absi

Aleutian and Bering Sea Islands Landscape Conservation Cooperative

Strategic Science Plan
Appendices B-H

Appendix B. Climate Variability and Change.

The resilience of many ecosystems is likely to be exceeded by an expected increase of 1.5 to 2.5°C in global average temperature over the 21st century. Associated disturbances affecting the frequency and intensity of storms, species range shifts and major trophic changes will likely combine with other threats. The overexploitation of resources, land-use change, pollution and fragmentation of natural systems are expected to profoundly affect all regions of the planet. The Intergovernmental Panel on Climate Change (IPCC) defines four areas of special concern, including two relevant to ABSI: the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities; and small islands where there is high exposure of population and infrastructure to projected climate change impacts. Changes in ocean and air temperature in the ABSI region have resulted in changes in sea ice extent and season, species shifts, changes in storm regimes and coastal erosion. Further changes are expected in ocean circulation, salinity, and sea level, which collectively are expected to further threaten resources and the resilience of human communities. Adding to the concern is the fact that the Bering Sea has historically been quite sensitive to climate variability, with abrupt but persistent shifts in nutrient cycling and species assemblages linked to climate. This regional variation further complicates evaluating the likely regional impacts of global climate change.

Key Affected Resources and Ecosystem Services: Subsistence Culture, Commercial Fishing, Marine Mammals, Seabirds, Trophic Structure, Community Resilience, Cultural Resources.

Introduction

Increases in greenhouse gases have led to rapid warming of the atmosphere and oceans. Oceans have warmed less than the land because of the greater thermal heat capacity of water, and high latitudes have warmed more than tropical regions. The 100-year linear trend (1906–2005) for ocean temperatures is 0.75 ◦C, and the slope has become steeper since 1960 (Bindoff et al. 2007). Fifteen of the hottest years on record since 1880 have occurred since 1998 (NASA 2013) There has been an increase of 0.32◦C since the 1950s in the top 300 m of the oceans (Levitus et al. 2000) with most warming confined to the top 700 m (Barnett et al. 2005). Warming within the top 300 m has stabilized recently though warming seems to be increasing at depths greater than 700 m (Balmeseda et al. 2013)   Satellite data for the Arctic since 1978 shows a 7.4% decrease in summer sea-ice extent per decade (IPCC 2007) with greater than expected decreases observed in recent years (NOAA 2011) though recent observations suggest great potential for seasonal variability in extent. Changes in precipitation and evaporation have led to a freshening of mid- and high latitude waters and increased salinity in low-latitude waters. The rate of sea level rise has accelerated with increased warming with an average of 1.8 mm per year during 1961-2003, and 3.1mm per year between 1993 and 2003.

There is very high confidence (the IPCC's 2007 assessment classification) that recent warming is strongly affecting terrestrial biological systems, including changes to the timing of spring events (e.g., leaf-unfolding, bird migration and egg-laying) as well as poleward and upward shifts in ranges of plant and animal species. There is high confidence that observed changes in marine and freshwater biological systems are associated with rising water temperatures, changes in ice cover, salinity, oxygen levels and circulation. Shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans have been observed alongside increases in algal and zooplankton abundance in high-latitude and high-altitude lakes as well as range changes and earlier fish migration in rivers. While there is increasing evidence of climate change impacts on coral reefs, separating these impacts from those of other stresses like overfishing and pollution is difficult (IPCC 2007).

Despite strong, evidence-based conclusions about the overall effects of climate change, implications for specific regions such as ABSI are challenging to predict. A significant source of uncertainty in the long term (past about mid 21st century) comes from the range in plausible greenhouse gas emissions scenarios. Emission scenarios drive the projections made by climate models by specifying future greenhouse gas and aerosol concentrations in the models. Scenarios project an increase in greenhouse gas emissions between 2000 and 2030 because fossil fuels are projected to maintain a dominant position in the global energy production. Hence the emissions between 2000 and 2030 are projected to grow 40 to 110% depending on a number of assumptions made about societal changes and other factors (IPCC 2007). The degree to which models project warming depends on whether actual GHG emissions are closer to the high (more warming) or low (less warming) end of this spectrum.

An additional aspect of uncertainty comes from the fact that global climate models make predictions at large spatial resolutions (e.g., 100-300km) and thus they aren't capable of capturing local details. Downscaling to finer resolution is required for regional applications and the Scenarios Network for Alaska and Arctic Planning (SNAP) at the University of Alaska has undertaken downscaling for northwestern North America, including Alaska (Murphy et al. 2011). The SNAP downscaling projections have less verification in the ABSI region given the lack of long-term weather stations available to contribute data (S. Gray pers. comm.), so there is less ability to correct for global climate model bias at specific locations when compared to other regions. The mechanics of the overwhelming oceanic influence in the region, which is not incorporated in current downscaling, may also make SNAP projections less precise, particularly for precipitation.

Temperature records for St. Paul and Cold Bay don't show the degree of overall warming experienced by other Alaskan communities, nor do they show a strong trend toward warmer winters (Table B1). Investigation of St. Paul air temperature records shows cool temperatures from 1917 to 1976, except for a brief warm interval in the 1930s. Similarly, tree-ring records from the Seward Peninsula show that warm season temperatures in the nineteenth century were colder than those of the twentieth (D'Arrigo et al. 2004).These records suggest that cold air masses have been dominant for at least most of the last two centuries over the Bering Sea. This evidence is further supported by Bering Sea taxa that are dominated by Arctic-adapted, long-lived species such as rockfish/flatfish and marine mammals.

Even with the AO and PDO creating large inter-annual variability larger global change appears to be affecting the region's climate (Bond 2011). There are some tentative indications that the Arctic is playing a role, if not controlling, the recent changes in the Bering Sea and Aleutian Islands region. As Bond (2011) puts it, "perhaps the most important point here is that the Bering Sea constitutes a sort of crossroads between the mid-latitude North Pacific and the Arctic Ocean and is therefore subject to changes inherent to the climate systems of both regions." The following analysis describes what is known about a series of drivers most relevant to the ABSI region.

Table B1. Change in mean seasonal and annual air temperature (˚F), 1949–2009. Source: Alaska Climate Research Center (http://climate.gi.alaska.edu/ClimTrends/Change/TempChange.html)

Region	Location	Winter	Spring	Summer	Autumn	Annual
Arctic	Barrow	6.7	4.5	3.0	3.7	4.5
Interior	Bettles	8.1	4.3	1.8	1.1	3.8
	Big Delta	8.9	3.4	1.2	0.0	3.4
	Fairbanks	7.4	3.6	2.3	-0.2	3.3
	McGrath	7.4	4.6	2.7	0.8	3.9
West Coast	Kotzebue	6.3	1.8	2.6	1.4	3.1
	Nome	4.2	3.3	2.5	0.4	2.6
	Bethel	6.6	4.8	2.3	0.0	3.5
	King Salmon	7.9	4.5	1.7	0.6	3.7
	Cold Bay	1.5	1.6	1.7	0.8	1.4
	St. Paul	0.8	2.1	2.6	1.1	1.6

Key Data and Information Sources

Ocean Temperature

A central driver for climate variation and change in marine environments is the temperature of ocean waters. Sea-surface temperatures (SST) in the Bering Sea have undergone pronounced warming since the mid-1990s (Overland and Stabeno 2004). For the Arctic Ocean over the last century, there was a period of cooling from 1930 to 1965, followed by a period of warming, particularly pronounced since 1995 (Steele et al. 2008) though in the past four years water temperatures have been much cooler than average (NFMS 2012). In 2007, SSTs along the Beaufort and Chukchi coasts of Alaska were 2–3°C higher than the average for the period 1982–2007 (Richter-Menge et al. 2006). From these observable changes in the Arctic it is clear that SST can be a powerful proxy for describing the structure and functioning of marine waters. Warming of surface waters makes the water column more stable, enhancing stratification and requiring more energy to mix deep, nutrient-rich water up into surface layers. At the very basic level this results in nitrate (the principal nutrient that limits phytoplankton growth) being less available as temperatures increase globally (Kamykowski and Zentara 1986). This nutrient limitation is greatest when warmer-than-normal conditions prevail in a region (Kamykowski and Zentara 2005) and can have cascading effects up the food chain to fish, marine mammals and seabirds (Richardson 2008).

Species Shifts

Like a similar transition zone in the eastern North Atlantic (Beaugrand et al. 2002), the Bering Sea is experiencing a northward biogeographical shift in response to changing temperature and atmospheric forcing. For example, a reduction in sea ice provides access for seasonally-migrant baleen whales to feed north of Bering Strait (Moore and Huntington 2008). Gray whales now feeding north of the Bering Strait are likely responding to declines in benthic amphipod populations in the historical northern Bering Sea feeding grounds (Grebmeier et al. 2012). Another change is in dominant clam populations in the northern Bering Sea, which have declined in abundance and biomass, as have Spectacled Eiders that preferentially consume these clams as prey. Modeling by Lovvorn et al. (2009) indicates that these diving birds lose more energy resting in the water between feeding bouts than when standing on ice. Thus, both the shift to more open-water conditions and the observed clam population declines are likely key factors creating energy stress for these diving seaducks.

Annual fisheries surveys conducted on the southeastern Bering Sea shelf by the National Marine Fisheries Service (NFMS) track the status of major species in terms of estimated recruitment (addition of young fish to a stock) and spawning biomass have been used to explore the effects of climate variation and change. For example Greenland turbot, a flatfish that prefers cold temperatures, had good recruitment in the cold years before 1977 but spawning biomass has decreased steadily since. Similar benthic flatfish like arrowtooth flounder, rock sole, and flathead sole had above-average recruitment in the 1980s, but have had decreasing spawning biomass since the mid-1990s (Wilderbuer et al.2002). By 2003, these primarily benthic flatfish made up an estimated 26% of the total groundfish of the Bering Sea. In contrast the more pelagic walleye pollock recruitment increased nearly 400% after 1978 (NPFMC 2003) indicating a shift in nutrients to from benthic to pelagic communities. If this shift continues over the next decade, it will have major impacts on commercial and subsistence harvests as Arctic species are displaced by sub-Arctic species. Similar negative consequences are likely for other ecosystem components (marine mammals, fish, and invertebrates).

Sea Ice Seasonality and Extent

Sea ice helps to define the ecosystem of the Bering Sea. It begins forming in the northern Bering Sea as early as November and may remain into June of the following year. Sea ice forms in the northern portions of the shelf and is then blown southward by prevailing winds into areas of warmer water where it begins to melt. This process affects water temperature, salinity and ocean currents and is critical to the physical conditions that influence the way the Bering Sea ecosystem works (McNutt 2012). The ice itself provides habitat for everything from microorganisms to birds and the region's marine mammals but more importantly its presence directly relates to the timing of the spring phytoplankton bloom that is the cornerstone of the Bering Sea ecosystem. Without ice after mid-March, the spring bloom does not occur until May or June. This results in maximum zooplankton growth being delayed until later in the season when ocean temperatures are warmer and stratification sets in at upper surface layers providing more nutrients to pelagic species. Primary production from an ice-associated bloom earlier in the year generally falls to the bottom, supporting benthic communities (e.g., Hunt and Stabeno 2002).

Additionally the formation, motion and melting of the ice edge plays an important role in controlling the heat exchanged between the ocean and atmosphere with profound implications on weather including changes in wind speed and direction as well as air temperature. The ice itself can affect the direction of storm tracks as well as storm frequency and intensity. The increase in open-water conditions enhances the probability that strong wind will result in a storm surge, because the presence of ice inhibits wave formation (e.g., Reimnitz and Maurer 1979). Reduction in summer sea ice diminishes reflection of solar energy and creates additional ocean heat storage in newly formed sea ice-free areas. The additional heat stored in the ocean during summer is given back to the atmosphere the following autumn, causing changes in normal patterns of weather and climate variability with global consequences. Recent studies support an increased connection between shifts in Arctic climate with climate variability in mid-latitudes. Such Arctic to mid-latitude connections can be expected to strengthen over the next decades with further sea ice loss (NOAA 2011).

Projections of a nearly sea ice-free summer in the Arctic by the end of the century, made just three years ago, have been revised recently and now indicate that ice-free summers may occur as early as the 2030s (Wang and Overland 2012). However, these projections are in contrast with recent observations. During a long-term decrease, occasional temporary increases in summer ice can be expected over timescales as long as a decade due to internal variability (Kay et al. 2011). For example, five of the past six years have had greater-than-average ice cover in the Bering Sea and the trends for winter and spring have been positive from 1979-2013 though not statistically significant (Cavalieri and Parkinson, 2012). Multiyear to decadal variability in Bering Sea ice cover over the past four decades may actually be masking any underlying trend. The projected reduction of winter sea ice is only about 10%, indicating that the Arctic will shift to a more seasonal sea ice pattern. Though this ice is thinner, it will likely cover much of the same area now covered by sea ice in winter (Rogers et al. 2013).

Sea ice will be a major driver of large changes across the Arctic and affects marine access, regional weather, ecosystem changes, and coastal communities. As the Arctic Ocean becomes seasonally passable and oil and gas exploration, shipping and tourism increase, floating sea ice will present a major threat to maritime safety and increase the potential for oil spills in the region. The ability to quantitatively forecast sea ice over varied time scales requires regular observation of atmospheric and ocean states. This includes monitoring circulation and sea ice characteristics; understanding of the interactions among clouds, radiation, and aerosols; and development of coupled atmosphere-ice-ocean models.

Storms and Coastal Erosion

Based on a range of models, the IPCC (2007) states that it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. It is not clear if the apparent increase in the proportion of powerful storms made by the IPCC translates well to the ABSI region. Research from the PROBES project in the southeastern Bering Sea in the mid-70s investigated the relationship of storm timing, magnitude and intensity with respect to nutrient mixing, bloom production, and reproduction events for commercial species like pollock. It also examined the role of oceanographic fronts and stratification with respect to herbivore cropping efficiency, coupling of pelagic and benthic ecosystems, and fish/crab production. Storms are frequent along the western coast of Alaska because the North Pacific and Bering Sea region is a center of storm initiation and storm-track activity. They tend to be most frequent and most powerful from mid-fall through mid-spring and longest in duration during the summer when the Bering Sea is ice free (Mesquita et al. 2010). However, temporal trends in storminess tended to be weak in this region, and sea-surface temperature did not emerge as a major control of storm activity. Flooding from these storms can be extensive, with important storms flooding low-lying coastal communities (Chapman et al. 2009, Mason et al. 1998). Storms also contribute to salinization of low-lying terrain, tapping and drainage of lakes near the coast, and thermal and chemical degradation of permafrost (Jorgenson and Dissing 2010).

Coastal erosion from storms is also a serious concern in low-lying areas with fine-grained coastal deposits, such as along the Kotzebue Sound, Seward Peninsula, Yukon-Kuskokwim Delta, and Bristol Bay. Long-term erosion rates from ~1950 to 2003 along the southeastern Chukchi coast from Wales to Kivalina averaged 0 to 3 m per year (Manley et al. 2008), with direct impacts including beach and bluff retreat, overwash deposition, migration or closure of inlets and lagoons, capture and drainage of thaw-lake basins, and release of sediment and organic carbon to nearshore waters. During winters of limited sea ice, exposed coastlines can be particularly at risk to larger wind-driven waves. Similarly, if summer storms linger for longer periods of time they have increased erosive effects (Atkinson 2005). Chapman et al. (2009) identified more than eighty coastal communities that border the Bering and Chukchi Seas at risk to erosion and flooding. The degree of risk for communities of the Aleutian Islands is less well understood.

Sea Level Rise

The IPCC (2007) reports that since the beginning of the 20th century sea level has risen about 1.7 mm/year ± 0.5 mm. Analyses of sea level records having at least 25 years of hourly data from stations around the Pacific Basin show an overall average mean relative sea-level rise of 0.7 mm/year (Mitchell et al., 2001). From a subset of pacific island stations with more than 50 years of data (only four locations), the average rate of sea-level rise is 1.6 mm/year (IPCC 2007). The rate of sea level rise is not clear within the ABSI region but changes measured at nine tide stations in Siberia averaged 2–3 mm per year from 1954–2007 (Richter-Menge et al. 2006). The recently completed, 2013 U.S. National Climate Assessment, suggests that "1 foot of global sea level rise by 2100 is probably a realistic low end. On the high end, recent work suggests that 4 feet is plausible." Sea level rise results from a combination of ocean expansion as water temperature increases, ice mass imbalance and precipitation-less-evapotranspiration (including runoff). Uncertainty of about the latter two, especially ice-mass balance has complicated efforts to make specific projections for the globe and regional variation offers a further challenge. Additionally, in seismically active regions, subsidence or uplift can potentially exacerbate or mediate sea level rise as can isostatic rebound (IPCC 2007).

Data and Information Sources

Substantial investment is being made from a variety of researchers into understanding the changes in the north pacific and arctic oceans. Researchers have invested tens of millions into direct measures and indicators for climate ranging from long-term in situ instrumentation to repeat measures of zooplankton and groundfish biomass. Many of these measurements have time series of the length necessary to explore climate variation and make inferences about climate change effects. A number of studies (most notably BEST/BSIERP) integrate various oceanographic data streams in order to understand ecosystem effects.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) developed an Arctic Vision and Strategy that identifies their priorities for the Arctic which includes Bering, as well as Chukchi, and Beaufort areas. This strategy is an outgrowth of their support for a number of efforts in the Arctic and focuses on six priority goals:

1. Forecast Sea Ice
2. Strengthen Foundational Science to Understand and Detect Arctic Climate and Ecosystem Changes
3. Improve Weather and Water Forecasts and Warnings
4. Enhance International and National Partnerships
5. Improve Stewardship and Management of Ocean and Coastal Resources in the Arctic
6. Advance Resilient and Healthy Arctic Communities and Economies

Notable efforts include the development of weekly seasonal ice forecasts to fill a critical gap in marine weather and climate services. It will also benefit community activities, support management of protected marine resources, and improve safe operations for marine transportation as industry use expands. An exploratory Sea Ice Outlook, led by NOAA and the National Science Foundation (NSF), in coordination with 20 international contributors, is piloting methods that will inform this program.

Over the last two decades specific marine sites have been occupied and re-occupied during both national and international ship-based projects. The data collected by these projects is forming a growing biologically-oriented time-series ranging geographically from the northern Bering Sea to Barrow Canyon. One of the most complete times-series is in the northern Bering Sea and includes sediment community oxygen consumption which is used as an indicator of carbon supply to the benthos. NOAA has made it a priority to support the continuation of this work as a Distributed Biological Observatory (DBO). The DBO is the result of coordination among scientists in the Pacific Arctic Group (http://pag.arcticportal.org/) and integrates biological and physical sampling from both mooring and dedicated repeat ship cruises. As the sea ice retreats, the DBO will track the rate of ecosystem change and a spatial shift northward in some fish distributions and marine mammal migrations, with direct impacts on habitat for ice-dependent species, such as walrus (Grebmeier et al. 2012). The full DBO network has collected data from 2010-2012 and results are available at http://www.arctic.noaa.gov/dbo/.

NOAA is similarly proposing to expand two existing programs: 1) the Bering-Aleutian Salmon International Survey (BASIS) and the Russian American Long-term Census of the Arctic (RUSALCA) which are cooperative international research programs in the Bering and Chukchi Seas. The efforts behind BASIS aim to understand potential climate implications and adaptive capability for salmon species in Japanese, U.S. and Russian waters. The RUSALCA Program is an annual cruise to work mainly in research areas of physics of the Bering Strait region. These annual cruises complement multidisciplinary and geographically more extensive research cruises every 2-4 years in the northern part of the Bering Sea, East-Siberian, Chukchi and Beaufort Seas.

With recent contributions from the North Pacific Research Board (NPRB) NOAA maintains four in situ monitoring sites at 70m isobaths (Figure B1). Since 1995, the M2 site has been recording the longest time series of physical, chemical and biological data on the Bering Sea shelf. A series of moorings were deployed at the M4 site in 1996 and have been continuous since 2000 with the M5 and M8 sites added in 2005 and 2004, respectively (Stabeno and Napp 2010).

Finally, during oil spills, NOAA is legally responsible for providing scientific support to the U.S. Coast Guard and conducting natural resource damage assessments following those incidents. NOAA and the University of New Hampshire's Coastal Response Research Center are partnering to expand Environmental Response Management Application (ERMA) coverage to one or two key areas of concern in the Chukchi and Beaufort Seas (NOAA 2011).

The Bering Sea Project (BEST/BSIERP)

A research consortium as launched by NPRB and NFS to conduct a comprehensive, $52 million study of the eastern Bering Sea ecosystem from 2007–2012. The effort included more than one hundred federal, state, university, and private institution scientists studying a range of issue, from atmospheric forcing and physical oceanography to humans and communities and associated economic and social impacts of a changing ecosystem. The foundations for

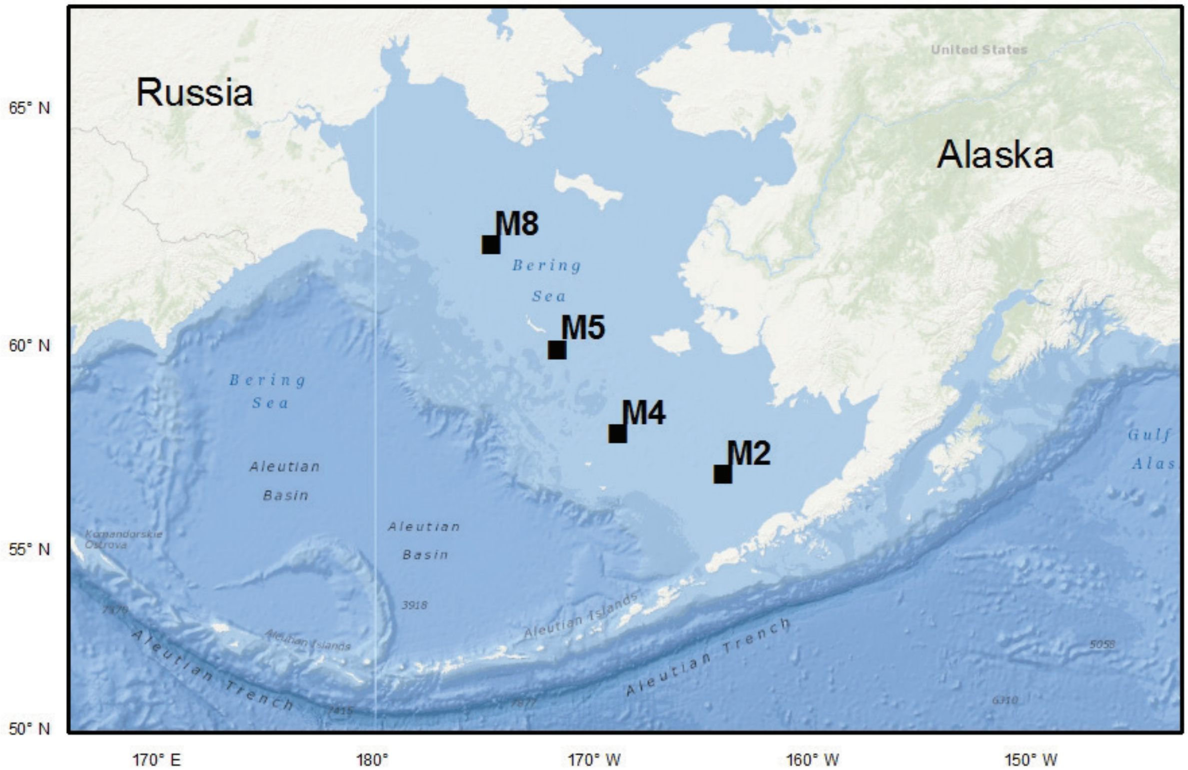

Figure B1. Four 70m isobath stations maintained by a consortium of researchers are the longest continuously running moorings in the eastern Bering Sea (adapted from Stabeno and Napp 2010).

this program are the NSF's 2005 Bering Ecosystem Study (BEST) and the NPRB's Bering Sea Integrated Ecosystem Research Program (BSIERP). Data collection has been largely completed and the next two years (though 2014) scientists will be integrating results from 43 integrated projects. Results from this work will likely inform a number of issues being explored by ABSI, but one of particular interest to climate variability and change is an effort to create a downscaled model of climate prediction for the Bering Sea. It will combine advanced sea ice and ocean circulation models with extensive data assimilation and realistic atmospheric, terrestrial, and tidal forcings. It will return downscale results for circulation and hydrograph fields at high-resolution (10 km2 for the entire Bering and 3km2 in the eastern) the results of which will be used to assess potential impacts through the fisheries food chain (Bond 2009).

North Pacific Research Board

Beyond their substantial investment in BEST/BSIERP program, NPRB has funded several studies in recent years that will be returning relevant results between 2012 and 2014. Efforts range from individual species inquiry (e.g., winter sockeye salmon survivability) to integrated ecosystem summarizing efforts made to evaluate climate in the region through the use of indicator species. Efforts that could directly benefit communities include evaluation the risk of harmful algal blooms and development of tools to assay bivalves for paralytic shellfish poisoning (PSP) have been launched alongside those to digitize weather observations logged by mariners from the region with records dating back to 1850. Investments also include support to long-term efforts like Continuous Plankton Recording, or CPR consortium. Collectively these projects and their contributors represent millions of dollars of investments addressing climate change implications in the ABSI region.

