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The Effects of a Changing Climate on Key Habitats in Alaska

by

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September 2010

**Alaska Department of Fish and Game
Divisions of Sport and Commercial Fisheries, Habitat, and Wildlife Conservation**



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Weights and measures (metric)		General		Mathematics, statistics	
centimeter	cm	Alaska Administrative Code		all standard mathematical signs, symbols and abbreviations	
deciliter	dL		AAC		
gram	g	all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.	alternate hypothesis	H _A
hectare	ha			base of natural logarithm	<i>e</i>
kilogram	kg	all commonly accepted		catch per unit effort	CPUE
kilometer	km	professional titles	e.g., Dr., Ph.D., R.N., etc.	coefficient of variation	CV
liter	L			common test statistics	(F, t, χ^2 , etc.)
meter	m	at	@	confidence interval	CI
milliliter	mL	compass directions:		correlation coefficient (multiple)	R
millimeter	mm	east	E	correlation coefficient (simple)	r
Weights and measures (English)		north	N	covariance	cov
cubic feet per second	ft ³ /s	south	S	degree (angular)	°
foot	ft	west	W	degrees of freedom	df
gallon	gal	copyright	©	expected value	<i>E</i>
inch	in	corporate suffixes:		greater than	>
mile	mi	Company	Co.	greater than or equal to	≥
nautical mile	nmi	Corporation	Corp.	harvest per unit effort	HPUE
ounce	oz	Incorporated	Inc.	less than	<
pound	lb	Limited	Ltd.	less than or equal to	≤
quart	qt	District of Columbia	D.C.	logarithm (natural)	ln
yard	yd	et alii (and others)	et al.	logarithm (base 10)	log
Time and temperature		et cetera (and so forth)	etc.	logarithm (specify base)	log ₂ , etc.
day	d	exempli gratia		minute (angular)	'
degrees Celsius	°C	(for example)	e.g.	not significant	NS
degrees Fahrenheit	°F	Federal Information Code	FIC	null hypothesis	H ₀
degrees kelvin	K	id est (that is)	i.e.	percent	%
hour	h	latitude or longitude	lat. or long.	probability	P
minute	min	monetary symbols		probability of a type I error	
second	s	(U.S.)	\$, ¢	(rejection of the null hypothesis when true)	α
Physics and chemistry		months (tables and figures): first three		probability of a type II error	
all atomic symbols		letters	Jan,...,Dec	(acceptance of the null hypothesis when false)	β
alternating current	AC	registered trademark	®	second (angular)	"
ampere	A	trademark	™	standard deviation	SD
calorie	cal	United States		standard error	SE
direct current	DC	(adjective)	U.S.	variance	
hertz	Hz	United States of America (noun)	USA	population	Var
horsepower	hp	U.S.C.	United States Code	sample	var
hydrogen ion activity (negative log of)	pH				
parts per million	ppm	U.S. state	use two-letter abbreviations		
parts per thousand	ppt, ‰		(e.g., AK, WA)		
volts	V				
watts	W				

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ALASKA**

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ABSTRACT

Scientific evidence shows that climate change is occurring throughout Alaska. These effects have the potential to impact the sustainability of Alaska's fish and wildlife resources and are beginning to impact Alaska's natural systems and the uses they sustain (ADEC 2009). The impacts from climate change, monitoring and research needs are identified for Tundra, Wetland, Coastal Marine, Freshwater Aquatic and Karst Cave habitat types, identified as the primary habitat types in Alaska in the State's Comprehensive Wildlife Conservation Strategy. In addition, the impact on fish and wildlife populations that use these habitat types are identified. Potential impacts of climate change in Alaska are extended, but not limited, to economics, stock abundance, ocean acidification, marine productivity, water quality, angler access, invasive species, species movement and distribution, habitat, educational programs and outreach, wetland diversity and wildfires as an agent of habitat change.

Key Words: Alaska, Climate change, research needs, tundra, wetland, coastal marine, freshwater aquatic, karst cave, fish and wildlife populations, habitat

INTRODUCTION

Scientific evidence is showing that climate change is occurring throughout Alaska. This is evident in warming temperatures, changing precipitation patterns, altered stream flows, loss of sea-ice, increased fire regimes, thawing permafrost, changing ocean salinity, and coastal erosion, amongst others (ACIA 2004). In combination, these effects are beginning to impact Alaska's natural systems and the uses they sustain (ADEC 2009).

The Alaska Department of Fish and Game's (ADF&G) mission is *"to protect, maintain, and improve the fish, game, and aquatic plant resources of the state, and manage their use and development in the best interest of the economy and the well-being of the people of the state, consistent with the sustained yield principle."* A changing climate has the potential to impact the sustainability of Alaska's fish and wildlife resources and their uses. It is therefore of interest to the Department to assess the likely impacts of climate change on fish and wildlife and their uses and to develop adaptation strategies the impacts.

Climate change will require resource managers to manage for healthy, productive ecosystems in uncertain future conditions to assure for continued sustained yield and the benefits it provides. Additionally, the consequences of climate effects will exacerbate other recognized impacts to fish and wildlife resources such as habitat fragmentation, degradation, and loss from changing land uses, pollution and sedimentation, deleterious or invasive species, and unsustainable use of natural resources.

This report examines the effects that a changing climate may have on key habitats that support Alaska's diverse fish and wildlife resources. The habitats selected for assessment were those previously identified in the department's Comprehensive Wildlife Conservation Strategy, (<http://www.sf.adfg.state.ak.us/statewide/ngplan/>). For each habitat type (Forest, Tundra, Wetland, Coastal Marine, Freshwater Aquatic, and Karst Cave), the likely impacts from climate change and monitoring and research needs are identified.

We identify likely potential impacts to fish and wildlife populations and their uses due to climate change.

FRESHWATER AQUATIC HABITATS

INTRODUCTION

Alaska has more than 40% of the entire nation's surface water resources. Approximately three-fourths of all freshwater resources in Alaska are stored as glacial ice covering about 5% of the state. Alaska has more than 3 million lakes greater than 5 acres (Harle and Estes 1993), over 12,000 rivers, thousands of streams and creeks, and an estimated 100,000 glaciers. Alpine glaciers, lakes, groundwater, glacial and clearwater rivers, streams, springs and ice fields connect the uplands to Alaska's estuarine ecosystem.

Alaska's largest rivers include the Yukon, Kuskokwim, Susitna, and the Copper. The state's longest river is the Yukon. At over 2000 miles long it is the third longest river in North America. It flows for 1280 miles through Alaska and drains a 204,000 mi² area. Alaska's rivers support many aquatic species including both anadromous and resident fish, and serve as migratory corridors to the many smaller tributaries and waterways that support spawning, rearing, and overwintering habitats. These same tributaries provide protective vegetative cover, a significant source of detritus, and terrestrial wildlife riparian migration corridors.

Lake Iliamna is Alaska's largest lake covering an area of approximately 1000 mi². It is 75 mi long and 20 mi wide. Other lakes of size include Lake Clark and Becharof, Naknek, Ugashik, Teshekpuk, Tustumena and Kenai lakes. The Wood-Tikchik Lakes system in Southwest Alaska consists of 13 lakes that range in length from 15 to 45 mi.

Alaska's freshwater ecosystems are found across the state from the temperate coastal rain forest of the Southeast region with maritime climate and dense riparian vegetation, to the boreal forest of Interior Alaska, with continental climate and modest riparian vegetation, to the Arctic tundra of the North Slope, with sparse riparian vegetation (Reynolds 1997). In terms of elevation, freshwater habitats are found from the highest alpine glacier and cirque lakes down to sea level, and flowing waters effectively connect the mountains to the sea.

Alaska freshwater resources are distributed throughout the state, from the mountains to the coastal plain, and they provide a wide variety of habitats. Aquatic habitats are complex and range from small, ephemeral streams to large, braided glacial systems that flow across entire regions of the state. Still water habitats range from tiny ponds to some of the very large lakes mentioned above. Headwater streams include pool, riffle, side channel, isolated pool and stream margin and backwater habitats. Floodplain characteristics include main channel, side channel, oxbow lake, backwater lake, meander, scroll depression, and backwater wetlands habitats. Lake and pond habitats include typical shoreline, pelagic and benthic areas.

FLOW REGIME

The flow regimes of Alaska's rivers and lakes include those influenced by glacial melt, snowmelt, precipitation, and ground water, including springs and upwelling areas. Three common types of streams occur in Alaska: ephemeral, intermittent and perennial streams. Directly correlated with precipitation, ephemeral streamflow is limited to short periods of a few hours or days immediately after storms and floods. In intermittent streams, flow occurs for several weeks or months each year when precipitation and ground water input is relatively high.

Perennial streams have a well-defined channel that contains water at least 90 percent of the time. They receive substantial ground water input and generally flow continuously throughout the year. Annual flows can vary widely and streams may be dry during periods of low precipitation, although ground water is generally near the surface. Water supply to Alaska's ponds and lakes is governed by the same types of flow regimes as for these 3 stream types.

SUBSTRATE AND MORPHOLOGY

The type and ratio of substrate materials offered by a waterway determines the habitat suitability for associated aquatic species. This is particularly true for aquatic species during differing life stages. Stream and riverbed substrates vary from large boulders to glacial silt or flour, clay, and mud. Large boulders provide resting areas for fish, while smaller cobbles and gravels allow for the required aeration and subsequent development of eggs buried in the streambed. Larger substrates provide greater surface area for aquatic invertebrate concentration and for the establishment of algae and mosses. Boulder and cobble bed streams are usually found in the upper portion of a watershed. These streams often have pockets of gravel and fines in the pools, behind large rocks, and on the inside of bends and other areas of reduced velocity. Mud, silt, or clay substrates are often represented in shallower and slower waters, or at the terminus of a waterway.

Many other physical factors contribute to the complexity of aquatic habitats, and channel morphology characteristics provide additional habitat diversity for aquatic species. Straight and meandering channels are both common, with extent of meandering largely determined by the stream gradient and underlying soils. Meandering waterways typically contain deeper areas of swift flow near the eroding outer edge of the meander, and areas of deposition and shallower water on the opposite bank. In broad valleys of major rivers, extensive meanders create oxbow lakes in abandoned channels. Braided channels are formed as a result of erosional and depositional processes, and are typical of large glacial rivers. Morphologic complexity, along with substrate material that provides channel roughness, contributes substantially to the habitat quality and quantity of a system for aquatic species.

Lake and pond habitats also vary with substrate, bathymetry, and shoreline contour. Flow regimes and depth contours are also important influences on nutrient cycling, hydraulic retention time and biological productivity in the relatively still waters of lakes and ponds. As with flowing waters, the origin of a lake basin determines its contour and morphometry.

MICROHABITAT

Differing hydrologic energy dissipation as a result of substrate conditions causes specialized microhabitats to develop in waterways. For example, riffles form in river and stream reaches where flow is slowed by rocks, gravel, or sand bars. In a healthy system, these features are interspersed with pools of deeper, slower water. Intermediate runs of moderate current are often found in larger streams and rivers. In the lower stream reaches, deep pools near undercut banks, and large woody debris are common. The representative biota residing in pool and riffles often contrasts sharply due to differing habitat niches offered by each. In lower elevation areas, backwater sloughs and their associated floodplains and wetlands provide some of the most physically protected and biologically productive freshwater aquatic habitats.

Large woody debris (LWD) is an important component of rivers and streams that helps to stabilize banks and substrate material, and provide cover from terrestrial predators. It also fosters

formation of pool habitats and provides spawning bed integrity and habitat for aquatic invertebrates, elevating in-stream productivity. In large rivers, LWD groundings often lead to formation of downstream islands, bars and slough habitats. In smaller streams, lakes, and ponds, LWD plays an important role in habitat creation immediately adjacent to the point of input. Decaying terrestrial debris also tends to accumulate near LWD, providing a food source for aquatic invertebrates. In Alaska, nutrient input from both allochthonous (originating outside the system) and autochthonous (originating within the system) sources contributes significantly to fresh waters, whether flowing or still (e.g., lake and pond habitats).

Cumulatively, stream- or riverbed material, channel morphology, and microhabitat characteristics increase the quantity of available aquatic habitat and the diversity of the aquatic environment. Similarly, pond and lake habitat are further diversified by the occurrence of differing substrates, depths, and contours.

GLACIAL WATERS

Glacially Influenced Rivers and Streams

The extent to which Alaska is covered with glaciers significantly influences its freshwater habitats. The area of glacier coverage in other states is less than 200 mi², and the glacier ice in the rest of the United States combined totals less than the area of a single large Alaska glacier (Molnia 2001). In Alaska, glaciers develop in high mountainous areas and often flow out of ice fields that span several peaks or an entire mountain range. Alaska's 300 mi² Harding Icefield, located in the mountains of the Kenai Peninsula, is the largest in North America and one of only four remaining ice fields in the United States. Thirty-five of Alaska's glaciers, some among the largest mountain glaciers in the world, stem from the Harding Icefield.

Glacially influenced waterways are those where glacial input is the dominant channel- or floodplain-forming mechanism, dictating the chemical and physical hydrology of the water itself. Glaciers feed and influence nearly all major rivers in Alaska and provide the headwaters to some of the state's largest rivers, including the Copper, Susitna and Tanana.

Alaska's glacially driven rivers exhibit high and variable rates of fluvial activity and channel adjustments from erosional and depositional processes (Wooster 2002). Rivers originating from glaciers tend to have high discharges, and generally have pronounced daily and seasonal stream flow fluctuations near the glacier and large year-to-year fluctuations in stream flow. Peak glacial river flows occur during the warmest months of the year, typically May through August. However, even during summer, water temperatures are measurably lower near a glacier than farther downstream. Glacial rivers tend to transport large volumes of fine-grained sediment and have steep channel slopes. In response to these conditions, braided river channels may develop containing multiple channels separated by bars or islands. During the colder winter temperatures, when base flow is derived entirely from ground water, glacial rivers generally run clear and low.

Depending on the channel slope and bed composition, glacial systems may show pronounced accumulation of deposited materials (i.e., aggradation) in their streambeds and valleys. Large, unstable, braided channels occur where the rate of aggradation is high (e.g., Matanuska glacier/ Matanuska River), and single channels occur where rates are low (e.g., Mint glacier/ Little Susitna River). Where they are associated with rivers, glacier-dominated lakes regulate the flow moving downstream and reduce the amount of sediment transported to the river's lower reaches.

Alaska's glacial hydrologic systems differ from clearwater systems in terms of runoff, water quality, and volume. The volume of flow from glacial rivers can be 10 times as much as that from clearwater rivers. The water quality difference between these streams is mainly expressed as turbidity: Glacial rivers and streams carry a large sediment load of clay and silt, giving the waters a cloudy-gray opaque color. Other glacially influenced rivers and lake waters appear turquoise blue-green in color. This is due to their absorption of all the colors of the spectrum except blue, which is reflected off the glacial sediments in the upper reaches of the system. Kenai Lake and the upper Kenai River demonstrate this phenomenon. Dissolved oxygen, conductivity, and pH of glacial versus clearwater systems are roughly equal.

Glacially Influenced Lakes and Ponds

Lakes form in glacier-dominated watersheds as a result of glacial advance and subsequent retreat. Most of the state's larger lakes, particularly those in Southwest and Southcentral Alaska, resulted from glaciation and are important to both resident and anadromous fish species for overwintering. Kenai Lake has glacial tributaries, while Iliamna Lake has clearwater tributaries. Both of these lakes are connected to rivers that support large and valuable runs of salmonids.

Two types of floods are common in Alaska's glacial waters, yet rarely occur in the rest of the United States. These are floods caused by the release of water from glacier-dammed lakes and by ice jams on rivers. Approximately 750 glacier-dammed lakes have been identified in Alaska. These lakes are formed in areas where glaciers flow across tributary valleys and trap runoff. Catastrophic flooding occurs when the ice dams fail. In some places, the dams fail predictably and/or annually. Others fail unexpectedly due to geomorphic glacial changes, with sudden outbursts resulting in floods (Snyder 1993). An ice jam is an accumulation of broken river ice in a narrow, shallow, or blocked part of the river channel. Backwater pooling from an ice jam can cause flooding upstream. When an ice jam suddenly releases, river discharge increases rapidly and causes downstream flooding.

CLEARWATERS

Clearwater Rivers and Streams

Clearwater rivers and streams are also common throughout Alaska. In contrast to glacial systems, these waterways exhibit low turbidity, high clarity and flow derived primarily from ground water and precipitation. Clear waters maintain less dynamic annual flows than glacial waters.

Clearwater systems have relatively narrower channel widths, stable well-defined beds and banks, relatively low sediment loads, and increased habitat complexity in the form of pools, riffles and LWD. Relative to glacial waters, clear waters generally are narrower, as a result, freeze up earlier in the winter months.

Clearwater Lakes and Ponds

As with flowing waters, the amount and quality of available habitat for biota in and around lakes depends on connections of the lake with surface and/or ground waters. Lake water level is related to the flow regime and can be perennial, with surface waters present year-round, or intermittent with water present seasonally. Lake level, thermal regime, and chemical composition may fluctuate depending on the groundwater source and connectivity.

Isolated Lakes and Ponds

Many lakes in Alaska are not connected to a river or stream via an inlet or outlet. For example, lakes and ponds of thermokarst, fluvial, and volcanic origin generally lack connecting tributaries. Isolated or landlocked lakes can also be extremely shallow during the winter.

Although landlocked ponds and lakes may appear to lack connections to surface waters, many “isolated” waterbodies are hydrologically connected to other lakes, wetlands, streams, or rivers by subsurface flows. For example, the state’s Arctic region is dotted with shallow ponds and lakes that were created during deglaciation of the area. These ponds are hydrologically linked via the underlying permafrost.

Because of their relative isolation, lakes and ponds with no surface connection to another water body are more likely to contain unique biota due to temporal isolation. A lake or pond may have either been originally connected to a river or stream, or created during deglaciation with no surface connection to other water bodies. Other lakes, such as isolated oxbow lakes on former floodplains, were once inundated by seasonal river flows but due to changes in river courses may be isolated beyond the active floodplain.

LIFE HISTORY VARIATION IN FRESHWATER FISHES

Within the various riverine and lake habitats in Alaska, freshwater fish have adapted to the wide variety of flow regimes, substrate and morphology, and microhabitats through variation in their life history characteristics. The major life history characteristics of freshwater fishes in Alaska are: migratory, spawning, rearing/feeding, and overwintering strategies. These life history characteristics are important in determining the distribution and productivity of each species of fish and will likely be major determinants of the responses of these species to climate change.

MIGRATORY STRATEGIES

Both migratory and non-migratory strategies occur in freshwater fishes in Alaska. The most notable migratory strategy is to move to saltwater to feed and grow to maturity, also called anadromy (e.g., Pacific salmon *Oncorhynchus* spp.). Many species of lamprey (Family *Petromyzontidae*), whitefish (largely *Coregonus* spp.), and char (*Salvelinus malma*) in Alaska also have anadromous forms and/or populations. However there are other migratory strategies that occur completely in freshwater, such as the movements of Arctic grayling *Thymallus arcticus* from overwintering to spawning areas and then to feeding areas that are each in different tributaries of a large glacial river system. Non-migratory strategies also occur, such as in large lakes where there may be a seasonal aggregation of adults for spawning, but the population largely stays in a lake throughout their lives (e.g., lake trout *Salvelinus namaycush*).

SPAWNING STRATEGIES

There are two primary spawning strategies of freshwater fishes in Alaska; spawn timing and lifetime frequency of spawning. Many species spawn during spring, with subsequent hatching and rearing of young during summer and fall. Examples of this strategy occur primarily in the salmonids such as Arctic grayling and rainbow trout *Oncorhynchus mykiss*, but also occur for northern pike *Esox lucius* and longnose sucker *Catostomus catostomus*. Conversely many species of freshwater fish spawn during summer or fall with subsequent hatching and rearing of young during the next spring. Examples of this strategy occur in Pacific salmon, char, and whitefish.

Lifetime frequency of spawning in freshwater fishes in Alaska is characterized by semelparity (single lifetime spawning event) and iteroparity (multiple annual spawning events). Pacific salmon dominate the fish species that are semelparous, although stickleback (Family *Gasterosteidae*) and smelt (Family *Osmeridae*) species are also semelparous. Many species of fishes in Alaska are iteroparous, with some obligate (e.g., Arctic grayling) and some facultative (i.e., skip spawning) species (e.g., many populations of some whitefish species) occurring. In general rates of maturation of freshwater fishes in Alaska show a latitudinal gradient, with later maturity and preponderance of skip spawning positively correlated with northward distribution within a species or family.

REARING/FEEDING STRATEGIES

Rearing (just after hatching) strategies of freshwater fishes in Alaska are highly variable, locally specific, and are largely dependent on spawning strategies. However there are some general strategies for rearing just after hatching that have relevance to the effects of climate change. For example, because of the small-sized embryo and short incubation time, rearing of spring spawning fish species tends to occur in warmer, low velocity backwater areas or side channel habitat of rivers or littoral areas of lakes, with the weak swimming juveniles developing rapidly after hatching. Conversely, many summer and fall spawning fish species build redds, with larger ova and longer incubation times that allow fully developed juveniles to inhabit and migrate to a wider variety of habitats, including brackish and saltwater areas. There are also some fall spawning fish species in Alaska that have smaller embryos, higher fecundity, and broadcast spawn over riffle areas, with juveniles rearing in backwater areas or adjacent lakes.

Feeding strategies of freshwater fishes are also highly variable in space and time, but can be thought of as keyed to the matching of feeding requirements to achieve maturity with the patchy and seasonal availability of preferred foods. For example, the seasonal movements of many freshwater fish species are keyed to the timing and location of spawning of Pacific salmon to take advantage of seasonally available eggs, ova, and carcasses as food. Similarly many fish species exhibit distinct seasonal aggregations and movements to feed on Pacific salmon smolts as they emigrate to saltwater.

OVERWINTERING STRATEGIES

As in rearing and feeding, overwintering strategies of freshwater fishes in Alaska are also varied and dependent on location and species. Some species have the capability of overwintering (actually feeding) in saltwater, while other species migrate to spring-fed areas or deep pools in rivers, or to lakes to overwinter. Many of these migrations are to avoid icing conditions, either sections of river freezing to the bottom or frazil ice. Other movements or migrations, especially in lakes, occur to avoid deoxygenated waters.

THERMAL GUILDS

Reist et al. (2006) proposed previously described thermal guilds for families or subfamilies of fish in the Arctic, including Alaska, to describe the effects of climate change on these fishes. Four guilds, based on temperature preferences from literature reviews were presented, ranging from Arctic to warm. The thermal guilds of the major families and subfamilies of freshwater fish in Alaska are presented along with the aforementioned migratory, spawning, rearing, and overwintering strategies in Table 1. Very few freshwater families or subfamilies of fishes in

Alaska are represented in the warm thermal guild (minnows, suckers, and sticklebacks), whereas most families or subfamilies were represented in the cool and cold thermal guilds.

Table 1.—Generalized migratory, spawning, rearing, and overwintering strategies, and thermal guilds of the major families, subfamilies or species of freshwater fish in Alaska.

Family, Subfamily, or Species	Migratory Strategy	Spawning Strategy	Rearing Strategy	Overwintering Strategy	Thermal Guild(s)
Lampreys	Anadromous/Resident	Semelparous/Spring	River/Lake	Saltwater	Cool
Lake chub	Resident	Iteroparous/Spring	Backwater/Lake	River/Lake	Warm
Longnose sucker	Resident	Iteroparous/Spring	Backwater	River	Warm/Cool/Cold
Northern pike	Resident	Iteroparous/Spring	Backwater/Lake	River/Lake	Cool/Cold
Alaska blackfish	Resident	Iteroparous/Spring	Lake	Lake	Cold/Arctic
Smelts	Anadromous	Semelparous/Spring	River/Lake/Saltwater	Saltwater	Cool/Cold
Pacific salmon	Anadromous	Semelparous/Summer	River/Lake/Saltwater	Saltwater	Cool/Cold
Trout/Grayling	Anadromous/Resident	Iteroparous/Spring	Backwater/Lake	River/Lake	Cool/Cold/Arctic
Charrs	Anadromous/Resident	Iteroparous/Fall	River/Lake	River/Lake	Cool/Cold/Arctic
Whitefish	Anadromous/Resident	Iteroparous/Fall	River/Lake	River/Lake	Cool/Cold/Arctic
Trout-perch	Resident	Iteroparous/Spring	Lake	Lake	Cool/Cold
Burbot	Resident	Iteroparous/Winter	River/Lake	River/Lake	Cool/Cold
Sticklebacks	Resident	Semelparous/Spring	Backwater/Lake	River/Lake	Warm/Cool/Cold
Sculpins	Resident	Iteroparous/Spring	River/Lake	River/Lake	Cool/Cold

ANTICIPATED CHANGES TO AQUATIC HABITATS

Based on projections of climate change in Alaska through the year 2099, significant changes in freshwater quantity and quality are anticipated in Alaska (University of Alaska-SNAP 2008). These projected changes to aquatic habitats are thought to ultimately cause a change in distribution of freshwater fish species in Alaska that will also cause significant changes in the productivity of individual stocks and populations of these species. Sustaining use of these fish stocks and populations will largely be guided by our understanding of how future climate conditions will affect the physical environment that freshwater fishes occupy. Although there is significant uncertainty in projecting changes in aquatic habitat and the resultant changes to freshwater fish production, several patterns of change can be generally described and research and monitoring programs tailored to investigate the validity of these projections through time.

TRENDS IN WATER QUANTITY AND QUALITY

The University of Alaska, SNAP program has developed models of climate change relevant to Alaska from the present to the year 2099 based on downscaled global general circulation models (GCMs) developed by the Intergovernmental Panel on Climate Change (IPCC 2007). Anticipated increases in mean winter (December-February) and mean summer (June-August) air temperature are projected for the entire state through the entire 21st century with the most change anticipated for mean winter temperature. This will likely result in warmer and wetter winters and summers in general across the state. Moreover, the number of days from thaw to freezeup will increase, with a shift to a later date of fall freezeup and earlier date of spring thaw, particularly in the Arctic and subarctic areas of the state.

The quantity of water available for freshwater fishes in aquatic habitats is projected to change as a result of these climactic changes (Wrona et al. 2006). Storage of freshwater in both glacial and clearwater systems in the form of glaciers and snowpack will likely decrease. Precipitation in the form of rain will increase. These two changes will work in concert to “flatten” the hydrograph of many drainages in Alaska, so that flooding during spring breakup will become less likely and flooding during summer and winter due to precipitation events will become more likely. Despite increased precipitation, mean summer flows will probably decrease due to a loss of stored water during winter. Newly melted landscapes, especially those prone to permafrost, are thought to experience an increase in groundwater flow with both losses of water (e.g., tundra ponds) and gains in water (e.g., glacial systems adjacent to frozen tundra) occurring.

In addition to the lengthening and timing of the ice free season, there will be physical and chemical changes to water quality as a result of climate change in Alaska. A decrease in permafrost is projected to increase nutrient, sediment, and carbon loading in river and lake systems (Wrona et al. 2006). A loss of spring freshet will likely decrease the seasonal sediment load and channel forming processes (e.g., channel avulsions due to logjamming) in clearwater rivers, although an increase in winter flooding may increase winter sediment loading. Similarly, the loss of glacial storage and scour will decrease overall sediment loading and channel forming processes in glacial systems. Lessening of ice cover on lakes is thought to change the timing and strength of stratification and nutrient exchange with associated changes in the thermal regime.

