large-scale mining activities throughout Alaska, intensive and expanding exploitation of marine fisheries, and anticipated climate change due to the "greenhouse effect" all pose threats to the biodiversity of Alaska's ecosystems and their sustained productivity. Research efforts should be focused on assessing the consequences of these human activities on Alaska's fish and wildlife and their habitats under the wide diversity of conditions that occur throughout the state's biogeographic regions. Other human activities with more localized consequences, such as expanding tourism; increased hunting, fishing, and other recreation; and conflicts between reindeer grazing and wildlife, also merit research efforts to provide a basis for the protection of natural ecosystems and their sustainable management.

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Acknowledgments

Constructive comments by L. Adams, D. Dirksen, E. Knudsen, L. A. Viereck, J. Schoen, and W. Seitz are greatly appreciated.

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