Alaska Ocean Observing System

The Alaska Ocean Observing System (AOOS) is a consortium of federal and state government agencies and industry affiliated with a national program of Integrated Ocean Observation System which aims to obtain, synthesize and rapid disseminate key coastal and ocean data. In Alaska they host the Arctic Assets portal that provides a variety of climate information and also host a number of real time weather sensors. They also synthesize data inputs and serve back spatial data, for example including sea ice distribution since 1978 derived from satellite data collected by the National Snow and Ice Data Center. A recent project Spatial Tools for Arctic Mapping and Planning (STAMP) is a collaboration with researchers from SNAP at UAF to providing future, spatially explicit, downscaled climate projections out to 2100 for the sea ice extent, storminess trends (wind vectors) and sea surface temperature (SST) for the Bering and Chukchi seas. Using established methodology (Walsh 2008, Chapman et al. 2008) they have identified three to four climate models that perform best in northern latitudes for sea ice extent and sea level pressure and allow for addressing possible scenarios of sea ice extent and seasonality. Preliminary results are expected in 2013.

Western Alaska LCC

The Western Alaska LCC has recently launched and effort to assess coastal hazards to communities of western Alaska resulting from coastal erosion and flooding. This will be a key focus area for their investments through 2013 and results may also be germane to understanding impacts within ABSI.

Threats to Resources and Ecosystem Services

The IPCC (2007) estimates that approximately 20-30% of plant and animal species assessed for impacts of climate change are likely to be at increased risk of extinction. Drastic changes in species composition and phenology are predicted especially for arctic environments and this is likely to impact communities in the ABSI region that are dependent on abundant wild stocks of fish, marine mammals, shellfish and seabirds.

Subsistence Culture

Cultural impacts are likely given already observable shifts in the distributions of harvested species like fish and marine mammals. Communities in the ABSI region have experience adapting to climate variation associated with extended periods of warming or cooling associated with PDO and AO dynamics. However, continuous warming trends are likely to be move many preferred (and culturally significant) species further north while temperate species, along with potential disease/pathogens move into warming waters of the north Pacific (Kovac et al 2010). Disease could affect target species (e.g., Frame and Lefebvre. 2010) but as in the case of paralytic shellfish poisoning, or PSP, can directly impact people. Further changes in the timing of seasonal harvest or changes in accessibility of preferred sites may impact harvest success and community tradition (IPCC 2007, NOAA 2011).

Fishes/Commercial Fisheries

Fish populations are known to be sensitive to regime shifts and long-term climate changes. (Francis et al. 1998, Hare and Mantua 2000, Visbeck et al., 2001). Temperature-induced changes in growth might make species grow more slowly and increase the vulnerability of some species to predation by keeping them at a more easily consumed size for longer. Climate and weather changes are also important in determining how many young survive to adulthood. Many fish species reproduce by releasing many thousands of eggs into surface waters. If winds move these eggs and hatching young fish into areas that are unfavorable, because of limited food or many predators, or the water is too turbulent for young fish to successfully capture food then they may decline in abundance (Livingston and Wilderbuer 2008).

Changes in the physical environment can influence the amount of food available to commercially exploited fish stocks. Strong year-classes of pollock in the Bering Sea (Bulatov 1995) coincide with above-normal air and bottom temperatures and reduced ice cover (Quinn and Niebauer 1995, Decker et al. 1995). However, recent work by Hunt et al. (2011) found that in warmer years the production of large crustacean zooplankton is reduced, depriving age-0 pollock of key lipid-rich prey in summer and autumn which reduces energy reserves. Additionally, predation increases as other fish switch from zooplankton to age-0 pollock, further reducing age-1 recruitment in the following year. Bryant (2009) cautions that anadromous fish response to climate change is complicated because individual stocks have different life history strategies—time of emergence, run timing, and residence time in freshwater and these relationships are often unique to regions and watersheds. For example, Farley and Turdel (2009) found lower growth rate potential in for sockeye in years with cooler SSTs and generally higher in years with warmer SSTs in eastern Bering Sea shelf suggesting warmer temperatures could be beneficial. However Davis et al. (2009) notes that an overall decline in the abundance of western Alaska Chinook salmon since the early 1980s (e.g., see Heard et al. 2007), as well as populations in other geographic regions, has generally coincided with periods of ocean warming.

Marine Mammals

Changing sea-ice formation, extent, and concentration are the most visible manifestations of climate change in the Arctic. Sea ice provides a resting platform and refuge from predators or inclement weather for walruses and ice-dependent seals as well as habitat for ice-associated fish and invertebrate prey of ice-adapted whales (e.g., Kovacs and Lydersen 2008; Laidre et al. 2008). For example, a growing body of data suggests that Pacific walruses are also showing negative impacts of sea-ice reductions (Vongraven and Richardson 2011). Abandoned calves have been reported at sea (Cooper et al. 2006), which suggests that females with dependent young might be experiencing nutritional stress and mothers and calves are certainly spending more time on land (Kavry et al. 2008 also see Arnbom 2009), where stampede incidents have recently caused significant mortality (e.g., Ovsyanikov et al. 2008; Fischbach et al. 2009). Sea ice also provides the primary platform on which polar bears travel, hunt, mate and, in some areas, den. Polar bears also prey primarily on ice-associated seals (ringed seals, bearded seals, harp seals, hooded seals). The Chukchi Sea population includes northern portions of the Bering and is in decline (Obbard et al. 2010) likely as a result of changes in sea ice distribution based on observed changes elsewhere in the species' range (Regehr et al. 2007).

As temperature changes lead to changing prey species assemblages, some hypothesize that lipid-rich arctic prey species will be replaced by leaner temperate species, reducing the ability of the most arctic-adapted marine mammals to replenish essential blubber stores (Kovacs et al. 2010). In addition to trophic changes and direct impacts through loss of sea ice, marine mammals in are likely to face increased disease and parasite risks (Harvell et al. 1999; Rausch et al. 2007; Van Bressem et al. 2009). For example domoic acid is a neurotoxin produced by members of a specific diatom genus, and has been responsible for the deaths of hundreds of California sea lions, and reproductive failure in many others. Increase in water temperature and reduction in sea ice could expand both the spatial and temporal range of harmful algal blooms particularly in the Eastern Bering Sea (Frame and Lefebvre 2010). Finally, arctic marine mammals will face increased impacts from human traffic and development in previously inaccessible, ice-covered areas (e.g., Kovacs and Lydersen 2008; Fuller et al. 2008; Ragen et al. 2008; AMSA 2009).

Uncertainty about how changes in production will affect trophic structure leads to concerns whether Arctic marine mammal species will continue to find adequate food and be able to compete with more temperate species in a warmer, more seasonally ice-free environment (Kovacs et al. 2010). Early loss of sea-ice over the continental shelf is predicted to reduce the productivity of the benthic communities marine mammals such as walruses and gray whales feed upon. Some walrus harvest data show that the proportion of females in the catch has increased while the relative proportions of pregnant females have declined and the age of first reproduction has shifted. These changes are suggested to be related to harvest management regimes and changing environmental conditions resulting in a distributional shift for females and slower rates of growth, perhaps due to food limitations caused by a shift from a benthic to a pelagic-dominated system (Garlich-Miller et al. 2006; Grebmeier et al. 2010). Additionally, if walruses become more spatially restricted because of distance to suitable haul-out areas, their numbers are likely to decline in most areas because of increased intraspecific competition for food (Kovacs and Lydersen 2008).

Birds

With warmer ocean conditions in the north pacific in the early 1980s, forage fish biomass declined and fatty forage species (e.g., capelin) were largely replaced in some seabird diets with juvenile pollock that are not as energy rich as species. Some seabird declines were attributed to these changes in diet with population declines in several species of seabirds in the Gulf of Alaska (USFWS 2009) and similar observations have been made throughout the Arctic (e.g., Irons et al 2008). Seabird colonies monitored over the past 30 years by the Alaska Maritime National Wildlife Refuge (Alaska Maritime) have shown trends that indicate population declines following a period of relatively cooler SST in the mid-1970s. The decade-long decline stabilized in the mid-1980s to mid-1990s with population numbers lower than before the warming trend (USFWS 2009). Declines in benthic bivalves, which are the winter prey for the threatened spectacled eider in the northern Bering Sea have been linked to sea ice retreat (e.g., Grebmeier et. al 2012). The Western Alaska LCC recently completed an expert driven analysis which identifies numerous potential climate change effects for key bird species also important in the ABSI region including: Red-throated and Yellow-billed Loons; Spectacled and Steller's Eiders; Kittlitz's Murrelets; and staging/winter shorebirds. In addition to trophic shifts and sea ice loss they also identified impacts from changes in coastal processes, sea-level rise, and severe storms (WALCC 2011).

Trophic Structure

Warmer global temperatures are likely to change species composition and the phenology of basic biological processes in northern regions of the globe (IPCC 2007). The asynchronicity in timing can disrupt the biological foundations of arctic ecosystems (e.g., Grebmeier et al 2006). Zooplankton is critical to the functioning of all ocean food webs primarily because of their sheer abundance, forage values, and pivotal role in ecosystem dynamics. Under cold, well mixed, and turbulent conditions, surface waters have abundant nutrients and a phytoplankton community dominated by centric diatoms. These conditions are favorable to a zooplankton assemblage dominated by large herbivorous copepods and euphausiids. The resultant food web can be characterized as short, efficient, and nutritionally rich, and able to support large numbers of fish, seabirds, and marine mammals. In contrast, under warm, stratified, and stable conditions, surface waters have less nutrients resulting in less nutritious zooplankton communities (Richardson 2008).

The seasonal presence and effects of sea ice are riving factors for of Arctic marine ecosystem structure and function. Ice zones have a direct influence on light and other ocean conditions that affect algal biomass and productivity. The timing and location of under-ice algal production events and associated grazing by zooplankton is thought to be critically important to under ice food webs and transfer of energy to benthic ecosystems (Grebmeier et al. 2011). Studies show increasing water temperature can enhance zooplankton growth and grazing efficiencies (Blume and Grebmeier 2011) and diminish the transfer of nutrients to benthic communities on Pacific/ Arctic shelves (Grebmeier et al. 2012).

Community Resilience/Adaptation

Sustainable development is often stated as an objective of management strategies to promote resilience and adaptation for communities. Relatively little work has explicitly considered what sustainable development means for islands in the context of climate change (Kerr 2005). The problems of small scale and isolation, current investment in specialized (often resource extraction-based) economies and the opposing forces of globalization may mean that current development in small islands becomes unsustainable in the long term (IPCC 2007). Nowhere is this likely to be more challenging than communities of the Arctic (NOAA 2011). From a human-use perspective, potential adaptation in the Arctic is extremely diverse and largely related to changes in the way water resources are managed and used. For example changes might be made from snow and ice travel to those taking advantage of open water transportation. Communities may have to make changes in harvesting strategies or tactics, and new investments to address flooding (Prowse and Beltaos, 2002) and coastal erosion. The strong cultural and social ties to traditional uses of resources by northern peoples would likely suffer and could complicate the implementation of adaptation strategies (McBean et al., 2005; Nuttall et al., 2005).

Similarly there can be complex public process resulting from multiple jurisdictions and stakeholders as well as extraordinary cost with providing the resources necessary for communities to adapt to a rapidly changing environment. The Arctic is already severely deficient in many of the capabilities that government agencies extend to the rest of the U.S. The region currently has very limited geospatial information. Even basic information needed for coastal planning such as elevation, tides, and currents can be nonexistent and often is not projected spatially to allow for and water-level projections for sea level rise or storm surge. Further much of the shoreline and hydrographic data is outdated resulting in poor-quality nautical charts. There is also insufficient weather and ice forecast coverage (NOAA 2011).

Cultural Resources

Coastal erosion that threatens the integrity of cultural resource sites along the coastlines of Aleutian and Bering Sea Islands have been documented by archaeologists and local residents (Grover and Laughlin 2012). A detailed compilation of affected sites does not exist but several have had consistent monitoring over the last few decades that evaluations of loss due to erosion has been assessed (D. Corbett pers. comm.).

Strategic Opportunities and Information Needs

There are numerous information needs associated with assessing threats of climate change and variation on resources and ecosystem services in the ABSI region. Unlike other regions of Alaska predictions about climate change have only recently been scaled down to local scales. Two contemporary efforts are creating downscaled climate projections for the ABSI region and exploring management implications through scenarios. Under the Bering Sea Project (BEST/BSIERP) a number of studies linked to climate projections are producing results that will inform understanding of climate change and variation effects on key species within the ABSI region. This effort integrates ecosystem models and their connections to key services like commercial fishing with downscaled climate projections specific to the Bering Sea. The results of these to efforts could be the foundation for a workshop targeted on identifying resources and ecosystem services at greatest risk in the ABSI region. AOOS is currently working with researchers from the University of Alaska Fairbanks to produce downscaled climate results that will inform management scenarios for the Bering Strait region and the broader Bering and Chukchi Seas. ABSI should work to convene a partnership between these two efforts that aims to understand vulnerabilities of key resources and ecosystem services.

Other information needs

- The vast and complex BEST/BSIERP program is producing final results in 2014 and efforts should be made to share results with ABSI region managers and stakeholders as well as explore potential steps toward integrating these results into impact analyses for our key resources and ecosystem services.
- Identify focal species for studies of effects of warming conditions using life cycle models leading to population and community level analyses.
- Review of temporal and spatial structure of existing regional monitoring networks to evaluate their utility to monitor trends and effects of climate change and variation.
- Climate change effects on island biogeography to determine how climate and other landscape processes may influence species distribution, abundance and population structure for fish, wildlife and plants.

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Appendix C. Commercial Fishing.

The Bering Sea and Aleutian Islands region supports some of the largest and most valuable commercial fisheries in the United States including the Bering Sea walleye pollock fishery and Bristol Bay red king crab and Bering Sea snow crab fisheries. Other important species that allow this region to claim almost %50 of U.S. seafood landings include golden king crab, Tanner crab, scallops, Dungeness crab, Pacific cod, sablefish, Pacific salmon, rockfish, Pacific herring, and several flatfish species including halibut. These fisheries provide vital, year-round economic opportunity for residents of coastal communities around the state. The largest fishery for groundfish (those species living on, in, or near the bottom) has been rigorously studied and monitored for potential environmental impacts ranging from individual species take, to habitat destruction by fishing gear and disruption of trophic connections by harvesting apex predators or key forage species. Though managers believe long-term impacts are currently minimal, a number of uncertainties exist around the cumulative effects of fishing relative to climate variation and change. Additionally, a number of ecological drivers and trophic connections of fisheries stocks remain poorly understood.

Affected Resources and Services: Fishes, Invertebrates/shellfish, Seabirds, Trophic Function, Coldwater Corals, Community Sustainability, Subsistence Culture, and Marine Mammals.

Introduction

The continental shelf and slope regions off of the coast of Alaska comprises some of the most extensive fishing grounds in the world (NRC 2003). The Bering Sea and Aleutian Islands (Figure C1) supports thriving groundfish, crab, halibut as well as salmon fisheries and is recognized as some of the most successful and sustainable worldwide (Worm et al. 2009). Each fishery is managed by a complex system of jurisdictions that is species and area specific. In general, the State of Alaska has management authority for salmon, herring, groundfish and shellfish fisheries, within three nautical miles of shore. Under the Magnuson-Stevens Act, the Federal government has management authority for the majority of groundfish fisheries from 3-200 nautical miles offshore in the Exclusive Economic Zone (EEZ) but has shared this authority in various ways with the State of Alaska with respect to crab and scallops. This Act also established the North Pacific Fishery Management Council (NPFMC) as one of the regional fishery management councils empowered to oversee the development and adaptation of fishery management plans (FMPs). Finally, the International Pacific Halibut Commission (IPHC) also has oversight over pacific halibut stocks in the region.

As described by Witherell (2004), fisheries in the EEZ in Alaska, as well as those managed in state waters, are managed under limited entry programs. These programs include Individual Fishing Quotas (IFQs) for halibut and sablefish, regional cooperatives for groundfish, and rationalization for crab fisheries. There are community development components to these programs which require that a portion of the quotas be allocated exclusively to designated Alaskan coastal communities. Livingston et al. (2011) describe these management actions as slowing the “race for fish” that is typically seen in non-rationalized fisheries, promoting increased safety at sea, and helping to ensure sustainability of coastal communities as well as the ecosystem by spreading out fish removal in space and time.

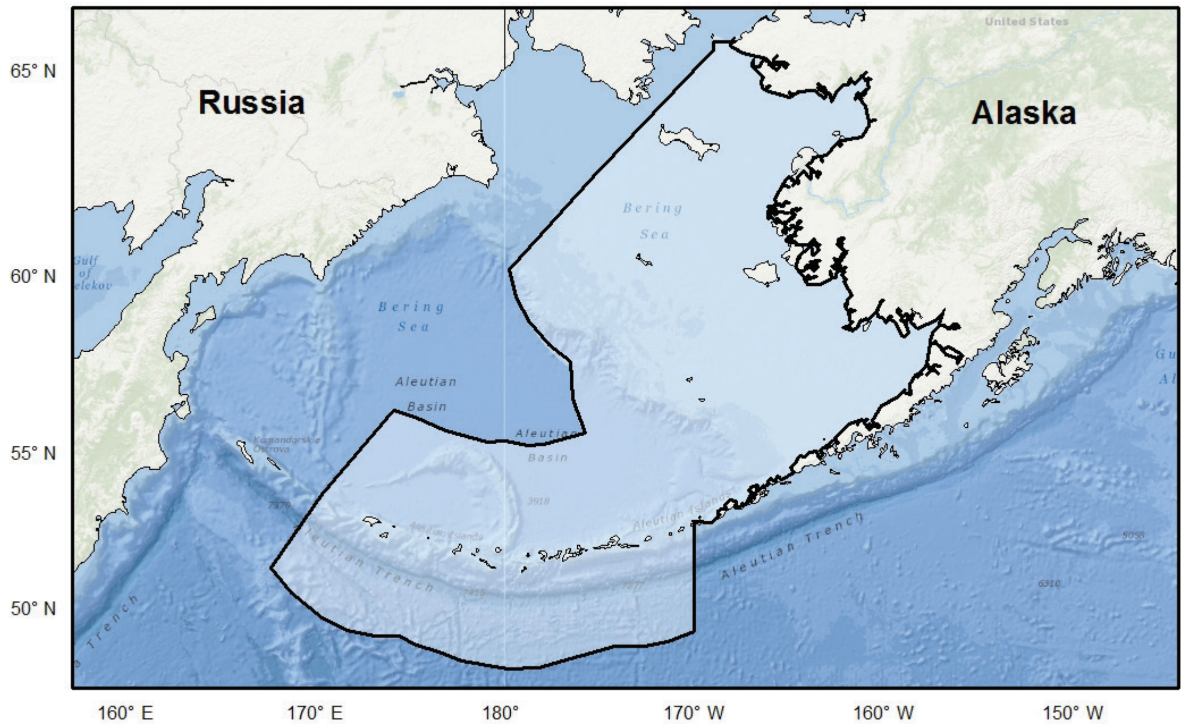

Figure C1. The management area for the Bering Sea and Aleutian Islands groundfish fishery management plan (adapted from NMFS 2012).

Ecosystem-based fishery management acknowledges that humans are part of the ecosystem, and is a component of the NPFMC's management approach as clearly outlined in its FMPs. These state that fishery management needs to consider the impacts of management decisions on fishing communities and to ensure that fisheries are socially and economically viable through community-based or rights-based management, while protecting the long-term health of the resources and their ecosystem. Major fishing/processing communities in the region include Dutch Harbor, Saint Paul, and Akutan.

Within commercial fisheries, groundfish have been a primary focus of research and management within in the eastern Bering Sea and Aleutian Islands. The dominant catch species include gadids such as walleye pollock and Pacific cod and numerous flatfish and rockfish species (Livingston and Boldt 2008). Domestic bottom trawling began in the Bering Sea in the late 1970s and trawl activities grew rapidly during the 1980s displacing foreign fishing by the end of the 1980s (NMFS 2004). Presently the fleet consists of three types of vessels mother ships, catcher-processors, and catcher vessels which use one of four gear types (trawl, longline, pot and jig). Mother ships are larger processing vessels that do not fish themselves but receive and process fish from catcher vessels while catcher-processor vessels both fish and process their catch at sea (Cahalan et al.. 2010). The gear used and target species are described in Table C1.

The majority of the groundfish are taken by bottom trawling (Cahalan et al. 2010) and virtually all areas of the Bering Sea have experienced some degree of exposure to bottom trawls (Figure C2). Relatively heavy trawling has occurred in three places: along the shelf edge, along the Alaska Peninsula near Unimak Island, and in Togiak Bay (Fritz et al. 1998). Bottom trawling in the Bering Sea during the early 1990s was most intense on the slope and shelf area north of the Aleutian Islands (NRC 2003). The Alaska Peninsula in the area of Unimak Island, east of

Table C1. The gear types used to fish target species in the Bering Sea and Aleutian Islands ground fisheries (NMFS 2004).

Area	Gear Type			
	Bottom Trawl	Pelagic Trawl	Pot Gear	Longline
Bering Sea	deepwater flat-fish, Pacific cod, rockfish	walleye pollock	Pacific cod, sa-blefish	sablefish, rock-fish, Pacific cod
Aleutian Islands	Pacific cod, Atka mackerel, rock-fish	walleye pollock	Pacific cod, sa-blefish, crab	sablefish, rock-fish, Pacific cod

the Pribilof Islands, west of Bristol Bay and off of Cape Constantine, was also heavily fished. However, large areas of the Bering Sea have no trawling activity because of closed management areas or less productive fishing grounds. Data on groundfish trawl effort is available for 1993-2012 is from the NMFS Fisheries Observer Program. During that 20-year period, a total of 615,052 trawls were observed within the Bering Sea and Aleutian Islands Fishery Management Area.

In addition to the trawling, data on longline fishing effort for Pacific cod, Greenland turbot, and sablefish from 1993-2012 is also available from the NMFS Fisheries Observer Program. There were a total of 239,710 observed longline sets in the in the Bering Sea and Aleutian Islands Fishery Management Area over this 20-year period. Spatial patterns of longline fishing effort are

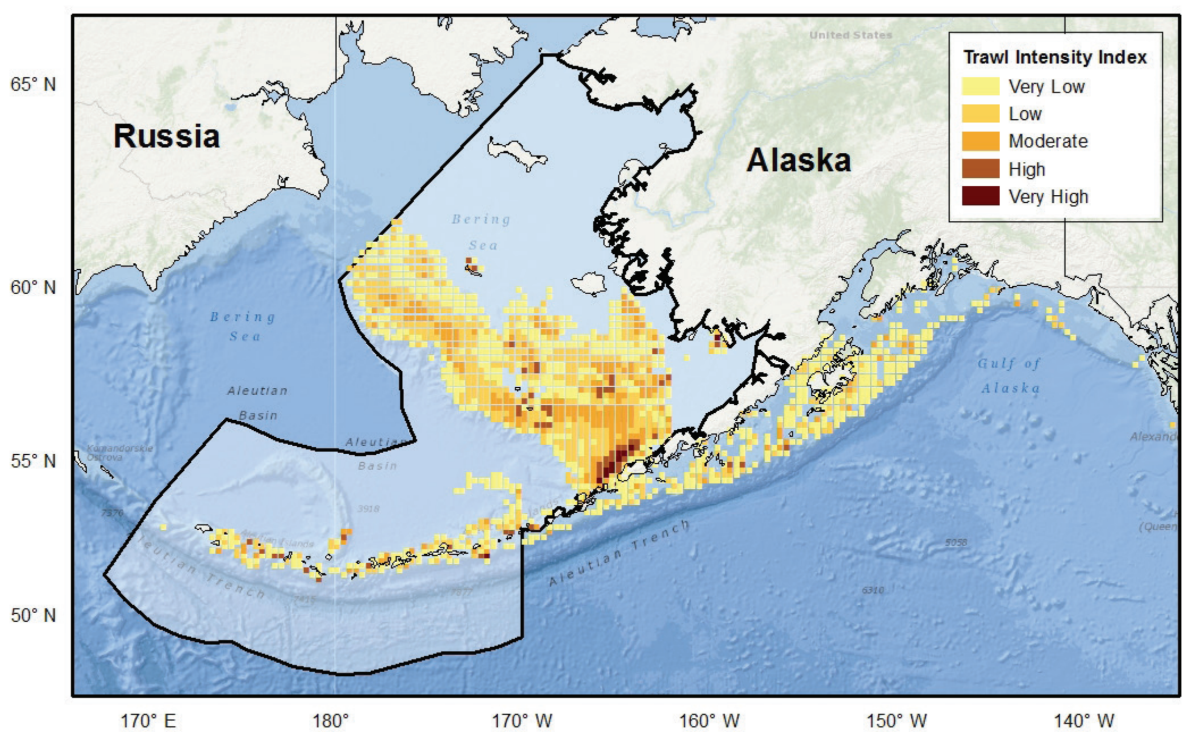

Figure C2. Observed groundfish trawling intensity summarized from 1993-2012 based on NMFS groundfish observer data. Source: http://www.afsc.noaa.gov/fma/spatial_data.htm. Shaded area represents Bering Sea Aleutian Islands Fishery Management Area.

summarized on a 400 km2 grid (Figure C3) and allow for the evaluation of cumulative effort by both the trawl and longline fleets.