CHANGES TO FISHERY RESOURCES

As changes to climate occur, changes to the quantity and quality of water supplied to aquatic habitats in Alaska will also change. The distribution and production of freshwater fishery resources in Alaska will ultimately be affected. Stock and population-level responses of freshwater fishes to climate change will vary due to microhabitat conditions and cannot be predicted with certainty. However, general responses of particular families, subfamilies and species of freshwater fish to climate change can be described based on their life history characteristics and thermal guild.

Distributional changes and productivity shifts will occur. Some positive some negative. Outcome highly uncertain at the stock/population level due to adaptability of species and changes at microhabitat scale.

Near Term (5-10 years)

Although significant climate changes may occur in Alaska during the next 5 to 10 years, little to moderate changes in freshwater fishery resources are anticipated. The life span or generation time of most freshwater fish species in Alaska is 5 or more years and changes in distribution and production will likely take several generations to manifest. Although the effects of climate change may be significantly affecting freshwater fish production during this time period, the manifestations (e.g., loss of production in some systems and/or an increase in production in other systems) will not be detectable due to the variability in response among stocks or populations across the state and the difficulty in detection and discerning true shifts in distribution at the earliest stages of these changes. Moreover, the first change in aquatic habitats due to climate change will be an increase in mean winter water temperature, which will likely promote increased production in all of the thermal guilds and not a loss of production or shift in distribution. This increased production will likely be the result of increased primary (e.g., diatom growth) and secondary production (e.g., aquatic insect production), with increased somatic

growth and survival of juvenile fishes. Increased water temperatures may also increase potential infestations of invasive species such as northern pike and Atlantic salmon *Salmo salar*.

Longer Term (Greater than 10 years)

As climate change continues to warm aquatic habitats in Alaska, significant changes to hydrography will occur. Ultimately, these changes will differentially affect freshwater fish resources across the state. Some species of fish in the Arctic and cold thermal guilds (Table 1) may face a loss in available habitat and contract their distribution due to changes in water temperatures during critical life stages. Most likely among these species are some of the blackfish, lake dwelling char, and whitefish populations in the Arctic. Conversely species of fish in the cool and warm thermal guilds (Table 1) may expand distribution northward and increase production due to these same changes. Examples of potential increases in distribution and production are specific populations of lake chub, northern pike (wild and invasive populations), longnose sucker, smelts, Pacific salmon, burbot, sticklebacks, and sculpins. Responses of riverine char, trout and grayling will likely be highly population specific, with some populations benefiting (increased distribution and production) from an increase in water temperature and others declining (contracting distribution and/or decreased production) due to increasing water temperature.

However, increases in water temperature may not be the greatest long term change that occurs in aquatic habitats. As water storage in the form of glaciers and snowpack decrease, there will be a significant loss in aquatic habitat, especially migration and spawning habitat during spring, in many of the largest river systems in the state. These changes will negatively affect river dwelling and spring spawning species of fish such as rainbow trout and Arctic grayling the most, but will also negatively affect populations of Pacific salmon that utilize large glacial systems (e.g., Susitna River) for spawning.

Warmer and wetter fall and winter conditions may cause losses in production of some populations of fall spawning fishes such as chars and whitefish. The loss will be due to the smothering and scouring of embryos from increased sediment loads during winter. Warmer winters may also cause a mismatch between hatching and availability of food for juvenile fish. For example, the timing of hatching of Pacific salmon alevins is due to the cumulative water temperatures experienced during the fall and winter months of incubation. However, the availability of food for juvenile Pacific salmon is due to available light to drive primary (algae) and then secondary production (insect). As a result, Pacific salmon alevins may emerge from the gravel well before the first algae blooms in spring and starve due to a lack of food resources.

MONITORING AND RESEARCH NEEDS

Although general qualitative trends in freshwater fish distribution and production can be inferred from changes in aquatic habitats due to climate change, actual changes to stocks and populations will ultimately be the impact most strongly felt by local communities and fisheries. Due to a lack of knowledge on these specific populations, changes at this scale will be very hard to predict in advance (Reist et al. 2006). As a remedy for our lack of knowledge and lack of predictive capability, a precautionary and adaptive approach should be taken by the state to develop monitoring and research programs to detect stock and population-scale changes and adapt fisheries to accommodate these changes in ways that continue to provide benefits to Alaskans.

MONITORING

As discussed earlier in this chapter, water quantity and quality will be the first changes to aquatic habitats due to climate change. Alaska is not adequately prepared to systematically detect these potential changes due to a lack of stream gaging sites statewide. Funding for planning and implementation of a comprehensive network of stream gages is needed as an early warning of changes in hydrology, and chemical and physical parameters in the various types of aquatic habitats.

In concert with increased funding for a comprehensive stream gaging network is the need for planning and implementing a systematic survey of the major drainages in Alaska to determine the distribution and relative abundance of freshwater fish communities in relation to the differing aquatic habitat types. The state will most likely be unable to detect shifts in distribution of fish species due to climate change without these systematically collected data. When methods of detection are lacking, fishery management will likely resort to highly conservative actions (e.g., closures of fisheries) in response to downturns in production of fishery resources. These same surveys could also be used to detect changes in distribution of existing or occurrence of new invasive species in the state.

RESEARCH

At present there is a poor understanding of the linkages between physical and chemical processes and the resultant biotic processes in freshwater ecosystems (Wrona et al. 2006). Research needed to increase our understanding of the linkages could be structured along two primary and competing hypotheses: 1) the top-down processes of competition and predation control the distribution and production of freshwater fishes; and, 2) the bottom-up processes of physical and chemical changes to aquatic habitats control the distribution and production of freshwater fishes.

Research on the top-down processes could be conducted via measurements of fish community structure and abundance, predator-prey studies, and feeding studies. By necessity, these types of studies would have to be long term (10 years or longer) and situated so that a variety of aquatic habitats are investigated, but also controlled for through replication.

Research on bottom-up processes could be conducted via observations of phenological changes in life history (e.g., spawn timing, hatch timing) as physical and chemical attributes of aquatic habitats are artificially manipulated or change naturally. Investigations into changes in primary and secondary production would also have to be conducted to make ecological linkages back to climate. Similarly, studies of limitation in freshwater fishes could also be conducted, where estimates of total available habitat (e.g., spawning habitat) are calculated and compared to estimates of this same habitat actually utilized in the absence of fishing. In this example, if spawning habitat were found to be limited (no excess spawning habitat available when the population is at carrying capacity), losses in spawning habitat due to climate change could then be inferred to result in a loss of carrying capacity and resultant production.

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WETLANDS

INTRODUCTION

Approximately 50% of Alaska is composed of wetlands and deepwater habitat types. Wetlands acreage approaches about 175 million acres and deepwater habitat acreage is roughly 30 million. Nearly 95% of wetlands in Alaska occur in the Interior, Arctic and Western regions of the State. Interior Alaska holds about 71 million acres; Arctic and Western about 93 million acres while Southern and coastal Alaska have about 9 and 2 million acres respectively. As such this section will focus on the potential effects of global warming on the wetlands of, primarily, northern Alaska (Interior, Western and Arctic). The vast majority of Alaska's wetlands are palustrine vegetated wetlands with a small component consisting of palustrine non-vegetated wetlands. The majority of palustrine vegetated wetlands exist as scrub/shrub wetlands followed by emergent wetlands. Forested wetlands represent the smallest percentage of vegetated wetlands in the state; about 8% of the total, just under half of which occurs in the Southern regions of the State (Hall 1994, USFWS).

Wetlands in Alaska are maintained by either permafrost or bedrock and precipitation or a combination. Most wetlands (non-estuarine) in Alaska are formed by the presence of discontinuous or continuous permafrost that underlies the relatively shallow active layer across most of the state. Water as precipitation is captured in the active layer and held more or less close to the surface by the underlying ice. As such, changes in ambient air temperature and precipitation rates have the potential to affect the vast majority of Alaska's wetlands particularly in areas of warm permafrost.

Combinations of various climate models have been used to predict shifts in average annual air temperatures, seasonal air temperatures, average annual precipitation rates, seasonal precipitation rates and shifts in the growing season. Most model scenarios discussed here make projections to the period around 2050-2060 or 2090-2100 or both. Using these climate projections and observed empirical data specialists have created additional models to illustrate how permafrost across the Arctic and in Alaska may respond. We attempt to synthesize some of these projections and make inferences as to the potential effects of the above results on wetlands of the state.

PROJECTED CHANGES IN CLIMATE AND PERMAFROST

Temperatures across the state are projected generally to increase by 2051-2060 as compared to the 1961-1990 baseline. Annual average temperature increases are projected to be most extreme in a roughly southeast gradient starting at the northwest coast of Alaska. Temperature increases range from 8.3 degrees F over much of the North Slope and the Seward Peninsula to about 3.7 degrees F in South East Alaska and the Aleutians (Larsen 2008). However, projections indicate that winter temperatures will increase considerably more than summer with average winter increases of 12 degrees F near Barrow, 11 to 10 degrees F for the remainder of the North Slope and 7 to 8 degrees F in the interior. Winter temperature increases decrease on a gradient towards South East Alaska. Model confidence is however, poor for temperature increases and model confidence follows a more or less southerly gradient from the North Slope at +/- 7 degrees to highest model confidence of +/- 2 degrees F in the interior and south east. Model confidence is

+/- 7 degrees F for much of the Slope where projections are most extreme (8.3 degree F increase) and +/- 2 degrees F in much of the interior and south east Alaska. Precipitation modeling is much less precise as equipment for measuring precipitation in winter are notoriously difficult to maintain. Precipitation rates are however, projected to increase across most the state. Summer precipitation is projected to increase by less than 1 inch to less than 1.5 inches over most of the North Slope and western coastal Alaska while summer precipitation is projected to increase 1.5 to 2 inches over the interior. Winter precipitation is also projected to increase similarly by approximately 1 to 2 inches over most of the State.

The seasonality of these changes are perhaps most significant. Estimates for the Arctic suggest shifts in seasonal temperatures will create earlier break-ups and later freeze-ups possibly increasing the open-water season by about a month by 2091-2100. The period of the year where air temperatures dip below 0 degrees F may only last for a little over a month as opposed to average baseline (1961-1990) condition with about a 5 month period of below 0 degrees F air temperatures. Precipitation, while projected to increase, will actually decrease during the hottest mid-summer months increasing during the transitional periods and during winter. Data suggest that we have already observed an increasing trend in the length of the growing season, although current length of the season only slightly exceeds those observed in the late 1920s in Barrow (Euskirchen 2008). Observations on the North Slope also suggest that in actuality precipitation has decreased in recent times (Shulski 2008).

Increases in air temperatures and the open water season coupled with the timing of increased precipitation ultimately are projected to lead to a drying in the Arctic. Estimates suggest that by 2040 the Arctic Coastal Plain will be about 10% drier and about 23% drier by 2080 (Larsen 2008). Estimates for the foothills are similar while estimates for the Brooks Range show a 35% drier condition by 2080. As a result wildfires will likely increase and have increased significantly even on the North Slope in recent years (Shulski 2008).

All of these factors combined are leading to large spatial scale warming of the wetland maintaining permafrost across the entire state and a thickening of the active layer in some areas (Romanovsky 2008). Areas of Interior Alaska are already showing some signs of areas where the active layer does not freeze back annually. Freeze back of the active layer on the North Slope has also been delayed in recent years. Generally, over the last 20 to 30 years, permafrost temperatures have increased 1 to 2 degrees C. There are areas that have shown no increase in temperature but there are no areas that have decreased in permafrost temperature over the preceding 20 to 30 years (Romanovsky 2008). Long term thawing has already begun in some locations. By 2050 2m depth permafrost temperatures across the state are projected to have warmed considerably with much of interior Alaska's annual mean permafrost temperatures warming to 0 to a few degrees below 0 C (Romanovsky 2008). Arctic permafrost also may have warmed considerably from the current -5 to -10 C mean annual temperatures to largely warmer than -5 C.

By 2100 all interior permafrost at the 2m depth will have an annual average temperature considerably above freezing; ultimately it will have become a thickened active layer at that depth. North Slope mean annual permafrost temperatures at the 2 m depth will also have warmed considerably and will hover between -2 C and +2 C. Mean annual permafrost temperatures on the Seward Peninsula will largely be above 0 C (Romanovsky 2008).

EFFECTS ON WETLANDS

Whatever magnitude of change occurs globally, it seems apparent that the Arctic and sub-Arctic regions have proceeded along an accelerated path of warming over the last decade and unless the pattern shifts, some degree of change is certain. Increased temperatures, growing seasons, and warmer winters are likely to interact to create a drier warmer climate in Alaska as it seems unlikely that the projected increased precipitation will exceed evapotranspiration over the longer thawed periods (Hassol 2004). Increases in permafrost temperatures and significant increases in active layer thickness are likely to occur statewide and will almost certainly be most extreme in the Interior, Arctic and Western Alaska; in which the vast majority of Alaska's wetlands exist. Greater than 90% of Alaska's wetlands are susceptible to changes in climate such as currently projected to occur over the next half century to century.

As active layer, temperature and thawed seasons increase, net drying of soils is likely to occur which will have effects on wetlands on the landscape level (Jorgenson 2008). However, intermediate effects on wetlands are tightly related to the current state of the land. Relatively dry wetland habitats and even uplands either will progress to shrub dominated habitats or, in areas of permafrost degradation, thaw to deep or shallow lakes. Through prolonged drying of lake and pond wetlands and erosion of lake/pond margins and paludification (accumulation of organics and shift to peat bogs), with associated acidification, lakes/ponds eventually progress to low productivity peat bogs and ultimately, over the long term, to shrubby tundra. The intermediate phases could consist of multiple wetland types of varying productivity. Existing lakes and ponds would also go through a similar process where by lakes would tap and drain to varying degrees bringing about the successional stages that lead to paludification and acidification and ultimately to a shrub dominated tundra (Jorgenson 2008a). The chemical properties of lakes and wetlands (and water ways in general) also could change as permafrost decreases and precipitation increases. Much of the Arctic coastal plain existed as an ancient sea bed and, as such, salt content of the frozen ground in areas is high. Salts would ultimately leach from the thawing material and increase surface water salinity (Jorgenson 2008a). Coupled with large scale paludification, some habitats on the North Slope are likely to acidify and become more saline. Ultimately, conditions will not support some of the more productive wetlands; arctophila fulva dominated emergent wetlands and their replacement with peat bog meadows and shrub would represent a significant loss of productivity in the ecosystem as a whole. However, over the near-term, wetland habitats will come and go. Some lakes and ponds will erode and undergo paludification and become less productive habitats but new lakes and ponds will also be formed. Nonetheless, a significant reduction in wetlands is probably likely in the long term. Changes on a landscape shift scale with respect to lakes are not expected for 8,000 years based on a 0.1% erosion rate per year (Jorgenson 2008b). However, the Arctic Climate Impact Assessment (ACIA) predicts the majority of the North Slope and portions of Western Alaska will be boreal forest habitat by 2090-2100 and that some of the western interior boreal forests will have progressed to tundra habitat; likely as a successional shift of existing forest to wetlands (Hassol 2004). Overall, significant portions of Alaska's wetlands are projected to convert to forest or shrub with even some potential for desertification. However, the ACIA vegetation predictions rely on only one climate model.

Successional changes of wetland types across the state are already beginning to occur in some places. Given the latitudinal expanse of Alaska we are in a unique position to predict what changes will occur in the near and long-term (Jorgenson 2008b). Wetlands in Northern Alaska

will tend to move towards wetland habitat types currently in existence in western Alaska, while western Alaska wetlands may tend towards interior Alaska wetlands types. Wetlands changes in the interior are more complex as many more types of wetland exist. However, it is likely that wetlands of the entire Interior would also progress to drier habitats, as is the case with fens conversion to near upland habitat types with only minor shifts in permafrost temperature. Klein 2005 (as summarized in Canada Institute for Scientific and Technical Information 2005), analyzed aerial photography of the Kenai Peninsula taken in 1950 and 1996 and documented that habitat shifts had already occurred there. Wooded areas on the peninsula had increased from 57 to 73% while wetlands decreased from 5 to 1% (Canada Institute for Scientific and Technical Information 2005). We can expect the landscape of Alaska, with respect to changes in wetlands, to progress towards those further south. Alaska is likely to have much lower overall land coverage in wetlands and likely would see an increase in forested wetlands on a statewide scale.

LIKELY IMPACTS ON FISH AND WILDLIFE RESOURCES

Translating the predictions for climate changes into predictions of effects on fish and wildlife resources is a major challenge. However, several impacts can be expected (Hassol 2004). If the declines in wetlands occur as projected, waterfowl dependent upon wetlands for reproduction and feeding could be negatively impacted. Other wildlife that depend upon wetlands could also be negatively impacted. Also, fishery resources that use wetlands as rearing habitats could be negatively impacted.

RESEARCH AND MONITORING

Emphasis should be placed on research and monitoring that focuses on the physical (mapping of existing wetlands and typing of those wetlands, water quantity, permafrost, icings, glaciers, erosion) and chemical (water quality) aspects of the state's wetlands. Basic **long term** water quantity and quality (pH, temperature, conductivity) measurements in specific regions (for example, cold permafrost, warm permafrost) and at specific sites should be started or continued (that is, use existing USGS gauging stations and expand these to include smaller drainages and wetland complexes). Emphasis should be placed on field data collection that is relatively simple, repeatable, cost effective, and done at predetermined intervals of time.

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MARINE HABITATS

PART 1: GULF OF ALASKA AND SOUTHERN BERING SEA

INTRODUCTION

This chapter presents a brief description of the nearshore marine environment of the Gulf of Alaska and southern Bering Sea as well as a proposal for monitoring and research by the Alaska Department of Fish and Game in response to potential impacts due to climate change. The geographic coverage extends from the Canadian border at Dixon Entrance in Southeast Alaska to Cape Pierce in the southern Bering Sea, including Bristol Bay and the Aleutian Islands chain. The nearshore environment is defined as state waters within 3 nautical miles of the shoreline.

ALASKA'S COASTAL MARINE ENVIRONMENTS

PHYSIOGRAPHIC SETTING

The nearshore marine environment from the eastern Gulf of Alaska to Bristol Bay and the Aleutian Islands encompasses a wide diversity in marine topography including estuaries, bays, unprotected coastlines, and open ocean over both the continental shelf and slope.

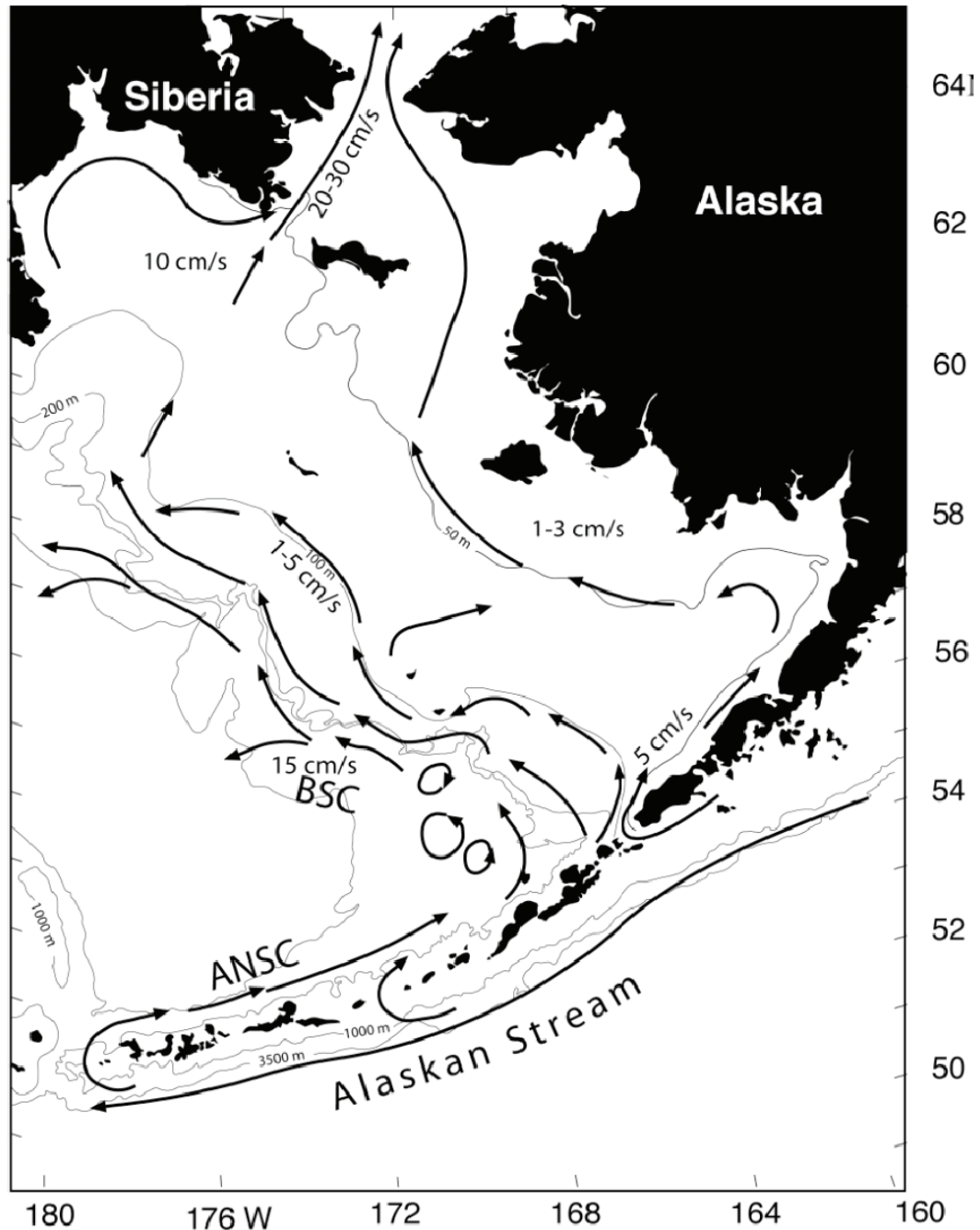
The Gulf of Alaska coast has a multitude of embayments and estuarine systems emptying into a continental shelf that is at its narrowest offshore of the Alexander Archipelago of Southeast Alaska. The shelf broadens off of Yakutat and reaches its greatest width on a broad sweep from Seward to the Shumagin Islands in the western Gulf, including the waters surrounding Kodiak Island. The Gulf coast from Yakutat to Kodiak has several large embayments and estuaries, including Yakutat and Icy Bays, the fjord complex in Prince William Sound, and Cook Inlet, including Kachemak Bay, all of which provide a mix of shallow and deep water habitats, typically with thick sediment deposits in the basins and rocky habitats on the flanks. Tidal mixing is often extreme, with mean tidal ranges as high as 9 m.

Bristol Bay and the nearshore waters of the southeastern Bering Sea are shallow continental shelf waters (Figure 1). There are huge submarine canyons dissecting the steep slope on the western fringe of the shelf. These canyons include Bering Canyon north of Unalaska Island, Pribilof Canyon southeast of St. George Island, and Zemchug Canyon far to the northwest (150 nm) of St. Paul Island, which rank among the largest canyons in the world (Normark and Carlson 2003). The Aleutian Islands chain is surrounded by steep marine topography, with a narrow continental shelf and continental slope waters (> 200 m depth) often within the 3 mile limit.

CLIMATE, CURRENTS, AND PRODUCTIVITY REGIMES

The often wet and windy weather of this region is largely attributable to the Aleutian Low, named for the area of recurring low pressure storms, typically centered over the Aleutian Islands, eastern Bering Sea, and Gulf of Alaska (Wilson and Overland 1986, Neibauer et al. 1999) that generally move from west to east. These low pressure systems are mainly generated by the

interplay of air masses and ocean waters in the western north Pacific, with stronger more intense systems in the fall and winter that generally intensify as they track east into the Gulf of Alaska, and with weaker systems in the summer that generally move on a more northerly course into the Bering Sea and Arctic Ocean (Weingartner 2005).



Note: ANSC = Aleutian North Slope Current; BSC = Bering Sea Slope Current. Modified from Stabeno et al. (1999).

Figure 1.—Schematic of mean circulation in the southeastern Bering Sea.

Currents play a major role in Alaskan waters carrying nutrients and plankton that in response to sunlight are the basis for marine productivity. Ocean currents in the Gulf of Alaska are driven largely by a counterclockwise circulation that starts with the subarctic current of the north Pacific moving eastward towards the British Columbia coast, where it splits into a northern branch called the Alaska Current and a southern branch called the California Current (Weingartner 2005; Figure 2). The Alaska Current is a wide sluggish offshore current that flows counterclockwise in the eastern Gulf, transforming into the swifter and narrower Alaskan Stream in the Central Gulf as it swings south of Kodiak and heads southwest offshore of the Alaska Peninsula and then out along the south side of the Aleutian chain. Significant flows from the Alaskan Stream move through many of the 14 main Aleutian passes, creating the North Aleutian Coastal Current, which heads back east along the north side of the chain towards Bering Canyon, north of Unalaska Island, where it swings northwest along the slope past the Pribilof Islands as the Bering Slope Current (Stabeno et al. 1999; Figure 1).

Inshore of the Alaska Current is the Alaska Coastal Current (ACC), which is typically confined to within 20 or so miles of the coast. This is a relatively swift current that moves north along the outside of the Alexander Archipelago (Southeast Alaska) past Yakutat, across as well as into the mouth of Prince William Sound, across the mouth of Cook Inlet, then southwestward through Shelikof Strait, down the south side of the Alaska Peninsula, and through Unimak Pass, where it turns east into Bristol Bay (Weingartner 2005, Stabeno et al. 1999).

The ACC is strongly affected by climatic interactions on land. There is an immense input of freshwater, coming largely from rainfall attributed to the moist ocean air hitting the tall coastal fringe of mountains in Southeast and Southcentral Alaska. The mean annual flow from this freshwater runoff has been estimated to be more than 20% larger than the average yearly flow of the Mississippi River (Royer 1982). The physical effect of the buoyant freshwater input is to push the ACC, enhancing its velocity and volume.

The counterclockwise winds in the Gulf of Alaska create an onshore movement of water via Ekman transport, resulting in a coastal downwelling of surface waters (Weingartner 2005). Downwelling systems are expected to be less productive compared to upwelling systems because nutrients are moved down away from the photic zone where they might otherwise be used by photosynthesizing plankton (upwelling zones are expected to be generally rich in nutrients brought up from bottom deposits).

Downwelling, as a factor that inhibits productivity in the Gulf of Alaska, may seem somewhat of a paradox, given that the Gulf of Alaska is a notably rich environment for fisheries. In fact, other factors are thought to be potentially important in delivering macro nutrients from the deep basin to the nearshore system. These include topographic steering, when water moves across submarine topography such as canyons and troughs, causing turbulence and uphill water movement carrying nutrients (Stabeno et al. 2004). Eddies are another potentially important factor, and appear as very large (over 100 miles wide) clockwise rotations of ocean waters, visible in satellite imagery, that typically form in the eastern Gulf of Alaska, often off of Sitka, may last for 2-3 years, and move with the general circulation from the eastern Gulf around towards Kodiak (Thompson and Grower 1998, Crawford and Whitney 1999). Although most of the eddies occur over the deep basin, those in contact with continental slope waters may, as they rotate (akin to a spiral galaxy), transport nutrients from the richer slope waters onto the shelf by onshore Ekman transport of nutrients (including nitrate) to the coastal waters. Another possible factor is the potential upwelling caused by strong along-shore winds. Known as border jets, these would be

strongest in fall and winter and would create upwelling on the shelf, offshore of the downwelling zone in the immediate vicinity of the coast (Stabeno et al. 2004).