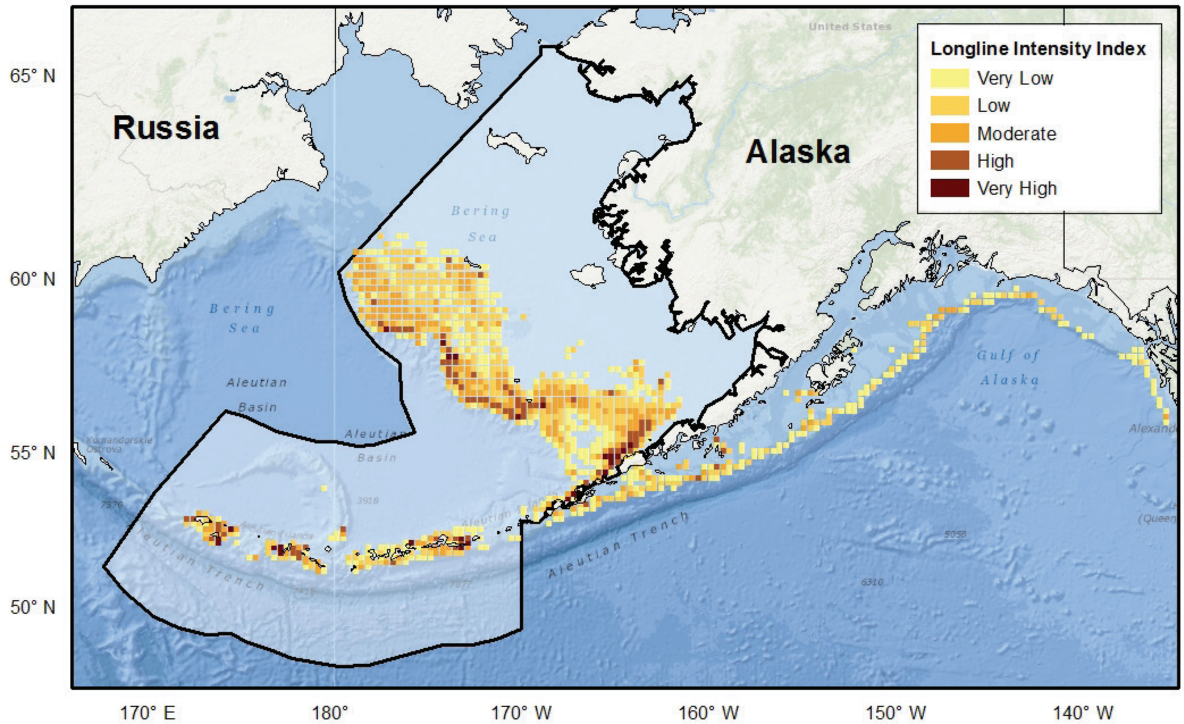

Figure C3. Observed groundfish longline set intensity summarized from 1993-2012 based on NMFS groundfish observer data. Source: http://www.afsc.noaa.gov/fma/spatial_data.htm.

Other key fisheries in the Bering Sea and Aleutian Islands include ten king and Tanner crab stocks: four red king crab (Bristol Bay, Pribilof Islands, Norton Sound, and Adak), two blue king crab (Pribilof District and St. Matthew Island), two golden king crab (Aleutian Islands and Pribilof Islands), and two Tanner crab stocks (NMFS 2012). The ABSI region also supports salmon fisheries within state waters which includes iconic runs like those from Bristol Bay and the Yukon and Kuskokwim Deltas. Halibut is another key commercial species in the region with an average annual removal over the past hundred years..

Overall potential impacts from commercial fishing for a variety of gear types were evaluated by NMFS (2004) as direct, or immediate impacts, and indirect whose effects are removed in space or time from the actual activity. Potential direct effects include:

- Mortality either as part of the catch or incidentally by killing benthic and demersal species or increasing their vulnerability to predators.
- Increased food availability for scavengers due to discarded fish, fish offal, and dead benthic organisms.
- Loss of habitat due to scraping and plowing of the sea floor.

While potential indirect effects include:

- Alteration of the physical structure of benthic habitats.
- Direct mortality of benthic organisms.
- Sediment suspension.
- Physical and chemical modifications to the water column.
- Benthic community changes.
- Ecosystem changes.

A complete review of specific effects from the Bering Sea and Aleutian Islands groundfish fisheries are discussed in NMFS (2004), many of which apply to the other fisheries in the region (e.g., salmon under NPFMC 2011a and crabs in NMFS 2011b). These include damage to underwater biological and physical substrates resulting from contact with fishing gear and direct mortality of benthic organisms like corals and sponge communities. These initial impacts can have cascading indirect impacts as the habitat these species provide for other species is reduced in quality and/or extent. Key indirect effects often focus on trophic changes to the ecosystem by removal of biomass and top-predators. Additional effects include potential groundings and spills from fishing industry vessels (see Marine Vessel Traffic Stressor) as well as the introduction of exotic/invasive species (see Invasive and Introduced Species Stressor).

Fishery Management

Marine fisheries management in Alaska has been cited worldwide as success story that effectively incorporates ecosystem considerations into harvest strategies (Witherell et al. 2000, Pikitch et al. 2004 , Marasco et al. 2007). Management is particularly complex because of interaction and coordination between respective Federal and State fishery management plans and jurisdictions; for example the State coordinates with the Federal government in State-waters for Pacific cod fisheries. Similarly, joint Alaska Department of Fish and Game (ADF&G) and Federal fishery management programs have been implemented regarding management of Bering Sea and Aleutian Islands crab and regional scallop fisheries (Hartill 2011).

The Bering Sea and Aleutian Islands ecosystems are presently dominated by groundfish fisheries that are providing relatively stable sources of production, without the collapses seen in other regions (Worm et al. 2009). The Groundfish FMP covers fisheries for all stocks of finfish and marine invertebrates except salmonids, shrimps, scallops, snails, king crab, Tanner crab, Dungeness crab, corals, surf clams, horsehair crab, lyre crab, Pacific halibut, and Pacific herring. The fishery is managed to balance fishing mortality and biomass where the maximum sustainable yield is the harvest limit (NPFMC 2013).

A combination of industry and onboard observer information is used to estimate total catch. Industry-reported data consists of catch and processed product amounts that are electronically recorded and submitted to NMFS. An extensive Fisheries Observer program is in place and provides information on species composition of the catch, length distribution of select species, and other catch components including bycatch. The biological status of groundfish stocks is summarized in annual Stock Assessment and Fishery Evaluation (SAFE) reports developed by NMFS, NPFMC, and ADF&G. Information in the SAFE reports is used to set catch limits for FMP managed species. In addition, FMPs describe policy for setting bycatch limits for some species, such as halibut and salmon, whose retention is prohibited in the groundfish fisheries (Cahalan et al. 2010).

There is also joint management of the Bering Sea and Aleutian Islands crab stocks. In addition to Federal management regulations, the ADF&G has developed harvest strategies to maintain sufficient spawning biomass for king and Tanner crab stocks in selected fisheries of the Bering Sea (NMFS 2011b). In addition to co-management of crabs, ADF&G also manages salmon, herring, groundfish, and other shellfish (e.g., scallops. Management in the Aleutians and Bering, as well as the Chukchi and Beaufort seas, falls within ADF&G's Westward Region and is implemented by its Commercial Fisheries Division. Management is accomplished under a limited entry system; participants need to hold a permit for a fishery and the number of permits for each fishery is limited. The vast majority of the EEZ is closed to commercial salmon fishing (NPFMC 2011a).

The halibut fishery has been closely managed for nearly 100 years by the IPHC which is jointly funded by the governments of Canada and the United States. Much is known about the history of fishery removals, population trends, and biological characteristics (Hare 2011). This stock has been managed as a single population extending from California through the Bering Sea, though some recent work by Seitz et al. (2011) suggests that the Aleutians and Bering Sea population is isolated from the larger population. Total halibut removals (including all sources of mortality: target fishery landings and discards, bycatch in non-target fisheries, research, sport, and personal use) have ranged from 34-100 million pounds over the last 100 years with an average annual removal over this period of ~64 million pounds. The results of the 2012 stock assessment indicate that the halibut stock has been declining continuously over much of the last decade as a result of decreasing size-at-age, as well as poor recruitment strengths (Stewart et al. 2012).

Management of all stocks under FMPs is enforced through a complex system of regulations with key tools falling into four categories: 1) species harvest levels; 2)bycatch monitoring and restrictions;3) habitat protection; and 4) endangered/protected species management.

Species harvest levels

This complex harvest control system is enforced through an extensive catch monitoring system that includes an at-sea Marine Observer and industry data collection program (Cahalan et al. 2010). This program allows managers to implement in-season management of catch quotas to prevent overfishing of target species, prohibited species, or non-target species. Unlike other regions, such as the northwest Atlantic, the trophic level of the catch in the eastern Bering Sea and Aleutian Islands has been relatively constant since the 1970s, suggesting an ecological balance in the catch patterns (Livingston et al. 2011).

One important indicator in the food web is the relationship between animal abundance and individual size diversity. Fishing can change this relationship over time, such that larger fish may suffer higher fishing mortality than smaller individuals causing the size distribution to become skewed toward the smaller end of the spectrum (Zwanenburg 2000). Unlike other marine ecosystems, the eastern Bering Sea has not shown a decreasing trend in groundfish size from 1982–2006 (Boldt et al. 2012). Other indicators of fishery health are the Shannon–Wiener diversity index and species richness. The effects of fishing on these indices are, however, unclear (Livingston et al. . 1999, Jennings and Reynolds 2000). Changes in groundfish and invertebrate species richness may be related to environmental variability and the resulting changes in fish species distribution (Mueter and Litzow 2008).

Bycatch monitoring and restrictions

Further efforts to reduce impacts include restrictions on the unintentional harvest of non-target, or bycatch species. For example a maximum retention allowance for forage fish bycatch within each groundfish fishery is set at 2% of the total fishery catch. Bycatch restrictions often aim to protect species that are commercial target species in other fisheries, or those protected for food web concerns like forage fish species (Livingston et al. 2011). Discarding of unwanted catch can also have ecosystem implications by re-directing the flow of energy through marine food webs (Livingston et al. 2005). In the U.S. groundfish fisheries in Alaska, discard has been restricted through improved utilization requirements . The requirement to retain all pollock and Pacific cod caught has been in place since 1998 and has been responsible for reducing total discards in groundfish fisheries by about half (Livingston et al. 2011).

Salmon bycatch in the eastern Bering Sea pollock fishery is a critical management and scientific issue. Chinook (king) salmon bycatch in this fishery increased sharply from 2001 through 2007 and a variety of management measures ranging from strict limits on total catch to closures have been proposed and will be implemented in the coming years. Research continues to provide a better understanding about the nature of the salmon bycatch. For example, beginning in 2011, NMFS is improving the genetic sampling of salmon caught in the Gulf of Alaska pollock fishery to allow for a better understanding of the stock composition. Researchers at the Alaska Fisheries Science Center (AFSC) are focused on using genetic analysis to determine where the fish originate in order to more precisely identify those salmon stocks affected by the groundfish fishery. Gear research continues to refine salmon excluder devices that could be used in this fishery (NMFS 2011a).

Habitat protection

Restrictions or closures have been implemented to protect ecological structure and function, conserve habitat, protect vulnerable stocks, and improve scientific understanding (Witherell and Woodby 2005). Some of the most substantial year-round fisheries closures are those protecting critical habitat around rookeries and haul-outs of the endangered western stock of Steller sea lions. Other closure areas have been established in cooperation with ADF&G to protect vulnerable benthic habitat from trawl damage including six coral garden areas in the Aleutians (Hartil 2011). Habitat protection is also accomplished through gear restrictions with almost half of the EEZ in Alaska closed to bottom trawling (Livingston et al. 2011).

Federal fisheries are required to identify essential fish habitat (EFH) and habitat areas of particular concern (HAPC) and to take actions to protect and conserve these habitats. Essential fish habitat is defined as “those waters and substrate necessary to fish for spawning, breeding, or growth to maturity” (NMFS 2005). Habitat areas of particular concern are specific sites within EFH that are of particular importance to the long-term sustainability of managed species, are of a rare type, or are especially susceptible to degradation or development. Areas of EFH have been established throughout the ABSI region (Figure C4) for salmon, crab, and groundfish and these include HAPCs like Bowers Ridge and Bowers Seamount (NMFS 2012).

Part of an analysis of the effects of fishing on EFH included application of a numerical model that provided spatial distributions of the effects of fishing on several classes of habitat features, such as infauna prey and shelter created by living organisms. The Long-term Effect Index (LEI) (Fujioka 2006), estimated the eventual proportional reduction of habitat features should the recent pattern of fishing intensities be continued indefinitely. Limited impacts were expected for different species groups with the exception of slow growing corals which are easily damaged by gear (NMFS 2005).

In anticipation of commercially important stocks shifting northward in response to climate change, the NPFMC established the Northern Bering Sea Research Area (NBSRA) in 2008 (Figure C4). This area is closed to non-pelagic (bottom) trawling pending understanding of its impacts on the near-pristine ecosystem. Alaska Native communities generally opposed opening the NBSRA to "commercial non-pelagic trawling" for fear of impacts to subsistence species and were joined by scientists and conservationists concerned about disturbance to protected resources and the environment (NPFMC 2012).

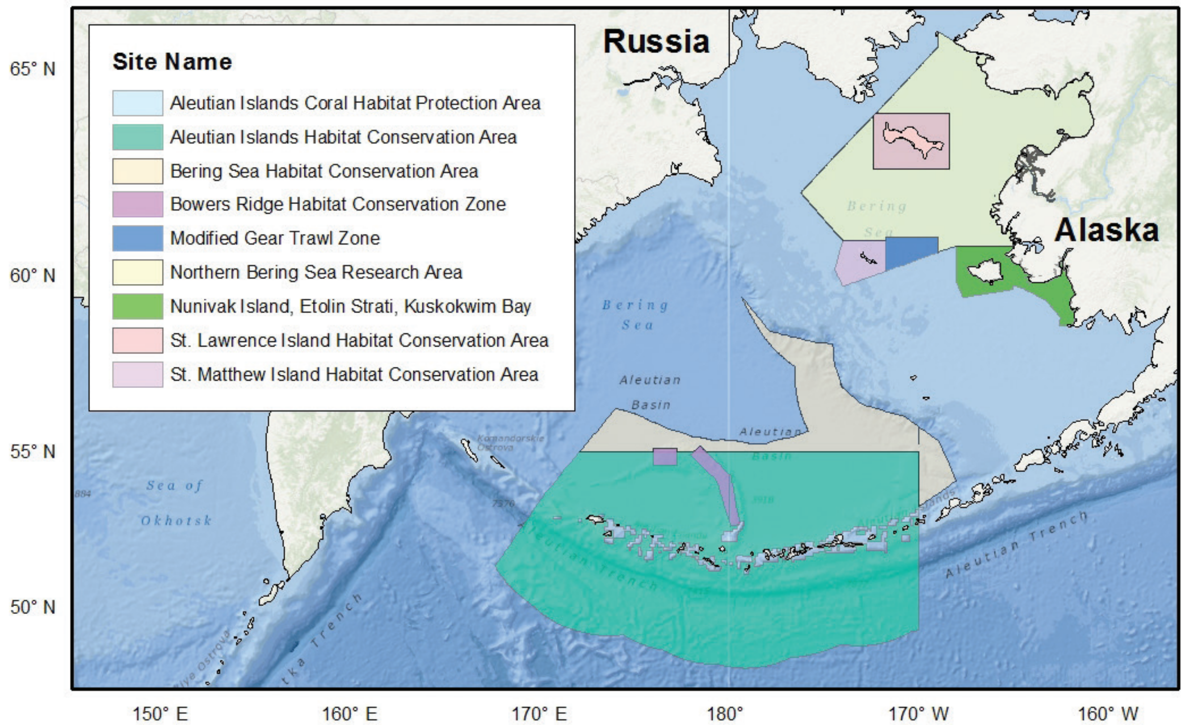

Figure C4. Protected sites for Essential Fish Habitat in the Aleutian and Bering Sea region (adapted from NMFS 2011).

Protected Species Management

A number of threatened or endangered marine mammal and seabird species, as defined by the Endangered Species Act (ESA), and their critical habitats, occur in the EEZ off Alaska. Other marine mammal species are protected under the Marine Mammal Protection Act (MMPA). The general approach to fisheries management aims to reduce direct takes of these species and to protect foraging habitat through closures, gear restrictions and regulations prohibiting fisheries on forage species. Restrictions that have been placed on Alaska groundfish fisheries through ESA considerations are primarily for protection of the western Steller sea lion and Short-tailed albatross. Measures to protect Steller sea lions focus on closures around critical habitat areas and overall harvest of key prey species like walleye pollock, Atka mackerel, and Pacific cod. (Livingston et al. 2011). The reasons for the slow recovery of the Steller sea lion population in the western Aleutian Islands is a continuing discussion. The primary management concern for the endangered short-tailed albatross is direct take in fisheries especially demersal longline fisheries. Seabird bycatch mitigation devices have been required for this type of gear since 1998 and have resulted in dramatic declines in numbers of seabirds taken as bycatch from 2001 onward, including albatrosses (Fitzgerald et al. 2008).

Climate Change Implications

In addition to commercial fishing, the marine ecosystems of the Bering Sea and Aleutian Islands are also subject to climate impacts. Therefore, the ability to separate climate from fishing effects on ecosystems is critical to direct the appropriate management responses or adaptations (Livingston et al. 2011). Climate pressures influence the distribution and production of ecosystem components including fish resources, and the fisheries that depend on them. Climate impacts on fish production can either be direct, like altering metabolism or growth or indirect like changing the distribution and abundance of prey such as zooplankton and forage fish. Further, a changing climate can alter nutrient cycling for benthic communities and result in species invasions of competitors or predators (Livingston et al. 2011).

Climate change and variability may be responsible, in part, for recent stress placed on walleye pollock, a nodal species in the food web as well as the major commercial groundfish species, which experienced a series of poor recruitment years during a warm period during 2000-2005 (Livingston et al. 2011). Similarly, stocks of snow crab have generally declined during warmer years after 1991 and the distribution of spawning females has contracted northward (Zheng et al. 2001, Orensanz et al. 2004) and it appears unlikely that the southern spawning group of females will re-establish itself (Parada et al. 2010).

The NPFMC and the State of Alaska have taken actions that indicate a willingness to adapt fishery management to be proactive in the face of changing climate conditions (NPFMC 2013 and NPFMC 2009). Much of the impetus for the bottom trawling closure in the NBSRA comes from the understanding that changing climate conditions may impact the spatial distribution of fish, and consequently, of fisheries (NPFMC 2012). In Alaska, annual assessments involve investigating the pressures ecosystems experience and indicators of the state of marine ecosystems (e.g., NOAA 2012). The primary intent of these annual assessments is to summarize and synthesize historical climate and fishing effects on the shelf and slope regions of the eastern Bering Sea, Aleutian Islands and Gulf of Alaska, and to provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function.

Key Data and Information Sources

The commercial fishing industry, researchers, and managers in the ABSI region have made tremendous investments toward promoting sustainable fisheries in the region ranging from inventory and longstanding monitoring efforts to species-specific research and ecosystem modeling. Brief descriptions of data and information sources for a selection of these efforts follows and is intended to illustrate the range of entities working in commercial fisheries in the region.

North Pacific Fisheries Management Council

The NPFMC is one of eight regional councils established by the Magnuson-Stevens Fishery Conservation and Management Act in 1976 to oversee management of the nation's fisheries. The NPFMC is likely the most significant consumer of scientific information describing the commercial fishing industry and its relationship to the ecosystems of the Bering Sea and

Aleutian Islands. It publishes a 5-year plan of research priorities focused on combination of immediate concerns and ongoing needs with the former aimed at responding to regulatory needs and the latter including longer term monitoring, research, or development needed to meet its goals around sustainable fisheries. In addition to being a management forum that meets regularly where issues and information needs can be identified the NPFMC also provides a number of resources and publications germane to fisheries management. It has a Scientific and Statistical Committee (SSC) that regularly reviews and comments on the scientific information contained in documents supporting proposed management actions.

Stock assessment and fishery evaluation (SAFE) Reports are prepared and reviewed annually for each FMP. These provide information to the NPFMC for determining annual harvest levels, documenting significant trends or changes in the resource, marine ecosystems, and each fishery over time, as well as assessing the relative success of existing State and Federal fishery management programs. They are available online at: https://alaskafisheries.noaa.gov/npfmc/resources-publications/safe-reports.html

National Marine Fisheries Service

The North Pacific Groundfish Observer Program provides essential information used to estimate total catch in the Federal groundfish fisheries off Alaska. The AFSC is responsible for the program which has been implemented since the early 1990s. While onboard private vessels, observers monitor harvest compliance and interactions with protected species. Data is incorporated into the NORPAC database which records the number and weight of the fishery catch by species in the species composition samples and the estimated weight of the entire catch in the whole haul or set. NORPAC also records the number of hooks or pots in the sample and the estimated number of total hooks or pots in the whole set (NMFS 2004). The unprocessed data collected by the observer program are available in a spatially aggregated form to the public on the AFSC website: http://www.afsc.noaa.gov/FMA . This program also supports the world's largest seabird bycatch monitoring effort with between 36,000 and 39,000 coverage days completed each year. The information collection was expanded in early 1999 to incorporate more detailed information about the frequency of measures used. Data and analysis reports on seabird bycatch is provided at: http://www.afsc.noaa.gov/refm/reem/Seabirds/Default.php

Essential Fish Habitat Mapper is an online application to provide the public and other resource managers an interactive platform for viewing a spatial representation of EFH. The database can be queried by species and life stage of sensitivity (eggs, late juvenile, mature, or all) and is available online at: http://www.habitat.noaa.gov/protection/efh/habitatmapper.html ArcGIS shapefiles of mapped distribution of EFH are also available online and the database covers the ABSI region for salmon, crab, and groundfish. It includes HAPCs as well as all areas with fishing protections in place.

Industry Reporting by vessels in Federal or State fisheries report groundfish landing and production through a web-based interface known as eLandings used by NMFS, ADF&G, and the IPHC since 2005. This system is supplemented by a combination of at-sea production reports on gear type used, areas fished and product weights after processing as well as discards by species. Further, landing reports are required at delivery to a shoreside plant as well as paper logbooks for all vessels over 60 feet in length and any IFQ halibut vessel greater than 25 feet in length (Cahalan et al. 2010). These data sources are confidential but can be shared with authorized persons or in summary form for public dissemination. Aggregated estimates of total catch are at: http://www.fakr.noaa.gov/sustainablefisheries/catchstats.htm

International Pacific Halibut Commission

Nearly all of the research done by the IPHC staff is directed toward one of three continuing objectives of the Commission: 1) improving the annual stock assessment and quota recommendations; 2) developing information on current management issues; and 3) adding to knowledge of the biology and life history of halibut. The IPHC monitors dozens of stock assessment 'stations' across five survey areas in the Aleutians and Bering Sea and publishes annual stock assessment data online. In a typical year, five samples are fished at each station between June 1 and August 31. The stations are arranged in a grid with 10 nm between grid lines and station locations have remained the same for over a decade. They also record data on seabird observations (2002-2012) made available through OBIS-SEAMAP at Duke University and includes thousands of observations from the Bering Sea and Aleutian Islands of over 30 species.

The North Pacific Research Board

The North Pacific Research Board (NPRB) funds scientific research focused on fishery management and ecosystem needs. Since their first RFP(Request for Proposals) in 2002, NPRB has funded 304 individual projects for a total of almost 50 million dollars that has been heavily leveraged by collaborators. These projects have heavily favored commercial fish and invertebrate species as well as species potentially affected by the industry. The concept of vertically Integrated Ecosystem Research Program (IERP) was first applied to a Bering Sea project by the NPRB in partnership with a complementary program from the U.S. National Science Foundation, the Bering Ecosystem Study, or BEST in 2004. This base funding was supported by federal agencies such as the National Oceanic and Atmospheric Association (NOAA), the U.S. Geological Survey, and the U.S. Fish and Wildlife Service . The team of over 93 scientists has been addressing the mechanisms that lead to the form and function of this ecosystem with the goal of linking ecosystem research with fishery management. In addition, an IERP for the Gulf of Alaska has been initiated and is currently in progress and discussions around development of an Arctic IERP are ongoing.