The southeastern Bering Sea is a particularly rich ecosystem supporting enormous populations of marine birds and mammals as well as globally significant fisheries. The physical characteristics that promote this richness include the broad, shallow shelf and the transport of nutrients from the slope (shelfbreak) onto the shelf by upwelling due to tidal currents and eddies (Coachman 1986). The shelf is structured by water masses in 3 domains (coastal, middle and outer) separated by structural fronts: the inner front at about the 50 m isobath, the middle front at about the 80 to 100 m isobath, and the outer shelfbreak front at the 170 m isobath. Circulation on the Bering Sea shelf has relatively low net flows and large tidal forcing as compared to the Gulf of Alaska (NRC 1996).

The nearshore oceanography of the Aleutian Islands is remarkably different from the southeastern Bering Sea. This difference is largely attributable to the steep topography and the very narrow continental shelf surrounding these volcanic islands, which rise from the subduction of the northward moving Pacific plate under the North American plate. The marine ecosystem of the Aleutian Islands shows a discontinuity at Samalga Pass in the eastern end of the chain (roughly at 170° W longitude), with a change in species composition among cold-water corals, zooplankton, fish, marine mammals, and foraging seabirds from east to west (Hunt and Stabeno 2005). Productivity is potentially lower west of the pass, and there are implications for management, including responses of management to climate change (Schumacher and Kruse 2005). Hypotheses to explain the discontinuity include the greater depth of passes to the west relative to the east, the origins of water in the passes (the net northward flow through the passes is primarily from the Alaska Coastal Current, whereas the cooler and more saline Alaska Stream is predominant west of the pass), and the relative width of the continental shelf (narrower in the west). There is also a climate transition, such that the eastern Aleutian Islands experienced the 1977 regime shift towards a warmer climate (see below) that was not apparent in the central and western Aleutian Islands, which experienced a long-term cooling trend from 1956 - 2002 (Rodionov et al. 2005).

EVIDENCE OF PAST CLIMATE CHANGE AS INDICATORS OF FUTURE IMPACTS

GULF OF ALASKA

If past climate changes are an indication, future climate changes are likely to have significant impacts on nearshore marine environments because of the strong causal relationships between atmospheric pressure and temperatures, winds, ocean temperature and currents, and marine productivity.

For example, there have been significant responses of marine ecosystems to changes perceptible on multi-year scales, particularly on decadal scales. A “climate regime shift” beginning in 1977 in the Gulf of Alaska led to a reorganization of the marine ecosystem from being crustacean dominated to one dominated by groundfish (Anderson and Piatt 1999). The regime shift has been correlated with the Pacific (inter) Decadal Oscillation (PDO; Wallace et al. 1992), which is a statistical expression of anomalies (values greater or less than the average) in sea surface temperature and sea level pressure in the north Pacific. In effect, the ocean surface became warmer with stronger winds and has stayed that way for decades with a consequent change in the

community of marine fish and shellfish. The shift was apparent with the demise of the huge shrimp industry in the Central Gulf of Alaska in the 1980s. There was a subsequent transition to a predominance of groundfish (including walleye pollock, Pacific cod, and several flatfish species), and a drastic decline in forage fish, including capelin, well as a decline in Tanner and red king crab as seen in small mesh trawl surveys in the early 1990s.

The mechanisms by which climate change led to the observed regime shift in the north Pacific has received considerable attention, with several hypotheses but nothing conclusive. Francis et al. (1998) hypothesized that marine ecosystem changes in the north Pacific are driven largely by changes in atmospheric pressure in that spatial pressure gradients create air movements, hence winds, affecting horizontal and vertical water movements, surface layer mixing, and depth of the surface layer where phytoplankton production takes place. Specifically, the positive phase of the PDO, with higher winds, would speed up the subarctic gyre and the ACC, increasing Ekman pumping at the centre of the gyre (Brodeur et al. 1996). This would lead to increased upwelling and transport of nutrients, phytoplankton, and zooplankton towards coastal areas of the Gulf, and an increase in coastal production. Warmer waters would also promote a positive response in phytoplankton and zooplankton, leading to improved feeding and survival of juvenile salmon in nearshore marine and estuarine areas. (Mantua et al. 1997).

A potential explanation for this reorganization is based on the “match-mismatch” hypothesis (Cushing 1995), which suggests that strong recruitment of forage fish and shellfish depends on the emergence of their larvae at the same time (matching) the availability of their zooplankton prey. Larvae of shrimp, crab, and capelin emerge in late spring and early summer in the Gulf of Alaska, which was matched in time with zooplankton production during the cool period prior to 1977 (Anderson and Piatt). Under the warm regime after 1977, zooplankton populations bloomed 1 to 2 months earlier, which may have favored larvae of pollock and some flatfish species that spawn relatively early. Predation on forage fish and shrimp by growing populations of predatory groundfish may have contributed to the decline.

The shift from a cold to warm regime was correlated with a negative impact on fish eating seabirds and marine mammals (Anderson and Piatt 1999). The overall decline in biomass of forage species such as capelin was expressed by their disappearance from the diets of seabirds and marine mammals, including common murre and Steller sea lions, which subsequently declined in productivity and abundance.

The abundance of sockeye and pink salmon in Alaska is also well correlated with the PDO in the past century, with high production following the 1977 regime shift, and an earlier period of high production from 1925 to 1946 (Mantua et al. 1997). An opposite trend was seen in west coast (Washington, Oregon, and California) coho and Columbia River Chinook salmon catches.

Beginning in 2008, a switch in the PDO from warm back to cool sea surface temperature anomalies has been recently recognized along the Alaskan and northeast Pacific coasts (Buis 2008). This recent shift in the PDO is not expected to bring about a simple switch in fish and invertebrate populations back to pre-1977 conditions, given the realization that there is no predetermined stable state for a complex ecosystem composed of a multitude of organisms, each on their own trajectories in abundance and distribution through time in response to changing environmental conditions.

BERING SEA

Relatively warm conditions in the Bering Sea between 1982 and 2006, and the observed decline in coverage of first year sea ice has coincided with a generally northward shift in fish and invertebrate distribution on the continental shelf where the average displacement of 40 taxa was 34 km north (Mueter and Litzow 2008). The mechanism for this change is hypothesized to be a northward shift of cold bottom water known as the cold pool, which forms as the eastern Bering Sea ice melts in the spring. The average southern extent of the cold pool, which can extend to the mouth of Bristol Bay, had shifted approximately 230 km north (to a position north of the Pribilof Islands) since the early 1980s due to a northward retreat of the maximum southern extent of the seasonal ice edge. In effect, with the cold pool displaced to the north, what had been an arctic benthic community with low species diversity and few groundfish was replaced by a more diverse subarctic community “rich in groundfish.” As the cold pool moved north, so did the center of distribution of snow crab (Zheng et al. 2001, Orensanz et al. 2004, Zheng and Kruse 2006), and this northern shift is correlated with lower catches in the commercial harvest (Mueter and Litzow 2008).

Although formation of the cold pool is attributable to melting sea ice, and ice formation clearly requires sub-freezing temperatures, the annual southern extent of the ice edge under current conditions is largely attributable to the duration of northerly winds (P. Staben, PMEL, pers. comm.) that push the ice south from the mostly south-facing coasts where the ice forms in winter (Muench and Ahlnas 1976). The maximum southern limit of ice cover occurs in a melting zone of the warmer waters of the Bering Slope Current flowing along the shelfbreak from Bering Canyon northwest beyond the Pribilof Islands (Muench and Ahlnas 1976, Niebauer et al. 1999). Presumably, warming conditions would be expected to eventually impact the formation process of the seasonal ice cover in the Bering Sea.

While it is tempting to draw general conclusions from the findings of Mueter and Litzow (2008), they concluded that species-specific responses to warming will be hard to predict based on water temperature alone. The general northward shift in distributions of many fish, invertebrate, and plankton species under warmer ocean conditions was not true for all species, and there were other unexplained factors involved. Also, their results pertain to the particular situation of the marginal ice zone on the continental shelf of the eastern Bering Sea and cannot be directly transferred to other, even nearby, marine areas.

QUANTITATIVE PREDICTIONS OF CLIMATE CHANGE IMPACTS

BERING SEA

General predictions of continued warming in this century have strong implications for marine species and our dependence on the Alaskan marine environment. Average surface air temperatures are predicted to increase approximately 1 to 1.5° C in the next 10 to 20 years and by 3 to 4° C by the end of the century over the Bering Sea with slightly smaller increases over the Gulf of Alaska (IPCC 2007). Average predicted surface warming in the arctic is even greater at 4 to 7° C by the end of this century. In the Bering Sea, average wind speeds are not expected to increase in the next 30 to 40 years; however, average sea level pressure is expected to be somewhat lower, potentially leading to more summer storms in the Bering Sea (N. Bond, University of Washington, pers. comm.).

Translating the predictions for climate changes into predictions of effects on marine ecosystems is a major challenge that has not yet been met, but there are two significant efforts underway, one in the Bering Sea and the other in the Gulf of Alaska. The Bering Sea Integrated Ecosystem Research Program (BSIERP) of the North Pacific Research Board (NPRB) and the Bering Ecosystem Study (BEST) of the National Science Foundation (NSF) have been blended to develop ecosystem modeling capabilities for the southeastern Bering Sea. The joint program, now in its second of three field seasons, is both multi-agency and multi-disciplinary, with 94 principal investigators, a \$52 million budget, and a 6 year timeline. The goal is to be able to make reliable, quantitative predictions of the effects of climate change on major ecosystem components, using output climate scenarios from the IPCC's general circulation models. Predictions are to include status of oceanographic processes and major taxa including pollock, cod, forage fish, plankton, seabirds, whales, and people in traditional coastal communities.

The potential impact of climate regime changes on the timing of the spring melt of seasonal (first year) sea ice in the eastern Bering Sea is an important focus of the BSIERP and BEST programs. According to the "Oscillating Control" hypothesis (Hunt et al. 2002), a late ice retreat is favorable to an early phytoplankton bloom in cold water occurring prior to development of a zooplankton community that would otherwise graze down the phytoplankton. The result is that as the phytoplankton die, they sink to the bottom, enriching the benthic community. Early ice retreat (before mid-March) and the resulting open water allows more wind mixing of the surface layer moving phytoplankton deeper out of the photic zone. This delays the spring bloom to a later time (May or June) when winds have calmed and the water column can stratify with warmer surface temperatures, conditions allowing zooplankton populations to grow and to take advantage of the bloom. The enriched zooplankton stocks are then available to small fish, enriching the pelagic community at the expense of the benthos. Under this hypothesis, if climate change leads to earlier melting, the pelagic community, including pollock, will be favored over the benthic community, including Tanner, snow, and king crabs, as well as various flatfish. The hypothesis predicts that warm regimes will be more favorable to sustaining fisheries for large predatory fish such as pollock and Pacific cod.

GULF OF ALASKA

A program similar to BSIERP was initiated for the Gulf of Alaska with a request for proposals by the North Pacific Research Board in 2008, albeit with considerably less funding (circa \$8 million). The intent of this 6 year program is to determine how "*environmental and anthropogenic processes, including climate change, affect various trophic levels and dynamical linkages among trophic levels, with particular emphasis on fish and fisheries, marine mammals and seabirds within the Gulf of Alaska*"? There is a strong history of prior oceanographic and marine ecosystem research in the Gulf of Alaska (e.g., FOCI, GLOBEC, and EVOSTC funded projects¹), and the success of the new Gulf program is likely to depend on how well prior studies can be used to develop hypotheses and quantitative models. If successful, this program will provide quantitative models for predicting impacts of climate change on one or more upper trophic level species including important commercial fish species.

One of the current challenges to making meaningful predictions of climate change impacts on marine ecosystems is the problem of spatial scale. The climate change predictions presented in

¹ FOCI = Fisheries Oceanography Coordinated Investigations; GLOBEC = Global Ocean Ecosystem Dynamics; EVOSTC = Exxon Valdez Oil Spill Trustee Council

the IPCC's Fourth Assessment Report (AR4) are based on a suite of 23 coupled atmosphere-ocean model simulations with spatial grids of approximately 100 nm on a side (range of 0.2° to 4° latitude, and 0.3° to 5° longitude). This resolution is generally too coarse to show substantial coastline features such as the Kenai or Alaska Peninsulas. As a first step, climate scientists are in the process of statistically scaling down the low resolution predictions to finer scales to provide preliminary indications of likely changes in ocean conditions that are important to marine organisms (Nicholas Bond, Univ. of Washington, pers. comm.). More direct simulations (dynamical downscaling) are also under development, using IPCC climate scenarios as input to regional ocean simulations with biological linkages to produce more explicit predictions of effects on marine life.

ALEUTIAN ISLANDS

Projected impacts of climate change in the Aleutian Islands marine ecosystem were summarized by Schumacher and Kruse (2005) as: (1) less severe but more frequent storms that are warmer and wetter, and (2) the volume of the Alaskan Stream flowing into the Bering Sea will decrease, but the volume flow of Alaska Coastal Current is likely to increase due to more precipitation in the Gulf of Alaska and adjacent coastal areas. As marine waters become warmer, the species of plants and animals is likely to shift from a subarctic to a more temperate composition.

INVASIVE SPECIES

Warming oceans, particularly in coastal waters, may facilitate the northward movement and colonization of invasive species into Alaska, allowing species to colonize habitats that might be outside of their temperature tolerance ranges. For example, recruitment of invasive sea squirts was enhanced with warmer minimum winter temperatures in New England waters (Stachowicz et al. 2002). There are potential and actual invasive species in the NE Pacific representing a variety of taxa. Marine species of immediate concern for Alaska include Atlantic salmon (*Salmo salar*), green crabs (*Carcinus maenas*), Chinese mitten crabs (*Eriocheir senensis*), and salt marsh cordgrasses (*Spartina alterniflora* and *S. densiflora*) as well as sea squirts (*Didemnum* sp.) which have been colonizing and overtaking patches of subtidal areas in British Columbia.

OCEAN ACIDIFICATION

BACKGROUND

As a result of industrial and agricultural emissions, carbon dioxide concentrations in the atmosphere have increased 100 parts per million in the past 250 years to the current level of 380+ ppm, which is higher than has been estimated to have occurred for at least the past 650,000 years (Siegenthaler et al. 2005). Approximately one-third of the anthropogenic carbon emissions in that time have been absorbed by earth's oceans (Feely et al. 2008). While this uptake by the oceans has been beneficial in that the carbon emissions would otherwise have added to greenhouse gas concentrations, increasing "ocean acidification" and the reduction in carbonate ion concentrations are likely to have serious consequences evident this century.

The pH of ocean surface waters is estimated to have decreased by 0.1 units (becoming more acidic) to a current average pH of 8.1 since the beginning of the industrial revolution (Feely et al. 2004, Gazeau et al. 2007) with a potential further decrease of 0.4 by 2100 (Orr et al. 2005). Increasing acidity may inhibit physiological processes, including growth, particularly in

invertebrates (Pörtner 2008); however, little is known about potential effects on fish (Ishimatsu et al. 2008).

Surface waters of the ocean are currently saturated with respect to calcium carbonate, which is essential for shell and external skeleton formation in organisms such as corals, shellfish (e.g., clams, scallops, and oysters), echinoderms (e.g., sea urchins and sea stars), and some plankton. However, as carbonate concentrations decline (that is, as the depth of undersaturation becomes shallower), which has been documented for the North Pacific (Feely et al. 2004), these organisms will have difficulty building and maintaining their external calcium carbonate shells and skeletons (Orr et al. 2005). Projections for the Southern Ocean indicate that surface waters will begin to become undersaturated with calcium carbonate by 2050, and that by 2100, the subarctic Pacific Ocean may be undersaturated as well. The depths of North Pacific saturation horizons (the depth below which carbonate is undersaturated) are already among the shallowest in the world (Feely et al. 2004) and the effects of ocean uptake of anthropogenic CO₂ have already increased the extent of the affected areas along the west coast of North America (Feely et al. 2008).

POTENTIAL IMPACTS IN ALASKA

Ocean acidification and decreased calcium carbonate concentrations may have serious impacts arising from losses low on the food chain that are amplified by reductions to upper trophic levels. An example would be the dissolving effect on pteropods, a pelagic invertebrate that is an important food for juvenile salmon, including pink salmon during their ocean life phase. In a three year study by Armstrong et al. (2005), more than 60% by weight of the diet of juvenile pink salmon was comprised of a single pteropods species (*Limacina helicina*). Pteropods are known to be highly sensitive to ocean acidification because their shells are highly soluble and will dissolve in undersaturated conditions (Fabry et al. 2008). Experimental exposures of live pteropods to predicted levels of undersaturation indicated that conditions detrimental to high-latitude ecosystems could develop within decades (Orr et al. 2005). There may also be physiological effects on non-calcifiers, including, for example, inhibition of nutrient uptake in phytoplankton with subsequent effects on overall marine productivity.

Given that the impact of lower calcium carbonate saturation is expected to occur first in deep waters, we would expect that initial impacts might be seen in the rich communities of deep sea corals. This could have a large and initially unobserved impact, particularly in the Aleutian Islands region as well as in the Gulf of Alaska, where deep water corals provide structural habitat to rockfish, crabs, and other species (Heifetz et al, 2007).

RESEARCH AND MONITORING

The conclusion one can draw from this review is that it is not possible to make definitive quantitative forecasts of changes in fish and wildlife populations in response to climate change in Alaska's marine environments. However, we can predict with confidence that there will be significant changes in both distributions and local abundances of many marine species, due at least to climatic changes of the magnitude seen historically, and as potentially modified by directional changes in climate.

Given that these changes are likely to have important impacts on the ecosystems and the people who depend on the marine environment for subsistence, commerce, and recreation, ADF&G proposes to design and implement a statewide marine monitoring program to provide timely

information on the status of the marine environment and of those fish and wildlife species for which the department has trust responsibilities. Recognizing that other agencies, primarily federal and tribal, also have interests and responsibilities in this realm, ADF&G will engage those entities to identify the important needs and gaps in data collection, and to avoid duplication of effort. ADF&G is uniquely positioned for a statewide monitoring effort due to the coastwide distribution of professional staff and facilities. Statewide monitoring efforts that we undertake could be significantly enhanced by partnering with stakeholders, particularly those in coastal villages.

The Alaska Ocean Observing System (AOOS) is poised to become the lead agency in coordinating marine monitoring activities in Alaska, but has only limited funding at this time. ADF&G is a partner with AOOS and will work with AOOS in coordinating our monitoring efforts with other entities, particularly with the Alaska Fishery Science Center of the National Marine Fisheries Service, which is developing an ocean acidification program for the north Pacific and Bering Sea.

Specific monitoring activities that we recommend at this time include:

- Statewide pH and pCO₂ measurements in coastal locations,
- Statewide monitoring of shell formation attributes of commercial shellfish
- Invasive species monitoring (already in place on a limited extent) focusing on Southeast Alaska and major ports in the Gulf of Alaska,
- Northern Bering Sea and Arctic coast salmonid distribution monitoring (already in place on a limited basis),
- Statewide sampling of coastal (including estuarine) waters for forage fish (e.g., capelin, sandlance, eulachon, arctic and saffron cods) and for juvenile fish, and
- Expansion of small mesh trawl surveys to a statewide basis, conducted in a manner similar to those that have been conducted in the Kodiak and western Gulf of Alaska since the 1950s.

These activities are in addition to the annual stock assessments now conducted regionally for herring, salmon, groundfish, various crab species, and miscellaneous shellfish (scallops, geoducks, urchins, and sea cucumbers).

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MARINE HABITATS

PART 2: CHUKCHI AND BEAUFORT SEAS

INTRODUCTION

This chapter presents a brief description of the nearshore marine environment of the Chukchi and Beaufort Seas as well as an identification of likely impacts to these environments from climate change and recommended monitoring and research by the Alaska Department of Fish and Game in response to potential impacts due to climate change. The geographic coverage includes the nearshore environment defined as state waters within 3 nautical miles of the shoreline.

ALASKA'S ARCTIC COASTAL MARINE ENVIRONMENTS

PHYSIOGRAPHIC SETTING

The nearshore marine environment from the Chukchi and Beaufort Seas encompasses a seasonally ice affected environment. Ice is present from November through June, with open water or broken ice being the norm the remaining period. A diversity in marine topography is present including bays, unprotected coastlines, and open ocean over both the continental shelf and slope.

CLIMATE, CURRENTS, SEA ICE AND PRODUCTIVITY REGIMES

Much of this area is north of the Arctic Circle. Thus, climate is affected by seasonal tilts of the earth. Summer months experience 24 hours of sun with cool temperatures. This contrasts with the winter months which are dark and cold. Springs and falls are short with rapid climate transitions. According to a University of Guelph study of Arctic Ocean currents (www.aquatic.uoguelph.ca/oceans/ArcticOceanWeb/Currents/frontpagecur.htm):

Generally, the surface waters of the Arctic Ocean circulate in a large clockwise rotational pattern moving from east to west around the polar ice cap. This rotating pattern, known as a gyre, occurs as a result of the clockwise winds that typically occur in this region. Only surface waters are exchanged via ocean currents because towering submarine ridges prevent the exchange of very deep waters. The lack of movement in the deep waters has caused a stagnant pool of very cold water to accumulate at the bottom of the Arctic Basin.

Known as the Beaufort Gyre, the Arctic current slowly swirls the surface waters of the Arctic basin, turning the Polar Ice Cap along with it, making one complete rotation about every 4 years.

The other predominant current in the Arctic Ocean, the transpolar drift stream. This stream carries water and ice from Siberia, across the pole and down the east coast of Greenland, joining the East Greenland current. This current flows in response to input from Siberian rivers, and a predominant westerly wind that pushes Arctic surface water eastward into the Atlantic.



Figure 2.–The main currents in the Arctic.

Source: Dr. P. D. N. Hebert project leader, University of Guelph, Ontario Canada. Canada's Aquatic Environments.

Within these general circulation patterns, several currents are also present. A strong west-to-east cold current flows along the north shore of Alaska, from the Chukchi Sea into the Beaufort Sea.

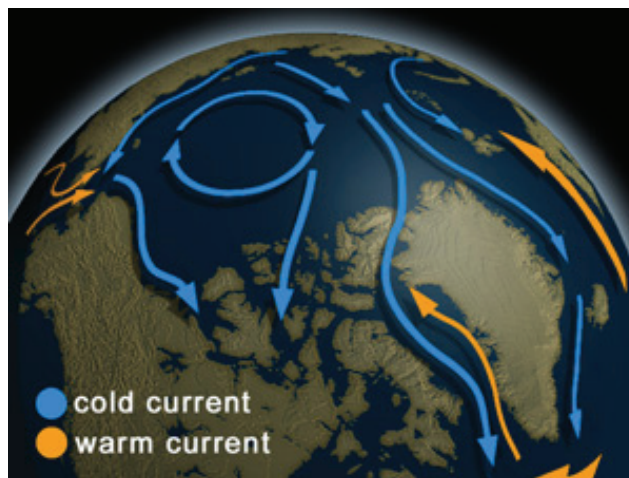


Figure 3.–Ocean currents and direction of movement, Northern Hemisphere.

Source: Dr. P. D. N. Hebert project leader, University of Guelph, Ontario Canada. Canada's Aquatic Environments.

A warm northerly current flows along the northwestern shores of Alaska. The sea ice is described by Maria Włodarska-Kowalczyk (www.marbef.org/wiki/Arctic_Ocean):

The polar halocline isolates surface water masses and sea-ice from warm deep water and thus acts as a determining factor for the existence of all-year sea ice cover. The ocean's interior is all year covered with perennial (multi-year) pack ice, while seasonal (first-year) ice-cover is formed on the marginal seas (including the Chukchi and Beaufort Seas) from October to June. The spatial extent of sea ice varies from 14-15 mln km² in March to 5-6 mln km² in September.

In 2007, a record minimum low occurred in the Arctic, with just over 4 mln km² being present.

The average thickness of sea ice in the Arctic Ocean is about 3 m. Land-fast ice (up to 2 m in thickness) grows seaward from the shore and usually extends to the 20 m isobath. Two forms of open water areas can occur in the winter ice-cover: 1) flaw lead systems – discontinuities between the land-fast ice and off-shore sea-ice or 2) polynyas – where ice is carried away by winds or currents or melted by the local convection of warm deep water masses. The Global Change Research Information Office (www.gcric.org/UNEP1998/UNEP98p42.html#T4) states:

The Arctic Ocean is a nearly closed water mass with limited water exchange with the Atlantic and Pacific oceans. It represents 25% of the global continental shelf and receives about 10% of the world river discharge. This considerable freshwater inflow causes pronounced stratification year round and is responsible for high concentrations of particulate and dissolved organic carbon.

The plumes of major rivers can be traced several hundred kilometers into the Arctic Ocean.

The Arctic marine ecosystem is seasonally very productive. The sea-ice edge and associated ecosystems contribute about 40-50% of the total annual productivity. Both endemic and migratory species breed and reproduce in these areas in the early spring and summer. In addition, many species of fish and shellfish are present in nearshore areas. Many of the eggs and early larval stages are found at or near the surface. Species of note that are present are shown in Table 1.

PREDICTIONS OF CLIMATE CHANGE IMPACTS

General predictions of continued warming in this century have strong implications for marine species in the Chukchi and Beaufort Seas. Average surface air temperatures are predicted to increase approximately 1 to 1.5°C in the next 10 to 20 years and by 3 to 4°C by the end of the century over the Bering Sea with slightly smaller increases over the Gulf of Alaska (Hassol 2004). Average predicted surface warming in the arctic is even greater at 4 to 8°C by the end of this century. Precipitation is also expected to increase from 6-20% over this period (Hassol 2004).

Translating the predictions for climate changes into predictions of effects on marine ecosystems is a major challenge. However, several impacts can be expected (Hassol 2004). As sea ice conditions change, marine species dependent upon sea ice, including ice-dependent seals, walrus, polar bears, and some marine birds will be impacted to varying degrees. As temperatures increase, the ranges of some plant and animal species may shift northward, which may impact endemic species. Changing ocean salinity may impact oceanic productivity and the dependent marine life. Changes in wind patterns may also increase the presence of toxins throughout the Arctic. This has the potential of impacting species higher on the food chain, such as top level predators. Warming temperatures could also increase disease vectors.

Besides have direct impact on the species themselves, these impacts could also affect uses that are supported by the affected resources. Many local communities along the Arctic coast are dependent upon subsistence fishing and hunting. These climate impacts have the potential of impacting subsistence uses.

While most impacts are projected to be negative, some may be positive. New opportunities may become available due to climate changes. For example, fishing opportunities may be available as ice diminishes or species distributions shift northward.

RESEARCH AND MONITORING

The conclusion one can draw from this review is that it is not possible to make definitive quantitative forecasts of changes in fish and wildlife populations in response to climate change in Alaska's arctic marine environments. However, we can predict with confidence that there will be significant changes in both distributions and local abundances of many marine species, due at least to climatic changes of the magnitude seen historically, and as potentially modified by directional changes in climate.

Given that these changes are likely to have important impacts on the ecosystems and the people who depend on the marine environment for subsistence, commerce, and recreation, ADF&G proposes to design and implement an arctic marine monitoring program to provide timely information on the status of the arctic marine environment and of those fish and wildlife species for which the department has trust responsibilities. Recognizing that other agencies, primarily federal and tribal, also have interests and responsibilities in this realm, ADF&G will engage those entities to identify the important needs and gaps in data collection, and to avoid duplication of effort. ADF&G is uniquely positioned for a statewide monitoring effort due to the coastwide distribution of professional staff and facilities. Statewide monitoring efforts that we undertake could be significantly enhanced by partnering with stakeholders, particularly those in coastal villages.

The Alaska Ocean Observing System (AOOS) is poised to become the lead agency in coordinating marine monitoring activities in Alaska, but has only limited funding at this time. ADF&G is a partner with AOOS and will work with AOOS in coordinating our monitoring efforts with other entities, particularly with the Alaska Fishery Science Center of the National Marine Fisheries Service.

Specific monitoring activities that we recommend at this time include

- Statewide pH and pCO₂ measurements in arctic coastal locations to assess ocean acidification;
- Invasive species monitoring (already in place on a limited extent) focusing on arctic environments;
- Arctic coast salmonid distribution monitoring (already in place on a limited basis);
- Monitoring of ice-dependent species to assess responses to changing sea-ice conditions;
- Assessment of responses of marine birds to changing environmental conditions; and,
- Assessment of fishery resources in the Chukchi and Beaufort Seas.

These activities are in addition to the annual stock assessments now conducted regionally for marine mammals and fish species.

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TUNDRA ECOSYSTEMS

BACKGROUND

The Background section below is reproduced from Appendix 5.2 of *Our wealth maintained: a strategy for conserving Alaska's diverse wildlife and fish resources*, Alaska Department of Fish and Game (2006).

Tundra refers to a cold-climate landscape that has vegetation but is devoid of trees. The absence of trees is typically related to regional climatic conditions. Alaska has 3 major types of tundra that can be generally described by the topographical and geographical location in which they occur. They include: 1) Arctic (high latitude) tundra, 2) alpine (high altitude) tundra, and 3) the maritime tundra present on Alaska's western and southwestern coast. The dominant plant species of tundra habitats are sedges, low and dwarf shrubs, and graminoids interspersed with forbs, in addition to mat and cushion-forming plants and scattered bryophytes (nonvascular plants).

Alaska's tundra climates are characterized by a short growing season, long, cold, dark winters, and low precipitation with strong, bitter, dry winds. Snow accumulation, where present, provides an insulating layer to the ground surface benefiting plant and animal communities. The number of plant species on the tundra is few, and their growth is minimal, with most of the biomass concentrated in the root system. Due to the short growing season, plants often reproduce by division, in addition to seed production.

Arctic Tundra

Arctic tundra is generally distributed above the latitudinal tree line in Alaska. This is the area from the crest of the Brooks Range northward to the Arctic Ocean known as the Arctic Slope. The Arctic Slope includes the north side of the mountains, northern foothills, and the flat coastal plain; it is the only truly Arctic biogeographic province in the United States. As a result of the Arctic region's high latitudinal position, it experiences less intense solar radiation and an exaggerated seasonal variation. Arctic tundra persists under cold air conditions originating off the permanent sea ice pack. This air has low moisture-holding capacity combined with minimal precipitation. The dominant vegetation type across the foothills and much of the coastal plain is tussock tundra, with willows in the small drainages, wet sedge tundra in old drained lakes, and *Dryas* tundra on drier ridges. Tussocks are formed of cottongrass and other sedges and forbs, with scattered dwarf shrubs. Prostrate woody shrubs, mosses, sedges, and lichen cover the mountainsides and valleys. The flat areas of the coastal plain are sporadically covered with small thaw lakes and ponds and rock polygons. These landforms are due to a continuous layer of underlying permafrost. Ice-rich permafrost is an important feature of Alaska's landscape that is not found elsewhere in the United States (Batten 1986). Trees are generally unable to establish in Arctic tundra habitats due to an underlying impermeable permafrost layer complemented by thin soils. These thin tundra soils trap moisture, holding it close to the surface, creating a tundra complex of wet and dry habitats. Relative to other locations of the state, regions where Arctic tundra habitat exists receive less annual snow and

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rainfall—less than 20 inches annually (Interagency Arctic Research Policy Committee 2002).

Arctic tundra plant communities found in mesic (dry) and hydric (wet) soil conditions include wet graminoid herbaceous types dominated by sedges or grasses. Areas of drier soils along the riverbanks, lakes, and coastal bluffs support dwarf scrub communities.

Typical mesic sedge communities are dominated by the water sedge (*Carex aquatilis*) and tall cottongrass (*Eriophorum angustifolium*). Mosses, usually consisting of *Scorpidium* spp. or *Drepanodadus* spp., may be common. Grass communities are dominated by tundra grass (*Dupontia fischeri*) and alpine foxtail (*Alopecurus alpinus*), with the emergent pendent grass (*Arctophila fulva*) prevailing where surface water is 15–200 cm deep.

Common dwarf scrub communities found in the more xeric (desert-type) soils of the Arctic tundra include entire-leaf mountain-avens (*Dryas integrifolia*), mountain-cranberry (*Vaccinium vitis-idaea*), four-angled cassiope (*Cassiope tetragona*), bearberry (alpine bearberry [*Arctostaphylos alpina*] and red-fruit bearberry [*A. rubra*]), and prostrate willows (netleaf willow [*Salix reticulata*] and skeleton leaf willow [*S. phlebophylla*]).

In addition, mesic graminoid herbaceous communities dominated by tussock-forming sedges are widespread. Typical species include tussock cottongrass (*Eriophorum vaginatum*) and bigelow sedge (*Carex bigelowii*).

Low shrubs, such as dwarf arctic birch (*Betula nana*), crowberry (*Empetrum nigrum*), narrow-leaf Labrador tea (*Ledum decumbens*), and mountain-cranberry (*Vaccinium vitis-idaea*) are frequently present and may be codominant with sedges. Mosses, such as the feather moss, *Hylocomium splendens*, and *Sphagnum* spp., as well as lichens, such as *Cetraria cucullata*, *Cladonia* spp., and reindeer lichen (*Cladina rangiferina*), are common between tussocks. Dwarf scrub communities are dominated by mat-forming *Dryas* species and ericaceous species, for example, blueberry (*Vaccinium* spp.), four-angled cassiope (*Cassiope tetragona*), bearberry (*Arctostaphylos* spp.), and prostrate willows (netleaf willow [*Salix reticulata*] and skeleton leaf willow [*S. phlebophylla*]). Open low scrub communities are codominated by the American green alder (*Alnus crispa*) and willows (Richardson willow [*Salix lanata*], diamond leaf willow [*S. planifoli*], and gray leaf willow [*S. glauca*]). Mosses (*Tomenthypnum nitens* and *Drepanocladus* spp.) may be common.

In the valley and lower hill slope areas, the drier, xeric soils support dwarf scrub communities, while mesic, graminoid, herbaceous communities inhabit the wet to mesic soils. Dwarf scrub communities are dominated by ericaceous species; an example community would consist of alpine bearberry (*Arctostaphylos alpina*), red-fruit berry (*A. rubra*), blueberry (*Vaccinium* spp.), narrow-leaf Labrador tea (*Ledum decumbens*), crowberry (*Empetrum nigrum*), four-angled cassiope (*Cassiope*

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tetragona), mountain-avens (white mountain-avens [*Dryas octopetala*] and entire-leaf (*D. integrifolia*)), and willows, such as least willow (*Salix rotundifolia*), arctic willow (*S. arctica*), and polar willow (*S. polaris*).

Herbaceous species (*Carex* spp., for example) and fruticose lichens, such as *Cladina* spp. and *Cetraria* spp., may codominate with shrubs in some of these areas.

Graminoid, herbaceous communities of the Arctic tundra are dominated by sedges (e.g., water sedge [*Carex aquatilis*] and bigelow sedge [*C. bigelowii*]) and willows (e.g., diamondleaf willow [*S. planifolia*] and Richardson willow (*S. lanata*)). Mosses (e.g., *Tomenthypnum nitens*, *Distichium capillaceum*, *Drepanocladus* spp., and *Campylium*

stellatum) are often abundant (Gallant et al. 1995). Other common mosses making up Arctic tundra vegetation include *Tomentypnum nitens*, *ditrichum* moss (*Ditrichum flexicaule*), *distichium*



Arctic tundra

G. Carroll, ADF&G

moss (*Distichium capillaceum*), and *Hypnum bambergeri* (Muller et al. 1999; Kade et al. 2005), as well as reindeer mosses (*Cladonia rangiferina*, *C. stellaris*). *Cetraria* lichens (*Cetraria cucullata*, *C. islandica*) are also prevalent in drier locations.

The Arctic tundra is represented by a low diversity of plant species and low plant biomass. These characteristics, combined with a short growing season, slow rates of growth, and vegetative reproduction, result in delayed recovery from disturbance (Oceanographic Institute of Washington 1979).

Arctic Tundra-associated Species

Snowy Owl, *Nyctea scandiaca*
Gyr Falcon, *Falco rusticolus*
Rough-legged Hawk, *Buteo lagopus*
Peregrine Falcon, *Falco peregrinus*
King Eider, *Somateria spectabilis*
Long-tailed Duck (Oldsquaw),
Clangula hyemalis
Yellow-billed Loon, *Gavia adamsii*

Smith's Longspur, *Calcarius pictus*
Spectacled Eider, *Somateria fischeri*
Steller's Eider, *Polysticta stelleri*
Buff-breasted Sandpiper, *Tryngites subruficollis*
Brown lemming, *Lemmus trimucronatus*

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Alpine Tundra

Alpine tundra occurs above tree line elevations in mountain ranges and exposed ridges in Alaska. Major mountain ranges of Alaska include the Alaska, Brooks, and Chugach ranges. Numerous, smaller ranges also occur throughout the state. At these higher elevations, the landscape is increasingly broken by rock outcroppings. Plant communities consist of prostrate, mat and cushion-forming species and shrubby species that are intermittent in their distribution. Barren and lichen-covered rocky areas are dominated by *Dryas* (mountain-avens) and mountain-heath communities. These plants are adapted to the scouring high winds and widely ranging temperatures of high elevation alpine regions. Due to steep slopes and relatively thin soils at the higher elevations, areas of alpine tundra lack trees and may or may not have permafrost.



Alpine tundra, McNeil River State Game Refuge D. Tessler, ADF&G

Alpine tundra transitions at lower elevations to subalpine forests or meadows and treeline habitats. In many areas, the subalpine region is a broad band where small islands of stunted trees are confined to sheltered sites. Subalpine plants represent the first distinctive type of vegetation below the alpine tundra. The transition to alpine tundra begins with communities dominated by shrubs, heaths and related families. Regeneration of alpine tundra plant species is often very slow following damage by fire or other disturbance.

Mountain-heath dwarf shrub communities are dominated by *Phyllodoce* spp. Associated dwarf shrubs include mertens cassiope (*Cassiope mertensiana*), starry cassiope (*C. stelleriana*), luetkea (*Luetkea pectinata*), bog blueberry (*Vaccinium uliginosum*), and dwarf blueberry (*V. caespitosum*). Many herbs including nootka lupine (*Lupinus nootkatensis*), Sitka valerian (*Valeriana sitchensis*), and roseroot (*Sedum rosea*) may also occur.

Dryas communities are dominated by species of the genus *Dryas* and codominated by dwarf shrubs, ericads, sedges or lichens. Common dwarf shrubs include ericaceous species, such as mountain-cranberry (*Vaccinium vitis-idaea*), bog blueberry (*V. uliginosum*), four-angled cassiope (*Cassiope tetragona*), crowberry (*Empetrum*

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nigrum), narrow-leaf Labrador tea (*Ledum decumbens*), alpine bearberry (*Arctostaphylos alpina*), red-fruit bearberry (*A. rubra*) and Alaskan cassiope (*S. lycopodioides*), and prostrate willows, such as netleaf willow (*Salix reticulata*) and skeletonleaf willow (*S. phlebophylla*). Other common dwarf willows include least willow (*S. rotundifolia*), polar willow (*Salix polaris*), and arctic willow (*S. arctica*). Common graminoids and herbs of the alpine *Dryas* tundra include meadow bistort (*Polygonum bistorta*), fescue grass (*Festuca altaica*), woodrushes (*Luzula* spp.), alpine holygrass (*Hierochloa alpina*), sandwort (*Minuartia* spp.), *Carex microchaeta*, northern single-spike sedge (*C. scirpoidea*), sedge (*Carex* spp.), black oxytrope (*Oxytropis nigrescens*), saxifrage (*Saxifraga* spp.), downy oatgrass (*Trisetum spicatum*), vetch (*Hedysarum* spp.), Arctic bluegrass (*Poa arctica*), and anemone (*Anemone* spp.). Mosses, such as moss-campion (*Silene acaulis* subspecies), *Tomenthyphnum nitens* and *Racomitrium* spp., *Dicranum* spp., and *Aulacomnium* spp., may be common. Lichens, such as *Cetraria cucullata*, *Cetraria* spp., *Cladina alpestris*, reindeer lichen (*Cladonia rangiferina*), *C. alpestris*, *Sphaerophorus globosus*, *Thamnolia* spp., and *Sterocaulon* spp., may also be common.

Dryas-sedge communities may be codominant with *Carex* spp., such as northern single-spike sedge (*Carex scirpoidea*), short-leaved sedge (*C. misandra*), and bigelow sedge (*C. bigelowii*), as well as *Kobresia myosuroides* and others. Common mosses, including *Tomenthyphnum nitens*, *Rhytidium rugosum*, and feathermoss (*Hylocomium splendens*), occur with fruticose lichens, such as *Cladonia* spp. and *Cetraria* spp.

Dryas communities codominated by lichens include *Alectoria* spp., *Cetraria* spp., *Cladina* spp., and worm lichen (*Thamnolia vermicularis*). Mosses, including *Tomenthyphnum nitens*, *Racomitrium* spp., and *Polytrichum* spp., may grow within *Dryas* mats (Vierick et al. 1992; Vierick et al. 1972).

Alpine Tundra-associated Species

Golden Eagle, *Aquila chrysaetos*
Rough-legged Hawk, *Buteo lagopus*
Barrow ground squirrel, *Spermophilus parryi kennicottii*
Alaska marmot, *Marmota broweri*
Glacier Bay marmot, *Marmota caligata vigilis*
Bristle-thighed Curlew, *Numenius tahitiensis*
Gyr Falcon, *Falco rusticolus*

Aleutian and Bering Sea Islands Endemic Species

Rock Ptarmigan (*Lagopus mutus evermanni*, *L. m. townsendi*, *L. m. atkensis*)

Maritime Tundra

Maritime tundra (or heath) is present along the coastal areas of southwestern Alaska and the western Alaska Bering Sea Islands. It is the product of the cool and damp climate generated by the cold waters of the Bering Sea. Seasonal weather patterns produce relatively milder winters, cooler summers and relatively high humidity. A gradual transition occurs from maritime to Arctic tundra in the region of Kotzebue

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Sound, and a transition from maritime to alpine tundra occurs where mountains extend into the region. Uplands and mountain slopes support mosses, lichens, and prostrate alpine plants, while lower areas are covered with herbaceous forbs. The latitudinal location, combined with the maritime climate and increased precipitation, generally defines and distinguishes this tundra from Arctic and alpine tundra types.

Maritime tundra is dominated by prostrate heath-scrub type communities interspersed with grass and forb meadows, with willows and alders present in the protected swales. Common

heath species include primarily crowberry (*Empetrum nigrum*), along with bog blueberry (*Vaccinium uliginosum*), mountain cranberry (*Vaccinium vitis-idaea*), and alpine azalea (*Loiseleuria procumbens*).



Southwest Aleutian maritime tundra

ADF&G

Grass and forb meadows composed of

mesic, graminoid, herbaceous communities are dominated by tussock-forming sedges in some areas, or by bluejoint, which forms meadows with codominant herbaceous species, such as sedges (*Carex* spp.), cottongrasses (*Eriophorum* spp.), and fireweed (*Epilobium angustifolium*). Mosses, such as *Pleurozium schreberi*, *Hylocomium splendens*, *Aulacomnium* spp., and *Sphagnum* spp., are abundant with common lichens, including *Cetraria cucullata*, *C. islandica*, *Cladonia* spp., reindeer lichen (*Cladina rangiferia*), and *Thamnolia subuliformis*.

Dwarf scrub communities of the maritime tundra are composed of low shrubs, grasses, and lichens. Communities are dominated by mountain-avens (*Dryas octopetala* and *D. integrifolia*) or codominated by a combination of mountain-avens and sedges (northern sickle-spiked sedge [*Carex scirpoidea*], short-leaved sedge (*C. misandra*), and bigelow sedge (*C. bigelowii*) or mountain-avens and lichen, for example, *Alectoria* spp., *Cetraria* spp., and *Cladina* spp. Other typical shrubs occurring in these communities are prostrate willows (netleaf willow [*Salix reticulata*] and skeletonleaf willow [*S. phlebophylla*]) and ericaceous species, such as four-angled cassiope (*Cassiope tetragona*), crowberry (*Empetrum nigrum*), bearberry (*Arctostaphylos* spp.), mountain-cranberry (*Vaccinium vitis-idaea*), and bog blueberry (*V. uliginosum*). Herbs, such as sedges (*Carex* spp.) and saxifrage (*Saxifraga* spp.),

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and mosses, including *Dicranum* spp., *Hypnum* spp., *Polytrichum* spp., *Rhacomitrium* spp., and *Aulacomnium* spp., are common. Lichens, including *Alectoria* spp., *Cladonia* spp., *Cladina* spp., and *Cetraria* spp., are also typical. Other mosses, such as *Tomethypnum nitens*, and *Rhytidium rugosum*, may be common.

Tall scrub communities are dominated by willows, including feltleaf willow (*Salix alaxensis*), diamondleaf willow (*S. planifolia*), and grayleaf willow (*S. glauca*). Also common are alders, such as American green alder (*Alnus crispa*) and Sitka alder (*A. sinuata*). A mix of ericaceous shrubs, for example, crowberry (*Empetrum nigrum*), narrow-leaf Labrador tea (*Ledum decumbens*), mountain-cranberry (*Vaccinium vitis-idaea*), bog blueberry (*V. uliginosum*), and alpine bearberry (*Arctostaphylos alpina*), with dwarf arctic birch (*Betula nana*) may also occur. A thick herbaceous layer is present in some areas consisting of oxytrope (*Oxytropis* spp.), vetch (*Astragalus* spp.), and bluejoint (*Calamagrostis canadensis*). Mosses, such as *Polytrichum* spp., *Hylocomium splendens*, *Hypnum* spp. and *Drepanocladus uncinatus*, may be abundant (Vierick et al. 1992; Vierick et al. 1972).

Maritime Tundra-associated Species

Bristle-thighed Curlew, <i>Numenius tahitiensis</i>	Arctic Loon, <i>G. arctica</i>
Tule White-fronted Goose, <i>Anser albifrons gambeli</i>	Rock Sandpiper, <i>Calidris ptilocnemis</i>
Spectacled Eider, <i>Somateria fischeri</i>	subspecies Pribilof Sandpiper,
Steller's Eider, <i>Polysticta stelleri</i>	<i>C. p. ptilocnemis</i>
King Eider, <i>Somateria spectabilis</i>	subspecies Aleutian Sandpiper,
Pacific Loon, <i>Gavia pacifica</i>	<i>C. p. couesi</i>
	subspecies Northern Rock
	Sandpiper, <i>C. p. tschuktschorum</i>

Bering Sea Island Endemic Species

McKay's Bunting, *Plectrophenax hyperboreus*

Bering Sea and Aleutians Endemic Species

Gray-crowned Rosy Finch, <i>Leucosticte tephrocotis tumbrina</i>	<i>T. t. kiskensis</i>
Winter Wren, <i>Troglodytes troglodytes meligerus</i>	<i>T. t. alascensis</i>
	<i>T. t. semidiensis</i>

Southwest Alaska/Bering Sea insular endemic voles, lemmings, and shrews:

<i>Sorex pribilofensis (hydrodromus)</i>	<i>Microtus abbreviatus abbreviatus</i>
<i>S. jacksoni</i>	<i>M. a. fisheri</i>
<i>Dicrostonyx groenlandicus stevensoni</i>	<i>Microtus oeconomus amakensis</i>
<i>D. g. unalascensis</i>	<i>M. o. innuitus</i>
<i>D. g. exul</i>	<i>M. o. unalascensis</i>
<i>Lemmus trimucronatus harroldi</i>	<i>Clethrionomys rutilus albiventer</i>
<i>L. t. nigripes</i>	

Ecological Role of Tundra Habitats

Alaska tundra habitats are somewhat unique relative to the contiguous United States. Although tundra is found in the higher elevations of the Lower 48, it is Alaska's Arctic tundra habitat that may be most familiar to the nation. This is primarily due to the high profile of development issues and concerns in the Arctic region, especially as it relates to the future of the Arctic National Wildlife Refuge (ANWR).

Alaska's tundra supports numerous avian migratory species during the spring, summer, fall and winter seasons, providing important breeding, rearing, staging, refugia, and overwintering habitat. It is one of the most productive and abundant habitats for shorebirds in Alaska and supports a diversity of breeding species. In addition, mammalian species, including muskox, caribou, foxes, wolves, bears, arctic ground squirrels, many small rodents, and raptors are widespread across the Arctic tundra. Nomadic caribou depend on tundra vegetation most of the year for survival, including during annual migrations to their calving grounds. Migratory species, such as falcons and terns, also use this habitat. Five species of raptors that regularly breed in the Arctic tundra region include the Peregrine Falcon, Gyrfalcon, Rough-legged Hawk, Short-eared Owl, and Snowy Owl. Raptors specialize in eating the lemmings, voles and hares that in turn are adapted to eating the tundra vegetation. Rock Ptarmigan breed on the Arctic coastal tundra. They make short migrations in winter to the foothills of the south slopes of the Brooks Range where willows, a primary food source, are more abundant (Johnson and Herter 1989). During spring, thousands of ptarmigan move north across the foothills to reach their breeding areas on the tundra. The Yellow-billed Loon is an Arctic tundra breeder that overwinters in the southern coast of the state. The Buff-breasted Sandpiper nests on the tundra of the Arctic coastal plain, while the Rock Sandpiper nests in the heath of the maritime tundra (Bowman 2004).

Rock Ptarmigan and Blue Grouse feed on seeds and berries of tundra vegetation. The Gray-crowned Rosy Finch feeds in the alpine tundra and subalpine meadows of the Aleutians and Bering Sea Islands eating tiny, wind-borne seeds and insects. Smith's Longspurs nest in the alpine tundra eating mostly plants, as well as invertebrates, including spiders, ants, and beetles. Mountain goats, Dall sheep, and brown bears also depend on alpine and subalpine habitats throughout Alaska.

The maritime tundra of the Yukon-Kuskokwim (Y-K) Delta of western Alaska is one of the nation's most important nesting areas for geese, including the Tule White-fronted Goose. Large numbers of ducks, tundra swans, and sandhill cranes also nest on the maritime tundra of western Alaska, particularly on the Y-K River delta. The Spectacled Eider and Steller's Eider, both federally listed as threatened (in 1993 and 1997, respectively) breed here, although Steller's Eider has become increasingly rare in this area. Most of the world's Bristle-thighed Curlews breed on western Alaska's maritime tundra. The USFWS listed the Bristle-thighed Curlew as a species of concern in 1996. McKay's Bunting is endemic to several Bering Sea Islands, where it breeds on the maritime tundra. This habitat is particularly important in sustaining existing healthy populations of this species.

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Conservation Status

Alaska's tundra habitat is generally healthy. Localized development will likely continue to result in habitat alteration. Opportunities should be sought that alleviate negative impacts and maintain connectivity, as well as suitable areas of quality habitat important to the sustainability of species.

Tundra habitats are increasingly susceptible to impacts from oil exploration and development, mining, transportation corridors, and associated human activities. This is particularly true in the Arctic North Slope region, where existing, proposed and active state and federal oil and gas leases continue to influence the Arctic ecosystems. Red Dog Mine, an active operation near the village of Kivalina, is currently the world's largest zinc mine.

Projects with potential impacts to jurisdictional tundra located within the state's designated coastal zone are subject to a review process via the ACMP that has historically been designed to avoid, minimize and mitigate impacts to wetland habitats, including tundra. Much of Alaska's tundra habitats are jurisdictional wetlands (see wetlands conservation status) subject to the regulatory authority of the COE under Section 404 of the Clean Water Act. Any placement of fill for road development, work pads, stream crossings, or material site development requires a permit from the COE which triggers a review by federal and state agencies and a public review under NEPA.

Best management practices and policies to avoid, minimize, and mitigate for unavoidable impacts to tundra habitats should be implemented at all levels of government. Cooperative working relationships, combined with expert knowledge regarding tundra habitats, are an important tool for managing and protecting these areas. Identifying and protecting areas important to maintaining fish and wildlife diversity should continue. In addition, citizens should be involved in the development of management agreements for the conservation and sustainable use of fish, wildlife and tundra landscapes.

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CLIMATE CHANGE ASSESSMENT

The state of California has listed a set of criteria that is very helpful in assessing the potential impacts of climate change. That report (California Natural Resources Agency, 2009, p55) lists climate change impacts to biodiversity in California to include:

- "Temperature-sensitive terrestrial plant and animal species must adapt to warmer temperatures either within their existing ranges or move to new habitats at higher altitudes or latitudes if possible.
- The amount of additional warming expected in California in the future may exceed the tolerance of some species, particularly endemic ones. Where relocation access is blocked off by natural landscape features or human development, species will need corridors to establish habitat connectivity or face a growing risk of extinction.
- Species migration/movement and invasions along with changes in behavior of temperature-sensitive species will cause imbalances and disruptions to current ecosystem dynamics.
- Barriers to species migration and movement.
- Temperature rise - lakes, streams, and oceans.
- Increase in Invasive species potential.
- Changes in natural community structure.
- Threats to rare, threatened, or endangered species.
- Altered timing of phenological events.
- Timing disruptions between predators and prey and pollinators and plants".

POSSIBLE CLIMATE CHANGE IMPACTS

HABITAT LOSS AND ALTERATION

Recent scientific evidence and events indicate that the tundra habitats in Alaska are undergoing dramatic alteration due to climate change. Of all Earth's regions, the High Arctic has experienced the greatest increases in temperature to date, and these increases are expected to result in an ever greater decrease in sea ice extent and a contraction of the ranges of high arctic ecosystems and species (ACIA 2005; Anisimov *et al* 2007). The warming of the Alaskan Arctic has accelerated over the last 30 years (Sturm *et al.* 2001). Lawrence *et al.* (in review) evaluated the impact of rapid sea ice loss on the terrestrial Arctic climate and the potential for the loss of permafrost. Their climate models and the recent loss of ice from ice in Arctic regions indicate accelerating warming will occur up to 1500 km inland with a yearly peak in the autumn. They also report that Arctic permafrost has already exhibited some warming due to recent climatic events and is expected to continue to degrade. Greenpeace (1998) scientific research indicates that there will be widespread thawing and disappearance of permafrost, resulting in a northward shift of the permafrost boundary. The Intergovernmental Panel on Climate Change (IPCC) concludes that permafrost loss will lead to changes in drainage and altered landscapes over vast

expanses (IPCC 2000). Climate models for the Canadian Arctic predict an increase in temperature, precipitation, and the frequency of severe weather events (Environment Canada 2002). The Canadian Government has concluded the Arctic will be especially hard hit by these changes, and that the Canadian Arctic tundra will shrink dramatically; some models predict a loss of two-thirds of the existing tundra habitats. The Intergovernmental Panel on Climate Change (IPCC 2000) predicts tundra regions will shrink globally by as much as 36%. Regional climate models predict a massive loss (77-99%) of Alaskan tundra in the next 100 years (Science News 2004). Although the predictive powers of climate models are poor over short time spans (5 years from now), they have a high degree of accuracy over larger time frames (for example a 20 year window 100 years from now). Under these models, the average annual temperatures in Alaska in 2100 could increase by 8 to 13 degrees Fahrenheit (Science News 2004). Polar warming is expected to result in northward (and “upward”) shifts of major biomes (e.g. boreal forest) with arctic tundra (and its associated fauna) diminishing largely as a consequence of the geography of the Arctic Ocean limiting its northward movement (IPCC 2000).