State of Alaska

As part of joint fishery management, ADF&G has implemented a number of fishery monitoring efforts in partnership with NMFS. It also produces annual harvest fishery management reports (e.g., Hartill 2011) for Bering Sea and Aleutian Islands crab, scallop and salmon fisheries as well as the State waters portion of the groundfish fishery. The Commercial Fisheries Entry Commission maintains databases describing the fishery participation and earnings, permit holders and vessel databases which include specific configuration and gear type information. These data have been used to characterize fishing communities relative to community resilience (e.g., Sethi and Knapp 2011) and are available in aggregate summaries since at least the 1990s at: http://www.cfec.state.ak.us/index.htm

Pollock Conservation Cooperative Research Center

The Pollock Conservation Cooperative Research Center (PCCRC) was established in 2000 to improve knowledge about the North Pacific Ocean and through research and education, focused on the commercial fisheries of the Bering Sea and Aleutian Islands. They are supported through a cooperative of commercial fishing companies active in the region and since 2011 PCCRC has invested $12.5 million into marine research and education on their behalf. They are the largest contributor to the marine science program at the University of Alaska Fairbanks, School of Fisheries and Ocean Sciences. Through this partnership they provide: (1) grants to faculty and research stipends to graduate students for research on pollock, other groundfish species, the fisheries for these species, and on marine mammals; (2) funding for marine education, technical training, and equipment; and (3) funding for research in marine resource economics.

Bering Sea Fisheries Research Foundation

The Bering Sea Fisheries Research Foundation (BSFRF) is a non-profit research foundation funded by both crab industry stakeholders and management agencies to provide a means for industry members, fisheries managers and crab scientists to interact. It has integrated researchers from NMFS and ADF&G as well as university scientists, graduate students, and international crab experts. The majority of funding for BSFRF comes from voluntary contributions from Bering Sea and Aleutian Islands crab industry members. Since its inception in 2003, the crab industry has continued to increase its participation in this cooperative research program with about 70% of the region's harvesters and processors now contributing to BSFRF.

Threats to Resources and Ecosystem Services

The 2005 EFH Environmental Impact Statement concluded that fisheries can have long term effects on habitat, but these impacts were determined to be minimal and not detrimental to fish populations or their habitats. The analysis found no indication that continued fishing activities at the current rate and intensity would alter the capacity of EFH to support healthy populations of managed species over the long term. This 2005 assessment was reinforced by a 5-year assessment of EFH. Nevertheless, the NPFMC acknowledged that considerable scientific uncertainty remains regarding the consequences of habitat alteration for the sustained productivity of managed species (NMFS 2010). The following summary pulls primarily from effects analyses conducted by NMFS and others focused on identifying potential impacts from commercial fishing.

Fishes

A broad suite of direct and indirect effects from commercial fisheries are thought to have potential population level effects on fish. Twelve target species/species groups in the ABSI region were assessed by NMFS in 2004 for impacts from the groundfishery. Key effects included:

- Mortality due to catch/bycatch and marine pollution and oil spills.
- Change in reproductive success due to removal of predators, cannibalism, spatial/temporal concentration of catch/bycatch, roe stripping, selectivity of juveniles.
- Change in prey availability due to fishery catch/bycatch of prey species, introduction of exotic species.
- Change in important habitat due to fishery gear impacts, marine pollutants and oil spills, introduction of exotic species.

Similar potential effects were specified for key species groups like salmon and forage fishes:

- Mortality due to bycatch of Pacific Northwest salmon.
- Reduced recruitment due to habitat degradation.
- Change in prey due to introduction of exotic species, marine pollution and oil spills.
- Change in important habitat due to fishery gear impacts, introduction of exotic species, marine pollution and oil spills.

Invertebrates/Shellfish

It is difficult to assess the effects of fishing on benthic organisms and habitat which include many species of invertebrates and shellfish (NMFS 2005). However, direct impacts from harvest have been observed for commercial crab species. Crab stocks are evaluated on a five tier system where higher numbers indicate greater concern for overfishing. Snow crab, Tanner crab, and Bristol Bay red king crab are managed as Tier 3 stocks. , with snow crab being declared overfished in 1999 and considered rebuilt in 2011. Pribilof Islands red and blue king crab and St. Matthew blue king crab are Tier 4 stocks where data on life history and a spawner-recruit relationship are lacking. St. Matthew blue king crab was declared overfished in 1999, was officially considered rebuilt in 2009. The Pribilof Islands blue king crab was declared overfished in 2002 and remains at a low biomass. The Tanner crab stock under Tier 3 management is no longer considered overfished.

Bycatch limitation zones have been established in a number of locations and several areas of the Bering Sea have been closed to groundfish trawling and scallop dredging to reduce the incidental capture of crabs. Beginning in 1995, the Pribilof Islands Conservation Area was closed to all trawling and dredging year-round to protect blue king crab habitat and in 1995, the Red King Crab Savings Area was established as a year-round bottom trawl and dredge closure area. Dredging for scallops in areas around Unimak has also been closed recently due to potential adverse impacts on the habitat for crab and other resources (NPFMC 2011b).

Seabirds

The risk of seabirds getting caught in fishing gear varies with the density and behavior of the bird species around the fishing vessel, the type of fishing gear used, and the techniques/devices used to avoid or deter birds. Many species are attracted to fishing vessels to forage on bait, offal, discards, and natural prey disturbed by the fishing operation. Seabirds are hooked on longline gear as they attempt to capture the bait or scavenge fishery wastes (NMFS 2004). Longline fishing has grown tremendously and is now considered the most serious global threat faced by albatrosses and other species of tubenoses (Brothers et al. 1999a). The primary management concern for the endangered short-tailed albatross is direct take in longline fisheries and as a result very low take limits have been set by NMFS (Fitzgerald et al. 2008).

Estimates of the annual seabird incidental take in the groundfish longline fisheries, based on data from 1993 to 2001, indicate that approximately 14,400 seabirds were taken annually in the Bering Sea and Aleutian Islands. The species composition of these birds was: 60% fulmars, 19% gull species, 12% unidentified seabirds, 4% albatross species, 3% shearwater species, and 2% all other species (NMFS 2004). Seabird bycatch mitigation devices have been required on vessels since 1998 and dramatic declines in the total number of bycatch seabirds since 2001, including albatrosses, has been attributed to these measures (Fitzgerald et al. 2008). Annual totals in the Bering and Aleutians from 2007-2010 have declined substantially following the use of mitigation devices though still range between ~4,500-8,500 (Fitzgerald 2011).

Other potential effects, such as oil spills, plastic pollution, and introduction of nest predators, are the result of vessel traffic rather than fishing effort. An oil spill from a shipwrecked fishing vessel or the accidental release of rats from ships to a seabird colony could have very substantial repercussions for one or more seabird species. Fishing vessels and other ships inadvertently transport rats to previously uninvaded islands when the rats jump ship at docks or after wrecks (Brechbill et al. 1977, Jones and Byrd 1979, Bailey 1993). Seabird species feeding primarily by surface-seizing or pursuit-diving have the highest frequencies of plastic ingestion, including the tubenoses and the parakeet auklet, whereas gulls and most alcids ingest little or no plastic. Species feeding on crustaceans or cephalopods also have high frequencies of plastic ingestion (NMFS 2004).

Trophic Function

Fishing results in selective removal of species and size classes that are important in marine food webs. The loss of key prey species or top predators has the potential to change trophic relationships and community structure. Fishing may also alter the amount and flow of energy in an ecosystem through the return of discards and fish processing offal back into the sea and through mortality from bycatch (Livingston et al. 2011). Removals concentrated in space and time may impair the foraging success of animals tied to land like nesting seabirds or pinnipeds that may have restricted foraging areas or critical foraging times. This was a key concern identified for Steller sea lions by NMFS (2010) relative to impacts from fishing.

Fishing gear may alter bottom habitat and damage benthic organisms and communities that serve important functional roles as structural habitat. Fishing can alter genetic-level diversity by selectively removing faster growing fish or removing spawning aggregations with different genetic characteristics. At present, no significant adverse impacts of fishing on trophic function are known from in U.S. fisheries off Alaska. However there are several cases where those impacts could be unknown because of incomplete information on population abundance of certain species such as forage fish or poorly understood habitat biota (Livingston et al. 2011).

Coldwater Corals

Many deep water areas are characterized as stable environments dominated by long-lived species. In such areas, the impacts of fishing can be substantial and long-term (Auster and Langton 1999). Species such as red tree coral (Primnoa spp.) are very long-lived (more than 100 years old) and slow growing, thus the habitat they provide does not easily recover if damaged by fishing (e.g., Risk et al.1998). Recent studies indicate long recovery rates for deep water sponges that have been damaged or removed by trawling (Freese 2003). Numerous studies have also documented damage to hard corals from trawls (e.g., Clark and O'Driscoll 2003), with one (Krieger 2001) that related damage to a known number of trawls in Alaskan waters. In sites formerly closed to fishing Krieger (2001) estimated 27 percent of the original volume of coral was removed by a single trawl effort. Corals had the highest LEI values with their very slow recovery resulting in predictions of long-term degradation effects (NMFS 2005).

Research on coral distribution and fishing impacts has moved forward, with studies by Stone (2006) and Heifetz et al. (2009). These studies found coral to be ubiquitous throughout transects across the central Aleutian Islands and damage to these correlated to the intensity of bottom trawling effort. Areas of highest coral density in the central Aleutian Islands were found to be deeper than most trawling effort but damage was noted in depths with little trawling effort, where longline and pot fisheries were the only gear contacting the seafloor. Their observations on effects of pot and longline gear on corals are some of the only such information available.

Community Sustainability

The challenge facing managers in the continuing process of comprehensive fishery management is to develop a program which slows the race for fish, reduces bycatch, provides for conservation and addresses the social and economic concerns of communities. For example 65 Bering Sea villages are eligible to participate in the Community Development Quota (CDQ) program that has provided eligible villages the opportunity to participate and invest in the Bering Sea and Aleutian Island fisheries while continuing the time-honored, artisanal fishing traditions that have shaped their existence and provide quality of life (e.g., WACDA 2011). Similarly, in 2005 the Bering Sea and Aleutian Island crab fisheries adopted a new share-based management program that recognizes the unique relationship between specific crab-dependent communities and their shore-based processors, and has addressed the codependence of these two sectors in local economies (NPFMC 2010b).

The NMFS (2004) assessment of socioeconomic impacts defines the following important factors for consideration:

- Regional impacts that include the Alaska Peninsula and Aleutian Islands from changes in processing, harvesting, payments to labor, and employment variables.
- CDQ-related impacts, including changes in community relationships and changes to the total allowable harvest.
- Impacts related to subsistence use of groundfish, Steller sea lions, and salmon, as well as opportunities for practicing subsistence.
- Environmental justice impacts resulting from changes in fishing activity, or impacts to the CDQ program or subsistence.
- Impacts on benefits from marine ecosystems including non-market (existence value and option value, etc.), and other uses of the ecosystem.

Subsistence Culture

Groundfish subsistence use occurs over a very large geographic area in the Bering Sea and Aleutian Islands, but in general, subsistence groundfish use levels are a relatively small proportion of subsistence resources overall, and in relation to other fish resources in particular (NMFS 2004). The bycatch of salmon species that are vital to the Alaska communities, particularly those harvested by Yukon and Kuskokwim residents, is a serious concern (e.g., Bering Sea Elders 2011). The potential of fishing impacts to Steller sea lions may also have contributed to decreases of abundance in this key subsistence species (NMFS 2010). The economic benefit brought to the region has also been identified as a contributing factor in decreasing participation in subsistence traditions. However it is also recognized that the funding, infrastructure, and equipment brought into the region by the commercial fishing also helps facilitate subsistence pursuits and provides opportunities for “joint production” (or harvest) with the industry (NMFS 2004).

Marine Mammals

Fisheries directly affect marine mammals when animals are incidentally caught, taken or entangled. Some species are more susceptible than others to interactions with fishing gear, depending on the extent of spatial overlap with the fisheries and on the animal's ability to detect and avoid gear. Fishery and marine mammal encounters that result in high levels of mortality and serious injury may have the potential to cause population-level effects. Other activities related to fisheries have the potential to affect marine mammal behavior including disturbance that may result from vessel traffic, fishing operations, or underwater noise. Fishery removals of marine mammal prey may cause food availability to become the limiting factor regulating the size of the marine mammal population (NMFS 2004, NMFS 2010).

The 2010 Biological Opinion conducted for the groundfish fishery in both the EEZ and State waters, focused its effects analysis on four species of endangered marine mammals including humpback, sperm, and fin whales, and the western Steller sea lion. Only in the case of the sea lion was commercial fishing identified as one of suite of factors negatively impacting the species. Specific concerns focused on reduction in the availability of prey resulting in a reduction of 'carrying capacity' for these avid predators. This was especially important to sea lions in the regions of western and central Aleutian Islands with prey resources being identified as "the essential feature of critical habitat" (NMFS 2010). Even though the causes for the decline and continuing lack of recovery of the Steller sea lion population are still the source of considerable scientific debate (National Research Council 2003), protection measures remain in place including an overall harvest limit of key prey species (walleye pollock, Atka mackerel, and Pacific cod) lower than the stock size harvest threshold (Livingston et al. 2011).

Strategic Opportunities and Information Needs

Given the substantial amount of research and management efforts focused on commercial fisheries within the ABSI region many information needs have been identified. However, with the jurisdictional responsibilities for NMFS, ADF&G and IPHC it is unlikely ABSI would lead on investments targeting these needs. However ABSI could play an important role in connecting the information collected by these agencies to other research focused on interacting landscape-level stressors in the region. Though it is difficult to identify specific products or outcomes, possible areas of collaboration include:

- According to NMFS (2004) the overall risk of an oil spill to commercial fishing depends on the number and condition of all vessels operating in a given area (including both those of the fishing fleet and marine shipping traffic). Due to the great number of variables, including spill type and volume, wind and ocean currents, and season, the overall risk of oil contamination has not been quantified.

- The risk posed by potential introduction of invasive species, either through rat spills, or as marine species has not been quantified. This information could be critical to preventing transport by a fishing fleet that includes vessels making regular transits and calling on ports throughout the Pacific Northwest where marine invasives have been well-documented.

- The net impact of the production of fishery wastes on seabird species, whether beneficial or adverse, has not been demonstrated in Alaska (NMFS 2004).
- Improvements in fisheries monitoring efforts should include better mapping of corals and other benthic organisms and the development of a system for prioritizing non-target species bycatch information in groundfish fisheries.
- Incorporation of socio-economic indicators of community sustainability into ongoing ecosystem assessments in the region, like those of the Aleutian Islands Ecosystem Assessment Team (NMFS 2012) that aim to identify the need for future changes in commercial fishery management.
- Improvements in understanding both the nature and direction of future climate variability and effects on biota critical to the trophic functions like small pelagics including myctophids and squids supporting the region's commercial fisheries.
- Nearshore habitat is not currently monitored, though a team is currently exploring approaches to monitoring benthic, nearshore habitat. This project has had its baseline year, but continuation is contingent upon funding and if continued, results would be included in future ecosystem assessments (NMFS 2012).
- While the genetic tools for discriminating differences among fish are well developed, more attention needs to be devoted to stock assessment and management tools that can use these data.

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Appendix D. Contaminants and Pollutants.

The Arctic acts as a “cold trap” and is a hemispheric sink for a number of pollutants and contaminants that are transported via prevailing atmospheric and oceanic currents from warmer, more densely populated regions of the globe. A number of these global transport pathways converge within, and travel through, the Aleutian Islands and Bering Sea bringing contaminants to the region ranging from harmful bio-accumulating heavy metals like mercury to Persistent Organic Pollutants (POPs) as well as plastics and other marine debris. The remoteness of this region has not spared it from local point sources of contaminants primarily from former military operations in the region. As a result, wildlife and people may be exposed to relatively high levels of contaminants from both distant and localized sources. Though remediation efforts are designed to remove contamination from known point sources, questions remain about the effectiveness of these cleanup efforts. Exposure to contaminants from distant sources is likely to increase due to increased globalization and the effects may be compounded by climate change.

Affected Resources and Services: Subsistence culture, marine mammals, seabirds, fishes, and commercial fishing.

Introduction

A wide range of POPs, heavy metals, radionuclides and hydrocarbon contaminants have repeatedly been detected in marine organisms in northern latitudes. These materials have well-documented negative effects on arctic species and the human communities dependent on them (AMAP 2011). Contaminants are transported to arctic and sub-arctic regions in the troposphere in gas phase, on particles, and by ocean currents (Muir et al. 1999) but also from freshwater discharge from rivers draining vast northern landscapes (Chemyak et al. 1996). They also reach remote regions via bio-transport as they are carried in the bodies of migrating fish and seabirds (Ewald et al. 1998, Zhang et al. 2001, Blais et al. 2005). Though long-range transport mechanisms are likely the most important pathway to the Arctic for POPs, heavy metals, and radionuclides, a number of local point sources of contaminants exist in the form of abandoned military and industrial facilities. These sources of environmental contaminants remain of concern to the health of local ecosystems because of their potential toxicity and effects on biological and human communities (AMAP 2011).

Beyond these local and globally-sourced chemical contaminants, unknown amounts of marine debris travel the same northward ocean currents and can also be introduced by local activities associated with commercial fishing and marine shipping. Marine debris, especially long-lasting plastic debris, has become a global problem (e.g., Morishige et al. 2007) with small pieces being consumed by some species with significant mortality effects (e.g., Cadee 2002). Also grounded debris, particularly fishing nets entangle and kill individual pinnipeds by “ghost fishing” (Zavadil et al. 2006). Plastic debris fragments adsorb, accumulate and transport POPs (Rios et al. 2007) and effects associated with micro-lized plastics (the tiniest particles of parent materials that don’t readily degrade and thus become biologically available at the lowest trophic levels) are starting to be realized (Arthur et al. 2009). Furthermore, plastic materials and the chemicals added to plastics have come under scrutiny because of their potentially harmful effects to human health. These include building blocks of plastic such as Bisphenol A (BPA), and added chemicals such as plasticizers (phthalates), fillers, antioxidants, flame retardants and dyes. The widespread distribution of these chemical additives in the environment and their adverse effects is becoming more understood (Halden 2010).

Beginning in the 1970s, the Russian Federation conducted a broad-based investigation of the transport pathways of chlorinated hydrocarbons associated with agricultural chemicals. A joint survey of the Bering and Chukchi seas with the United States began in 1984 to describe the distribution of agricultural chemicals. Pesticides like triazines, acetanilides, organophosphates and organochlorines widely used at the time were detected throughout the region. Chlorpyrifos and trace levels of endosulphan were the most frequently identified contaminants in seawater. Chlorpyrifos and atrazine were found on marine ice and concentrations of chlorpyrifos were highest on the ice and from seawater near the ice edge. The pesticide Endosulphan was widely distributed in the polar atmosphere and marine fog was found to contain pesticides (chlorpyrifos, trifluralin, metolachlor, chlorothalonil, terbufos and endosulphan) at concentrations several times higher than in adjacent waters or ice. The greatest concentration of any one single agrochemical was trifluralin (1.15 mu g/l) in a Bristol Bay marine water surface sample (Chernyak et al. 1996).

Some legacy POPs, like PCBs and DDTs have been shown to have declined in Arctic biota over the last 20–25 years, (AMAP, 1998). For example POPs in ringed seal blubber and seabird eggs in the Canadian Arctic show declining PCBs and DDTs from the 1970s to the 1980s, then a leveling off by the early 1990s. POPs in murre eggs monitored in the Bering Sea and Aleutians appeared to be stable or decreasing at all sites with the exception of St. George Island, where they have increased in thick-billed murre eggs since 2002 (Ricca et al. 2008). However data are more limited for other types of POPs and significant declines over time are less apparent, or are difficult to detect (Muir et al. 1999).

Some contaminants may increase in Alaska marine mammals with continued use and translocation to Arctic regions from lower latitudes through global redistribution. Similarly, more water soluble POPs are slower to accumulate in Arctic and subarctic food webs but may be slowly increasing (Wania and Mackay 1999). Concentrations of polybrominated diphenyl ethers (PBDEs) also appear to be increasing in marine mammals (Ikonomou et al. 2002). Further, mercury concentrations appear to be higher in more recent samples from the mid-1990s than in the 1980s and 1970s, and rates of accumulation also appear to be higher than 10–20 years ago (Muir et al. 1999).

Researchers caution against the perspective of contaminants being a 'legacy of the past' with POPs like flame retardants (Stapleton et al. 2005; de Wit 2002) and perfluorinated compounds (Yamashita et al. 2005), being part of an emerging array of contaminants ranging from those used in personal care products (e.g., Muir and Howard 2006) to those involved in the production of plastics (Halden 2010) the effects of which are only just beginning to be understood. Over 100,000 new chemicals have been introduced to the environment in recent decades (Bornehag and Nanberg 2010) including 20 groups of plastics (Halden 2010).

Transported Pollutants

The Artic Monitoring and Assessment Program (AMAP) described atmospheric deposition as the most important long-range transfer route of POPS and mercury into the Arctic. During the winter the Aleutian low pressure system pulls air from Eurasia across the Pacific Ocean and through the Bering Sea into the Arctic. Along this path contaminants are deposited to the Earth's surface via precipitation, particularly through winter snow with its crystalline surface that readily adsorbs both vapor and particulate compounds. Transported contaminants break down at slower rates in Arctic climates, primarily due to less microbial degradation of organic material in low temperatures. Thus, mercury deposited in snow re-enters the environment through melt water causing spikes in concentration during spring and summer (AMAP 2013). Figure D1. depicts the physical pathways of contaminant transport with full descriptions of these available through AMAP's web site at: http://www.amap.no/

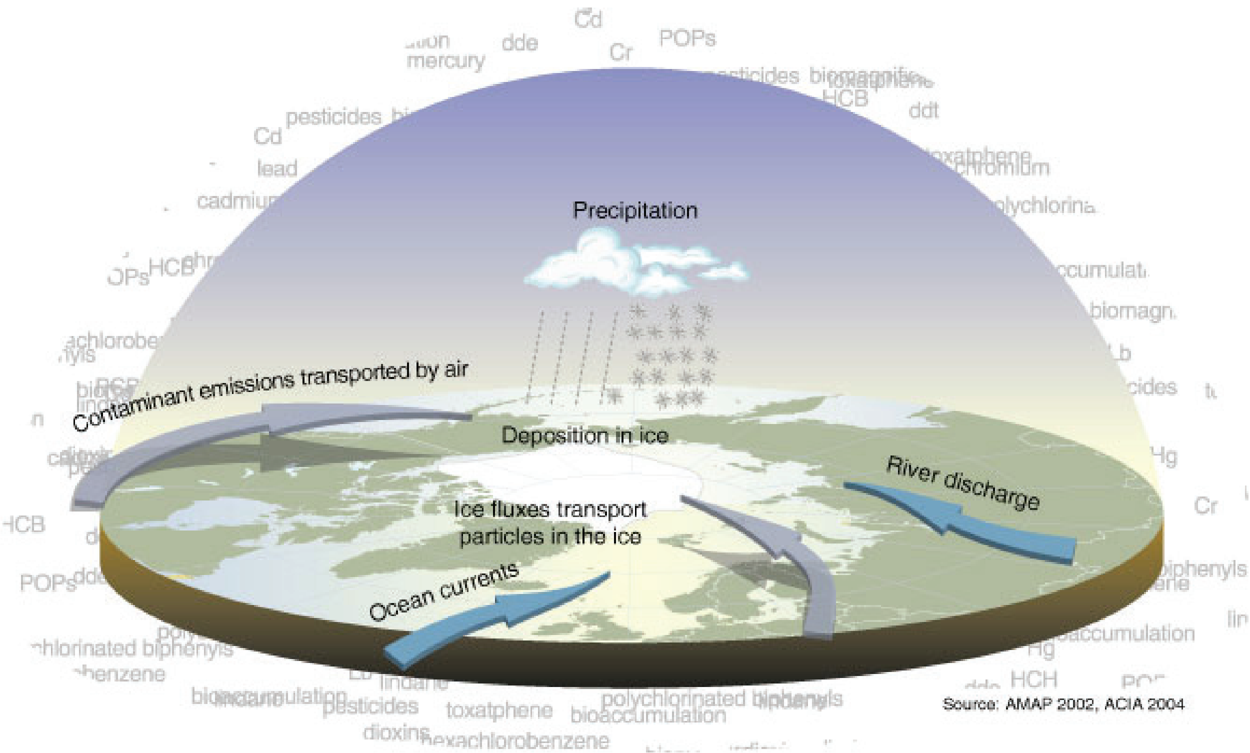

Figure D1. The global transport pathways for contaminants converging on northern latitudes adapted from AMAP (2002) and ACIA (2004).