HYDROLOGIC CHANGE

Current annual precipitation in Arctic Alaska is roughly equivalent with California’s Mojave Desert. The major hydrologic difference between these regions is the amount and timing of evaporative demand: over 2.5 meters of water are lost throughout the year in the Mojave compared with only about 40cm melting and evaporating over the course of the Arctic summer (Patric and Black 1968). Many climate models predict substantial increases in both temperature and precipitation in the Arctic, with these coupled changes manifesting in a dramatically altered hydroperiod. Both the total volume of water and the timing of its availability to plants and animals may be significantly altered, resulting in shifts in the composition of the biotic community. While precipitation is expected to increase in the form of winter snowfall (Borner et al. 2008), rates of melting and evapotranspiration are already accelerating and are also expected to increase (McDonald et al. 2004), meaning wetter springs dryer summers, and disappearing wetlands. In addition, melting of permafrost, which is forecast to continue at an accelerated rate is already causing the draining of Arctic wetlands in Alaska (Yoshikawa and Hinzman 2003). In regions of thawing discontinuous permafrost in Siberia, the number of large lakes declined by 11% and overall wetland surface area declined by 6% since the 1970s (Smith et al. 2005). Since the 1950s, closed-basin wetland surface area decreased between 4 and 30% across Arctic Alaska (Riordan et al. 2006). These changes in hydrologic regimes and wetland extent can be expected to have consequences for the composition of vegetative communities and the trophic webs they support.

HABITAT EFFECTS

Serreze (2000) reports warming in both the winter and spring over the northern continents. Polar warming probably will increase biological production but may lead to different species composition on land and in the sea (IPCC 2000). Permafrost has warmed in Alaska and Siberia, resulting in greater plant growth and shrub abundance and a northern migration of the tree line. Borner et al. (2008) predict that warmer temperatures and a moderate increase in snow depth which will lead to an increase in deciduous shrubs in Alaska tundra ecosystems. They note that a drastic increase in snow depth may reduce the growing season and reduce or eliminate an important graminoid (*Eriophorum vaginatum*) and shrubs. Knapp et al. (2008) report shrub encroachment onto shrub-lands (including Arctic tundra). They also note that plant species

richness declined steeply with shrub encroachment. Shrub biomass in tundra ecosystems is increasing (Science News 2008, Shaver et al. 2001).

Higher summer temperatures and a decrease in peak season moisture levels suggest an increased potential for fires. Sediment cores indicate that historically, conditions were warmer and fires were more prevalent than today in the Arctic tundra regions (Science News 2008). Alaskan fossil records studies (USGS 1997) indicate that during the warmest part of the previous interglacial (about 130,000 to 120,000 years ago), average growing season temperatures in Alaska appear to have been at least 5° F warmer. In this period, the current lowland tundra vegetation was absent and spruce-dominated boreal forests ranged from north of the Brooks Range and west to the Bering Sea coast. Forests also expanded into higher elevations which greatly reduced the area covered by upland tundra communities for thousands of years. Their study of the fossil record also indicates that the magnitude of future global scale climate changes and ecological responses will be greater at high latitudes than at lower latitudes. Sturm et al. (2001) document widespread increase in shrub abundance over a 320 km² section of Arctic tundra. There has been a widespread increase in alder (*Alnus spp.*) abundance and distribution; increases in dwarf birch (*Betula nana*) and willow (*Salix spp.*) tend to occur at site specific locations. Climate change will increase moss production and/or create shifts of vegetative zones that would decrease cryogenic activity on non-sorted circles in the low arctic. The potential loss of non-sorted circles will decrease landscape heterogeneity in arctic tundra habitats (Kade and Walker 2008).

In addition to decreasing numbers of wetlands and losses of wetland surface extent, corresponding shifts in the physical, chemical, and biological attributes of freshwater systems are expected to lead to change in aquatic food webs. Between the late 1980s and early 2000s in the Yukon Flats National Wildlife Refuge wetland extent, chemistry and aquatic community changed dramatically (Corcoran et al. 2009). The surface area of surveyed wetlands decreased by 19%; total nitrogen and most metal cations (Na, Mg, and Ca, but not K) increased; and total phosphorus and chlorophyll *a* (Chl *a*) declined. These chemical changes were accompanied by a shift in the invertebrate community from one dominated by benthic and epibenthic deposit-feeding invertebrates to water-column grazers. Such changes, if widespread, could pose serious consequences for the hundreds of thousands of breeding waterfowl and waterbirds dependant on Arctic lakes and ponds.

CONSEQUENCES FOR WILDLIFE

The warming of tundra ecosystems in Alaska will also have an adverse affect on many animal species. Polar warming probably will increase biological production but may lead to different species composition on land and in the sea (IPCC 2000). Many Arctic species, adapted to extreme environments, are expected to be displaced, in part, by the encroachment of more southerly species and ecosystems (Post *et al* 2009). Limited functional redundancy in arctic ecosystems poses a particular risk as loss of a single species could have dramatic and cascading effects on an ecosystem's state and function (Post *et al* 2009).

The Arctic Species Trend Index (ASTI) is a tool intended to illustrate overall Arctic vertebrate population trends starting with 1970 as the baseline. The ASTI is compiled from survey and census data from 965 populations of 306 species (representing 35% of all known Arctic vertebrate species). While it has obvious limitations, the ASTI can be a useful tool for recognizing patterns and making inferences on the trajectory of arctic ecosystems (CAFF

International Secretariat 2010 – in review). The ASTI demonstrates high Arctic vertebrate abundance has declined an average of 19% across all taxa, with the decline for terrestrial species around 28%. The decline in the index for high Arctic terrestrial vertebrates (mostly composed of herbivores including caribou lemmings and waterfowl) appears driven primarily by declines in caribou and lemmings. However, the recent, largely synchronous declines of caribou across the Arctic are believed to be natural: wild barren-ground caribou and reindeer herds are known to naturally cycle over long time periods. But declines in other species, such as lemmings in Greenland, Russia and Canada may be in part, the beginning of a negative response to a dramatically changing system.

Caribou (*Rangifer tarandus*) productivity is strongly tied to forage availability and quality; and climate change has a huge potential to adversely affect caribou population dynamics (Lenart et al. 2002). Climate change causes increased nutrient cycling resulting in a change in arctic ecosystems to fast growing species with high nutrient requirements becoming more common. The changing of the tundra ecosystem to a mosaic of taiga forest and shrub land will result in increased food competition with other ungulates and even elimination of food sources, especially in winter. An immediate climate change effect would be a reduction in forage quality due to a likely decrease in shade causing less nitrogen to be available from forage plants (Lenart et al. 2002). Joly et al. (2007) report shifts in caribou diets between 1995/96 and 2005 were lichens are now less prevalent and graminoids more prevalent in current caribou diets. This shift corresponds to similar vegetative changes that have been documented in long term studies in northwestern Alaska. Their study was not in a position to make any inferences whether this change in diet will affect caribou populations. Earlier onset of the spring season may result in caribou being stuck on winter ranges as summer ranges green up earlier. Tundra habitat shrinkage will be especially hard on Muskoxen and caribou. Icing conditions would have a negative impact on caribou grazing energy requirements (Environment Canada 2002).

Kutz et al. (2005) explore the impact of climate change on host-parasite systems in the Arctic. The occurrence of a lung-dwelling parasite (*Umingmalstrongylus Pallikuukensis*) in muskoxen (*Ovibos moschatus*) in the Canadian Arctic is a function of soil surface temperatures. Soil temperatures are expected to rise with global warming, causing an increase in this parasite in muskoxen (Kutz et al. 2005). Snow cover and thermal insulation are very important to microtine rodent populations such as lemmings. The predicted impacts of climate change in the arctic include longer falls which combined with more frequent freezing and thawing could have an adverse affect on lemming population cycles and even put these populations at risk. Lemmings are the base of the Arctic ecosystem, a significant drop in their numbers could be catastrophic for predators like the Arctic fox (*Alopex lagopus*) and the snowy owl (*Bubo scandiacus*). The bigger and more aggressive red fox (*Vulpes vulpes*) is encroaching on the Arctic fox. This phenomenon is hypothesized to be related to global warming (Eurek Alert 2007).

The wetlands of the Arctic and Coastal Tundra in Alaska are critical breeding grounds for millions of shorebirds, waterfowl, and waterbirds from around the world. Several of these species, including Spectacled eider, Steller's eider, and the yellow-billed loon are already federally listed as threatened or are under consideration for listing. The predicted loss of between one and two-thirds of Alaska's Arctic tundra habitat, coupled with the forecast diminishing number and size of Arctic wetlands means there will be substantially less habitat available for all birds dependent upon Arctic wetlands, potentially pushing many more species towards protected legal status.

Warming is predicted to increase the length of the growing season in the Arctic; and just as this change in season length affects the timing of precipitation and evaporation, it will also impact the timing of availability or abundance for preferred prey or forage. Many wildlife species may be unable to adjust to new temporal patterns of habitat optimality, resulting in a “phenological mismatch.” This mismatch between behavior and environment is expected to be a particularly difficult hurdle for migrating species.

In the Arctic National Wildlife Refuge, the spring of 1990 was the earliest in nearly 40 years, resulting in springtime caribou foods going to seed before caribou arrived from their winter range (Greenpeace 1988). This substandard browse quality has a negative effect on caribou calves and could result in decline in caribou populations (Greenpeace 1988). Post and Forchhammer (2008) note that in highly seasonal environments the timing of offspring production of herbivores coincides with annual peak browse availability (trophic match). They document climate change in Greenland has caused peak plant phenology to occur earlier than caribou calving. They also found that caribou calf mortality has risen and calf production has dropped fourfold.

Across North America, short-distance migrant birds are arriving 12-14 days earlier now than they were 50-100 years ago, while long-distance migrants have seen an advance of spring arrival date by only 3-4 days. Meanwhile, Insects in the northern breeding grounds are also hatching earlier in the spring. When insects emerge sooner, birds must lay eggs sooner if they are to raise their young when caterpillars and other insects are at maximum abundance (Crick 2004). Many long distance migratory birds may arrive on the breeding grounds too late to provide adequate food for their young because they use seasonal changes in daylight rather than climatic cues to start their migrations northward (Wormworth 2004).

Earlier mosquito emergence will increase the vulnerability of bird chicks to loss of blood or abandonment of the nest by the parents (Environment Canada 2002). Pika (*Ochotona collaris*) are very sensitive to high temperatures and are being pushed upward in their mountain habitat in the Great Basin area of the Western United States (University of Washington 2005). Similar loss of habitat in Alaska is expected, since the polar regions will experience the most dramatic increases in temperature. Copeland et al. (in press) used telemetry locations of 562 wolverine reproductive dens from Fennoscandia and North America and found that all were associated with sites that had persistent spring snow cover. Reductions in spring snow cover, due to climate warming, will likely reduce wolverine habitat and may result in loss of connectivity of some habitats.

In the short-term, 10-25 years, the recent warming trends in Alaska may be moderated by a cooler phase of the Pacific Decadal Oscillation (USFWS 2008).

NEEDED RESEARCH AND MONITORING

MONITORING

Our current, mostly, single species approach to monitoring with a bias towards charismatic species over functional species limits our ability to detect and understand critical changes in the Arctic’s ecosystems. A broader and more integrated approach is needed to facilitate a better understanding of how Alaska’s biodiversity is responding to a changing Arctic and how these changes might reflect or counter global biodiversity trends.

Large scale monitoring of shrub encroachment should utilize the techniques of Sturm et al. (2001). Microtine populations are the base of the tundra ecosystem and should be monitored. However, microtines are eruptive breeders, and microtine densities can vary greatly in space and time making monitoring their population levels directly over the wide geographic areas a very difficult task. Microtines are a main prey item for snowy owls and their density levels are closely tied to those microtines over large areas. Snowy owl populations should be monitored as an index of microtine population health. Caribou numbers and forage quality should be monitored not only because Caribou are an important subsistence food resource, but because they are also a functional keystone species of the tundra biome, and they may be particularly vulnerable to the effects of climate change. Trophic mismatch studies (Post and Forchhammer 2008) on caribou in Arctic tundra regions should be undertaken. If this mismatch is found, monitoring efforts should be expanded to other caribou ranges. Pika, with their very narrow thermal tolerances are uniquely vulnerable to the direct effects of climate change, and their status is demonstrative of the impacts of warming in alpine tundra ecosystems: we should understand current Pika distribution with effective surveys, and monitor changes in their abundance. The wood frog is one of the most widely distributed vertebrates in North America, and is the only amphibian found north of the Arctic Circle. Amphibians in general are extremely sensitive indicators of changes in water quality and chemistry, and the wood frog is an important predator of freshwater invertebrates and is itself important prey for a wide variety of aquatic and other birds. The woodfrog makes an excellent monitoring subject for a variety of reasons: It is an excellent indicator of water quality and the relative health of freshwater ecosystems, and it is not imperiled but is abundant and widespread. In addition, their because their current distribution in Alaska is just beginning to encroach into Arctic and Coastal tundra, monitoring this species would provide an excellent gauge for monitoring the pace of the northward expansion of environmental conditions and other species. Piscivorous water birds like the Yellow-billed and Arctic loons are also good indicators for the condition of freshwater ponds and lakes because they are the apex predators of those systems. Loons make an attractive monitoring subject because of the conservation concerns for them, and the relatively high trust responsibility the state has for them. Additionally, their breeding population numbers are relatively easy to monitor from the air.

AT RISK SPECIES

Arctic fox
Pika
Caribou
Muskoxen
Wolverine
Lemmings
Snowy Owl
Spectacled eider
Steller's Eider
Yellow billed loon

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BOREAL FOREST AND COASTAL TEMPERATE FOREST

BACKGROUND

The Background section below is reproduced from Appendix 5.1 of *Our wealth maintained: a strategy for conserving Alaska's diverse wildlife and Fish Resources*, Alaska Department of Fish and Game (2006).

There are approximately 120 million acres of forestland (land with > 10% tree cover) in Alaska (Hutchison 1968). That area can be further classified depending on where it occurs in the state. The vast majority of forestland, about 107 million acres, occurs in Interior Alaska and is classified as "boreal forest." About 13 million acres of forest occurs along Alaska's southern coast, including the Kodiak Archipelago, Prince William Sound, and the islands and mainland of Southeast Alaska. This is classified as coastal temperate rain forest. The Cook Inlet region is considered to be a transition zone between the Interior boreal forest and the coastal temperate forest. For a map showing Alaska's land status and forest types, see Figure 5.1 on page 2.

Boreal Forest

The boreal zone is a broad northern circumpolar belt that spans up to 10° of latitude in North America. The boreal forest of North America stretches from Alaska to the Rocky Mountains and eastward to the Atlantic

Ocean and occupies approximately 28 % of the continental land area north of Mexico and more than 60 % of the total area of the forests of Canada and Alaska (Johnson et al. 1995). Across its range, coniferous trees make up the primary component of the boreal forest. Dominant tree species vary regionally depending on local soil conditions and variations in microclimate.

Broadleaved trees, such as aspen and poplar, occur in pure stands or mixed with conifers. "Boreal forest" and "taiga" are often used interchangeably to refer to the plant communities in this region. Taiga is a Russian word originally applied to the broad ecotone between sub-Arctic forest and tundra in Eurasia. Its use has been expanded to include sub-Arctic forests in Eurasia and North America.

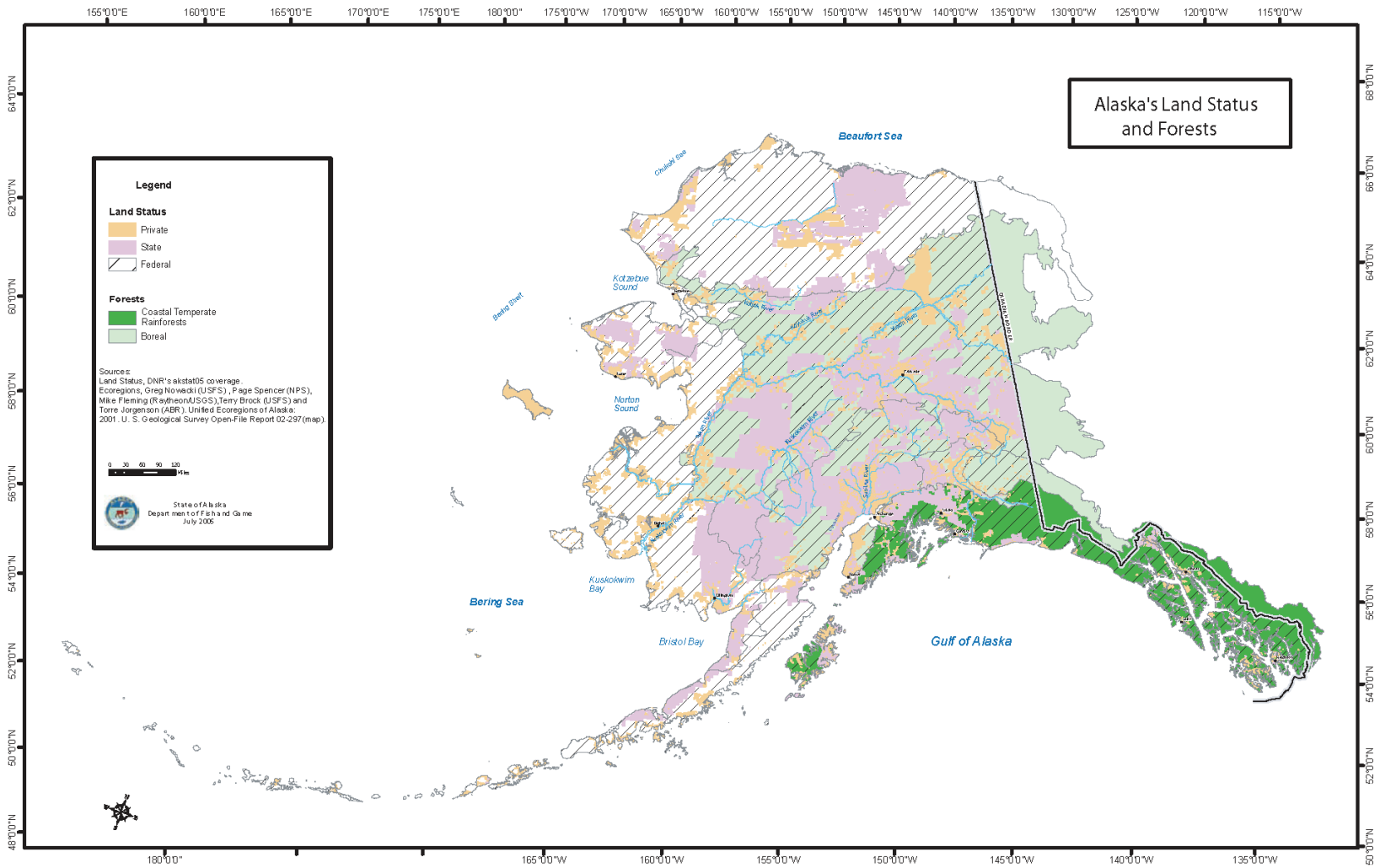


Boreal forest, Nabesna

D. Ryland, ADF&G

In Alaska, the boreal biome stretches from the Kenai Peninsula to the south slope of the Brooks Range (Viereck and Little 1972). A transition zone exists south of the Alaska Range in the region surrounding Cook Inlet and stretching northward into the Susitna River Valley.

Reproduced from Appendix 5.1 of *Our wealth maintained: a strategy for conserving Alaska's diverse wildlife and fish resources*, Alaska Department of Fish and Game (2006).



Appendix 5.1. Alaska's land status and forest types.

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Boreal Forest-Associated Species

Varied Thrush, *Ixoreus naevius*
American Three-toed Woodpecker, *Picoides tridactylus*
Black-backed Woodpecker, *Picoides arcticus*
Northern Flicker, *Colaptes auratus*
Violet-green Swallow, *Tachycineta thalassina*
Hermit Thrush, *Catharus guttatus*
White-crowned Sparrow *Zonotrichia leucophrys*
Belted Kingfisher, *Ceryle alcyon*
Dark-eyed Junco, *Junco hyemalis*
Northern Hawk Owl, *Surnia ulula*
Boreal Owl, *Aegolius funereus*
Great Gray Owl, *Strix nebulosa*
Great Horned Owl, *Bubo virginianus*

Merlin, *Falco columbarius*
Harlan's Hawk, *B. j. harlani* or Red-tailed hawk, *Buteo jamaicensis*
Sharp-shinned Hawk, *Accipiter striatus*
Northern Goshawk, *Accipiter gentilis atricapillus*
Olive-sided Flycatcher, *Contopus cooperi*
Blackpoll Warbler, *Dendroica striata*
Rusty Blackbird, *Euphagus carolinus*
Wilson's Warbler, *Wilsonia pusilla*
Keen's mouse, *Peromyscus keeni complex*
Kenai marten, *Martes Americana kenaiensis*
Kenai red squirrel, *Tamiasciurus hudsonicus kenaiensis*
Kenai brown bear, *Ursus arctos*
Columbia spotted frog, *Rana luteiventris*

Interior Forested Lowlands and Uplands¹

Needleleaf, broadleaf, and mixed forest communities occur across a variety of sites in the boreal zone. Communities composed of tall scrub typically exist in areas of exposed alluvial soil, such as floodplains, streambanks, and lake margins, on burned or otherwise disturbed areas, and near timberline. Low scrub communities develop in moist areas and on slopes with northern aspects. The wettest sites support a mixture of tall scrub swamps, low scrub bogs, or scrub/graminoid communities.

Coniferous forests in the boreal ecoregion are dominated by spruce and occur over a variety of site conditions. White spruce (*Picea glauca* [Moench] Voss) occurs on warm, dry, south-facing slopes on well-drained sites along rivers where permafrost is absent, and at timberline where drainage is good. Dominant understory components in white spruce stands include shrubs such as resin birch (*Betula glandulosa* Michx.), prickly rose (*Rosa acicularis* Lindl.), alder (*Alnus* spp.), willow (*Salix* spp.), buffaloberry (*Shepherdia canadensis* [L.] Nutt.), highbush cranberry (*Viburnum edule* [Michx.] Raf.), and bearberry (*Arctostaphylos* spp.). Herbs such as twinflower (*Linnaea borealis* L.); feathermosses (e.g. *Hylocomium splendens*, and *Pleurozium schreberi*), club lichens (*Cladonia* spp.), and leaf lichens (*Peltigera* spp.) are widespread throughout the boreal forest.

Black spruce (*Picea Mariana* [Mill.] B.S.P.) forests are found on floodplain terraces and flat to rolling uplands on well-drained to poorly drained soils. Tamarack (*Larix laricina* [Du Roi] K.

¹ Plant community descriptions primarily taken from:

Gallant, A.L., E.F. Binnian, J.M. Omernik, and M.B. Shasby. 1995. Ecoregions of Alaska. USGS Professional Paper 1567. U.S. Government Printing Office, Washington, DC. 73 p.

Viereck, L.A., C.T. Dyrness, A.R. Batten, and K.J. Wenzlick. 1992. The Alaska Vegetation Classification. USFS General Technical Report PNW-GTR-286. Portland, OR. 278 p.

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Koch) may be associated with black spruce in wet bottomland areas. Low shrubs typically associated with black spruce include Labrador-tea (*Ledum* spp.), prickly rose, *Vaccinium* spp., and resin birch. The ground is usually covered with a continuous layer of mosses (e.g. *Hylocomium splendens*, *Pleurozium schreberi*, *Polytrichum* spp., and *Sphagnum* spp.) and lichens (e.g. *Peltigera* spp. and *Cladonia* spp.).

Deciduous forests of balsam poplar, quaking aspen, or a mix of the 2 develop on floodplains of meandering rivers. These forest types often follow the establishment of alder and willow thickets and may be subsequently replaced by stands of white spruce. Understory shrubs associated with broadleaf forests include alder, willow, and prickly rose. Herbaceous species typically found in the understory include horsetail (*Equisetum* spp.), bluejoint grass (*Calamagrostis canadensis* [Michx.] Beauv.), and cow parsnip (*Heracleum lanatum* Michx.). Mixed forests are dominated by different combinations of spruce, birch, and aspen. Understory species include alder, bluejoint grass, bearberry, and Labrador-tea.

Interior highlands consisting of rounded low mountains primarily sustain dwarf scrub vegetation and open spruce stands, with graminoid-herbaceous communities occurring in poorly drained areas. Open coniferous forests and woodlands typically dominated by white spruce with black spruce, birch, and aspen codominants are often found above 500 m up to timberline. These forest types contain an open shrub layer consisting of resin birch, alder, willow, prickly rose, buffaloberry, and other ericaceous shrubs. Ground



cover generally consists of a layer of mosses and lichen similar to those found in conjunction with black spruce.

Boreal forest, Susitna Basin

D. Ryland, ADF&G

Interior bottomlands associated with the larger rivers in the Interior are typified by poorly drained, shallow soils, often over permafrost. Bottomland coniferous forests are dominated by white spruce, black spruce, or a combination of the two. Closed stands of white spruce occupy terrace locations with well-drained soils. Understory vegetation consists primarily of low and dwarf scrub such as *Vaccinium* spp. and dwarf birch often accompanied by twinflower and horsetail. A well-developed layer of feathermoss is also common. Closed stands of black spruce occur on floodplains often associated with white spruce and paper birch on well-drained sites. Understory vegetation is composed of alder, prickly rose, willow, Labrador-tea, *Vaccinium* spp., and a moss layer including *Hylocomium* spp. and *Pleurozium* spp. Colder, wetter sites are occupied by black spruce woodlands with a tall shrub understory consisting of alder, willow, and resin birch. On these sites, the tall shrub understory is a more important component of the habitat

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than in closed stands. Ericaceous shrubs (e.g. *Vaccinium* spp., *Ledum* spp., and *Empetrum nigrum*) commonly occur with sedges (*Carex* spp.), bluejoint grass, mosses, and lichen.

Bottomland deciduous forests consist primarily of closed stands dominated by balsam poplar (*Populus balsamifera* L.) or quaking aspen with an understory of alder, willow, prickly rose, highbush cranberry, buffaloberry, and red-osier dogwood (*Cornus stolonifera* Michx.). An herbaceous layer consisting of northern bedstraw (*Galium boreale* L.), dwarf dogwood (*Cornus canadensis* L.), horsetail, and bluebell (*Mertensia paniculata* [Ait.] G. Don) is typical. Mixed forests are predominantly made up of paper birch with spruce cohorts or white spruce with balsam poplar. Understory species are generally the same as those found with broadleaf or white spruce-dominated stands.

Cook Inlet: A Transition Zone

The area around Cook Inlet is a transition zone between the coastal rain forest and the Interior boreal region. This ecoregion has the mildest climate in the boreal region of Alaska and is generally free from permafrost. Tall scrub communities dominated by alder and willow, either alone or in combination, form thickets on streambanks, floodplains, and drainage ways. Mesic graminoid herbaceous and low scrub graminoid communities occur across a range of moist to dry sites. Dry to mesic sites may be dominated by a combination of grasses (*Festuca* spp., *Deschampsia beringensis*, *Poa eminens*), forbs such as monkshood (*Aconitum delphinifolium* DC.) and bluebell, and ericaceous shrubs. Coniferous, deciduous, and mixed forest stands are common. Needleleaf forests include white, black, and Sitka spruce depending on soil conditions and microclimate. Deciduous forests are dominated by quaking aspen, paper birch, balsam poplar, and black cottonwood. Mixed forest types may contain codominant cohorts that include spruce in combination with any of these broadleaf species.

White spruce forests are typically found on well-drained sites. Black spruce, paper birch, balsam poplar, and aspen are common codominant components with white spruce. Low shrubs associated with white spruce stands include dwarf birch (*Betula nana* L.), *Vaccinium* spp., Labrador-tea, crowberry (*Empetrum nigrum* L.), buffaloberry, and prickly rose. Herbaceous cover varies depending on canopy density and local moisture regime. Horsetail, twinflower, and bluejoint grass are all commonly found in conjunction with white spruce. Mosses, such as *Hylocomium* spp. and *Pleurozium* spp., often form a continuous layer under dense canopies.

Quaking aspen can form almost pure stands on relatively warm, well-drained, upland soils. Stands often contain balsam poplar, spruce, and paper birch cohorts. Associated shrubs include alder, willow, prickly rose, buffaloberry, and highbush cranberry. Herbaceous cover is generally sparse under closed stands but may include scattered bluejoint grass, fireweed (*Epilobium angustifolium* L.), horsetail, northern commandra (*Geocaulon lividum* [Richards.] Fern.), and northern bedstraw. Lichens and mosses are scarce. Open stands of quaking aspen tend to have a denser herbaceous understory.

Paper birch generally occupy dry to moist sites in the Cook Inlet region. Open stands of paper birch on drier, warmer sites may include white spruce, while wetter sites may include a black spruce component; however, spruce are not usually abundant in closed paper birch stands. Understory components include alder, prickly rose, and highbush cranberry. Stands that are more

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open may include resin birch. The herb layer is usually dominated by bluejoint grass; however, horsetail and bluebell are common understory components.

Black spruce tends to be dominant on poorly drained sites and may include a paper birch cohort. Alder is the most common tall shrub associated with black spruce. Low shrubs include prickly rose, willow, Labrador-tea, twinflower, and *Vaccinium* spp. Feathermosses are common, along with *Sphagnum* spp., on wetter sites. Open black spruce forests or stands may include bush cinquefoil (*Potentilla fruticosa* L.), crowberry, and resin birch along with willow, alder, and herbs, such as horsetail and bluejoint grass.

Ecological Role of Boreal Forest Habitats

Forest ecosystems support relatively high levels of biodiversity because they have many vertically differentiated niches, and because they have large accumulations of biomass that can support a diverse food web. Forests with high structural and/or vegetative diversity will also include horizontally differentiated niches, such as edges between forest communities and meadows, or where different vegetative conditions meet within a plant community. The boreal forest region is a large and diverse patchwork of distinctive ecosystems and flora in which complex interrelationships between climate, solar radiation, surface water, slope, aspect, soil characteristics, permafrost, and disturbance regimes create patterns of vegetation across the landscape. As a result, the boreal forest includes a range of habitat types that vary from closed forest to open shrub and herbaceous communities that inhabit both uplands and wetlands.

Birds represent the largest class of vertebrates in the boreal forest. Over 80 % of all terrestrial vertebrates associated with the western boreal region of Canada are birds (Niemi et al. 1998). Of the various species that rely on the boreal forest, approximately 20 % are permanent residents; the remainder are migrants that spend the summer breeding season in the boreal forest (Smith 1993). Birds play a fundamental ecological role in the forest, and data supporting the importance of birds in maintaining healthy forested ecosystems is increasing. During summer, most forest birds eat insects, particularly moth larvae. Research indicates that birds can reduce insect densities (Holmes et al. 1979; Atlegrim 1989), especially when the insect populations are at either low or endemic levels (Crawford and Jennings 1989; Holmes 1990; Torgerson et al. 1990).

For birds in the boreal region, there appears to be a close relationship between habitat diversity and species diversity (Kessel 1998). Some deciduous forest types in the boreal region have a great potential for providing multiple habitat niches. Cottonwood forests in the upper Susitna River basin were found to support high numbers of breeding species of boreal forest birds and the greatest density of breeding territories compared to other boreal forest types in the area. Kessel (1998) hypothesized the high occupancy and species richness found in the cottonwood forests was due to the high productivity of the floodplain ecosystems where these forests were found and the structural diversity within the forest that created many vertical habitat niches. While boreal spruce forests tend to have lower bird densities and species richness than deciduous forests, they provide more stable habitat for resident species, such as Boreal Chickadees, White-winged Crossbills, and Great Horned Owls. The greatest densities of permanent residents occur in forests dominated by white spruce (Kessel 1998).

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In the boreal forest, harvest of floodplain white spruce has the potential to reduce age-class diversity at the landscape level. Forest on floodplains and islands have a lower probability of experiencing stand-replacement fire, and therefore, grow considerably older and more complex than forest stands that experience frequent fires. These stands support a large proportion of the boreal forest's species diversity, particularly invertebrates and nonvascular plants.

Kessel (1998) concluded that most bird species are relatively specific with regard to aspects of their structural habitat requirements across their geographic ranges and that much of the habitat variation previously reported in North America is the result of considering only macrohabitats or measuring factors only indirectly related to a species' ecology. Many boreal forest birds use macrohabitat across forest types while occupying specific habitat niches. For example, across most of Alaska, Gray-Cheeked Thrush, Fox Sparrow, and White-Crowned Sparrow occupy shrub habitats. However, where specific shrub habitat features occur within a forest, these species will nest under the canopy and superficially appear to be birds of forest habitat (Kessel 1998). Even small patches of different habitat within uniform stands can be enough to account for the occurrence of a particular species. For example, in their analysis of habitat associations of breeding birds of boreal forest in Alaska, Willson and Comet (1996) noted that 1–2 spruce trees in a deciduous stand was enough for Ruby-Crowned Kinglet or Hermit Thrush to hold a territory, and that these species would forage in the surrounding deciduous vegetation.

Many forest bird species, such as flycatchers, thrushes, and wood warblers, use boreal forests for breeding and rearing young, but winter as far away as Central or South America. Such birds require boreal forest habitats for survival. Many of the long-distance migrants are particularly sensitive to fragmentation of breeding habitat (Smith 1993), and Alaska's boreal forest is an important part of the breeding range of several species of boreal forest landbirds known to be declining in other portions of their North American range.

Boreal Forest Conservation Status

Overall, Alaska's forest habitats are generally healthy. However, localized development will likely continue to result in substantial habitat alteration. Opportunities should be sought that alleviate negative impacts, and maintain connectivity and suitable areas of quality habitat important to the sustainability of species.

Approximately 37% of the total area in Alaska's boreal forest region lies within state or federal conservation units, including federal and state wildlife refuges, parks, national monuments, and other designations. These areas were designated by the state and federal governments to preserve unique or fragile ecosystems and historic sites and to protect essential fish and wildlife habitat. The remaining lands consist of other state lands, municipal or borough lands, Native allotment and corporation lands, and other private holdings.

Management goals and objectives for the conservation units reflect the importance of each area with regard to conserving essential fish and wildlife habitats, and as such, there are usually some restrictions on development within these areas. Generally, the laws and regulations, management plans, goals, and objectives written to guide the management of these areas recognize their importance as essential fish and wildlife habitat, along with the protection of important cultural

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and historic sites. As a result, development activities on some lands are often restricted or closely controlled to prevent changing the natural character of the lands and waters.

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Coastal Temperate Rain Forest

Coastal temperate rain forests are rare globally, occurring in only 6 or 7 places in the world, where mountains abut the ocean at higher latitudes. These areas experience a maritime climate, with cool summers, warm winters, and abundant precipitation distributed throughout the year.

As trees in this forest age and become decadent, they either die in place or are toppled by wind, creating a small gap in the overhead canopy. This break in the canopy allows light to reach the forest floor, promoting the growth of new trees and understory vegetation. Over time, this high-frequency, low-intensity disturbance results in a forest with many ages of trees and many small gaps intermingled on a fine spatial scale. Such forests are called “old growth.” Essential features of old growth include a multilayered canopy, the presence of large (for the site), old trees, a well-developed understory, and dead and down trees on the forest floor.

The vast majority of Alaska's coastal temperate rain forests are in an old-growth condition. Young, primary forests develop on lands newly exposed by landslides, receding glaciers, or beach uplift. When old-growth forests are felled, either by clearcutting or by catastrophic winds, secondary succession also creates a new, young forest. Whether the young, developing forest is the result of primary or secondary succession, the 2 are similar structurally and functionally. These young forests are characterized by uniform tree ages less than 150 years old, a single-layered canopy, and a relatively depauperate understory. It takes 200–300 years for young-growth stands to develop the compositional and structural characteristics of old growth.

Coastal Temperate Rain Forest Types

Alaska's old-growth rain forest can be further subdivided into different forest “types,” or habitats, based on the dominant tree species and on forest productivity. The dominant tree species and major types are described below.

Species— The cooler temperatures, low sun angles, and short summer growing season in higher-latitude forests favor dominance by conifers. In coastal Alaska, the most abundant tree species is western hemlock (*Tsuga heterophylla*), followed by Sitka spruce (*Picea sitchensis*), mountain hemlock (*Tsuga mertensiana*), Alaska yellow cedar (*Chamaecyparis nootkatensis*), western red cedar (*Thuja plicata*), and lodgepole pine (*Pinus contorta*). Deciduous hardwoods, including alder (*Alnus*



Coastal temperate rain forest

J. Schoen

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spp.) and cottonwood (*Populus balsamifera*), are least common, being found mostly on avalanche slopes, active riparian zones, and mainland river drainages in Southeast Alaska.

Western hemlock is ubiquitous throughout the Alexander Archipelago and predominates on well-drained, organic soils. There, individual trees may be > 6 ft in diameter and > 500 years old. At higher elevations, higher latitudes, and colder temperatures, western hemlock is replaced by the closely related mountain hemlock (*Tsuga mertensiana*). Both species gradually fade out as one moves north and west through the coastal temperate rain forest ecosystem, where Sitka spruce becomes more dominant.

Sitka spruce occurs throughout the coastal temperate rain forest. On Kodiak and Afognak islands, the forests are nearly pure Sitka spruce stands. In Southeast Alaska, Sitka spruce occur most often in mixed stands with hemlock and cedar, but do occur in pure stands on some active alluvial and colluvial soils, including riparian areas, avalanche slopes, and uplifted beach zones. Sitka spruce are less shade tolerant than other species, and they disproportionately colonize new openings following wind-throw, or clearcutting. In Alaska, the largest Sitka spruce trees can exceed 225 ft in height and 12 ft in diameter.

Western red cedar and Alaska yellow cedar represent a small but important component of the coastal temperate rain forest in Southeast Alaska. Yellow cedar occurs throughout the Alexander Archipelago and Prince William Sound. Western red cedar is restricted to the southern half of the Alexander Archipelago. Both species are most abundant on poorly drained, acidic soils, where they are able to outcompete hemlock and spruce. Natural resistance to decay by both cedar species results in an abundance of dead-standing snags in the forest, but rot-resistant heartwood means relatively few cavities for nesting, roosting, and foraging. Both species are economically valuable and have been disproportionately targeted for logging in recent years. In addition, stands of Alaska yellow cedar have been experiencing a significant natural decline since the late 1800s. Whether this is a function of climate change or some biotic factor is currently unknown.

Major habitat types in the coastal temperate rain forest are defined in terms of their relative mix of species. The species mix, in turn, is a function of soil type and drainage, elevation, and latitude. For the coastal temperate rain forests of Alaska, the major forest types include: western hemlock (46% of area), mixed hemlock/spruce (26%), Sitka spruce (17%), cedar (5%), and hardwood/deciduous (4%) (Hutchison 1968).



Coastal temperate forest, sixty-year growth

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Productivity— There is a second dimension, or criteria, against which forests in Alaska can be classified. Forest “productivity” refers to the rate of tree growth and is reflected in the overall size and biomass of trees on a given site. Highly productive forests are different structurally than unproductive forests, and they tend to occur in different landscape positions than unproductive forests. For example, we might find a stand of large hemlock trees growing on the toe-slope of a hillside at low elevation and a sparse stand of small hemlocks growing on a wind-battered ridge at high elevation. Both stands would have the same species composition, but they would look, and function, very differently in terms of wildlife habitat value. The productivity of the forest also has obvious importance from the timber industry’s standpoint, with more productive stands being much more profitable to log. As a result, forest inventories often include a breakdown by forest productivity, or size class.

At the coarsest level, the forest can be classified as “commercial” or “noncommercial,” depending on whether the forest meets certain requirements for timber extraction. It reflects an economic, not ecological, judgment, but it suffices as a coarse-scale separation of forest types based on size and structure, and so has value as a descriptor of habitat conditions. All of Alaska’s forestland has been classified in those terms, and we adopt them in this plan.

Beyond this coarse scale breakdown, the commercial (or productive) forestland can be further defined in terms of tree size (e.g., mean tree diameter or height) and stand biomass (e.g., wood volume per acre). These descriptors are more difficult to discern from remote sensing (i.e., from aerial photographs), involve more subjectivity, and thus, have more error. Although these distinctions are important from a wildlife standpoint, they are probably more detailed than we need consider for the purpose of this plan. It is important, nonetheless, to recognize a general pattern within productive forestland across Alaska, and particularly within the coastal forest type: The forest acreage at the lower end of the productivity scale vastly outweighs the forest acreage at the highly productive end. In other words, the bigger the trees in a stand are, the rarer the stand is. Not surprisingly, the more productive stands in the forest have been disproportionately logged in the past and wildlife biologists have identified this “high-grading” as a long-term conservation concern (Schoen et al 1988; Kiester and Eckhardt 1994).

Within the coastal temperate rain forest, most of the forested land is noncommercial, or “unproductive.” Approximately 5.9 million acres, or 45%, is classified as commercial forestland. Of that commercial forestland, the vast majority (85%) exists in Southeast Alaska (i.e., south of Yakutat). The balance exists in Prince William Sound and Afognak Island. The vast majority of forestland in coastal Alaska falls within one of two national forests: The Tongass National Forest in Southeast Alaska, and the Chugach National Forest in Southcentral Alaska. These are, by far, the two largest forests in the National Forest system.

Coastal Forest-Associated Species

Marbled Murrelet, *Brachyramphus*
marmoratus

Prince of Wales Spruce Grouse, *Falcipennis*
canadensis isleibi

Blue Grouse, *Dendragapus obscurus*

Canopy nesting Pacific-slope Flycatcher,
Empidonax difficilis

Golden-crowned Kinglet, *Regulus satrapa*
Townsend’s Warbler, *Dendroica townsendi*

Varied Thrush, *Ixoreus naevius*

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White-winged Crossbill, *Loxia leucoptera*
 Rufous Hummingbird, *Selasphorus rufus*
 Belted Kingfisher, *Ceryle alcyon*
 Black-backed Woodpecker, *Picoides arcticus*
 Dark-eyed Junco, *Junco hyemalis*
 Wilson's Warbler, *Wilsonia pusilla*
 Hermit Thrush, *Catharus guttatus*
 White-crowned Sparrow, *Zonotrichia leucophrys*
 Pine Grosbeak, *Pinicola enucleator*
 Red Crossbill, *Loxia curvirostra*
 Pine Siskin, *Carduelis pinus*
 Red-breasted Sapsucker, *Sphyrapicus rubber*
 Hairy Woodpecker, *Picoides villosus*
 Northern Flicker, *Colaptes auratus*
 Boreal Chickadee, *Poecile hudsonica*
 Chestnut-backed Chickadee, *Poecile rufescens*
 Red-breasted Nuthatch, *Sitta Canadensis*
 Brown Creeper, *Certhia americana*
 Smith's Longspur, *Calcarius pictus*
 Northern Pygmy-Owl, *Glaucidium gnoma*
 Barred Owl, *Strix varia*

Northern Saw-whet Owl, *Aegolius acadicus*
 Western Screech Owl, *Otus kennicottii*
 Great Gray Owl, *Strix nebulosa*
 Great Horned Owl, *Bubo virginianus*
 Bald Eagle, *Haliaeetus leucocephalus*
 Merlin, *Falco columbarius*
 Sharp-shinned Hawk, *Accipiter striatus*
 Northern Goshawk, *A. g. atricapillus*
 Queen Charlotte Goshawk, *A. g. laingi*
 Northern Goshawk, *A. g. atricapillus*
 Black Merlin, *F.c. suckelyi*
 Wood frog, *Rana sylvatica*
 Long-toed salamander, *Ambystoma macrodactylum*
 Rough-skinned newt, *Taricha granulosa*
 Ermine, *Mustela erminea complex*
 Marten, *Martes Americana/caurina complex*
 Flying squirrel, *Glaucomys sabrinus griseifrons/alpinus*
 Long-tailed vole, *Microtus longicaudus/coronarius complex*
 Keen's mouse, *Peromyscus keeni complex*
 Sitka tundra vole, *Microtus oeconomus sitkensis*

Ecological Role of Coastal Temperate Rain Forest Habitats

Coastal temperate rain forests are characterized by cool summers, mild winters, and abundant precipitation distributed throughout the year (Alaback 1991). The absence of a dry season makes wildfire extremely rare, so individual trees can live to very old age. Many trees are > 300 years old, while the oldest trees may be > 1000 years old. Trees can live to extremely old age (800 years or more) before succumbing to disease or rot. The primary agent of disturbance in this forest is wind, which typically topples 1–3 trees at a time, creating a constantly shifting fine-grained mosaic of small openings within the forest (Lertzman et al. 1996; Ott 1997). This gap-phase dynamic produces, over time, a forest with trees of many ages, a multilayered canopy, a diverse, lush understory, and an abundance of dead trees either standing (snags) or lying on the ground in various stages of decay (Capp et al. 1992). These structural and compositional features make old growth valuable as habitat for many wildlife species.

The wind-dominated disturbance regime produces a structurally diverse and highly productive forest. Where it occurs in the Pacific Northwest, this forest type produces more living plant biomass than any other terrestrial ecosystem, including tropical rain forests (Waring and Franklir 1979). Its structural complexity provides niches for diverse animals, including at least 53 species of mammals, 231 birds, and 5 species of amphibians and reptiles (Taylor 1979; MacDonald and Cook 1996a, 1996b). For the coastal rain forest habitat type, the Strategy primarily highlights

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nongame species, subspecies, and endemics that are associated with it; these species were selected because of conservation concerns, economic importance, or as indicator species for the health of this biome.

Marbled Murrelet

Following is an illustration of the ecological role of coastal temperate rain forests for one species, the Marbled Murrelet (*Brachyramphus marmoratus*); the health of its Alaska population is closely tied to health of this particular biome and the adjoining marine environment.

The Marbled Murrelet is a small seabird that ranges along the northwestern coastline of North America, from central California to Alaska's Aleutian Islands. It spends most of its life at sea, but unlike other seabirds, flies inland to nest in the forest on mossy platforms near the tops of old-growth trees (Nelson 1997). Marbled Murrelets are currently listed as a threatened species in California, Oregon, Washington, and British Columbia, but are relatively abundant in Alaska, where an estimated 91% of the world's population exists (McShane et al. 2004). Estimates of the Alaska population are driven in large part by a single at-sea survey conducted by the USFWS in 1994, which placed the population in Southeast Alaska at 687,061 ($\pm 201,162$) *Brachyramphus* murrelets (Agler et al. 1998). By these estimates, Southeast Alaska alone contains approximately 65% of the world's Marbled Murrelets, making it the geographic and demographic epicenter of the bird's range.



Juvenile Marbled Murrelet
R. MacIntosh, USGS

A number of studies have demonstrated that Marbled Murrelets have declined dramatically in the southern half of their range, primarily due to loss of suitable nesting habitat from logging (Bryan et al. 1997; McShane et al. 2004). In the Pacific Northwest, approximately 5% of the original, coastal, old-growth forest remains. Other factors that may contribute to the decline include increased predation (by crows, jays, and other corvids), entanglement in gillnets, and oil pollution.

Like other seabirds, the Marbled Murrelet has low fecundity, becoming sexually mature between 3 and 5 years old, and then laying only a single egg per year. Because it nests in trees, it is exposed to avian predators in the form of ravens, crows, Steller's Jays, Northern Goshawks, Peregrine Falcons, and various owls. Preferred nesting habitat is 20–40 meters up in old-growth trees. Murrelets prefer to nest near the tops of trees but beneath overhanging limbs to provide cover from overhead predators. The bird does not add material to a nest, but looks for a broad, mossy platform that occurs naturally in these wet forests. Because the platform must be broad to support the bird, it nests primarily in older trees that have had time to develop these structures.

Research on nesting habits of these birds suggests that within forest stands, Marbled Murrelets tend to select for older, larger trees (Hamer and Nelson 1995). Older trees tend to have larger limb structures and larger moss platforms, which provide more suitable nesting sites for the

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birds. The disproportionate logging emphasis on larger trees (e.g., high-grading) in Southeast Alaska may be having a disproportionately high impact on the nesting habitat of these birds.

One of the essential attributes of old-growth forest is the existence of gaps in the canopy that allows Marbled Murrelets to access nest stands and fly below the canopy. Conservation of these types of forest stands is important for the long-term conservation of murrelet nesting habitat.

Other species

In the case of the Marbled Murrelet, coastal old-growth forests provide important structural attributes needed for nesting and reproduction. Other species, including many woodpeckers and owls, depend on large-diameter snags for excavating cavities for nesting and roosting, or in the case of the Rufous Hummingbird, build their nests from the mosses and lichens they find in old-growth forests. Other species depend on coastal forests because their primary food lives in the forest. Examples include the Northern Goshawk, which hunts beneath the overstory and captures a variety of old-growth associated birds and small mammals, or the brown creeper, which forages in the bark crevices of larger, old-growth trees. Still other animals are dependent on the perpetually moist, humid environment of the rain forest, including species like the rough-skinned newt, the wood frog, and long-toed salamander.

The coastal, old-growth rain forest is an extraordinarily complex, stable habitat type. Over thousands of years, many wildlife species have evolved in special ways to exploit this forest for food, shelter, and security. The ecological web of interactions in the coastal rain forest is rich, and understanding of its complexities is only now starting to emerge through ongoing scientific study.

Coastal Temperate Rain Forest Conservation Status

Coastal temperate rain forests are rare worldwide. Only 30–40 million ha (2–3%) of the world's estimated 1.3 billion ha of temperate forest can be classified as coastal temperate rain forest (Ecotrust et al. 1995). Alaska contains approximately 6,649,460 ha of coastal temperate rain forest, of which about 800,000 ha has been altered by human impacts (Ecotrust et al. 1995). Most of this development has come in the form of clearcut logging and associated road building, especially on the more productive forest lands in Southeast Alaska.

Some of the more intensively logged areas in Southeast Alaska include the northern half of Prince of Wales Island, northern Kuiu Island, Northeast Chichagof Island, North Baranof Island, Zarembo Island, Mitkof Island, Heceta Island, Tuxekan Island, and Long Island. Heavily logged areas overlap to a great extent with underlying calcium carbonate soils, or karst, which allows for good drainage and more productive tree growing conditions. There has been less logging in Southcentral Alaska and the Kodiak Archipelago, primarily because tree size and growth rates diminish with increasing latitude (Farr and Harris 1979). Logging on private, Native corporation lands has been significant throughout this biome, accounting for approximately half of all logged areas.

Over 95% of the coastal temperate rain forest land lies within the Tongass and Chugach National forests—two of the largest national forests in the United States. These lands are managed for multiple uses, including a mix ranging from wilderness to intensive development. The allocation

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of lands to conservation or development status is governed by a comprehensive Forest Plan, which is developed through a public process, and revised every 10–15 years. The Tongass is currently managed under a Forest Plan that was finalized in 1997. The Chugach is managed under a Forest Plan that was revised in 2001. About 22% of the Tongass National Forest is zoned for development, and about 18 % of the forested acres of the Tongass are currently available for commercial timber harvest purposes (http://www.fs.fed.us/r10/TLMP/ROD/ROD_COV.PDF). About a third of that available forested acreage has been harvested since the 1950s.

Although a relatively small percentage of the forest area has been logged, much of the logging to date has been concentrated in the most productive stands with the largest trees. Not only are “big-tree” forests unique structurally and functionally (Kirchhoff and Schoen 1987), but they tend to occur in certain landscape positions that make them especially valuable to particular wildlife species. For example, big tree forests are often found on alluvial soils (the flood plain of rivers and streams), or on colluvial soil types (the toe slopes of steep hill sides), where species like brown bears (*Ursus arctos*) and Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) find preferred habitat (Schoen et al. 1988). These floodplains and alluvial soils are often also associated with highly productive streams and aquatic habitats.

The disproportionate harvest of relatively rare, “big-tree” stands has been a primary conservation concern in Southeast Alaska for decades (Kirchhoff 1989; Keister and Eckhardt 1994). Maintaining sustainable and well-distributed populations of all fish and wildlife species should focus on preserving the natural diversity of forest conditions (species, structure, and landscape position) within this biome.

Threats to Alaska's boreal forest and coastal temperate rain forest habitat range from minor, short-term impacts that may occur in association with virtually any forestland use activity, to the potentially significant loss of habitat due to the conversion of forestlands to other uses. These losses may be partial or complete, but they are often permanent changes to the landscape.

Timber harvesting activities, if properly planned and implemented, should result in only short-term impacts to the forest habitat. If, however, harvest activities are not conducted in accordance with appropriate best management practices (BMPs), such as those found in regulation under the Forest Resources and Practices Act, there is the possibility that they will affect slope stability or disrupt soil regimes. These in turn could lead to such impacts as increased soil erosion or even mass wasting, reduced natural regeneration or shifts in vegetative species composition, impacts to water quality, excessive windthrow, and increased fire risk.

Many timber roads and landings constructed for harvest are temporary or seasonal. If properly constructed with issues such as drainage adequately addressed, they represent short-term impacts. Permanent roads, however, can lead to long-term impacts associated with habitat fragmentation.

The fragmentation of forest habitats is a more significant threat to wildlife because it tends to be long term. The construction of permanent roads, and the installation of pipelines and other utilities impact forested areas via ground disturbance, the clearing of trees and understory species, as well as the bisecting of habitats.

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Habitat fragmentation from road construction and pipeline installation occurs on lands that are open to development activities regardless of ownership. These impacts can be local, such as for a subdivision road or oil pad development, or regional as is the case for many oil and gas pipelines. The construction of roads often opens areas for additional settlement or development and can lead to the loss of habitat through conversion to other uses.

In May 2005 the Roadless Area Conservation Rule was repealed by the Bush Administration. This rule was issued by the USFS in January 2001 to protect areas within national forests that were currently roadless. "Roadless areas" are places where no roads have been constructed, and where as a result, no logging or other development has occurred. These areas provide unfragmented habitats that support fish and wildlife species under unaltered conditions, an increasingly rare situation.

Large-scale land conversion for development and settlement is the single greatest threat to Alaska's forest habitats. The loss of forest habitat through conversion to another use often results in a permanent loss of that habitat. Many of these land use conversions are relatively unregulated, at least in comparison to timber harvest activities. The FRPA (Forest Resources and Practices Act) does not apply to the clearing of timber in order to convert the land to another use, and there is no comparably comprehensive act that addresses the development of land for uses such as agriculture, golf courses, mining, subdivision development, or other commercial uses.

Mining activities in Alaska threaten forest habitats by conversion, and may contribute pollution to associated waters from mine tailings and chemicals used during the extraction process. Recent advances in technology have allowed for the use of lower grade ores and spurred renewed interest in mining operations.

Lastly, impacts such as insect infestation, similar to the spruce bark beetle that may flourish under warming climatic conditions, will likely continue to alter Alaska's forest habitats.

The Alaska FRPA and its associated regulations govern commercial timber harvest activities on state, municipal, and private forestlands. This statute identifies and requires the use of specific best management practices (BMPs) for timber harvest activities. The Alaska Department of Natural Resources Division of Forestry (DOF) administers the provisions of the act and provides oversight of commercial forest harvest activities pursuant to FRPA.