The majority of these POPs and mercury come from China and southern Asia with mercury being a key byproduct from the burning of fossil fuels, especially coal. Mercury transported by air can take only a few days to reach the region while that transported by ocean currents may take decades (AMAP 2013). Higher concentrations of mercury have been shown to occur in seabird (Ricca et al. 2008) and fresh water fish (Kenney et al. 2012) from the more western of the Aleutian Islands as a result of increased exposure to atmospheric mercury. Anthony et al. (2007) also found an east to west increase in DDE and mercury concentrations in bald eagle eggs, consistent with Eurasian sources, and they also noted a similar pattern with lighter molecular weight PCBs, which were greatest in eggs from Attu and Buldir, the most western Islands sampled. Contaminant patterns in pelagic cormorants from the archipelago have revealed a similar westward increase in DDE (Rocque and Winker 1994). Reese et al. (2012) did not observe a similar concentration gradient for chlorinated pesticides or PCBs in blue mussel samples (point source issues provided a stronger signal), but their results did suggest recent inputs of the pesticide DDT to western Alaska.

Ocean currents sourced from Asia flow across the northern Pacific, spinning off of the Alaska Gyre and flows westward along the Pacific side of the Aleutians before entering the eastward-flowing Commander Current along the Bering Sea side primarily through Amukta Pass in the east and Amchitka Pass in the west (Stabeno et al. 1999). Figure D2 shows regional subtleties in these circulation patterns from AMAP (2007). Prevedouros et al. (2006) found oceanic transport of perfluororcarboxylates to be the most significant pathway for this class of POPs to

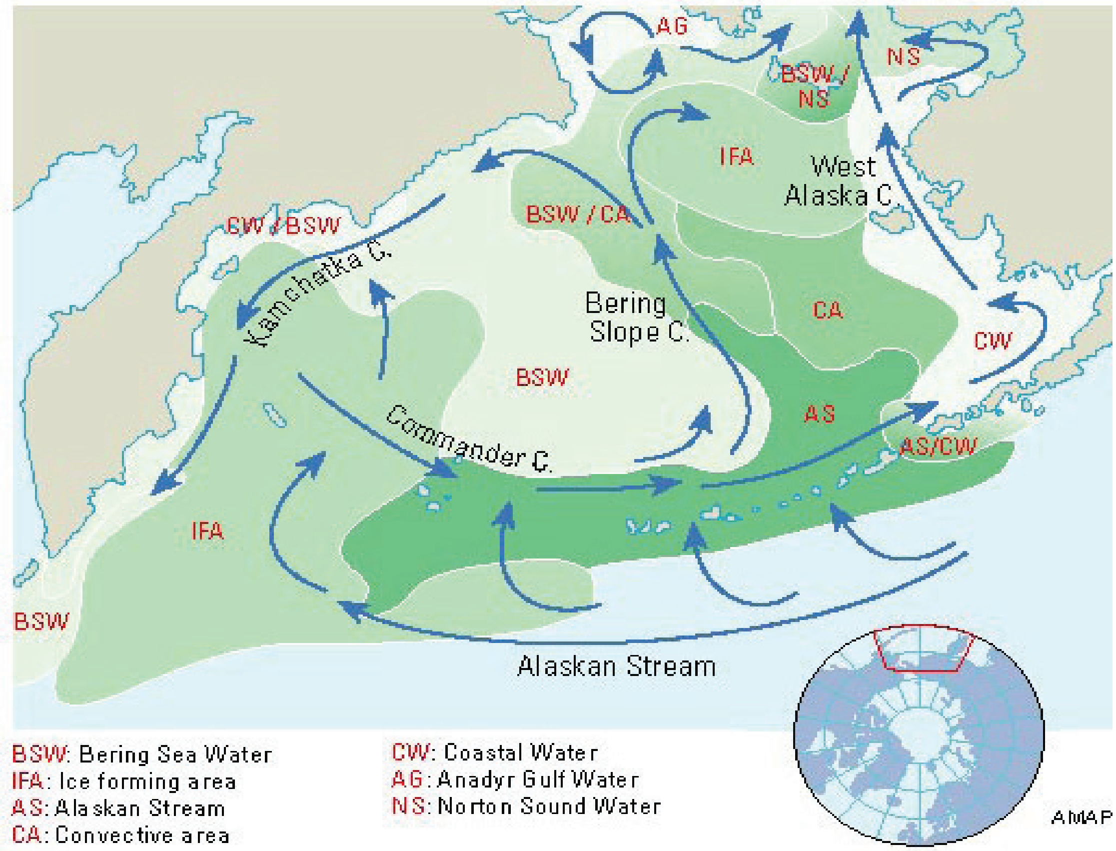

Figure D2. Ocean current circulation in the Bering Sea relative to contaminants transport adapted from AMAP (2007).

Arctic waters. Li and Macdonald (2005) documented the transport of contaminants by currents moving through the Bering Strait. Recent analyses suggest that these currents with long-term transportation cycles continue to bring legacy contaminants (whose production has been widely halted) into the western Arctic resulting in continued exposure to arctic biota (Addison et al. 2009).

Other significant contributors of contaminants are large river systems that drain northern landscapes. Russian rivers are thought to be some of the largest contributors of POPs within the Bering and Chukchi seas (Chernyack 1996). Recent research on mercury in common and thick-billed murre eggs found consistently higher concentrations in Norton Sound, compared to the Bering and Chukchi seas leaving Roseneau et al. (2012) to identify the Yukon River as the largest single point source for mercury in Norton Sound and suggest it should be recognized as the major transport pathway for mercury in western Alaska's marine environment. Similar observations about northern rivers being the largest contributors of mercury to Arctic waters have been made by Schuster et al. (2011) and Sonke and Heimburger (2012).

Contaminated Sites

The Aleutian Islands were a major battleground between United States and Japan during World War II with Attu and Kiska islands occupied by both Japanese and U.S. forces. Umnak and Unalaska islands both served as military bases during that time along with Ogliuga and Tanaga islands. Adak Island was an air base and port facility during World War II and a major naval air station thereafter. Amchitka Island also served as a military base during World War II, an underground nuclear test site in the 1960s -70s and was a surveillance site for the U.S. Navy during the 1990s (Merrit and Fuller 1977, Reese et al. 2012). A significant legacy of military contamination remains, including nuclear test sites, abandoned installations, orphaned landfills, uncontrolled releases of various hazardous materials, groundwater contamination, and presence of abandoned munitions and unexploded ordnance (Rudis 2012).

A number of studies have been conducted in the Aleutians attempting to describe contaminant concentrations in wildlife and fish species across the Aleutians. Relatively high PCB concentrations occur near some of these point sources, For example, Reese et al. (2012) observed PCB concentrations in mussels from Dutch Harbor on Unalaska Island and from two sites in Sweeper Cove on Adak Island, that would have ranked 1st, 8th and 10th respectively among the most contaminated sites in the U.S. when comparing these Alaska results to NOAA mussel-watch samples. (Lauenstein 1995). Reese et al. (2012) obtained similar results with concentrations greatest at Dutch Harbor where point sources were implicated as the likely cause of high concentrations of PCBs in blue mussels near former military installations on Adak and Amchitka islands. Sea otters in the vicinity of these same islands had elevated concentrations of PCBs (Bacon et al. 1999) as did seabirds from east Adak studied by Ricca et al. (2008). Fish collected in the marine waters around Adak military base had concentrations of POPs that would trigger consumption advisories based on EPA risk-based guidance (Hardell et al. 2010).

These formerly-occupied defense sites have been the focus of a substantial inventory and remediation in recent years through the efforts of a consortium of government agencies led by the U.S. Army Corps of Engineers. The Army Corps has established a program to clean up 31 sites along the Aleutian Archipelago through 2022 in a substantial effort to remove contaminants associate with non-munitions sites (P. Johnson pers. comm.). Similar remediation efforts have taken place on St. Lawrence Island. A multi-year National Institute of Health study is exploring pathways of exposure that may still exist following these remediation efforts (F. Von Hippel pers. comm.). Other communities in the region with significant cleanup action that have been followed up by water quality monitoring include a suite of 96 former NOAA sites on St. Paul and St. George Islands (Rudis 2010). Rigorous efforts such as these, to evaluate the effectiveness of multi-million dollar remediation efforts in terms of reducing environmental contaminants have not been conducted in the Aleutians.

The U.S. Fish and Wildlife Service (USFWS) is completing a comprehensive contaminants assessment for the Alaska Maritime National Wildlife Refuge that includes the lands they manage in the Bering Sea (Rudis 2010) and Aleutian islands (Rudis 2010) and Atti and Kiska Islands (Rudis 2013, in press), and other Aleutian Islands. These documents identify the risk of oil or other contaminants spills (including invasive species) as some of the greatest threats to the region (see Appendices E and F).

Biotransport

At the global scale, species migrations are a source of biological transport of contaminants from more industrialized locales to northern ecosystems (Blais et al. 2005). Recent research has documented contaminants transport occurring via migrating seabirds, salmon and whales that have accumulated contaminants such as POPs and metals in their body tissues. Contaminant transport processes also occur at more local scales in marine food webs (e.g., seabirds and fish) and anadromous species introductions into freshwater systems (e.g., Brimble et al. 2009, Michelutti et al. 2009). Trophic transfers are suspected to be occurring in freshwater ponds and lakes associated with seabird activity in the Aleutians (Kenney et al. 2012). Most migratory species tend to be apex predators feeding at higher trophic levels and, through metabolic processes either accumulate or transform toxic compounds in their tissues. Eventually these compounds can be released into freshwater bodies or surrounding environs through shedding of feathers, decay of carcasses, or further trophic processes and ecosystem interactions. In the case of Pacific salmon and other anadromous fishes, contaminant burdens in returning adults represent a lifetime of bioaccumulation from physical and biological exposures in the marine environments being delivered reproductive and nursery river sites (Blais et al. 2007). Similarly, the ecological connections between seabird species feeding at different trophic levels allowed population trends based on contaminants loads to be described in eider and tern colonies in the Canadian arctic (Michelutti et al. 2009).

In the Aleutians, several independent studies suggest that biotransport of contaminants may be an important factor at islands with large seabird nesting colonies. For example Reese et al. (2012) found a significant correlation between seabird density and pesticide concentrations in blue mussels. Further, the greatest concentration of DDT and its metabolites was found in mussels at Buldir Island, which lacks major contaminant point sources and supports large populations of nesting seabirds. In contrast, marine fish sampling (Miles et al. 2009) did not find greatly elevated POPs concentrations at Buldir. Ricca et al. (2008) observed POPs concentrations in Buldir seabirds (total PCBs, p,p′ DDE, and total chlordanes) that were elevated and statistically similar to samples from Adak Island. They attributed this to long-range transport from Asia (Buldir was their most western sample in that study) and/or biotransport. Anthony et al. (2007) found high concentrations of DDE, PCBs and mercury in bald eagle eggs from Buildir, which were attributed to non-point sources including atmospheric transport and biotransport. Interestingly, bald eagles on Buldir have low productivity compared to other Aleutian Islands (Anthony et al. 2007).

Marine Debris/Plastics

Ubiquitous in the marine environment, marine debris, especially long-lasting plastic debris, has become a global problem (e.g., Morishige et al. 2007). In addition to grounded debris, particularly fishing nets, causing direct damage to marine mammals through entanglement like in Northern Fur Seals (e.g., Zavadil et al. 2006), many seabird species ingest floating plastic while feeding on or near the surface of the ocean, picking up anything that might resemble their natural food (Minchin 1996, Auman et al. 1997, Blight and Burger 1997, Cadee 2002). There are many examples throughout the North Pacific of seabirds packed with plastic particulates to the extent that they are unable to feed properly resulting in diminished condition and, in some cases, starvation (e.g., Young et al. 2009).

The problem of microplastic marine debris (plastic particles smaller than 5mm) has reached the attention of the international community (Arthur et al. 2009). In the marine environment plastic shows a high resistance to aging and minimal biological degradation (Rios et al. 2007) meaning that tiny pieces of plastic remain biologically available to lowest trophic levels in the marine food chain allowing them to accumulate upwards. Blue mussels were found to transfer plastic particles from the gut to the circulatory system where they persisted for 48 days (Browne et al. 2008). Laboratory trials have shown that amphipods, barnacles and lugworms can ingest particles of microplastic (Thompson et al. 2004). Further indication of increasing risk to seabird species is the recent discovery of plastic particulates, chemical plasticizers, and breakdown products in seabirds from localities as remote as the Near Islands at the western end of the Aleutians (D. Causey pers. comm.) These chemical contaminants and plastics are known to have endocrine disrupting properties that interfere with wildlife estrogen, androgen, or thyroid signaling, hormones that are critical to reproductive health in all vertebrates (Carr and Norris 2006). Finally, as a result of their chemical composition, plastic debris can adsorb, accumulate and transport other POPs making them yet another vector for global distribution of contaminants (Rios et al. 2007).

Currents within the North Pacific Gyre gradually aggregate marine debris from shipping and ocean and coastal dumping. Over time, various physical, chemical and biological processes alter and degrade the retained debris. One of the most notorious examples is the vast accumulation of plastic debris in the North Pacific Gyre (the "Great Pacific Garbage Patch"), possibly encompassing millions of tons of debris covering millions of square kilometers. A synthesis of information obtained from scientific surveys, beach clean-ups, and drifting buoy tracks examined the transport and fate of marine debris (Stabeno 2003). This author reported that: "(1) Eddies, particularly their central cores, can collect and hold debris. (2) Islands and capes/points that stick out into the Alaska Coastal current collect debris on the beach and in the sea grasses of island shoals. The lee side of these islands will often have semi-permanent eddies which also collect debris. (3) Current speeds through the Aleutian passes are very high (up to 340 cm/s). Debris does not tend to collect there or on the Aleutian Islands." To what degree these processes have actually impacted deposition of debris, or are useful for prediction is difficult to evaluate. Scientists continue to refine their assessment of marine debris, including using remote sensing efforts under the GhostNet program (e.g., Pichel et al. 2012).

Certainly debris is readily observed in the region (D. Causey pers. comm.) and has been identified by the Alaska Maritime National Wildlife Refuge as a concern –though to what degree it may be more locally sourced vs. from trans-Pacific transport is not clear. Howell et al. (2012) offers a contemporary description of the transport system at work in the Pacific and Dianskii et al. (2012) developed a predictive model to show how debris infusions like that from the 2011 Japanese Tsunami or shipwrecks might disperse across the Bering Sea.

Climate Change Interactions

Climate change is expected to alter environmental distribution of contaminants through changes in transport, partitioning, carbon pathways, bioaccumulation and degradation process rates, as well as their toxicity and organism's susceptibility to hazardous substances. Toxicity of POPs could be altered as a direct result of changes in temperature. These changes could enhance the toxic effects of POPs on wildlife, increase disease risks, and increase species vulnerability (AMAP 2011). Climate change will also alter ocean salinity; affect eutrophication and water oxygen level; as well as the nutritional status and distribution of species. These changes could cause POPs to impede physiological, behavioral and ecological adaptations to climate change, thereby influencing the ability of organisms, populations, communities and ecosystems to adapt to climate change (Jenssen 2006, Wingfield 2008). Figure D3 attempts to synthesize climate change impact on ecosystems and biota and how they interact with contaminants (Schiedek et al. 2007).

Recent investigations of mercury availability indicate a number of linkages to observed effects of climate change including increase transport into marine waters from large arctic rivers systems during summer (Sonke and Heimburger 2012). This influx is thought to be linked to increased thawing of permafrost as well as from melting snow and ice sources (Fisher et al. 2012). Recent

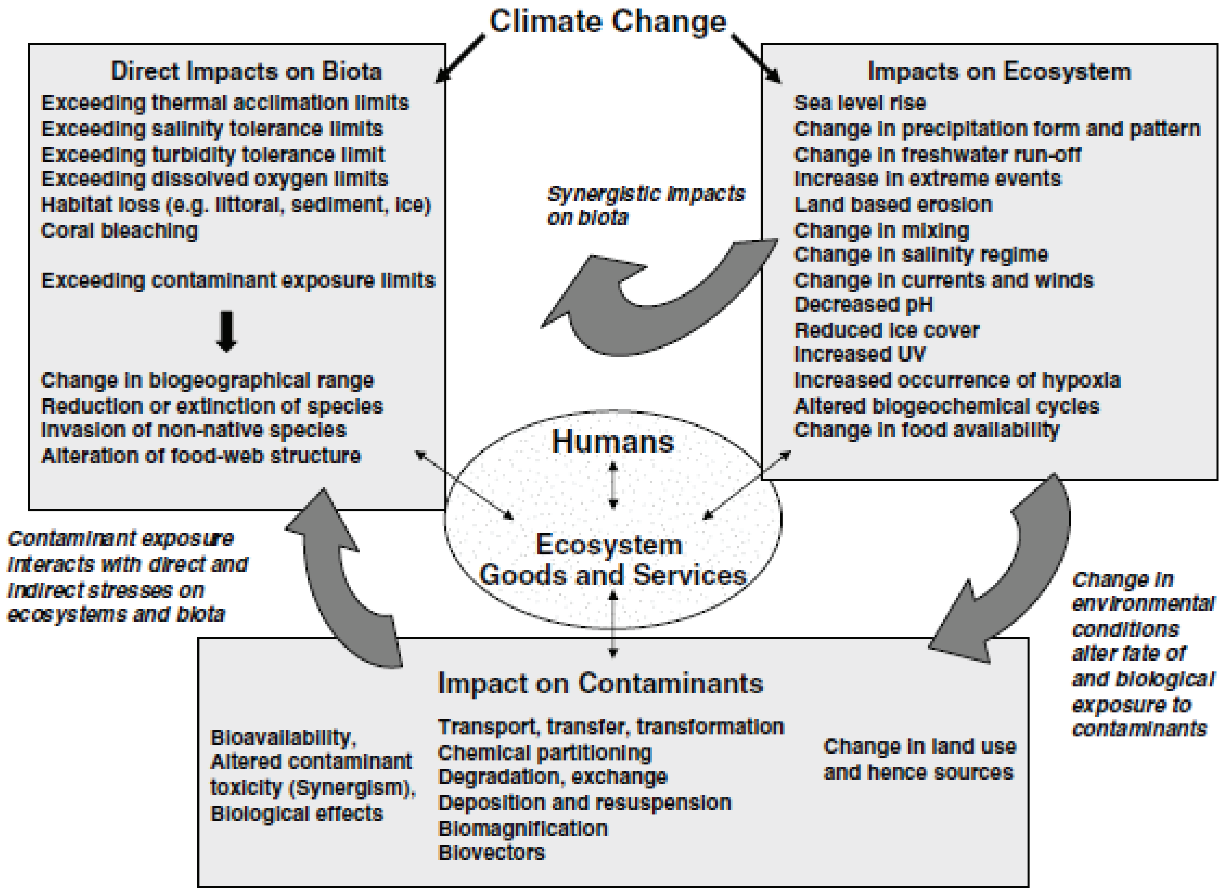

Figure D3. Climate change impacts on ecosystems and biota and how they may interact with contaminants, and their fate and effects adapted from Schiedek et al. (2007).

work by Point et al. (2011) makes a connection between spikes in biological availability of mercury and rapid melting of arctic sea ice.

Further, temperature changes the chemistry of many chemical pollutants resulting in significant alterations in their toxicities. For fish, higher water temperatures generally increase the rate of uptake of pollutants via changes in ventilation rate in response to an increased metabolic rate and decrease in oxygen solubility (Kennedy and Walsh 1997). For a variety of freshwater fish species it has been shown that the upper temperature tolerances decrease in the presence of certain organic chemicals (Cossins and Bowler 1987, Patra et al. 2007). The bioavailability of specific contaminants like metals is greatly affected by salinity (e.g., McLusky et al. 1986) and studies have shown increased uptake by diverse aquatic organisms at reduced salinities (Hall and Anderson 1995, Wright 1995) that may result with increased freshwater input.

A small number of studies have used chemical tracers to directly measure climate change-associated trophic changes and contaminant concentrations in Arctic biota. Researchers in the Beaufort Sea found that dramatic increases in mercury concentrations in Beluga livers since the early 1990s could be attributed to changes in sea ice regimes (Lockhart al 2005). Higher mercury concentrations in ring seals in the western Canadian arctic followed relatively short ice-free seasons due to consumption of older, more highly contaminated, cod cohorts. Mercury was also high during long ice-free seasons because of increased survival and abundance of Arctic cod resulting in more overall fish consumption (Gaden et al. 2009). McKinney et al. (2009) reported that increasing contaminant concentration in Hudson Bay polar bears could in part be attributed to differences in timing of the annual sea ice break-up and the resulting increase in consumption of open water-associated seal species. These studies support hypotheses that climate change will influence contaminant levels, pathways and fates within arctic environments. Changing physical conditions, distributional shifts and community assembly that affect trophic function will be further complicated by contaminant interactions and effects.

Key Data and Information Sources

A number of ongoing contaminants research, monitoring, and synthesis efforts exist for the broader Arctic that attempt to describe global transport of contaminants and risks for human and animal communities. Those efforts, combined with localized monitoring, inventory and remediation actions, offer data and information relevant to the ABSI region.

Arctic Monitoring and Assessment Program

The Arctic Monitoring and Assessment Program (AMAP) was established in 1991 to implement the Arctic Environmental Protection Strategy adopted by the environmental ministers of the eight Arctic countries: Denmark, Finland, Iceland, Norway, Sweden, Russia, Canada and the U.S. AMAP was tasked with preparing an assessment of the state of the Arctic environment with respect to pollution issues initially with a large focus on POPs. This included implementing a circumpolar monitoring program in Arctic countries, initiating new research and compiling data from these activities. AMAP released its first global assessment in 1998 and since that time has released numerous contaminants assessments ranging broadly from human health in the Arctic (AMAP 2009) to mercury emissions and impacts (AMAP 2013). Their assessments focus heavily on implications of climate change and contaminants (AMAP 2011).

Alaska Department of Environmental Conservation

The Alaska Department of Environmental Conservation (ADEC) maintains a spatial database of point features representing contaminated sites attributed with information regarding the nature of the contaminants as well as the status and history of any remediation and monitoring efforts. The database returns hundreds of individual sites in the ABSI region, primarily around former military or other government facilities and existing communities. These sites can be accessed by ArcGIS online via web browser or downloaded for use within ArcGIS. This database is widely considered to be the best characterization of known point-source contaminants (P. Johnson pers. comm.). An underground storage tank database searchable by community is also maintained by ADEC and contains records from ABSI region communities as does the Environmental Protection Agency's Brown Lands program, which is administered by ADEC. The ADEC also maintains a list of impaired waters, and water bodies that require establishment of a TMDL (Total Maximum Daily Load) or water body recovery plan. Sources of impairment in this part of Alaska have included petroleum discharges and seafood processing wastes. Some of these water bodies that are, or were previously impaired, occur in the ABSI region (ADEC 2012).

Also, ADEC laboratories, via the fish monitoring program, are tasked with monitoring heavy metal, POP, and other contaminant concentration in fish from Alaska waters. The fish monitoring program has been of paramount importance in both studying contaminants trends in fish in Alaska waters and informing fish consumption guidelines, which are developed by the Department of Health and Social Services.

U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (USFWS) has been active in the ABSI region primarily in efforts to assess the risk of former military and government sites to trust resources like seabirds and marine mammals. Their Contaminant Assessment Process (CAP) compiles known past, present and potential future contaminant issues on National Wildlife Refuges. These CAP reports have been completed for the Bering Sea unit of the Alaska Maritime National Wildlife Refuge ("the Maritime Refuge" (Rudis 2010) as well as for Attu and Kiska Islands (Rudis 2012). The two reports summarize the nature of key point-source sites within the ABSI region as well as describing other contemporary risks from oil spills and rat invasions associated with marine shipping to accidental contaminants releases (e.g., petroleum products) associated with the local fishing industry [See Appendix F.]. The Service's environmental contaminants program has conducted studies of contaminant threats to trust resources within the ABSI LCC (e.g., Trust et al., 2000; Stout and Trust 2002; Miles et al., 2007) and elsewhere in Alaska. Service toxicologists bring a management perspective to the study and review of contamination issues, given the agency's trust responsibilities for refuge lands (a major manager in the Aleutian Islands), migratory birds, certain marine mammals (sea otters, walrus, polar bear), and species listed under the Endangered Species Act.

National Oceanic and Atmospheric Administration

The NOAA marine debris program provides scientific expertise (such as remote sensing, debris modeling), collects information on debris suspected to be associated with the devastating tsunami in Japan in 2011. NOAA also sponsors marine debris removal actions.

Department of Defense

The Defense Department and/or its contractors prepare various site-specific remedial documents during the cleanup process (e.g., site inspection, remedial investigation reports, and records of decision) which provide site-specific information on the nature and extent of contamination, and proposed future cleanup operations.

Threats to Resources and Ecosystem Services

Humans, seabirds, marine mammals and fish within ABSI often feed at the top of the marine trophic system thus have elevated exposure to bio-accumulated contaminants that exist in relatively high concentrations within the ABSI region (AMAP 2009). A variety of marine bird and mammal species in this region have undergone precipitous population declines over the past several decades and though explicit effects studies are limited (Letcher et al. 2010) anthropogenic contaminants have been implicated in the declines of some species. Further, the exposure of northern communities to contaminants has gained broad attention and was largely the impetus for much of the initial work on contaminants in the Arctic (AMAP 1998). The following list is presented in order of relative concern.

Subsistence Harvest

Collectively, research results indicate that human health effects attributable to POPs in the Arctic may increase substantially in coming years (AMAP 2009). This high level of exposure due to global transport mechanisms happens against a background of contaminated sites located near communities and perhaps of greatest concern from bioaccumulation in traditional foods (AMAP 2006). Communities that depend largely on subsistence harvested foods including marine mammals, fish, and seabirds are well documented from around the Artic as well as within specific communities in the ABSI region like those on St. Lawrence (Welfinger-Smith et al. 2011) and the Aleutians (Burger et al. 2007). Individuals consuming traditional foods are making risk-balancing decisions, eating those nutrient rich foods that sustained them and their culture, while at the same time exposing themselves to contaminants. Consumption guidelines and risk models (e.g., Loring et al. 2010) have been developed for a variety of subsistence foods that consider contaminants like mercury but without contaminants monitoring of food sources people are left making these decisions with limited information (Burger et al. 2007) and are currently in process of being updated (A. Hamade pers. comm.). A successful example of the use of food source contaminant monitoring for public health purposes is ADEC's fish monitoring program, which monitors contaminant concentrations in fish and some other subsistence foods, that is critical in developing the guidelines for acceptable fish consumption guidelines developed by the DHSS Section of Epidemiology (Verbrugge, 2007). Beyond foods, the presence of hazardous sites near communities, and the unknown effectiveness of many of the remediation efforts in the region (F. Von Hippel pers. comm.), represent an additional threat.

Fishes and commercial Fisheries

Fish harvested from the Pacific Ocean are a major contributor to human methyl mercury exposure (Sunderland et al. 2009). Annual monitoring conducted broadly by ADEC for commercially valuable species has detected relatively low levels of mercury in Alaska (ADEC 2012). Walleye pollock from Japan Sea showed higher concentrations of DDTs and HCHs compared to fishes from Bering Sea and Gulf of Alaska but these Alaskan fish showed slower declines of DDTs and CHLs and an increasing pattern of PCBs concentrations during 1982-1992. This suggests continuous input of POPs by long-range transport and/or longer persistency in these cold regions. Walleye pollock from Bering Sea and Gulf of Alaska showed higher proportions of alpha-HCH and p,p'-DDE in the composition of HCH isomers and DDT compounds e.g., POPs with higher transportability also suggesting long-range transport (de Brito et al. 2002). Survey efforts near Adak found fish at with high levels of POPs (Hardell et al. 2010) as well as toxic metals (Burger et al. 2007) likely from point sources. Freshwater fish monitored in the Aleutians show high levels of contaminants in three-spine stickleback, a prey species for many birds and fish as well as arctic char (a subsistence species), attributed to local point-sources as well as atmospheric and possibly biotransport by seabirds (Kenney et al. 2012).

Marine Mammals

Contaminants detected in Alaskan pinnipeds include a suite of POPs, arsenic, mercury, cadmium, lead and radionuclides (e.g., Kucklick et al. 2002, Castellini et al. 2012, Rea et al. 2013). These have been found to produce immunotoxicity, hormonal perturbation, reproductive impairment, and other health problems in pinnipeds (Hutchinson and Simmonds 1994). Concentrations of POPs (PCBs and DDT) measured in a few Steller sea lions during the 1980s were the highest recorded for any Alaskan pinniped. These contaminants appeared more elevated in the Gulf of Alaska and Bering Sea than southeast Alaska and could not be ruled out as potentially contributing to species declines (Barron et al. 2003). Similarly, , Rea et al. (2013) found concentrations of total mercury in the hair of some western Aleutian Steller sea lion pups that have been shown to cause adverse neurological and reproductive effects in other fish-eating mammals. Wang et al. (2009) suggested that PCB concentrations in northern fur seals could produce neurotoxic effects even while their overall levels in this species appeared to decline. Marine debris is also a known physical hazard for pinnipeds (Zavadil et al. 2006, Raum-Suryan et al. 2009) with less known about potential chemical exposure from trophic accumulation.

Polar bears are seasonal inhabitants of the northern reaches of the ABSI region. Kannan et al. (2005) studied chlorinated, brominated and perfluorinated chemicals in Alaskan polar bears liver tissue, comparing the Southern Beaufort Sea and Chukchi/Bering Sea sub-populations. Chukchi/Bering Sea bears, PFOS, a relatively new and persistent POP, had the greatest concentration, followed by PCBs, chlordanes, PFNAs, HCHs and other compounds. Overall, however, most contaminant concentrations were significantly higher in the Beaufort Sea stock, except for HCHs and and PFNA, which were greater in the Chukchi Sea population. McKinney et al. (2011) found ΣHCH and β-HCH levels to be positively correlated with longitude, and state their findings likely reflect greater use of technical HCH (a pesticide) in Asia. They also noted that β-HCH, the predominant HCH isomer in polar bears, is subject to oceanic transport to the Arctic from the North Pacific, via the Bering Strait (e.g., Li and Macdonald 2005). Routti et al. (2012) found that Bering–Chukchi Sea polar bear liver tissue concentrations, adjusted for carbon and lipid sources, were lower than other Arctic subpopulations.

Long-lived top predators, like killer whales can have a body burden of contaminants from decades of bioaccumulation (Hickie et al. 2007) that may be triggered when, for example, when stress on food supply and the whales mobilize large quantities of stored fat reserves. Since 1999 contaminant levels in bowheads have either remained stable or decreased with the exception of contaminant levels in bowhead whale meat from a recent study of subsistence harvested whales from St. Lawrence Island (Welfinger-Smith et al. 2011).

Seabirds

Many seabird species ingest floating plastic while feeding on or near the surface of the ocean, picking up anything that might resemble their natural food (Minchin 1996, Auman et al. 1997, Blight and Burger 1997, Cade´e 2002). Plastic items may weaken or kill seabirds through ingestion hazard, starvation, stomach lining irritation, and failure to develop fat stores needed for migration and reproduction (Moore 2008). New risks relative to chemical additives and their breakdown within the marine environment also threat seabirds via POPs via the food chain as do other bioaccumulating contaminants like mercury and other metals known from the ABSI region (Burger et al. 2009). The level of contaminants exposure for seabirds across the Aleutians as described by Ricca et al. (2008) showed greater exposure in proximity to known point sources of pollution (former military sites), those breeding closer to Asian transport pathways as well as birds feeding at higher trophic levels (e.g., pelagic cormorants and pigeon guillemots). Longer-lived seabirds like northern fulmars in this study had 2-20 times higher concentrations of mercury. Additional concern has been expressed for those species wintering in the western pacific, closer to contaminants sources in Asia (e.g., Minh et al. 2002 and Lukyanova et al. 2007).

Strategic Opportunities and Information Needs

A number of contaminants and pollutants monitoring efforts have been launched in the ABSI region and are generating data relevant for evaluating risks to species and human communities. There is a community of researchers with substantial investments in the region from state and federal agencies as well as universities, to Alaska Native entities and local communities. A key role that the ABSI LCC could play is fostering communication between these entities and finding ways to launch collaborative analyses and synthesis of existing data sources that would illuminate risks to key species and communities.

University of Alaska Anchorage Contaminants Monitoring

In 2002, researchers from University of Alaska Anchorage (UAA) began working in partnership with the Maritime Refuge to inventory the level of mercury contamination in freshwater fish species along a longitudinal gradient across 20 Aleutian Islands. Annual monitoring of mercury levels has continued at several of these sites (in association with Maritime Refuge seabird monitoring sites) since 2006. The effort has produced recent publications (e.g., Kenney et al. 2012) and is being expanded and connected to other North American efforts describing mercury contamination. UAA is also exploring contaminants exposure associated with plastics in seabirds from the ABSI region with a the focus of understanding the nature and effects on the plastics and their breakdown products, such as phthalates and other plasticizers. Other studies in conjunction with this work will examine trends in other contaminants, including PCBs and heavy metals such as mercury and cadmium. The ABSI LCC could seek the expertise of these researchers and look for ways to leverage their sophisticated laboratory capacities as well as capitalize on their data resources to explore bioaccumulation pathways and better understand emerging threats from plastics.

UAA also leads a research project investigating exposure to two classes of emerging endocrine-disrupting chemicals (EDCs) with the Yupik people of St. Lawrence Island. The project will assess exposures to two types of POPs: polybrominated diphenyl ethers (PBDEs) and perfluorinated compounds (PFCs) that will be assessed in surface waters through analyses of contaminant levels and biomarkers for xenobiotic chemicals in the threespine stickleback fish. The research team will also analyze household dust as well as the subsistence foods which are likely a major exposure pathway due to the biomagnification of POPs in marine mammals and fish. The research team collaborates with the leadership, elders, and youth to develop measures to prevent and mitigate environmental exposures through community educational programs and public policy actions, including community-based research institutes for college credit, health fairs for all community members, and workshops for health care providers. This effort is part of a multi-million dollar, five-year grant awarded by the National Institute for Health (NIH) to a partnership including UAA, Alaska Community Action on Toxics (ACAT) and the residents of St. Lawrence Island (F. Von Hippel pers. comm.). The ABSI LCC might use this approach as a model for community collaboration efforts to collect contaminants sample data.

University of Alaska Fairbanks Wildlife Toxicology Laboratory

The Wildlife Toxicology Laboratory (WTL) has worked in collaboration with the Alaska Department of Fish and Game to measure total mercury in hair, blood and tissues of Steller sea lions in the Aleutian Islands and other regions of Alaska and Russia. This research has also included pilot projects to investigate methylmercury and selenium concentrations in various tissues. A recent collaboration with the commercial trawl fishery (Ocean Peace Inc.), ADF&G and the Water and Environmental Research Center at UAF is investigating total mercury concentrations and stable isotope values in several Steller sea lion prey species collected in the Aleutian Islands. Researchers from WTL are also collaborating with ADEC to evaluate contaminants in ground fish collected from throughout Alaska marine waters. The ABSI LCC could seek the expertise of these researchers and look for ways to leverage their efforts and resulting datasets to inform contaminants exposure pathways.

NOAA and National Marine Fisheries Service

National Marine Fisheries Service, Office of Protected Resources, in collaboration with the National Institute of Standards and Technology (NIST) maintains the National Marine Mammal Tissue Bank for long-term cryogenic archival of selected marine mammal tissues. Specimens from Alaska are provided to the bank through the Alaska Marine Mammal Tissue Archival Project (AMMTAP) which was initiated in 1987. This bank contains samples from 18 species of Alaska marine mammals many of them collected within the ABSI region (Kucklick et al. 2006). It defines 13 indicator species relative to contaminants including: northern fur seal, ringed seal, harbor porpoise, beluga whale, bowhead whale and the polar bear which are available to researchers for determining temporal trends of contaminants in these animals. One example of use of these samples has been the recent comparison of temporal trends in contaminants in Bering Sea population of belugas with the Cook Inlet population (Reiner et al. 2011; Hoguet et al. 2013).Finally, with 70 percent of the world's population of northern fur seals breeding on St. Paul and St. George Islands and NOAA has supported regular evaluation of contaminants in this population (e.g., Beckman et al. 1999, Wang et al. 2010). In addition, NIST is analyzing subsamples of banked northern fur seal tissues collected by AMMTAP over a 20-year period at St. Paul Island to determine temporal trends in POPs, including perfluorinated compounds and brominanted flame retardants, and heavy metals in these animals. The ABSI LCC could seek the expertise of these researchers, and their data resources, to explore bioaccumulation pathways and associated species and human community risks.

The NOAA Marine Debris Program has taken the lead on coordinating the efforts of various Federal, State and Provincial agencies, providing scientific support (modeling, remote sensing) and serving as a limited funding source for cleanup operations. The ABSI LCC could play a role in sharing the results of these efforts with manager and stakeholders in the ABSI region.

Alaska Department of Environmental Conservation

Supported by funding from EPA, NOAA and BOEM the ADEC monitors levels of contaminants in all five salmon species, halibut, pacific cod, sablefish, black rockfish, sheefish, lingcod, pollock as well as commercially valuable shellfish and some other freshwater species. Since 2001, data has been collected annually for metals including methyl mercury, total mercury, selenium, copper, lead, and cadmium. A subset is also evaluated for POPs including dioxins and furans, organochlorine pesticides, PCB congeners and brominated fire retardants. Samples are collected primarily in coastal marine waters throughout the state with some fresh water species from some coastal water sheds and lakes in the Koyukuk, Kuskokwim, Yukon, and Susitna River drainages and are archived and available for research purposes. Recently ADEC has approached University of Alaska system researchers to assist with more in depth analysis of the extensive data collected by this program. The ABSI LCC should stay abreast of this work and look for potential collaboration opportunities with DEC to explore risks to fishes as well as commercial and subsistence harvest efforts. The ADEC Contaminated Sites Program oversees contaminant cleanups. The ABSI LCC might consider collaborative efforts to evaluate and improve upon methods for remediation that have been completed or are being planned for lands within the ABSI region.

Alaska Department of Fish and Game

Supported by funding from NOAA and the State of Alaska legislature, the ADF&G Steller sea lion research program investigates concentrations of stable isotopes, mercury and POPs in Steller sea lions from across Alaska, with a focus on those animals captured within the Aleutian Islands. This research began in the 1990's and has benefited from collaboration with the National Marine Mammal Laboratory (NOAA) and the Environmental Assessment Program at the Northwest Fisheries Science Center (NOAA). This research is currently funded under a 2013 NOAA Species Recovery Grant awarded to ADF&G. The ABSI LCC could seek the expertise of these researchers and look for ways to leverage their efforts and resulting datasets to inform contaminants exposure pathways.

U.S. Fish and Wildlife Service

The USFWS has received Department of Energy funds for 2013 to build additional capacity in assessment and review of the hundreds of millions of dollars of remediation efforts proposed for 31 sites on the Maritime Refuge (primarily in the Aleutians). The USFWS will provide oversight to ensure that remediation doesn't conflict with fundamental refuge responsibilities. The Maritime Refuge also initiated a marine debris monitoring program at its permanent research camps during the summer of 2012 using a protocol established by NOAA for shoreline monitoring (Opfer et al. 2012). Six of these camps occur within the ABSI region and this initial baseline may prove useful should debris associated with the March 2011 Japan Tsunami eventually reach this area. This baseline will also be useful in evaluating the amount of marine debris that comes from other sources (e.g, commercial fishing, and marine shipping). The ABSI LCC should work with the FWS to explore ways of incorporating some sort of simple monitoring into DOD-sponsored cleanup efforts of formerly used defense sites. This could be of mutual benefit for evaluating the biological availability of contaminants and could inform the DOD about the efficacy of these costly and complex operations.

The Maritime Refuge in partnership with NIST also conducts the Seabird Tissue Archival Monitoring Project (STAMP) project that was initiated in 1999 to track long-term contaminant trends in seabird colonies using eggs collected with standardized protocols (York et al. 2001). The primary species being addressed by STAMP are common and thick-billed murres and a major part component of this project are murre colonies located in the ABSI region. Example products include an analysis of murre and gull eggs for establishing a baseline of contaminant levels for various POPs and mercury (Day et al. 2012). Another effort documented a general trend of lower contaminant concentrations in murre eggs from St. George Island as compared to the Gulf of Alaska (Day et al. 2006, Vander Pol et al. 2004). This project has also produced results that have provided evidence on the role of the Yukon River in elevated levels of mercury in Norton Sound using mercury stable isotopes in murre eggs (Day et al. 2012). The ABSI LCC could assist by connecting data from this long-term monitoring project with data for other monitoring efforts in the region.

North Pacific Research Board

The North Pacific Research Board (NPRB) has focused its efforts around three primary risks of contaminants moving through food webs. These include toxicity to individual organisms; toxicity to humans (especially Alaska Natives who depend predominantly on aquatic foods) and contamination of commercially-fished species, which may affect marketability and cause health problems (NPRB 2005). The NPRB has included a contaminants priority in each of its RFPs since 2002 and has invested in understanding sources, transport, and accumulation of contaminants and their effects on ecosystem structure and function. NPRB has also funded research on contaminants exposure of blue mussels to petroleum hydrocarbons and implications for Steller's Eiders in Nelson Lagoon (Lance et. al 2012) as well as efforts to understand the risk posed by paralytic shellfish poisoning (PSP) (RaLonde and Wright 2011) and inform 21 Aleut communities (Wright et al. 2008). The ABSI LCC should consider collaborating on joint funding opportunities that leverage NPRB research funds and should stay abreast of the results of research efforts that they sponsor.

Initial efforts to address effects of contaminants can be considered along three tracts of focus. The first is best described as risk assessments for exposure pathways to key species and human communities. These would include efforts to understand variation in exposure relative to climate change and could likely be explored initially using existing data and understandings about exposure pathways –especially in the case of mercury or other heavy metals. The second type relates to projects that improve management efforts around remediation of sites or improves early detection efforts for communities relative to hazards in food resources. A third category would be research and/or tools that help inform managers about emerging exposure threats (e.g., from new contaminants associated with marine plastics) to species and communities. Each of these types of efforts would likely benefit from integrating local knowledge into the development of risk models, research and possible monitoring approaches.

- Collaborate or leverage regional synthesis efforts to understand transportation pathways and deposition rates for contaminants that include predictions about variation in those rates relative to climate change with a focus on providing insights into exposure of key species and human communities.
- Collaborate or leverage ABSI community efforts aimed at monitoring the contaminants present in subsistence foods within the region and connect those efforts to larger scale contaminants monitoring in the region. Such an effort would ideally include collaboration with the Alaska Department of Health and Social Services, Epidemiology to evaluate risks from avoidance of traditional food consumption based on concerns about the presence of contaminants.
- Evaluate the distribution and composition (given recent findings about plastic-associated chemical contaminants) of marine debris including inventory, monitoring and sampling guided by predictive models of accumulation.
- Remediation of a number of former military and government sites have been implemented and more are planned within the ABSI region in the coming years yet very limited monitoring for environmental contaminant happens following these actions. An experimental simple application of contaminants monitoring (e.g., using bio-indicators) could look at persistence of biologically available contaminants following remediation actions.
- Synthesize information about contaminants cycling that incorporates expected changes in meteorologic, hydrologic, oceanographic, and biogeochemical cycling resulting from climate change and/or ocean acidification.
- Develop decision support technologies (e.g., integrated databases, and models, risk assessment, cumulative effects) that inform managers and communities about contaminants risks. New research and tools (gene expression bioassays, molecular tools, rapid diagnostics of health and exposure, models, etc.) that allow better understanding of the long-term effects and consequences of sub lethal exposures.

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Appendix E. Invasive and Introduced Species.

The introduction, establishment and subsequent spread of invasive species potentially threaten to harm native flora and fauna, disrupt ecosystems, and cause significant socioeconomic damage. The severe consequences of introduced rats, foxes, cattle, and reindeer are of particular concern for terrestrial ecosystems in the ABSI region. Predation, competition, and habitat alteration by these non-indigenous species has impacted the abundance, diversity, and distributions of native species. Less is known about possible threats from aquatic invertebrates, bacteria, diseases or viruses inadvertently introduced by ships transiting ABSI that have potential to disrupt marine communities. Similarly, invasive plant species have established themselves in locations near communities but little is known about their distribution or effects on native plant communities and wildlife habitats.

Affected Resources and Ecosystem Services: Seabirds, terrestrial vegetation, commercial fisheries, subsistence culture and invertebrates.

Introduction

The many problems caused by non-native species are becoming more apparent, and the World Conservation Union (IUCN) identifies them as the second most important cause of loss in global biodiversity (IASC 2010). Williamson (1996) described the “10:10 rule”, suggesting that 10% of species introduced to an area would establish themselves and that 10% of those established species would become “pests”. While this rule is thought to apply reasonably well for plants, others have speculated that it underestimates the numbers of vertebrate animals that become problematic (Usher 2002). Stringent plant and animal transportation laws, along with geographic isolation, harsh environments, small human population size, and relatively pristine habitat, are factors which may hinder the establishment of exotic species (ADF&G 2002). The IASC (2010) describes the Arctic as currently facing less problems from invasive species and a major synthesis volume completed during the 1980s (Drake et al 1989) does not mention the Arctic as an area of high risk. A similar conclusion was reached by Ruiz and Hewitt (2009) though they warn about interactive effects from climate change and increased human activities at high latitudes which may change invasion dynamics.

Terrestrial Invasives

Numerous extinctions and drastic reductions in seabird populations have been caused by the intentional and unintentional introduction of non-native mammalian predators to nesting habitats, especially on islands where they did not evolve with such a threat (e.g. Jones and Byrd 1979; Moors and Atkinson 1984; Burger and Gochfeld 1994). Predation impacts are greatest for ground-nesting seabirds that nest in high-density colonies and shorebirds are also extremely vulnerable to nest predators (Byrd et al. 1997). Foxes rodents, cattle, and reindeer have also destroyed seabird nesting habitat, resulting in the elimination (or reduction to remnant populations) of burrow and ground-nesting species at a number of locations (Ebbert and Byrd 2002).

The effect of introduced Arctic foxes on seabird populations is an example that links the marine and terrestrial environments. Several seabird populations have declined when mammalian predators were accidentally or intentionally introduced to nesting islands (Burger and Gochfield 1994). Arctic foxes were introduced to several Aleutian Islands for fur farming in the late 1800s and early 1900s. Before these introductions, the islands supported large populations of breeding seabirds and had no terrestrial predators. Although most fox farming ended prior to the Second World War, the introduced animals persisted on many islands, preying on breeding seabirds at rates affecting their population sizes (Baily 1993). According to a comparative analysis of seabird colonies in the Shumagin Islands by Jones and Byrd (1979), foxes were likely responsible for the reduced seabird populations. Those species nesting underground, in burrows or in rock crevices, were less affected (Byrd et al.1997).

Foxes have been eradicated from several Alaskan islands and the responses of seabird populations have been dramatic (Bailey 1993). As of 2012, foxes have been cleared from about 40 islands mostly on Alaska Maritime National Wildlife Refuge lands (Ebbert and Byrd 2002; S.E. Ebbert, pers. comm.). The benefit to seabirds where foxes have been eliminated has been great. On Alaid and Nizki islands, many seabird species increased 5-15 fold and occupied larger areas after fox removal (Byrd and Bailey 1990; Zeillemaker and Trapp 1986; Ebbert and Byrd 2002). Whiskered auklets also increased throughout the Aleutians following such removals (Williams et al., 2003). The Aleutian subspecies of the Cackling Goose (Branta hutchinsii leucopareia), once threatened with extinction and formerly an Endangered species, has made a dramatic population recovery and has re-established nesting populations on several islands from which foxes were eradicated (Byrd 1998).

Recent invasive rodent eradication efforts have also been successful on the Rat Islands (USFWS 2010). Investments have also been made in preventative measures including a Rat Outreach Team that was established in 2006 and included a variety of member organizations to enlist help from the public to prevent further rat introductions (USFWS 2009). Community-based preventative efforts by the Tribal governments on the Pribilof Islands are thought to be the most effective methods of dealing with such predators. Anti-rat measures have been implemented around harbor facilities resulting in St. Paul and St. George being two of the very few islands with port facilities that are rat-free. A 2013 expansion of these efforts is being conducted by Island-Tribal Government-Ecosystem Conservation Office for the Aleut Community of St. Paul in partnership with the U.S. Fish and Wildlife Service (Lestenkof 2012).

A less obvious result of the introduction of non-native species to the region is the conversion and degradation of avian habitat due to trampling and overgrazing by animals. Reindeer, cattle, and horses have been introduced to many ABSI islands. These large herbivores can produce marked changes to these sensitive terrestrial systems (USFWS 2009; Alaska Shorebird Group 2008) and have been shown to degrade cultural sites of significance within the Aleutians (Gililand 2006, D. Corbett pers. comm.). Further, Croll et al. (2005) were able to demonstrate that by preying on seabirds, foxes were able to reduce nutrient transport from ocean to land on several Aleutian Islands. This reduction in nutrients affected soil fertility and transformed formerly grassland dominant islands into dwarf shrub/forb-dominated ecosystems. A similar ecosystem cascade effect for was found where invasive rats depressed numbers of avian species foraging in the intertidal. As a result of predation by rats on these species, the intertidal community structure changed from algae-based ecosystem to one dominated by invertebrates.

Marine Invasives

The marine waters of ABSI are also vulnerable to invasive aquatic species arriving via the transport from one aquatic system to another. The only marine invasive currently documented from the Bering Sea region is the Atlantic salmon (Salmo salar) which has also been recorded throughout Southeast Alaska (Wing et al. 1992, Brodeur and Busby 1998). Other marine invasive taxa already present in state include boring sponge (Cliona thosina), golden star tunicate (Botryllus schlosseri), glove leather tunicate (Didemnum vexillum), violet tunicate (Botrylloides violaceus), skeleton shrimp (Caprella mutica), encrusting bryozoan (Schizoporella japonica), and the seafood gastroenteritis bacteria (Vibrio parahaemolyticus) (Fay 2002, AISWG 2010, Shaw 2010a). Two non-native seaweed species, wireweed (Sargassum muticum) and purple laver (Porphyra purpurea) have also been introduced in Alaska; however, the extent to which these are invasive is unknown (AISWG 2010, Shaw 2010a).