The Department of Environmental Conservation (DEC) and DNR's Office of Habitat Management and Permitting (OHMP) coordinate with the DOF in implementing FRPA and perform specific oversight roles themselves. DEC is given deference in matters related to water quality issues, and the OHMP receives deference in regard to the protection of riparian buffers within harvest areas.

Timber harvest activities on federal forestlands are not subject to FRPA; however, the management standards on federal land generally meet or exceed the FRPA standards. Most timber harvest occurs on Alaska's 2 national forests, and falls under the regulatory jurisdiction of

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the USFS. The forest planning process allows for public review and has a large public involvement component.

The State of Alaska owns approximately 24.9 million acres of forested lands (Department of Commerce Community and Economic Development 2005). The use of these lands is regulated by area or regional plans. Generally, regional plans have been developed, or will be developed under the sustainable yield and multiple use principles and for consistency with AS 41.17. Regional plans have been completed for about two-thirds of all state land. Where no plan exists, a site-specific plan must be adopted under AS 38.04.065(h) to classify the land before a timber sale can occur.

Approximately 2 % of the state's forested lands, or just over 2 million acres, is within 2 designated state forests. The 247,000-acre Haines State Forest, established by the legislature in 1982, includes the Chilkoot, Chilkat and Ferebee drainages in the northern portion of Southeast Alaska. In Interior Alaska, the 1.8 million-acre Tanana Valley State Forest, which extends from Manley to Tok, was created in 1983. The primary purpose in establishing state forests is to provide for the production, utilization, and replenishment of timber resources while allowing other beneficial uses of public land and resources (AS 41.17.200[a]).

The DOF manages forests on state land that have been classified as timberlands via implementation of the FRPA. The FRPA delineates 3 management regions: Region I, Region II, and Region III. These regions correlate with the Southeast, Southcentral, and Northern areas of the state. The FRPA establishes district riparian standards for each of these regions.

The DOF plans for timber management on state lands by first reviewing existing regional plans to ensure that proposed actions are consistent, and then preparing a Five-Year Schedule of Timber Sales. These schedules are prepared annually by each of the DOF's 10 area offices, and provide the public, the timber industry, and agencies with an overview of proposed timber harvest areas, timber sale access and reforestation plans.

The next step is preparation of a Forest Land Use Plan (FLUP) for each proposed timber sale or personal use harvest area on state lands. FLUPs provide information on the location, access, harvest methods, duration, and proposed reforestation for individual sale. FLUPs are required to follow the multiple use and sustained yield principles. Consideration must be given to current, past, and potential uses of the land, including timber harvesting for commercial and personal use fish and wildlife habitat; water bodies, water quality and watersheds; riparian, wetland and ocean shoreline vegetation; recreation and tourism; agriculture and grazing; mining and material extraction; and soil characteristics. FLUPs are subject to public and agency review for sale approval or denial. Current FLUPs exist for Fairbanks, Delta, Kenai-Kodiak (combined), Northern Southeast (Haines), southern Southeast (Ketchikan), and the Matanuska-Susitna areas.

Once a timber sale is adopted, a contract is issued either through the bid process or via negotiations. The FRPA requires that timber operators submit a Detailed Plan of Operation (DPO) for timber harvest activities that are subject to the Act. In addition to state lands, this includes harvests on municipal and private forestland.

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State timber sales with the Coastal Zone must be consistent with the ACMP and local Coastal Zone Management Plans. The standards contained in the FRPA are the coastal standards for timber harvesting, so if timber sales comply with the act, they are consistent. The DOF must issue proposed and final coastal consistency determinations under the timelines set by 11 AAC 150.

As mentioned above, timber harvests on municipal and private lands are also subject to provisions found in the FRPA. These provisions apply to the harvest activities themselves; municipal and private lands do not typically have a planning process that is analogous to that for state lands. The FRPA does treat municipal and private lands differently from state lands with regard to riparian standards. Public lands typically have stricter riparian standards than private lands, including having wider riparian buffers with wider no-cut zones adjacent to water bodies.

In Alaska, private forestlands include those owned by Native corporations, universities, the Alaska Mental Health Trust Authority, and private citizens. Approximately 30 million acres of Alaska's forestlands are privately owned (Department of Commerce Community and Economic Development 2005). Timber harvests on municipal and privately owned forestlands within the coastal zone are regulated in the same manner as state lands. DPOs must be submitted, and the DOF is responsible for ensuring consistency by regulating adherence to the FRPA standards. Forest habitats within legislative designated Special Areas are afforded some protection from development under management plans specific to those areas.

Federal forested lands fall under the jurisdiction of federal management agencies. Approximately 77 million acres of Alaska's forests are federally owned (Department of Commerce Community and Economic Development 2005). The USFS is responsible for Alaska's 2 national forests, the Chugach and the Tongass. The Tongass National Forest is the largest single forest ownership in the state. It is located in Southeast Alaska and contains 46% of Alaska's timberland. The Tongass National Forest consists of 16.9 million acres, of which 4% is available for commercial timber harvest. The second largest federally owned forest is the Chugach National Forest. Located in Southcentral Alaska, this forest encompasses much of the Prince William Sound area and consists of 5.3 million acres.

Federal lands managed by agencies other than the USFS are not typically managed for commercial timber harvest. There are 17 units of the National Park System in Alaska under the management of the National Parks Service; 10 were created in the 1980s through ANILCA. The USFWS manages the 16 national wildlife refuges in Alaska. The BLM manages its own lands specific to their land-use plans developed to sustain the health and diversity of natural resources.

Recommended conservation actions for Alaska's forest habitats include the establishment and maintenance of protected areas, forest practices that provide for sustainable timber harvest in designated areas, support for efforts to eliminate wasteful consumption and lastly, where needed, appropriate forest restoration programs.

Projects involving the development of protected forested areas, understanding species/habitat relationships and sustainable forest management are critical to the conservation of Alaska's boreal forests and coastal temperate rain forests.

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Monitoring and research efforts that reduce impacts to forest habitats from mining operations, road construction, and timber harvest should be emphasized.

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ANTICIPATED CHANGES TO FOREST HABITATS DUE TO CLIMATE CHANGE

Many areas in Alaska are already showing signs of climate change. Scientists have reported observations of wetland drying, glacial and polar sea ice recession, spruce-bark beetle infestations, changes in species range and behavior, and an increase in fire frequency and intensity throughout the state. A better understanding of where and when such changes could occur is needed to help decision makers identify how Alaska's ecosystems may change and how managers may respond.

In order to understand what these changes may be like, the University of Alaska SNAP program developed models of climate change relevant to Alaska based on five downscaled global general circulation models developed by the Intergovernmental Panel on Climate Change to assess decadal averages of future temperature and precipitation values. These models assume a steady increase in carbon dioxide (CO₂) emissions from fossil fuel combustion over the first several decades of the 21st century, followed by a gradual decline in emissions as several kinds of low-emission energy alternatives become more prevalent. This emissions regime is considered a "moderate" estimate. Several other scenarios have predicted higher emission rates, and scientists have since determined current levels are significantly greater than even the most extreme concentrations analyzed by the Intergovernmental Panel on Climate Change. Higher emissions rates will likely accelerate changes in climate and lead to more severe ecosystem impacts.

In the past three decades, Alaska has warmed at a rate approximately twice the global average, and additional warming of 5-13°F is projected over the next 100 years. Rapid warming has substantially affected Alaska's marine, terrestrial and freshwater ecosystems (ACIA 2004). The resilience and ecological integrity of these ecosystems varies, depending on the sensitivity of the physical environment to warming and the capacity of the current dependent-species to adapt or move in response to environmental changes. Warming also brings the arrival of new species (including invasive species) that can modify natural ecosystems in ways that challenge their resilience to environmental change.

TERRESTRIAL ECOSYSTEMS

Although effects will vary in different regions of the state, Alaska's terrestrial ecosystems are generally expected to experience warmer and drier conditions with climate change. Thawing permafrost and increases in the active soil layer will alter the hydrologic regime. In southeast Alaska, changing seasonality is expected to shift temperatures across the freezing threshold, significantly impacting the amount of precipitation that falls as rain vs. snow and impacting ecosystem water availability. Vegetation zones in Alaska are likely to shift, with tree line moving northward and to higher elevations, and forests replacing a significant fraction of existing tundra. Animal species' diversity, ranges, distribution and abundance will change, with new species arriving (including invasive species) and some current species no longer able to thrive. Impacts of warmer and drier conditions may include increased area and frequency of wildland fire, increased insect outbreaks, retreat of inland glaciers, decreases in the area of continuous and discontinuous permafrost and lakes, and an expanded growing season. These potential changes – some negative, some beneficial – will substantially affect a wide range of human uses of terrestrial resources, including forestry and subsistence harvest of fish and wildlife.

FOREST ECOSYSTEMS

Assessing Climate Change Impacts on Forested Ecosystems of Alaska

The Alaska Center for Climate Assessment and Policy (ACCAP) and the University of Alaska SNAP program have partnered with the Pacific Northwest Research Station (PNRS) to assess the climate change impacts on forested ecosystems in all regions of Alaska. Stakeholder involvement is a significant component of this project. This assessment will include identifying historical long-term datasets, determining key current patterns and processes that are important to stakeholders, and projecting those key patterns and processes into the future under various climate change scenarios. Specific components are to review and synthesize existing knowledge, provide a baseline and scenarios of change, and identify data gaps and uncertainties. An outline of the proposed report can be found at:

<http://www.uaf.edu/accap/documents/USFS%20Assessment%20Outline.pdf>.

ACCAP hosted an all-day workshop addressing climate change impact on Alaska's forests November 5, 2009. The workshop provided an opportunity to engage with the core research team and discuss what issues are important, and how they can be addressed. The resulting report is relevant and useful. Information and contacts for the project are provided on the AACAP dedicated Internet site *Assessing climate change impacts on forested ecosystems of Alaska*: http://ine.uaf.edu/accap/research/forest_assessment.htm

ADF&G currently is not involved in this effort, although both the Alaska Department of Environmental Conservation and the Alaska Department of Natural Resources, Division of Forestry, did participate in the stakeholder workshop. Given the importance of forest habitats to wildlife populations and their management, we recommend that ADF&G look for opportunities to become engaged in this effort.

When complete, this effort will provide an up-to-date assessment of climate change impacts on forests in Alaska, which should be useful for determining future research, monitoring and adaptation needs, as well as effective decision-making.

A detailed climate change analysis was developed by the University of Alaska SNAP and The Wilderness Society for the Sitka National Historic Park; it can be found at <http://www.snap.uaf.edu/downloads/climate-change-summary-reports>. Expected changes in temperature and precipitation are described below, and serve as an example of the climate changes that will impact forests in southeast Alaska.

Temperature Changes in Sitka National Historic Park and Surrounding Area

Temperatures are projected to increase over the coming decades at an average rate of about 0.6°F per decade. Average annual temperature is expected to rise by about 3°F by 2040 and almost 6°F by 2080. Considering the natural variation in temperatures across the study area, this is likely to result in a transition from average annual temperatures near 42°F to temperatures approaching 48°F. A likely outcome of these changes is a lengthening of the growing season, a change that could have profound affects on wildlife mating cycles, plant growth and flowering, water availability in soil and rivers, and hunting and fishing. Winter temperatures are projected to change the most dramatically. Mean winter temperatures could reach a high of 42°F by 2080, a figure that represents more than a 6°F rise from the historical 36°F average. Average summer temperatures are

projected to rise by almost 5°F by 2080 (from ~51°F to ~56°F). Some species may benefit from these changes and the associated shifts in vegetation, while others may not be able to adapt or find suitable habitat conditions to sustain their populations.

Precipitation Changes in Sitka National Historic Park and Surrounding Area

Precipitation is predicted to increase across the study area. Despite this area-wide increase, conditions are expected to become substantially drier in the summer and fall. Although summer rainfall is expected to rise by 8%, this increase is unlikely to be enough to offset an increase in evapotranspiration caused by warmer temperatures and a longer growing season. Winter precipitation may increase by as much as 10% and is likely to fall in the form of rain depending on the temperature. Ultimately, the timing and intensity of precipitation will determine how these changes affect the landscape and hydrology of the Preserve.

Summary of Findings

Sitka National Historic Park and surrounding area is projected to become warmer and drier over the next century. Warmer temperatures and a longer growing season are expected to increase evapotranspiration enough to outweigh a regional increase in precipitation. Seasonal changes in climate will have profound impacts on the condition and health of wildlife habitat, lead to increased fire risk, and contribute to the likelihood of wetlands, streams, and lakes drying. It is important to note that predicting changes in environmental variables is difficult, especially in Alaska where historical climate monitoring data is sparse. Increasing the scope of precipitation, temperature, and ecological monitoring throughout Alaska is one of the best strategies for improving our understanding of changes in climate and the response of ecosystems.

MANAGEMENT PRINCIPLES

The following management principles should guide initial ADF&G response to climate change (based on recommendations from the AFWA Climate Change Committee):

- Healthy and robust forests are necessary to support fish and wildlife conservation.
- The reduction of non-climatic stressors on forest ecosystems will help to reduce the impacts from changing climate conditions.
- Forest systems in transition will present management challenges commensurate with the rate and extent of climate change.
- Some wildlife populations will decline or even become extirpated or extinct, while others will increase or adapt under changing climate conditions.
- Long-term management objectives and implementation options will be influenced by changes in land use and changes in species compositions, distributions, and interactions with humans.
- Short-term and transitional management strategies will play an important role in species health and conservation.
- Effective partnerships and collaborations at state, regional, and international levels will be needed to address climate change challenges.

KEY INITIAL ACTIONS

The following set of actions will help ADF&G incorporate climate change into its wildlife programs (based on the recommendations of the AFWA Climate Change Committee).

- Identify the likely and potential impacts of climate change on forests and their uses at state, regional, and national levels. *(ACCAP, SNAP and the PNRS currently are assessing the climate change impacts on forested ecosystems. ADF&G must plan for the appearance and implications of novel communities/ecosystems and consider appropriate spatial and temporal scales including where species and habitats are likely to occur.)*
- Conduct a vulnerability assessment (including threat assessment) that considers the ecological, economic, and socio-political ramifications of climate change effects on forests and their uses at state, regional, and nation levels.
- Incorporate forest climate change considerations into all fish and wildlife management plans, including fish habitat action plans, local area management plans, migratory waterfowl plans, species conservation plans, state wildlife action plans, and others.
- Implement research and monitoring to assess the impacts of forest climate change on fish and wildlife.
- Adaptively manage forest species and habitats in light of their vulnerability. *(This could include the development of testable hypotheses based on climate change forecasts.)*
- Identify and address statutory changes needed at the federal, state, and local levels to effectively address and manage climate change impacts on forest wildlife.
- Evaluate budgetary needs to respond to climate change impacts and allocate existing funding to implement first order priorities.
- In coordination with AFWA, identify and actively pursue new sources of funding to effectively respond to climate change issues.
- In coordination with other state resource management agencies, identify and actively pursue new sources of funding to effectively respond to climate change issues.
- Identify or develop regional partnerships to address common climate change goals and strategies.
- Develop effective communication systems and outreach efforts for state agencies, researchers, policy makers, planners, natural resource managers, and stakeholders to enhance collaborative efforts.

MONITORING AND RESEARCH NEEDS

GOVERNOR'S SUBCABINET ON CLIMATE CHANGE

A number of general and specific actions have already been identified by the Alaska governor's subcabinet on climate change. These can be found at: <http://www.climatechange.alaska.gov/> , and in reports from the Adaptation Advisory Working Group and the Research Needs Work Group. Some of the more critical efforts for addressing climate change impacts on forest ecosystems are presented below.

Reduce Introduction and Spread of Invasive and Eruptive Species

The combination of changing climate (lengthening growing seasons and warming temperatures) and increasing globalization has dramatically increased the rate of introduction and the spread of non-native, invasive species in Alaska. Invasive plants, eruptive insects and diseases, and invasive marine species have the potential to damage important economic sectors such as fisheries and forestry, as well as to alter fire cycles and subsistence opportunities, spread disease, and contribute to population declines and extinctions of native species.

NS-4 Invasive and Eruptive Species Prevention and Response

Reduce introduction and spread of invasive species and eruptive species in the context of climate change. NS-4 recommends that the State of Alaska immediately join in the work underway to address invasive species in Alaska. ADF&G, DNR, DEC and Department of Transportation and Public Facilities (DOT&PF) need to be fully involved. Establishment of the Alaska Invasive Species Council would cement the partnership between the state and other levels of government, and would provide leadership, policy decisions, and leverage and coordination of resources and authorities to implement effective prevention and response actions.

Many actions to prevent introduction and to control invasives already in Alaska could be implemented within the short- to mid-term (two to five years). Funding for two state positions (ADOT&PF vegetation management and DNR plant/wood products inspector) is recommended to address two significant points where invasives can be effectively controlled. It is *much more cost-effective to invest in prevention and early control of invasive and eruptive species*, than to combat their spread and their substantial impacts to Alaska's ecosystems and economy in the future.

Provide for Adaptive Management of Fish and Wildlife

The State of Alaska will improve its capability to manage fish and wildlife species adaptively in Alaska to assure sustainable management of these important resources under conditions of rapid and substantial climatic change

NS-5 Adaptive Fish & Wildlife Management proposes two specific actions under the leadership of ADF&G:

- 1) Develop and adopt a more timely regulatory process for the harvest of wildlife to adapt and respond to short- and long-term changes in climate that can decrease harvest success under a static harvest season.

2) Develop a coordinated framework that documents existing fish and wildlife monitoring efforts (for both harvested and non-harvested species), identifies priorities for monitoring in the context of climate change, and identifies gaps and potential for collaboration. This option would also include development and use of a common structure for cataloging and disseminating monitoring information.

Research Changes to Vital Ecosystem Services.

The cascading effects of large scale environmental change can affect critically important natural services and economic resources, such as water supply, air quality, ocean fisheries, etc. For example, large scale changes to boreal forest are expected, with uncertain effects to other factors. Information about potential “tipping points” could help to avoid situations where vital ecosystem services are no longer being provided (e.g. wildlife and fisheries population crashes).

Gaps in Geospatial and Remote Sensing Data

In order to assess and forecast climate change impacts, we must fill gaps in geospatial data coverage, aerial photography, digital elevation models (DEM), and remote sensing data.

There are highly important specific early needs to facilitate other data gathering efforts. For example, accurately represented coastal land elevations are needed for modeling how sea level rise will affect low lying coastal areas.

Develop and refine down-scaled climate models

Global Climate Model data is too coarse to inform communities and local resource managers about probable changes at local levels.

Coordinate climate and ecosystem monitoring programs

Coordinating programs among agencies, organizations and institutions will promote long-term datasets with reliable indicators and across large geographic areas (regional and continental scale). These are essential to determine climate and resource condition trends.

Work with communities to improve monitoring of climate change and its impact

In order to understand and fully monitor climate impact we must:

- Work with communities to determine appropriate indicators of climate change and community impacts.
- Improve monitoring of key climate change indicators and effects, with emphasis on effects having large societal impacts.
- Monitor climate change indicators and their societal impacts.

Improved monitoring of key climate change indicators relevant to Alaska will allow for tracking of climate change effects and will contribute data to modeling and assessments. Monitoring of locally appropriate indicators and development of thresholds is needed to determine when change is occurring to rapidly for communities to adapt to impacts related to climate change. This information is needed to inform assessments of societal impacts and support planning and adaptation.

Vegetation Maps

There is a need to acquire or produce vegetation maps, usually compiled from satellite imagery. Ortho rectified imagery would show human improvements and vegetation. A base map is needed for the state.

Understanding changes in landcover types is critical to assessments related to fire, forestry, wildlife, fisheries, etc. GIS and maps are basic tools needed for many analyses.

Assess Communications Strategies for Climate Change Information

Poorly communicated information about climate change can cause more harm than good.

Expand Modeling of Wildland Fire, Fuel, and Smoke

Fire hazards are expected to increase with rising air temperature, longer growing seasons, and increased soil dryness. Dense and long-lasting smoke from wildland fires can result in severe acute and chronic health impacts in affected communities.

Review and Coordinate Wildland Fire Policies with Canadian Counterparts

Determine efficacy and ecological effects of different fire management policies. Current wildland fire policy is not Full Suppression. Research would inform policy makers about potential positive and negative effects to wildlife habitat of allowing wildland fires to burn.

Develop projections of future changes to potential wildlife habitat that are likely to result from climate-driven changes to landscape, landcover (vegetation), wildfire frequency and intensity, permafrost thaw/thermokarst, and fragmented migratory corridors.

Climate change will have cascading effects on multiple physical, biological, social, and cultural resources. However, the scope and scale of those effects is largely undetermined.

Identify How “Sentinel” Ecosystems are Changing

Continued monitoring in those areas where there are already long-term records could provide valuable trend information.

Research and Monitor Forest Response After Disturbance

Research ecological “tipping points.” Trees are moving into higher altitudes and higher latitudes as climate warms. Many common species are experiencing severe and recurring pest outbreaks (e.g., bark beetles, budworms, leaf miners) related to climate change (increased temperatures and transpiration, reduced soil moisture). Fire effects are increasing as flammable shrubs and trees expand into tundra, and as fire frequency increases in boreal forests. However, the full scope and trends has not been determined.

Assess effects of salvage logging

Assess efficacy, economics, and ecological effects of salvage logging to produce timber and wood biomass fuels from fire and insect killed trees.

Climate change-related warming and drying is likely to result in more insect and fire-killed timber and biomass.

ADF&G STRATEGIES AND ACTIONS ON CLIMATE CHANGE

In addition to the activities outlined above, the following strategies and actions will help the department fulfill its mission and responsibilities.

- Continue to fill information gaps on species of conservation concern, potentially avoiding future listings under the state and federal endangered species acts.
- Identify priority forests for wildlife conservation and management, and work with the University of Alaska SNAP program to develop climate change scenarios similar to the example presented above for the Sitka National Historic Park.
- Expand the scope of NS-4 to fund an additional position that would implement the Alaska Rat Plan and coordinate eradication efforts. Current regulation for importation of exotic species as pets should be reviewed and potentially revised in light of predicted climate changes.
- Look for opportunities to become engaged in the ACCAP, SNAP and PNRS assessment of climate change impacts on forested ecosystems in all regions of Alaska.
- Develop strategy for effective partnering in FWS Landscape Conservation Cooperatives. During the next 12-18 months, the Service will work with states and other conservation partners to refine the LCC framework. The FWS has \$20M and USGS has \$5M, in FFY 2020 budget.
- Designate dedicated staff for the department and each division to engage in climate change workshops and discussions, to build program capacity by identifying funding and other resources to meet program needs. The science behind climate change is evolving rapidly, yet the department has limited capacity to engage in these efforts and pursue strategies that enhance our mission.
- Complete vulnerability assessments since they are the key to developing effective adaptation strategies. These assessments will describe the exposure, sensitivity and the capacity to adapt to climate change for each target species or habitat. The relative vulnerability of species or habitats can be used to set goals, determine management priorities and inform decisions about appropriate adaptation strategies.
- Implement streamlined and affordable monitoring programs that inform management decisions under a changing climate; consider working with partners to monitor species and habitats across their entire range. Complement these efforts with research monitoring, effectiveness monitoring and implementation monitoring
- Increase public outreach and involvement to improve understanding of the impacts of climate change to wildlife and gain support or acceptance since the potential for controversy associated with climate change could be high, and there may not be agreement on messages or approaches.

KARST CAVE HABITATS: ENTRANCE ZONE, TWILIGHT ZONE, AND DEEP CAVE ZONE

BACKGROUND

The Background section below is reproduced from Appendix 5.6 of *our wealth maintained: a strategy for conserving Alaska's diverse wildlife and fish resources*, Alaska Department of Fish and Game (2006).

Karst landscape is an area of underlying limestone (carbonate bedrock) in which erosion and dissolution by ground water/chemical weathering has produced fissures, sinkholes, underground streams, and caverns. The high soil acidity and damp conditions of temperate rain forests and muskeg are ideal for creating interconnected dissolved features in alkaline calcium carbonate bedrock. This network of caves and tunnels is a distinct habitat type located underground but connected, in varying degrees, to the overlying landscape through sinkholes (also called dolines or collapse pits), cave entrances, and subsurface hydrology.

In Alaska, karst landscape is primarily located in the Alexander Archipelago, which includes Prince of Wales, Dall, Coronation, Sumner, Heceta, Baker, Kosciuszko, Kuiu, Long, Etolin, Revillagigedo, Kupreanof, and Chichigof Islands (Baichtal 1996; Experts group). The mainland near Haines, Haines State Forest in Southern Chilkat Valley (Streveler and Brakel 1993), and the Wrangell-St. Elias Mountains also contain areas of karst. Outside of Southeast Alaska, the only other karst landscapes overlain by temperate rain forest are located in Chile and Tasmania. Other karst areas in Alaska include the Lime Hills on the west side of Cook Inlet, the Jade Mountains in northwest Brooks Range (sinkholes, springs, and underground streams) and the White Mountains in the Interior. The karst cave systems in Southeast Alaska are the most extensively studied; very little is known about the extent and ecology of Alaska's northern and western karst areas. The following habitat descriptions address karst cave conditions in Southeast, in the coastal areas of Canada, or generalized cave conditions.

Within the karst cave system are several zones of differential habitat use and characteristics. The "entrance zone" is located immediately around the cave or tunnel opening and is the most influenced by surface conditions. The "twilight zone" extends from the entrance to mid-depth and is best characterized by decreasing light levels and connectivity to the exterior. The final zone is the "deep cave" area, which is almost entirely isolated from exterior conditions. Within and between these zones are a range of characteristics that affect species distribution: light level; temperature; the range of temperature variation; air flow patterns; cavern size; the cave's depth below land surface and elevation relative to sea level; humidity; substrate type; connectivity to surface water/flow levels; level of human disturbance; turbidity, pH, and conductivity of water; nutrient input to the system; and thickness of epikarst (Aley and Aley 1997). The one factor that influences all of these habitat characteristics is the degree of connectivity between the surface and subsurface. In a karst cave system, the speed and magnitude of transfers between surface and subsurface is controlled by sinkholes and hydrologic flows (Karst Task Force for the Resources Inventory Committee 2001; Baichtal 1993).

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Nutrient input to cave systems depends on surface organics being transported through connections from the surface. These nutrient sources may take the form of debris falling into sinkholes or being washed into cave systems by sinking streams (streams descending through the cave system).

Karst cave inhabitants can be obligate, opportunistic, or accidental. Accidental inhabitants are those organisms introduced into the systems through sinkholes or flushed in by water flow. While accidental species rarely survive, they present an important influx of nutrients to the system. Opportunistic use is generally limited to terrestrial or littoral openings, but this use does represent a wide range of taxonomic groups.

Obligate cave inhabitants consist of troglobite (terrestrial cave dwellers) and stygobite (aquatic cave dwellers) invertebrates and bats. The most extensive invertebrate surveys to date were conducted in 1992 and 1995. Collections from over 300 cave and resurgence



Starlight Cove, Prince of Wales Island

T. Heaton, University of South Dakota

sites in Southeast yielded at least 5 troglobitic and 40 troglomorphic invertebrate species (Carlson 1997a). Another extensive survey of cave invertebrates conducted in 1997 on Vancouver Island initially identified 192 taxa. Investigators in this study found "remarkable" similarities between cave fauna compositions on Vancouver Island and in Southeast (Shaw and Davis 2000).

Entrance Zone

The entrance zone is characterized by lower light levels and higher relative humidity than exterior conditions, and more dramatic temperature variations and higher nutrient availability than interior areas of caves. Davis et al. (2000) defined the entrance zone as 0–10 m from the entrance of the caves, but actual entrance zone parameters may exist in varying locations depending on cave entrance size.