Marine invasives are well known passengers on the world's international shipping system and the Bering Sea is key corridor for international shipping traffic along the Northern Great Circle Route (See Appendix F). Analysis of data generated by Halpren et al. (2008) shows this route to rank among the world's highest in terms for commercial shipping traffic. Dutch Harbor also consistently ranks as the most productive fishing port in the nation since the late 1970s and serves as operation hub for the industry in the region (Sepez et. al 2007). Many fishing vessels home ported in more southerly, continental waters routinely make the trip to Dutch Harbor and the Bering Sea for a series of annual fishing seasons. As with commercial shipping, the commercial fishing fleet may also serve as an important vector for invasive species that are able to survive conditions in the Aleutians and Bering Sea. For example, according to an evaluation of permits maintained by the Alaska Commercial Fisheries Entry Commission (CFEC), 52% of commercial salmon fishing vessels active in the Bering Sea are home ported along the northwest coast of the U.S. in Washington, Oregon and California (CFEC 2012). A recent study based in California found that fishing vessels were an important vector for invasive aquatic species in that state's waters (Davidson et al. 2012).

Non-indigenous species are typically introduced into marine areas as a result of commercial shipping through ballast water (Fofonoff et al. 2003). To stem the tide of increasing introductions through ballast water, efforts have been made to curtail ballast water discharge in coastal waters. Vessels traveling into U.S. waters from outside the Exclusive Economic Zone (EEZ) are defined as overseas vessels and with some exceptions, are required to exchange or treat their ballast water (33 CFR 151.2035). They may discharge ballast water in U.S. ports, however, the vessel must discharge only that amount of ballast water operationally necessary to ensure the safety during cargo operations (33 CFR 151.2037). Vessels involved in coastwise trade (within the EEZ's of the U.S. and Canada) are not subject to the same requirements (33 CFR 151.2036) leaving open a possible route for the spread of invasives into near-shore waters of the North American continent.

The movement of large ships carrying ballast water from the U.S. West Coast and Asia (see Appendix F), as well as fishing vessels docking at commercial fishing facilities have the potential to introduce marine invasives (NPRB 2005). Biofouling is the result of organisms attaching themselves to vessel hulls and port facilities. These organisms can spread immature life stages and/or adults via release of planktonic spores or larvae, detached individuals or colony fragments which can settle and re-grow (e.g., Davis 2012). Additional risk of introductions could result if shipping through the Bering Strait intensifies with a loss of sea ice which could result in introductions of invasive marine organisms from vessels transiting the Arctic Ocean (NPRB 2005). Additional risk may come for industrial development which could result in nearshore discharges of ballast water from support vessels. Similar equipment used in offshore drilling could serve as another possible vector.

Ports like Dutch Harbor with high volume international traffic likely have the highest potential as initial points of aquatic species introduction either via ballast water or biofouling. Recent citizen science efforts lead by Prince William Sound Regional Citizens Advisory Council (RCAC) attempt to monitor invasive aquatic invertebrate species through the use of settlement plates deployed at harbors. Through these efforts RCAC has provided the initial detection of an invasive Asian barnacle species in Prince William Sound (SERC 2011).

A related biofouling threat comes from marine debris sourced from Asia or other parts of the globe washing ashore on remote ABSI beaches. A contemporary example comes from Japan Tsunami marine debris when a 60' dock washed ashore on the Oregon coast that hosted four species known to invade near-shore waters of the Pacific Northwest (C. Rich, pers. comm. 2012). Another vector for the arrival of aquatic invasive species is via aquaculture operations. In Alaska, such industries are currently limited to shellfish farming (~60 farms rearing oysters, mussels, and other bivalves; all farmed oysters are grown from juvenile "spat" imported from other Pacific coast hatcheries), algae mariculture, and salmon ocean "ranching"(NPRB 2005).

Climate Change Interactions

As fishing, shipping, and other development activities in the ABSI region continue and expand, the risk of introducing non-indigenous wildlife -- including rats, mice, fleas, cockroaches, jellyfish, mussels, clams, snails, fish, bacteria and algae, and other organisms -- will likely increase (World Wildlife Fund 2004). This could include increased risk of rat infestations due to the expansion in high latitude shipping routes (AMSA 2009) and the increased potential for severe storm activity that may increase the risk of shipwrecks in remote areas such as the Pribilof Islands (Fritts 2007). Scientists also hypothesize that climate change may create conditions which could increase risks from invasive taxa in the ABSI and other sub-polar/polar eco-regions (NPRB 2005; USFWS 2010). It should also be noted that the introduction of disease organisms for wildlife and people (see Appendix B) is a distinct possibility for Arctic regions (IASC 2010).

Key Data and Information Sources

There is not a comprehensive data sources for invasive/introduced species in the ABSI region and though some databases exist that could host records, in most cases they are not populated with observations from the region. As has been the case for other invasive species summaries in Alaska most records reside in a combination of anecdotal observations, trip reports or treatment summary documents (T. Gotthardt pers. comm.).

The Alaska Maritime National Wildlife Refuge

The Maritime Refuge has the most detailed information available on terrestrial invasive/introduced vertebrates in the ABSI region. Their removal and prevention efforts have documented the presence (and contributed to the absence) of a number of species in recent years. This data exists in a combination of published (e.g., Ebbert and Byrd 2002) and unpublished documents as well as the project working files of their active removal program.

Alaska Natural Heritage Program

The Alaska Natural Heritage Program (ANHP) serves as a leader in summarizing data on invasive/introduced species. They host the Alaska Exotic Plants Information Clearinghouse (AKEPIC) which adds as many as 20,000 new records of plant infestations annually (T. Gotthardt pers. comm.). It currently has no records of invasive plants in the region though some infestations are known (G. Graziano pers. comm.) They also update and maintain range maps for invasive animal species and have completed a regional invasive species risk assessments (e.g., Gotthardt and Walton 2011) for a variety of invasive taxa in other parts of Alaska.

National Ballast Information Clearing House

Data on the location, volume and method of ballast water exchange are compiled by the National Ballast Information Clearinghouse (NBCI). These data come primarily from commercial vessels and include ports of origin, destination as well as vessel name and type. This clearinghouse was created by a partnership between the US Coast Guard and Smithsonian Environmental Research Center (SERC) to track the arrival patterns of ships and quantify their ballast water activities to better understand the magnitude and characteristics of this important pathway of biological invasion. At present, NBIC receives roughly 115,000 ballast water reporting forms per year from overseas and coastwise arrivals. According to a NBCI query between 2004 and 2012, Dutch Harbor leads all Alaskan ports in overseas traffic and is the third overall in total numbers of ships conducting ballast water exchanges in Alaska, with about half of all discharge reported coming from coastwise traffic.

Threats to Resources and Ecosystem Services

Invasive and introduced species threaten survival of native plants and animals by changing species abundance and distribution, reducing biodiversity, and increasing the likelihood of threatened or endangered species listings (Carlton 1989, Lassuy 1995,). The effects of introduced and invasive vertebrates (foxes, rats, and ungulates) on terrestrial ecosystems and key species like seabirds are well documented in the ABSI region. Disruptions to key ecosystem services like commercial fishing and subsistence harvest can result from impacts on target species via predation and or competition (ADF&G 2002, Pimentel et al. 2005). These same threats likely exist from marine invasive species though they are much less well understood especially in Alaska marine waters (AISWG 2010).

Seabirds

Introduced predators like fox, mink, and rats prey on seabird eggs and chicks with devastating results, particularly for ground nesters such as storm petrels, murrelets, auklets, and puffins (Bailey, 1990; Bailey and Kaiser, 1993; Kondratyev et al., 2000). Rats are found on at least 21 islands in the ABSI region, and eliminating the presence of rats and mice on island ecosystems is a more daunting task than fox removal, due to their small size and high fecundity. The potential introduction of rats to the Pribilof Islands poses a serious threat to ground-nesting birds (A. Sowls, pers. comm.). Islands with large and complex geography are most at risk because treatment options for rats have not been demonstrated and success of eradication is very low (S. Ebbert, pers. comm.). Introduced ungulates can contribute to the loss of vegetative cover which subsequently may adversely affect nest concealment which could result in increased nest predation. Further, these changes to vegetative cover may alter the invertebrate community, potentially eliminating key prey sources which support shorebird adults and chicks during their breeding period (Alaska Shorebird Group 2008).

Commercial Fishing and Subsistence Culture

While biofouling, aquaculture industry, bait, and aquarium trades can be vectors for invasive/ introduced species introductions, typically these species are introduced into marine areas as a result of commercial shipping through ballast water (Carlton 1985, Carlton and Geller 1993, Fofonoff et al. 2003). In 2010, AISWG identified 70 potential aquatic invasives for Alaska. Further, competition between Atlantic salmon and native Pacific salmon for spawning or rearing habitats and food is potential threat to commercial and subsistence fisheries (ADF&G 2002, Wing et al. 1992). Invasive invertebrates like the European Crab and can also compete with important native crabs (Jamieson et al. 1998, ADF&G 2002, Davidson et al. 2009, See and Feist

2010). Finally, damage to equipment and infrastructure can result from extensive biofouling of fishing gear, and port/dock infrastructure by tunicates (Shaw 2010). Further, the Tunicate, Didemnum vexillum can affect commercial ground fisheries by converting heterogenous substrates important for rearing juvenile ground fish into homogenous tunicate mats (Valentine et al. 2007).

Terrestrial Vegetation

Caribou introduced to St. Matthew in 1944 over-grazed and exhausted their food resources (Klein, 1968) resulting in lasting damage to fragile, lichen-dominated upland tundra (D. Ruthrauff pers. comm.). Reindeer have been introduced to Umnak, Atka, Unalaska and Adak Islands. The Navy closed its base on Adak in the mid-1990s, and with less hunting pressure the herd is now overgrazing the island (USFWS 2009) and recently have expanded to Kagalaska (Ricca et al. 2012). Caribou on the Pribilof Islands have been an important food resource for island inhabitants for 100 years but vegetation has been subjected to conversion and degradation (Alaska Shorebird Group, 2008). The U.S. Fish and Wildlife Service continues to work with herd owners to reduce grazing pressure. They have also removed cattle from three islands in the Alaska Maritime National Wildlife Refuge in 1985 but active ranching of cattle and bison continues today on both Refuge and private/state lands in the Aleutians (T. Lestenkoff, pers. comm.). Cascading changes to vegetative communities can also occur as a result of declines in seabirds (e.g, Croll et al 2005) following introductions of nest predators.

Further vegetative change can result from invasive plants though it is currently not known to what extent infestations may occur within ABSI though at least one large orange hawkweed infestation (a species of significant management focus in other parts of Alaska) has been treated on Adak (G. Graziano pers. comm.). Efforts to inventory invasive plant species on the refuge have been a lower priority relative to vertebrates (S. Ebbert pers. comm.) and the prominent assumption is that the islands of the ABSI region have not been surveyed for invasive plants (G. Graziano pers. comm.). It has been speculated that parts of the ABSI region may be vulnerable to invasion because of a relatively mild climate in the south, open habitats and places with high nutrient loads and soil disturbance, including seabird colonies which have been shown to be areas susceptible to invasive weeds in other regions (M. Carlson pers. comm.).

Invertebrates

Ecosystem conversions such as the conversion of mudflat ecosystems to salt marsh by the cordgrass Spartina (Morgan and Sytsma 2010), may decrease important habitat for species clams, and crabs (ADF&G 2002). Competition with, and predation on, native species can come from invaders like the northern European green crab and the Chinese mitten crab (NPRB 2005).

Strategic Opportunities and Information Needs

Rosentrater and Ogden (2003) caution that the risk of introducing any non-native species into the Arctic must be established before the species is introduced. Experience worldwide indicates that it is often too late if the risk is assessed after the introduction; it might then also be too late to control the spread and effects of the invasive species. The precautionary action is to stop the arrival of the invasive species in the first place because its later eradication may be impossible, and even if possible worldwide experience shows that it is likely to be extremely expensive (IASC 2010). Understanding and addressing the vectors of invasion may be the most effective approach.

Alaska Natural Heritage Program

Currently there is no database for invasive animal species in Alaska. The ANHP is interested in establishing a statewide database that would track invasive animal infestations and treatment actions taken to address them. A number of nationwide databases have been developed and ANHP currently maintains a statewide database for invasive plant species. Examples include NEMESIS maintained by the Smithsonian Environmental Research Center as well as a nationwide database being developed by USGS in 2013, Biodiversity Information Serving the Nation (BISON). The ANHP has reviewed these models and recently explored using the www.ImapInvasives.org database for Alaska, in part because of its tools that allow residents in local communities to upload observations to a centrally curated database that is connected to databases being maintained by 14 other states and 1 Canadian province. This model is compatible with other NatureServe databases currently used for biological inventories by the Natural Heritage programs of all 50 states and the Conservation Data Centres of Canadian provinces. A single repository for invasive animal data which could facilitate community-based input would be essential for early detection and prevention efforts as well as tracking species invasions. The AHNP has experience maintaining such databases and is connected to other states and provinces with similar potential invaders as ABSI.

Alaska Maritime Refuge

The LCC could work with the Alaska Maritime refuge to compile a current status distribution of introduced/invasive vertebrate species in partnership with the ANHP so that refuge data could feed into statewide efforts to track invasive species status. The Maritime Refuge is making continuing efforts to manage impacts form introduced ungulates on the refuge and may have common interest with other regional land managers to mitigate these impacts on key species as well as ecosystem function and cultural resource sites in the Aleutians.

Aleut Community of St. Paul

In 2013, a U.S. Fish and Wildlife Service Tribal Wildlife Grant was awarded to the Tribal Government-Ecosystem Conservation Office. This grant will enhance efforts initiated in 2007 in order to: “1) Formalize existing and develop new partnerships with the agencies, businesses, and organizations involved in rat prevention on St. Paul Island. 2) Evaluate the effectiveness of current rat stations, defense strategies, and control techniques of the rat prevention program on St. Paul Island. 3) Update the current rat prevention data collection and sharing methods of the rat prevention program on St. Paul Island. 4) Implement and train rat prevention staff on suggested rat station improvements, detection and defense strategies, and data collection and sharing methods. 5) Educate our community and vessels using our port on the importance of rat prevention in the Pribilof Islands, Alaska.” (Lestenkof 2012). An ABSI-supported expansion of these efforts after this evaluation could help export this effective program to other regional communities.

The Alaska Sealife Center

Scientists and education specialists from the Alaska Sealife Center have hosted forums, developed materials, and worked collaboratively with managers to promote the awareness of the threats posed to Alaska’s marine system from invasive species. Their communication expertise and capacity could compliment the applied research efforts of ABSI relative to both terrestrial and aquatic invasive species.

Committee for Noxious and Invasive Plants Management in Alaska

This group known as "CNIPM" is a state-wide source of expertise on invasive plants monitoring and treatment. They have organized efforts share knowledge about assessment and treatment of invasive plant species including annual conferences in Alaska. They have also helped organize local treatment actions and could be an asset assuming ABSI aimed to establish some sort of community-based weeds monitoring program in the region.

A number of important information needs exist for invasive and introduced species, including:

- Complete a data review and summary of the occurrence and likely sources of invasive animal species within ABSI. This summary would be paired with an evaluation that considers distribution, dispersal capability, ecological impacts, and feasibility of control to assess the relative risk of potential invasives (e.g., Gotthardt and Walton 2011) within the ABSI region. An analysis for ABSI would include a spatially explicit evaluation of major transmission vectors from marine ballast water and coastwise fishing fleet as well as international traffic. The ANHP has developed an approach for this type of species summary and risk analysis and would be a logical partner.

- Implement a program of basic inventory and monitoring for the most invasive aquatic invertebrates at ports within the ABSI region using early detection/rapid assessment tools to detect infestations and if cost efficient could be tied to efforts that evaluate vitality of organisms collected using molecular/genetic diagnostics. These actions have been successfully implemented by citizens in ports of Prince William Sound and have resulted in the initial detection of invasive species. The Alaska Sea Grant program through the University of Alaska Fairbanks or Alaska Sealife Center could be potential partners in such an endeavor with data managed by ANHP.

- Complete a data review and summary of the invasive plant species occurrence, likely vectors for invasion, invasiveness risk and for those determined to be of greatest threat early detection/rapid assessment tools. Such tools have been successfully used throughout the state by agencies in partnership with citizens and have resulted in initial detections of many high priority invasive plant species.

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Appendix F. Marine Vessel Traffic.

Large commercial vessels currently use transportation routes through the Bering Sea and pose a variety of significant environmental risks to ABSI resources and services including contaminant spills, disturbance of marine mammals and seabird habitat, accidental invasive species introductions and direct mortalities resulting from collisions. In the North Pacific, a great circle route from the western United States to eastern Asia passes through Unimak Pass and the western Aleutian Islands. It crosses the transit lanes and fishing grounds of the largest fisheries in North America, as well as the Alaska Maritime National Wildlife Refuge (home to 40 million seabirds and numerous marine mammals). As many as 9-12 vessels per day use this route through the Aleutian Archipelago at Unimak Pass, with many continuing on and passing west of Tanaga Island. A second great circle companion route passes south of the Aleutians and is generally used for voyages from East Asia to North America. Assuming trade continues to expand between Asian markets and the U.S., traffic will likely increase in coming years. In addition to these historically well-travelled routes, traffic along the North Sea Route through the Bering Strait is currently 4-5 vessels week during the summer season and will likely increase as transpolar routes become more accessible due to reduced summer sea ice in the Arctic Ocean.

Affected Resources & Ecosystem Services: marine mammals, seabirds, invertebrates/shellfish, fishes, subsistence culture and commercial fishing.

Introduction

In 2004 the Arctic Marine Shipping Assessment (AMSA) estimated there were 6,000 individual vessels making multiple voyages through the Arctic region and more than half of these were operating on the Northern Great Circle Route that crosses the Aleutian Islands. Of the 6,000 vessels reported, approximately 1,600 were fishing vessels with the next largest group being bulk cargo carriers (AMSA 2009). According to the AMSA the most significant threat from ships "is the release of oil through accidental or illegal discharge". Additional potential impacts include ship strikes on marine mammals, the introduction of invasive species, disruption of migratory patterns of marine mammals and anthropogenic noise produced from marine shipping activity. The AMSA predicts that changes in Arctic sea ice will provide for longer seasons of navigation possibly resulting in increased interaction between migrating species and ships. Their assessment identified the Bering Strait as a key region in need of formally established vessel routing to reduce the risk of vessel accidents that could injure its highly productive ecosystem that supports many species of marine mammals, seabirds, fish and unique indigenous communities (AMSA 2009).

Recent incidents involving freight vessels in transit through the Aleutians have focused attention on the oil spill risk within the productive fishing grounds and sensitive wildlife habitats of the Aleutian archipelago. In December 2004, the *M/V Selendang Ayu* lost power, drifted aground, and broke apart near Unalaska Island, spilling an estimated 336,000 gallons of intermediate fuel oil and marine diesel oil. This followed the grounding of another freighter (*M/V Kuroshima*) seven years prior at Unalaska Island that resulted in a spill of ~40,000 gallons of Bunker C fuel oil. In July 2006, the car carrier *M/V Cougar Ace* capsized while transferring ballast approximately 200 nautical miles southwest of the Aleutians, and was ultimately towed to Unalaska Island. While the *Cougar Ace* incident did not result in a significant spill, it was the third major freight vessel casualty in the vicinity of the Aleutian Islands within a decade (Nuka Research 2006).

Following the *Kuroshima* incident, the State of Alaska passed a law requiring non-tank vessels greater than 400 gross tons that call on Alaska ports to file oil spill contingency plans. The federal government has recently followed suit with a law requiring oil spill contingency plans for non-tank vessels calling on U.S. ports. However, international law exempt vessels engaged in "innocent passage" (ie., not calling on US ports) through Alaskan (e.g., the *Selendang Ayu*) or international waters as was the case with the *Cougar Ace* (Nuka Research Group, LLC & Cape International, Inc., 2006).

In Alaska, marine vessel traffic (including oil tankers, oil rig support, cargo, fishing, and recreational vessels, and cruise ships) varies regionally, seasonally, and by vessel size. During the summer months, this activity increases and overlaps in some areas with peak numbers of marine mammal and seabird species, which may coincide with their breeding season (USFWS, 2009). Additional issues related to shipping in the ABSI region include the likely expansion of vessel traffic through Bering Strait as seasonal commercial traffic transits the Arctic due to reduced summer sea ice (NPRB 2005). Because the Bering Strait is home to --and also a major seasonal migration corridor for many species of marine mammals, fish, and birds. Scientists and local stakeholders have raised similar concerns over the risks associated with vessel groundings, contaminant spills, and disturbance to sensitive species (AMSA 2009, Laughlin et. al 2012).

A contemporary Port Access Route Study for the Bering Strait was launched in 2010 (USCG 2010) and further development of ports throughout the Arctic has potential implications for the ABSI Region. According to Clement et al. (2013) marine shipping experts say that a significant expansion of shipping in the U.S. portion of the Arctic would require the development of deep-water ports for ship refueling, cargo transfers, materials storage, and visitor access. A evaluation of potential deep water ports in the Bering Sea by the U.S. Army Corps of Engineers (USACE) identified Nome and Port Clarence as likely candidates which could alter shipping patterns in the northern Bering Sea (USACE 2013). Recent workshop efforts have identified a series of recommendations and international collaboration that is necessary to minimize impacts to communities in this region (McConnell et al. 2013)

The Northern Great Circle Route is the most heavily used route in the ABSI region (Figure F1). Approximately 9-12 large commercial ships (MXAK 2009) use the northern route through Unimak pass into the Aleutian Archipelago with the southern route generally used for voyages from East Asia to North America. Thus, deep draft commercial ships on trans-Pacific voyages generally follow a counter-clockwise route from North America through the Aleutian Islands to Asia, then back to North America southward of the Aleutians and have been used for hundreds of years. These trade routes take advantage of the prevailing ocean currents in the Northeast Pacific. For example, the *Selendang Ayu* had just cleared Unimak Pass headed to Dalian, China from Seattle when it lost power; the *Cougar Ace* was headed to Vancouver from Tokyo on the southern great circle route below the Aleutians. (Nuka Research Group, LLC & Cape International, Inc., 2006).

Vessel Traffic

A study completed by Halpern et al. (2008) showed that the intensity of use along the Northern Great Circle Route is on par with some of the world's leading shipping routes. A key tool used to track traffic is the Automatic Identification System (AIS). International efforts to enhance maritime safety by tracking ships over 300 tons and all passenger ships have resulted in over 40,000 vessels worldwide equipped with VHF transmitters that send signals to AIS base stations. These signals identify the location, speed, direction of travel as well as a number of

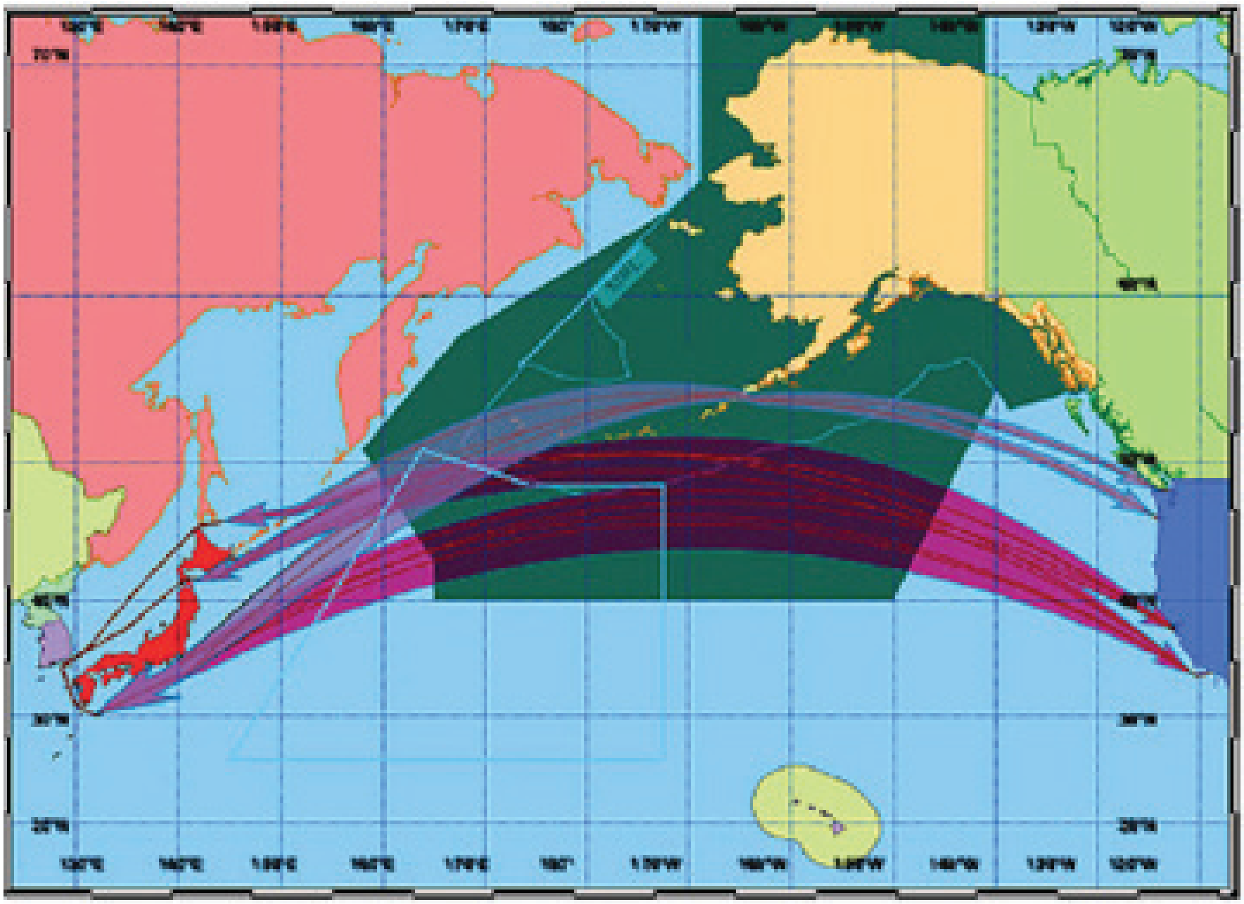

Figure F1. Map of the northern and southern great circle routes across the Pacific. Source: U.S. Coast Guard Maritime Domain Awareness Center.

attributes specific to individual ships including length, beam, draft, cargo type, destination and origin ports, vessel name, and country of registry. The Marine Exchange of Alaska (MXAK, at www.mxak.org) has established and operates a network of over 100 terrestrial based Automated Identification System (AIS) base stations throughout coastal Alaska. This network of AIS receivers is continually being expanded. The AIS data can be collected and stored or visually inspected in almost real-time through a tool developed by MXAK accessed over the web.