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Terrestrial openings are used by various species of bats for swarming and feeding activities. Temporal, gender, and life cycle differences in cave use relate to the elevation, temperature, variation of temperature, humidity, and size of the cave. Caves at lower elevations are used by *Myotis* spp. females and juveniles in late summer months (Davis et al. 2000).

Aquatic invertebrate accidentals washed into Vancouver Island cave habitat are mostly from the taxonomic groups Plecoptera, Ephemeroptera, and Trichoptera. Terrestrial beetles and mosquitoes also use cave entrances. The highest invertebrate diversity occurs in the entrance area, and the composition is dominated by taxa that would likely be found elsewhere in similar surface environments. Near-entrance fauna is dominated by a number of flies and associated predators, such as spiders and weevils (Shaw and Davis 2000).

Additional habitat functions of the entrance zone include denning by black and brown bears, river otters, wolves and mustelids, although there is uncertainty about the extent of this use (Streveler and

Brakel 1993). Sitka black-tailed deer use the thermal

buffering effects of air currents at cave entrances both summer and winter (Baichtal and Swanston 1996). This effect has been called "cave breath" and may allow some species or individuals to live at the temperature limits of their distribution (Streveler and Brakel 1993). Both songbirds and seabirds use openings for nesting and feeding depending on proximity to shore (Baichtal 1995).

Entrance Zone-associated Species:

Little brown bat, *Myotis lucifugus*

Keen's bat, *Myotis keenii*

California myotis, *Myotis californicus*

Long-legged bat, *Myotis volans*

Silver-haired bat, *Lasionycteris noctivagans*



California myotis (*Myotis californicus*)

M.R. Stromberg, University of California, Berkeley

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Twilight Zone

The “twilight zone” extends from the entrance to mid-depth; it has sheltering characteristics but is not completely isolated from the surface. Most invertebrates found in caves reside in the twilight zone. Few true obligate troglobites occur here, but there is large potential for finding as yet undescribed and unidentified species. Other species may have certain portions of their life cycle that necessitate different zones of the caves. The twilight zone is the area of a cave used by roosting bats (Davis et al. 2000).

Twilight Zone-associated Species

Little brown bat, *Myotis lucifugus*

Keen's bat, *Myotis keenii*

California myotis, *Myotis californicus*

Long-legged bat, *Myotis volans*

Silver-haired bat, *Lasionycteris noctivagans*

Deep Cave Zone

The deep-cave zone is a very stable, insulated habitat, but this stability is a function of a very narrow range of habitat conditions. Deep cave invertebrates (hypogean invertebrates) are highly specialized to cave conditions, with extremely limited tolerance for light, humidity, temperature, and pH variations, but with the ability to exploit low nutrient and oxygen levels (CWCS Expert Group 2004). The interior of a deep cave generally has little organic debris, no light, temperatures slightly above freezing, high humidity (100%), a pH near neutral (a consequence of the buffering effects of the dissolved calcium carbonate), and a very limited input of new species, predators, or competitors. One possible example of a hypogean adaptation is amphipod development of reduced metabolic rates compared to their epigean counterparts in response to limited food availability or low oxygen conditions (Spicer 1998).

In deep-cave habitats, collections of invertebrates were dominated by collembola, symphyla and diplura with infrequent captures of other taxa, such as acarina (*Robustocheles occulta*), diptera or siphonaptera. In the Lower 48, for both stygobites and troglobites, only number of caves (in a system) was a significant predictor of distribution (Culver et al. 2003). For example, the more extensive a system, the more cave-adapted species it supports.

Myotis spp. use deep cave areas of high elevation caves (800 m) as hibernacula. These hibernating locations are characterized by temperatures close to freezing, with a small range of temperature variation and high humidity levels (Davis et al. 2000). However, *Myotis* spp. depend on caves of varying depths and locations at different points in the species' lifecycle.

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Deep Cave Zone-associated Species

Collembola	<i>Hydaticus</i> larvae
<i>Arrhopalites hirtus</i>	<i>Rhynchelmis</i> spp.
Arachnida	<i>Polycelis</i> spp.
Acarina	<i>Candona</i> spp.
<i>Robustochela occulta</i>	<i>Acanthocyclops</i> spp.
Crustacea	<i>Dacyclops</i> spp.
<i>Stygobromus quatsinensis</i>	
	Keen's bat, <i>Myotis keenii</i>

Interactions with Overlying Landscape

The connectivity between karst systems and the overlying landscape also benefits the overlying forest. In Southeast Alaska, karst areas are better drained and have less acidic soil, promoting growth of larger trees than in nonkarst areas. Dissolved fissures in the bedrock allow deep root growth making large trees more windfirm. The

underground portions of streams can provide buffers for water pH, water temperature, and flood discharges. For example, acidic water (pH 2.4–5.8) flowing into karst areas may exit the cave system with a pH of 7.5–9.0 (Aley et al.

1993; Baichtal and Swanston

1996). Water with dissolved minerals from contact with a karst system typically has a higher specific conductance than waters from nonkarst systems (Karst Task Force for the Resources Inventory Committee 2001). Compared with other North American karst systems, Southeast karst landscapes in particular have mid-range conductance values and high runoff values, accelerating dissolution and cave formation processes (Aley et al. 1993). These dissolved minerals represent an important source of calcium and carbon for use in biological systems.



On Your Knees Cave inside Bear Passage. Sedimentary layers and spring.

T. Heaton, University of South Dakota

Ecological Role of Karst Caves

Protection of the karst landscape is important to preserve the state's species biodiversity. The narrow range of interior conditions supports communities of species that are specifically adapted to unique environmental conditions. In addition, these environmental conditions generally occur in isolated pockets that preclude migration of individuals between habitat patches. As a result, obligate cave fauna, especially deep-cave inhabitants, have population characteristics of a species highly susceptible to rapid evolutionary change via endemism (Culver et al. 2003).

Locations of invertebrates and bats in Southeast karst caves often represent the northernmost known extent of these species' distribution. Prince of Wales Island holds records for northernmost locations of *Stygobromus* sp. and the bats *M. keenii* and *M. volans* (Baichtal 1996).

Bats are particularly vulnerable to human disturbance while hibernating. Bats do not store a lot of fat in preparation for hibernation (as bears do), and disturbance and rousing of hibernating bats can cause 10–30 days of fat to be metabolized (Brady 1982). Southeast karst caves may be extremely important to the perpetuation of bats in general in the state of Alaska. Of the 5 species of bats in the state only one, *M. lucifugus*, has a range extending northward of Southeast. *M. lucifugus* is widely distributed, with its summer range extending into the Yukon Territory. However, little is known about where the species overwinters. The Yukon Government theorizes that *M. lucifugus* migrate to the Alaskan coast to hibernate for the winter. Northern populations of *M. lucifugus* have larger females than males (southern populations do not have this sexual dimorphism). One suggested explanation for this is that juvenile bats must be larger at birth to have sufficient body resources to survive their first winter of hibernation. This may represent an adaptation unique to northern areas.

Karst caves are used as birthing dens by otters, and resting and denning sites for deer, bears, wolves and small mammals. Some bird species, including dippers, thrushes, and swallows, are known to use cave entrances for nesting and feeding. Aquatic habitats associated with karst landscapes are more productive than nonkarst aquatic habitats (USFS 1997). Streams flowing through karst areas support larger coho salmon fry and parr than Southeast streams without karst. Higher alkalinities of karst streams are positively correlated with higher fish densities (Bryant 1997).

A consideration for preserving biodiversity in karst caves is the potential to discover previously undescribed species. A 2002 article in *Acta carsologica* identified the world's most diverse caves as having 41 to 84 species of stygobites and troglobites (Culver and Sket 2002). Meanwhile, a study of cave fauna on Prince of Wales Island preliminarily identified 77 invertebrate taxa even without many samples being identified to the species level (Carlson 1997b).

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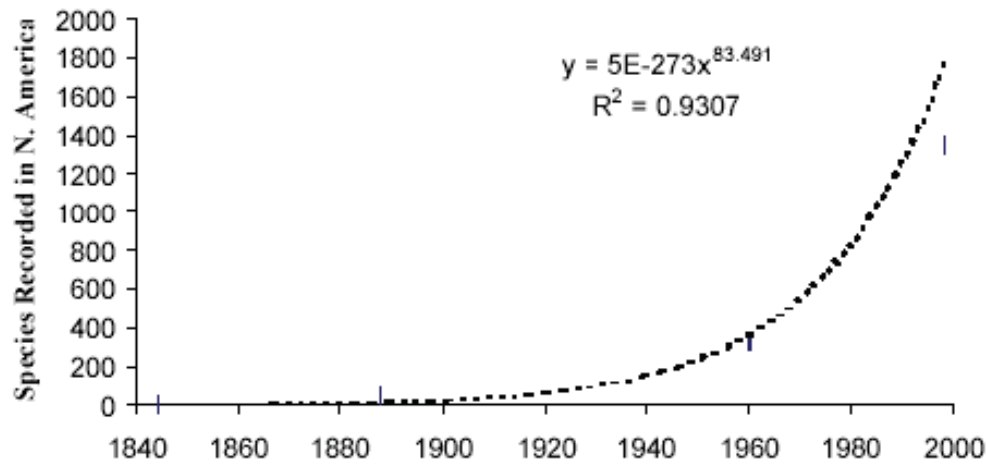


Figure 5.2. Graph showing exponential increase in the number of known obligate, cave-dwelling species in North America (DeKay, 1844; Nicholas, 1960; Packard, 1888; Peck, 1998) and a power function trend line fitted to the data.

From SUBTERRANEAN BIODIVERSITY PROJECT, Research Proposal Submitted to the Arkansas Game and Fish Commission. A.V. Brown and G.O. Graening, March 6, 2000.

Conservation Status

Alaska's karst cave habitat is generally healthy. Localized development will likely continue to result in habitat alteration. Opportunities should be sought that alleviate negative impacts and maintain connectivity, as well as suitable areas of quality habitat important to the sustainability of species.

The conservation of both karst cave habitats and associated species communities is complicated by the limited knowledge of the cave ecology in Alaska. Many unknown or poorly understood variables could impact species survival. Some of these variables include identifying links to the overlying landscape and connections to ground water and surface water systems. Hydrologic systems expand the area of impact and effects far beyond the physical limits of a cave. Habitat assessment can be complicated because karst drainage does not coincide with surface drainage patterns or even watershed or hydrologic unit boundaries (Karst Task Force for the Resources Inventory Committee 2001). Significantly, karst formation processes are impacted by both glaciers and permafrost. In Arctic regions, ground water circulation can be impeded by static ice masses (glaciers) that form in caves (Ford 1993). Little study has yet been conducted on the effects of climate change and karst cave fauna. To fully conserve karst caves and their resources, the caves and their karst landscapes must be managed as a whole.

Road development, land clearing, timber harvest, and mining activities all have the potential to alter subsurface water and nutrient flows. Timber harvest and related road construction in the vicinity of caves increase runoff and sedimentation, which may

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flood, scour, or fill previously stable cave environments. Debris accumulates and blocks cave entrances and exits through practices of disposing of slash and rerouting of surface flows into sinkhole ponds or dry sinkhole pits. Recreational users pose another, more direct, risk to cave habitat. A high volume of visitors can destroy terrestrial habitat in caves by compacting cave sediments (IUCN 1997). Bats are susceptible to human disturbance; caves can be gated with “bat friendly” gates to exclude human disturbance, but these can unintentionally exclude other nonhuman species that depend on, or opportunistically use, karst caves.

Karst caves have high value for paleontological research because fossils preserved in caves create records of species distribution through the last millennia and provide insight into the location and extent of glacial refugia during the last Ice Age. Species distribution may also provide insight into climate conditions when early bands of humans may have migrated through the area (Heaton 2002). There is an ongoing study funded by the National Science Foundation, National Geographic Society, Tongass National Forest, and University of South Dakota to inventory and identify paleontological deposits in caves in the Tongass National Forest.



El Capitan Cave. Female black bear skeleton radiocarbon-dated to be 10,750 years old (Late Pleistocene Epoch)

T. Heaton, University of South Dakota

The protection of a karst cave is very much dependent on the ownership of the overlying land. On state and private lands there is minimal to no protection. As of January 2005, the State of Alaska Division of Forestry did “not recognize karst topography as a significant resource to be managed on the State’s limited land base in southeast. The DOF will protect karst formations that affect water quality as per the Alaska Forest Resources and Practices Act and Regulations. If significant recreational activity is found to be dependent on a karst resource, it will be taken into account during the development and implementation of the Forest Land Use Plan (FLUP) process for a proposed timber sale (Division of Forestry, Coastal Region).” In 1992 the state legislature attempted but failed to pass an Alaska State Cave Protection Act.



El Capitan Cave fish fossils; otoliths, vertebrae, spines and jaws dated to the early Holocene

T. Heaton, University of South Dakota

There is a higher level of protection for caves on federally owned lands due to the Federal Cave Resources Protection Act of

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1988. This act applies to listed “significant caves” on federal lands. The significance is determined by criteria established by the Secretary of the Interior or his/her delegates. In Alaska, a large amount of the karst landscape is located on federal lands: Portions of the White Mountains are under BLM management; many of the caves in the Alexander Archipelago are in the Tongass National Forest; karst landscape is located in Wrangell–St. Elias National Park and Glacier Bay National Park; and the Lime Hills and the Jade Mountains are both located on a mixture of federally owned and Native-owned or -selected lands.

The 1997 Tongass Forest Plan Cave Standards and Guidelines (USFS 1997) implemented a karst resources management strategy that included developing an inventory of caves and hydrologic systems and protecting and maintaining significant caves and cave resources to the extent feasible. These guidelines fulfill responsibilities under the Federal Cave Resources Protection Act. The Forest Service in the Ketchikan area has developed a cooperative effort with the Alaska Cavers Association to inventory and document caves. The Thorne Bay Ranger District has developed trails and viewing platforms and tours for 2 of the larger caves in Southeast. Even within the Tongass National Forest, different land designations (monuments, wilderness areas, etc.) may affect the degree of cave protection (Streveler and Brakel 1993).

There are no species-specific legal protections for obligate cave inhabitants on nonfederal lands. *M. keenii* is on the “Red List” of potentially endangered species in Canada. Many troglobite invertebrates in the Lower 48 states are listed as endangered species due to their high degree of endemism and limited distributions.

One of the most important aspects of conserving karst caves is the preservation of aquatic systems. Currens (2001) documented changes in ground water flow after applying best management practices for protection of a karst aquifer similar to riparian best management practices instituted to protect ground water quality. Sinkholes should be recognized as a direct link to underground streams and vegetated buffer zones required around the sinkhole, as well as surface use restrictions in the immediate drainage area. Rapid transmission of ground water with little filtering through external vegetation and karst makes underground aquatic systems susceptible to pollution inputs (IUCN 1997).

Conservation actions that focus on cooperative working relationships between land managers and speleologists regarding karst cave habitats are an important tool for managing and protecting these areas. Identifying areas important to maintaining species diversity should continue.

Recommended conservation actions for karst caves include the inventory of caves in northern and western Alaska to acquire basic knowledge, such as extent, location, and any ecological use. Efforts toward achieving protected species status for rare, endemic cave fauna, such as the identification and description of Southeast invertebrate species and their associated habitat, should be supported. Research

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regarding the effectiveness of best management practices in karst areas to protect hydrology and prevent introduction of debris and contaminants is critical to sustaining healthy karst cave habitats. In addition, investigation of the use of instream flow reservations for ground water and subsurface ownership to protect cave resources should be considered. Final recommendations include support for identification of caves, and the establishment of guidelines for recreational use through working relationship with Alaska Caver's Association.

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POSSIBLE CLIMATE IMPACTS

Water is one of the fundamental ingredients in karst processes. Any significant change in the supply of water therefore could affect karst geomorphic processes and the resultant karst ecosystem. In southeast Alaska, precipitation is expected to increase in karst areas (SNAP). This could result in more frequent cave floods, which may in turn result in increased erosion, transport, and deposition of sediment within caves (Sharples 2006).

Temperatures are also expected to increase in karst areas in southeast Alaska (SNAP). Increasing temperatures could increase surface soil biological activity, which could in turn release more carbon dioxide that could increase the acidity of groundwater. More acid water could percolate into caves resulting in increase dissolution of some cave speleothems.

It is also possible that rising sea levels could also impact karst caves in southeast Alaska. Rising sea level could result in additional landwards intrusions of saltwater into the groundwater which in turn could affect cave water quality.

NEEDED RESEARCH

Very little is known about karst caves in Alaska. Increased monitoring should be implemented. One option would be to select a “representative” karst cave for long-term monitoring. Information to be collected would include water chemistry, species diversity, temperature, and water flow.

AT RISK SPECIES

Climate-related impacts will likely affect the species diversity present in the karst caves. These species have adapted and specialized to the unique features present in the karst caves. Changes to these features will likely impact uniquely adapted species including:

Entrance Zone-Associated Species:

Little brown bat, *Myotis lucifugus*
 Keen's bat, *Myotis keenii*
 California myotis, *Myotis californicus*
 Long-legged bat, *Myotis volans*
 Silver-haired bat, *Lasionycteris noctivagans*

Twilight Zone-Associated Species

Little brown bat, *Myotis lucifugus*
 Keen's bat, *Myotis keenii*
 California myotis, *Myotis californicus*
 Long-legged bat, *Myotis volans*
 Silver-haired bat, *Lasionycteris noctivagans*

Deep Cave Zone-associated Species

Collembola	<i>Hydaticus</i> larvae
<i>Arrhopalites hirtus</i>	<i>Rhynchelmis</i> spp.
Arachnida	<i>Polycelis</i> spp.
Acarina	<i>Candona</i> spp.
<i>Robustocheles occulta</i>	<i>Acanthocyclops</i> spp.
Crustacea	<i>Dacyclops</i> spp.
<i>Stygobromus quatsinensis</i>	
	Keen's bat, <i>Myotis keenii</i>

POTENTIAL IMPACTS TO FISH AND WILDLIFE POPULATIONS AND THEIR USES

POTENTIAL IMPACTS TO COMMERCIAL, RECREATIONAL, AND PERSONAL USE FISHERIES

- ↗ Geographic boundaries of areas open or closed to fishing may need to be revised as stocks shift in distribution (e.g., northward movement of stocks into the northern Bering Sea and southern Chukchi Sea).
- ↗ Extended economic losses are possible as traditional target stocks change in relative abundance and location (e.g., northwestward movement of Bering Sea pollock). This could result in a drop in fish tax revenues as well as income to fishers and CDQ groups. Economic opportunities may arise, but there may be a time lag prior to capitalizing on these.
- ↗ Increases in predatory fish (e.g., arrowtooth flounder, mackerels) may lead to lower guideline harvests for targeted fish (other groundfish and salmon).
- ↗ Ocean acidification due to CO₂ buildup may seriously disrupt shell formation in crab, shrimp, and other shellfish, potentially leading to collapse of shellfish fisheries in the long-term. This could also affect zooplankton development, thereby affecting fish survival of species (e.g., sockeye salmon) dependent upon zooplankton.
- ↗ The potential for decreased production of some recreationally targeted fish stocks and increases in others may necessitate geographic realignment of fisheries and adjustment of management plans.
- ↗ Changes in stream flows and water quality may alter the type and intensity of fish stock assessments in these streams. Instream flow needs for fish will also need to be reevaluated.
- ↗ Access by anglers to waterbodies may improve, degrade, or change significantly as climate changes the extent of wetlands of drainage basins. Managers will need to anticipate and mitigate for these changes.
- ↗ Fishery managers will need to increase efforts for prevention of invasion, for monitoring, and possibly for control/eradication of invasive species that will be expanding their ranges or those newly arriving.
- ↗ Fishery regulations will need to adapt to a longer open water season, allowing for potentially higher harvest rates on some recreational fish stocks.
- ↗ Requests for stocking of non-native fishes that are better adapted to warmer water temperatures (e.g., walleye) will need to be considered and policy decisions made regarding these requests.

- ↗ New assessments of fish habitat (e.g., anadromous waters or fish community data) will need to be prioritized and implemented to meet our statutory and regulatory responsibilities.
- ↗ Adjustments to outreach, education, and involvement programs will need to be made to inform and educate the public about changes in fish and fisheries (both good and bad) due to climate change.

POTENTIAL IMPACTS TO WILDLIFE

- ↗ Changes in species distribution and behavior may necessitate adjustments of management plans and harvest regulations.
- ↗ New population survey and monitoring strategies may need to be developed; this may require research into new techniques.
- ↗ The effect of climate on wildfires is of great interest and concern, since over much of Alaska fire is the predominant habitat change agent and since our main big game species are fire-adapted in different ways. Similarly, we may see a trend where the boreal forest will transition toward grasslands, which would favor a different species mix.
- ↗ In the last couple of years the Board of Game have been faced with unusual regulatory requests for extended or extra late hunting seasons to compensate for people's observations that animals' (generally moose) movement timing and pattern have changed. This type of input from villages is anecdotal, and there is no way to know if it has been influenced by the increasing worldwide coverage of climate issues. However, DWC staff have agreed that in several cases, the weather patterns and seasonal temperatures have been unusual (late and warm) and would conceivably affect wildlife movements in the way described by the proponents of the late seasons. This could necessitate changing or adjustment of management plans.
- ↗ Changes in sea level and increases in storms and erosion could result in multiple effects:
 - ↗ Coastal dependent species could lose low-lying habitats that are critical to their productivity and welfare. These include Pacific brant (Y-K breeding colonies, North Slope molting areas, critical Izembek fall staging), emperor geese (Y-K breeding, molting), cackling Canada geese (Y-K breeding/molting), spectacled eiders (Y-K breeding).
 - ↗ Low-lying coastal staging areas that support millions of shorebirds, geese and ducks during spring and fall staging could degrade. Key examples: Stikine Delta; Copper River Delta and barrier islands; Cook Inlet marshes; Alaska Peninsula flats at Pilot Point, Nelson Lagoon, Izembek Lagoon; Y-K Delta coastal flats and marshes; Safety Lagoon near Nome; Kotzebue Sound lowlands; North Slope salt marshes and onnected lakes from Elson Lagoon, Teshekpuk Lake, Colville Delta, Sagavanirktok Delta, Canning Delta, and low barrier islands.
 - ↗ There could be positive changes for dusky Canada geese if brackish/salt intrusion is restored to the Copper River Delta (reversion to graminoid sedge marsh from current shrub/forest succession).

- ↗ Changes could occur in marine productivity (sea temps, nutrient distribution, forage fauna, benthic communities). This could affect food webs important to bird species. Examples include critical clam beds used in winter by the world population of spectacled eiders; impacts on Izembek Lagoon affecting eel grass for brant and fish, benthos for Steller's eiders; marine invertebrates for shorebirds; loss of productive coastal shoals used by 100,000s of sea ducks.
- ↗ Very little information on trends in environmental variables is available, and we have no basis for projecting changes--or deciding whether they will be positive or negative. Changes can be modeled, but the availability of regional and local weather data is key. We need to support the efforts of other agencies (like the National Weather Service) to obtain better information.
- ↗ Changes in climate could warm interior Alaska river basins. These basins are tremendously productive for ducks because of extensive wetland expanses in river valleys, and the dynamics of river flooding and periodic fire. Wetland diversity is changing as permafrost melts and shallow wetlands dry; if river flows are altered--especially seasonal flooding--low habitats could be lost and productivity could drop; increased fire frequency could affect +/- nutrient inputs to riparian systems.
- ↗ It will be important to monitor species expanding their ranges into Alaska that could impact hunted species and other wildlife with conservation concerns.
- ↗ Changes to general climate patterns and phenology of seasons could have major effects (+/-) over the long term. Breeding success of geese is mostly controlled by the timing of snow melt and mild weather. If spring storms or flooding make breeding more risky, production drops; conversely, far north species controlled by spring weather (early = boom; late = bust) could benefit--snow geese could increase rapidly, eiders could succeed more. In theory, dabbling and diving ducks usually centered in the prairies could increasingly succeed farther north; currently many (e.g., pintails) come to Alaska when prairies are bad, but do not produce much. The latitudinal range of productivity could shift north (not a bad thing), but although the weather may be better, environments would have to become more productive to provide food, brood-rearing conditions, and staging wetlands.
- ↗ Climate change outreach and education currently is underway, but may need to be expanded to include additional target audiences.
- ↗ Alaska's Comprehensive Wildlife Conservation Strategy was developed to assess species at risk throughout Alaska due to a variety of factors, including climate change. The Species Templates included in the strategy identify specific conservation actions relating to climate. A major contribution to the management of identified species of greatest conservation need would be to model potential impacts of climate change on the habitats that support these species.

POTENTIAL IMPACTS TO SUBSISTENCE USERS

- ↳ The degree of adaptation in subsistence practices and reliance may change over time due to climate change. To assess potential impacts it will be necessary to monitor economic parameters that characterize the mixed cash-subsistence economies of rural Alaskan communities. The degree of potential effects to rural economies, especially if salmon are adversely impacted, could mirror the economic disasters declared in the previous decade.
- ↳ Environmental monitoring will be needed to document the degree of changes in conditions that may affect populations of wildlife and stocks of fish upon which subsistence users have customarily relied. Some examples follow.
 - ↳ Changes in freshwater and near shore hydrological conditions may increasingly impact species, populations, and life cycles of fisheries and wildlife resources customarily harvested. Monitoring will be needed to assess changes in water volumes, water courses, currents, distribution and duration of winter ice, and other characteristics that influence abundance and availability of species important to subsistence harvests. Examples include traditional knowledge indicating changes such as lakes drying up, lakes draining, river flows significantly changing, and other dynamic variables such as water temperature that may affect spawning, migration, disease susceptibility, and other aspects of fisheries population biology and management for harvests. Subsistence uses of fish, large mammals and migratory birds may all be affected by such changes.
 - ↳ Various hydrological changes can significantly affect subsistence users' access to harvest either fish or wildlife. Examples include recent incidence of historically low water in interior Alaskan locations such as McGrath. Such conditions may increase or recur more frequently if future years' conditions include less snow and melt water to replenish rivers and lakes to historic flows or levels. Changes in the seasonality of events such as river freeze up and break-up are having significant impacts on subsistence users' opportunities for customary and traditional uses of fish and wildlife.
 - ↳ Changes to terrestrial conditions also can be expected to influence availability of wildlife and fish species to harvest, as well as access to harvests. For example, if wildfires increase in frequency and extent, winter range for caribou and moose, as well as riparian buffer zones, may be adversely impacted over larger areas and result in longer recovery times than in the recent past.
 - ↳ Range extensions of more temperate plants and animals also may impact subsistence resources and resulting harvests. Monitoring and assessment of changing distribution patterns will be detected in community harvest surveys, as well as biological inventory and monitoring studies. For example, chinook salmon are reportedly showing up in North Slope subsistence net fisheries, in which they damage the type of gear customarily used for the smaller fish historically present, but also may represent a developing fishery. We also have received reports of cutthroat trout being caught on the lower Kuskokwim River.
 - ↳ Monitoring of subsistence harvests at the community level is needed to assess harvesting adaptations to changing conditions and flux in available fish and wildlife

resources to harvest. Subsistence practices are fundamentally adaptive and need to be monitored to determine the variability and extent of adaptive uses of fish and wildlife resources. For example, hunting marine animals on sea ice has already been changing significantly in arctic regions where nearshore ice no longer persists for much of the traditional harvesting season.

- ↳ Evaluating the levels of confidence needed to detect and monitor change is a critical scientific need for any programmatic effort to assess biological or harvest-related changes associated with climate change.