Currently there are a number of MXAK receiving stations monitoring key shipping travel routes in the ABSI region including Unimak Pass and the Bering Strait (Figure F2) but coverage in the western Aleutians is sparse. Globally, a few private companies (e.g., ExactEarth http://www.exactearth.com/) have recently established satellite networks capable of receiving the same VHF signals picked up by AIS base stations from orbit. Dynamics of orbital paths and the few numbers of satellite receivers do not allow the near real-time resolution of shipping traffic of MXAK's stations but do expand global coverage of ship tracking beyond the reach land-based station network --typically 50-100 miles from a given station (E. Page pers. comm.).

Analysis of three years of data (2006-2009) from the AIS base station at Unimak Pass reveals that an average of ~4064 or, 9-12 deep draft vessels a day transited the pass on trans-Pacific voyages (Table F1). These data confirm that the North Pacific great circle route through Unimak Pass is used primarily (75%) by vessels traveling west from North America to ports

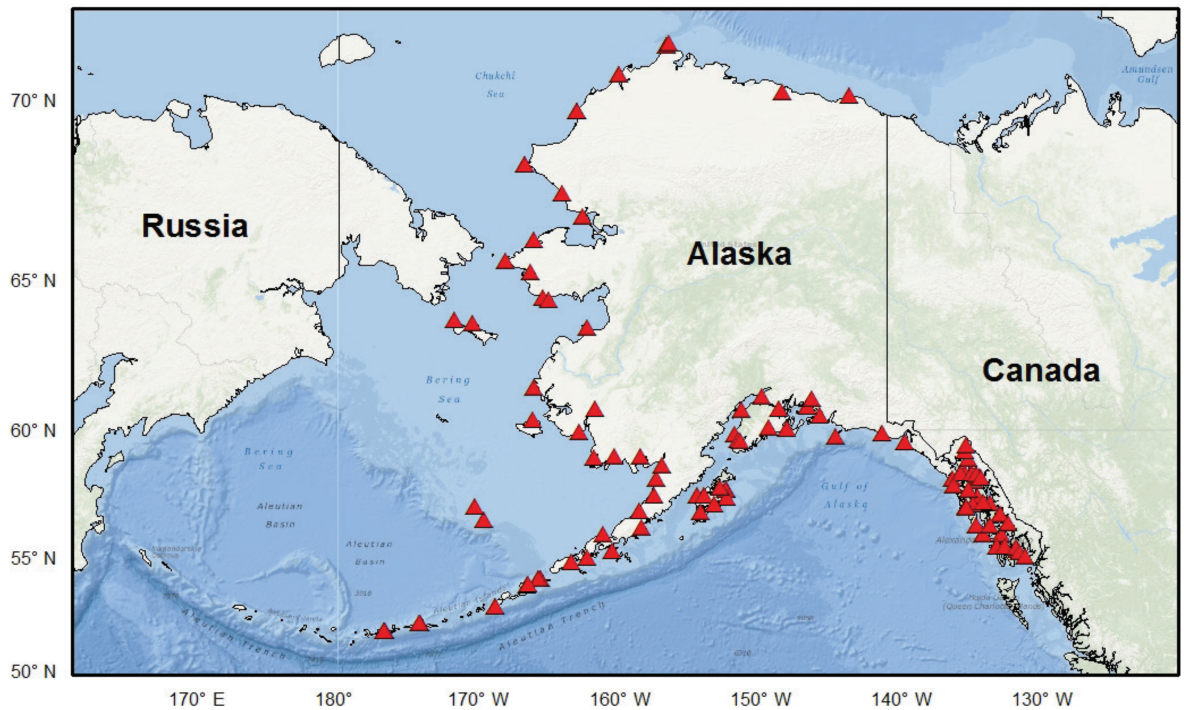

Figure F2. The locations of Automated Identification System (AIS) base stations operated by Marine Exchange of Alaska in western Alaska as of August 2013.

on the East Asia coast and somewhat less so (~25%) by vessels headed eastward from Asia to southwest ports in North America (Table 1) (MXAK 2009). Vessels on this route pass through the Aleutians twice – once at Unimak Pass and once at a point west of Tanaga Island (Nuka Research Group, LLC & Cape International, Inc., 2006). A recent report from MXAK (2009) showed an unexpected large number of ships chose to transit south of the Aleutian Archipelago rather than through Unimak Pass to Asian ports.

Diminishing Arctic sea ice is likely to encourage growth of commercial shipping via international trans-Arctic routes, though the time horizon for such an expansion is unclear. These routes may

Table F1. Vessel transits as reported by an Automated Identification System (AIS) receiving station at Unimak Pass in the Aleutian Islands.

Year	Westbound	Eastbound	Total	Per Day
2006	2,923	568	3,491	9.56
2007	3,581	890	4,471	12.25
2008	3,274	957	4,231	11.59

reduce transit distances between Europe and Asia by as much as 5,200 miles (8,369 km) (AMSA 2009). In the Bering Strait, receivers on St. Lawrence Island and the mainland of Alaska in the village of Wales, recorded traffic transiting the Bering Strait from 2009-2011. Approximately two vessels every three days passed through the strait during the ice-free season between May and October (Table F2). The majority of traffic was found to pass between Little Diomede Island and Wales into Arctic Alaska or Canada with some small portion of the traffic headed to the Russian Arctic and another group transiting between Europe along the Northern Sea Route (MXAK 2012). The Northern Sea Route Information Office [http://www.arctic-lio.com] permitted a total of 213 transits along the North Sea Route for 2013. Assuming these voyages happen that would represent a four-fold increase in transits compared to 2012.

Table F2. Vessel transits through the Bering Strait as reported by an Automated Identification System (AIS) receiving station array on St. Lawrence Island and Alaska mainland.

Year	Northbound	Soundbound	Total	Per Day
2009	136	126	262	0.72
2010	128	114	242	0.66
2011	124	115	239	0.65

Contaminants Spills

In 2007, the Alaska Department of Environmental Conservation (ADEC) issued a report on oil spills in the Aleutians. During the period of 1981–2005 there were 26 known vessel spills of more than 1,000 gallons, averaging approximately one per year. Seven of these spills were over 35,000 gallons with the largest being a 2 million gallon diesel spill form a tank barge in 1988 and a 2004 spill of heavy bunker oil from the *M/V Selendang Ayu*. Ninety-eight percent of spills were of "non-crude oil" with most being either vessel fuels or refined products in transit to island locations in the region (ADEC 2007). A report by NOAA indicates that almost no oil has been recovered from all known vessel spills in the Aleutians (NOAA 2000). Though the largest volume spilled has been from just a few significant commercial vessel incidents, fishing vessels have contributed to the largest number of individual spills (NAS 2009). The 2007 ADEC report summarizes discernible trends for spills and concludes that the total number of spills appears to have been on a general decline. They also describe the frequency of spill as declining during October through January, possibly because of the timing of the fishing season.

Data on vessel type and fuel capacity for non-tank vessels is attainable from applications for Certificates of Financial Responsibility (required for vessels over 400 gross tons operating in Alaska state waters) that are issued by ADEC. Nuka Research Group, LLC & Cape International, Inc., (2006) analyzed vessel traffic in Aleutian waters using ADEC data combined with 2005-2006 AIS data from Unimak Pass. Persistent fuel oil (heavy or intermediate types with specific gravities near 1.0, not including diesel) capacity was estimated by ship type for 92% of the ocean-going vessels passing through the Aleutians on Northern Great Circle voyages (Table F3). This analysis shows that some 3,000 ships transport 2.9 million gallons of persistent fuel oil through the Aleutians each day. A key finding showed that an additional 400 million gallons of fuel oils each year are transported by 20-22 tankers not included in their analysis that also use this route.

There has been less analysis on the potential risk of spills through the Bering Strait. Proceedings from a recent workshop in Nome described the potential for spills and accidents as a serious concern. Participants felt that "...high winds, poor visibility, sea ice, major storms and the lack

Table F3. Persistent fuel capacity for estimated annual number of trips of large commercial ships transiting Unimak Pass in the Aleutian Islands via the Northern Great Circle Route.

Vessel Type	Median Persistent Fuel Oil capacity per ship (gallons)	Estimated annual # of ships transiting the Aleutian Islands	Proportion of all ships (%)
Container ships	1,600,000	1,200	39%
Bulk/general freight ships	470,000	1,300	41%
Motor carriers	500,000	265	8.5%
Refrigerated cargo ships	317,000	110	3.5%

of spill response infrastructure in the Bering Strait region will likely render effective response extremely difficult if not impossible, especially if the region is ice-covered" (Laughlin et al. 2012). A 2013 U.S. Coast guard exercise, Arctic Shield, was focused on improving response capabilities in the Bering Strait.

Key Data and Information Sources

A number of federal and state agencies are involved in management and oversight of marine shipping. The effects of marine shipping are probably best understood through an evaluation of the seasonal distribution of traffic and understanding the types of ships and cargo being transported. Following the *Selendang Ayu* casualty, the State of Alaska increased efforts to monitor the amount of vessel traffic moving through the Aleutians (Nuka Research Group, LLC & Cape International, Inc., 2006) including:

- Number, size, and type of vessels that transit the great circle route between the coastal ports of North America and East Asia as well as type of fuel oil and capacity.
- Number, type, and size of vessels calling at Aleutian ports.
- Type and quantity of oil transported as cargo to and through the Aleutians.
- Current tugboat traffic in the Aleutians, particularly with regard to tugs that may be able to come to the aid of a stricken vessel.

The Marine Exchange of Alaska

The Marine Exchange of Alaska was established in 2000 to bring the Alaska maritime community together with the common goal of: "providing information, communications and services that aid safe, secure, efficient and environmentally responsible maritime operations". A key data service they offer is archived point locations for millions of vessel locations collected by their network of AIS receivers. These data sets date back as far as 2006 and 2009 for Unimak Pass and the Bering Strait, respectively and establish an important baseline for vessel traffic. In areas without AIS coverage MXAK uses several different forms of satellite tracking, including a 2013 partnership with ExactEarth to track vessels well offshore, or in very remote areas of Alaska marine waters. Though these locations are usually only once every several hours (MXAK 2012), they prove useful for describing traffic patterns outside of AIS coverage. This data can be used to explore relative intensity of traffic in terms of seasonality and specific locations across much of the ABSI region.

Shipwreck and Vessel Incident Data

A variety of data sources exist on ship wrecks and groundings for the Pacific region and the ADEC has published a currently unpopulated GIS layer of shipwrecks in Alaska. Some further inquiry might find that these data sets can be mapped with relative ease and compared to other existing databases for marine incidents and ship wrecks including those maintained by, USGS, NOAA, the Maritime Refuge and the State Historic Preservation Office (SHPO). Analysis of these layers could demonstrate specific areas where vessel grounding has been a problem in the ABSI region.

Threats to Resources and Ecosystem Services

The migration corridors used by marine mammals and birds correspond broadly with the North Sea Route into and out of the Arctic in the region of the Bering Strait. For the Bering Strait there is less overlap during the spring migrations as shipping activity will typically occur later in the spring than the animal migrations. In the fall, there is likely more opportunity for interaction between ships and migrating species, as both are leaving the Arctic ahead of the formation of the pack ice. As the climate continues to change, it is very likely that the shipping season could extend earlier in the spring and later into the fall. The Northern Great Circle Route is a high volume shipping route through the Aleutians, passing in close proximity to important marine mammal haul-outs and nesting sites for seabirds. It also passes through the most productive commercial fishing grounds in the United States and one of the largest protected essential fish habitats in the world (AMSA 2009). Further, its proximity to key subsistence harvest areas for Bering Sea and Aleutian subsistence communities is a concern both from potential displacement of target species but also from potential contaminant spills (Bering Sea Elders 2011, Laughlin et al. 2012). Additionally, accidental introductions of invasive species such as marine planktonic species or pathogens released from ballast water and rats from grounded ships represent another threat [See Appendix E].

Oil Spills

Marine Mammals, Seabirds, Invertebrates, and Fishes would all experience substantial negative impacts from a large oil spill in the ABSI region. Innumerable species key to the function marine ecosystems could potentially be impacted directly by oil (and other contaminants) spilled from ships grounding or other maritime incidents. The difficulty of effectively cleaning up an oil spill (e.g., Torrice 2009) and the long-term persistence of oil in cold water environments (Short et al. 2007) would result in prolonged availability of oil in the ecosystem if spilled into the ABSI region. Oil can directly affect wildlife in two primary ways 1) inability to keep warm if oil on feathers or fur reduces thermal properties and 2) contamination from ingesting, inhaling or absorbing toxins found in oil. Species that tend to congregate in large concentrations like pacific walrus (Garlich-Miller et al. 2011) and wintering Spectacled Eiders (Peterson et al 1999) may be especially vulnerable to population level effects from spills. Effects from spills can also move through food chains because hydrocarbons are taken up by bottom feeding invertebrates, which then end up as prey for sea birds, marine mammals and fish species (AMSA 2009). Further consideration should be given to potential impacts to larval stages of fish and invertebrates that are more sensitive to the acute toxicity of oil chemicals. Similarly sustained damage to important habitat can have resulting impacts on food availability lasting beyond direct impacts from a spill. Cascading effects from the damage done to these systems would also damage the fishing industry and subsistence harvesting communities (AMSA 2009, NOAA 2013).

Marine Mammals

Research into the impacts ship noise on the ability of marine mammals to survive and reproduce and cumulative consequences for populations already imperiled is in its infancy. It is known that increased noise levels associated with shipping can interfere with communication, foraging, prey evasion and other important life history functions (Wright et al. 2008). Increased aquatic noise disturbance from marine vessel traffic within the narrow Bering Strait could affect acoustically-sensitive marine taxa displacing them of traditionally used habitats which may have cascading effects for subsistence communities (Laughlin et al. 2012). There is also some risk of direct injuries or mortalities from whales accidentally struck by vessel hulls (e.g., Laist et al. 2001). This is of special concern for those species with threatened or endangered populations where even loss of a few individuals is cause for conservation concern (Berman-Kowalewski *et al.* 2010).

Seabirds

Though there is some evidence that seabirds are temporarily disturbed by shipping traffic (e.g., Schwemmer et al. 2011) the conservation implications for these disturbance events are less clear. Seabirds have also been known to collide with lighted ships or those in dense fog but conservation implications are unclear (AMSA 2009). Further, marine shipping is known to be a major contributor to floating plastic marine debris which has significant effects to many seabird species [See Pollutants and Contaminants Stressor].

Subsistence Culture

The 2009 AMSA describes Arctic peoples as heavily dependent on marine resources for subsistence and local economies. It describes residents of remote, indigenous, coastal communities as especially vulnerable to marine accidents that threaten vital marine resources and therefore the natural foundation of their cultures and way of life. A combination of over-the-ice travel and small boat transport is essential for successful fishing and hunting over large marine areas and both can be impacted by shipping traffic. The 2009 AMSA specifically describes Bering Strait mainland communities (in both Russia and the U.S.) as well as those of Gambel and Savoonga on St. Lawrence Island, as especially vulnerable to impacts of shipping traffic. A 2012 workshop in Nome identified a number of Bering Strait community concerns. Disturbance of marine species was a major issue of concern. Residents described many marine mammals and birds are extremely sensitive to noise. Noise, particularly from icebreaking ships, may travel long distances and was thought to disrupt migration patterns as the result of ocean warming and changing patterns of sea ice. Such disruptions could severely affect hunters who have to travel farther distances accruing greater risk and costs to find animals. This was of particular concern when marine mammals crossed into Russian waters (Laughlin et al 2012).

Strategic Opportunities and Information Needs

There are substantial efforts underway within the ABSI region to improve marine safety. A number of these aim to understand and mitigate the risks of vessel incidents that could result in oil spills. As such, there is a natural intersection where ABSI might be able to supply needed information relative to the distribution and seasonality of resources and ecosystem services that could be impacted in areas especially vulnerable to potential spills from shipping traffic.

Aleutian Islands Risk Assessment

In 2007, the National Fish and Wildlife Foundation (NFWF), the U.S Coast Guard (USCG) and ADEC initiated the Aleutian Islands Risk Assessment (AIRA) to "assess the risks and potential mitigation measures associated with maritime transportation in the Bering Sea and the Aleutian Archipelago". This effort has resulted in a suite of interconnected studies and analyses ranging from experimental evaluation of response equipment to improvement of spill response strategies. Of particular interest to ABSI could be the an evaluation of Particularly Sensitive Sea Areas (PPSAs) within the region and an effort to identify potential places of refuge for stricken vessels, as well as the collection and synthesis of community and resource data to refine Geographic Response Strategies (GRSs) specific to shorelines of individual islands.

Arctic ERMA

Arctic Environmental Response Management Application (ERMA) is an online tool to aid response to an oil spill managed by NOAA. Arctic ERMA is an online platform of data such as the location, extent, and concentration of sea ice; locations of human infrastructure like ports; as well as the distribution and seasonality of vulnerable environmental resources. This interactive map-based tool also includes subsistence resources based on traditional and local knowledge. Currently it does not include spatially explicit shipping data or data on existing contaminated sites, archaeological/cultural resource sites, or the distribution of invasive species. The NOAA managers of Arctic ERMA believe such data would aid in ensuring spill cleanup operations don't have unintended negative consequences and ABSI could play a role in serving up these data for responders and other stakeholders in the region.

Oil Spill Risk Assessment for Alaska

This risk analysis is being initiated by NOAA in 2013 and will help mangers determine the probabilities of spills occurring with respect to geographic location, source type, oil type, and season, as well as the potential impacts from an oil spill considering oil toxicity, persistence, and the vulnerability of the Alaska's marine and aquatic resources at particular locations and times of year. The analysis will also address expected changes in the types of spills that might occur in the future with changes in vessel traffic, oil exploration and production activities, as well a other changes in the regional economy (S. Allan pers. comm.). The ABSI LCC can likely contribute spatial data on resource and ecosystem service distribution to help relate this risk assessment to specific populations of species and areas of socioeconomic concern within the Aleutians and Bering Sea.

Northern Waters Task Force

In 2010, the Alaska State Legislature established the Alaska Northern Waters Task Force (ANWTF) to identify opportunities to increase the state's engagement in marine shipping issues. The ANWTF recommends that the U.S. with the participation of the state of Alaska, work with the international community to finalize the Polar Code for ships operating in Arctic waters and examine whether to establish an offshore vessel routing scheme for circumpolar marine traffic, including through the Aleutians. The ANWTF supports extending AIS vessel tracking and endorses completing the AIRA as well as encouraging the state of Alaska to support and participate in the USCG Port Access Route Study and USACE Alaska Deep-Draft Arctic Port System Study. The ANWTF also legislatively created the Alaska Arctic Policy Commission (AAPC) that is working on policies and actions that should be taken for the protection of coastal communities and the marine environment. The panel directing this task force is comprised of individuals representing state, federal and local governments whose activities could be informed by marine shipping analyses and data layers compiled by the ABSI LCC.

The Alaska Maritime Prevention and Response Network

The oil spill removal capabilities in Western Alaska do not fully meet the Coast Guard requirements. The only current compliance option for oil tankers and vessels transporting oil as a secondary cargo through these waters is by participation in the Western Alaska Alternative Planning Criteria or WA-APC. The Alaska Maritime Prevention and Response Network is a non-profit organization established to provide the capabilities needed to implement WA-APC. The focus of the WA-APC is on the implementation of measures and capabilities that prevent oil spills rather than on resources that remove oil after it is spilled. The ABSI-LCC might be able to provide spatially explicit projects of oil spill risk to inform the activities of this group as well as become better connected to industry through these collaborations.

Initial gains to address applied science needs associated with this stressor are likely best made by pulling together resource and ecosystem service data layers so that they might be associated with marine shipping distribution and seasonality. Future analysis of these layers to allow for more spatially and temporally explicit simulations to inform oil spill risk would help fill a gap in information for managers and stakeholders. Investments in data layers necessary to enhance spill response capabilities would also be beneficial contributions from the ABSI LCC. Examples include:

- Conduct analyses explicitly describing the specific transit pathways and seasonality of shipping traffic based on available data to be compared with similar characterizations of resources like seabirds and marine mammals --as well as areas supporting commercial fishing and subsistence harvest.
- Conduct a spatial and seasonally explicit travel simulation of commercial shipping traffic along the Northern Great Circle Route and through the Bering Strait to examine the relative risk of spills over a 20+ year horizon. A scenario-based approach could be used to look at a variety of simulated scenarios of vessel types as and traffic intensities. Ideally, simulations would be integrated with oceanographic data to inform oil dispersal models and cleanup/vessel response times to quantify risk parameters for marine mammals and seabirds as well as high value commercial fishing and subsistence resource areas. Such an effort should occur as a joint venture with some combination of NOAA, BOEM, ADEC, and USCG regulatory specialists to ensure maximum utility for managers.
- Support efforts to collect/update shoreline data useful for oil spill response such as Shorezone and Environmental Sensitivity Index layers.
- Continue and expand efforts in the Aleutian Islands and the Bering Strait to collect and synthesize data on the amount of commercial traffic, types of vessels, and quantities of hazardous materials carried on commercial vessels which transit these waters.

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Appendix G. Ocean Acidification.

Climate models predict a decrease in pH of approximately 0.3 by the year 2100. This change will significantly alter the acidity of marine waters, quality of habitats, and potentially composition of biological communities in coastal and ocean areas around the globe. This trend of increasing acidification is the result of the world's oceans absorbing carbon dioxide released from anthropogenic sources following industrialization. Increased acidity already is being documented in the Arctic Ocean and Bering Sea and is of special concern in Alaska due to the prevalence of cold marine waters, global and smaller-scale oceanic circulation patterns, and rapid climate changes resulting in more inputs of freshwater. Increased acidity impacts the physiology, energy use, and ability of marine calcifiers, such as plankton, corals and shellfish, to make shells, plates and skeletons. There are direct implications for commercial and subsistence fisheries targeting mollusks and crabs and indirect effects to higher trophic organisms through food web effects. Ocean acidification is poorly understood and research, in the laboratory and field, is urgently needed to understand population and ecosystem level effects.

Affected Resources and Services: Invertebrates/shellfish, Trophic Function, Fishes, Coldwater Corals, and Commercial and Subsistence Fisheries.

Introduction

Ocean carbon chemistry is changing in response to increasing concentrations of atmospheric CO_2 (Caldeira and Wickett 2003, Feely et al. 2004). Higher atmospheric CO_2 levels cause dissolved CO_2 to increase and seawater pH and bicarbonate ions to decrease, a process collectively called ocean acidification (Royal Society 2005). The Intergovernmental Panel on Climate Change estimates that by the year 2050 anthropogenically –derived atmospheric CO_2 levels could be 500 ppm, and over 800 ppm near the end of the century. Major sources of CO_2 include the burning of fossil fuels and changes in land-use. Marine absorption of this CO_2 is expected to decrease surface water pH conditions by approximately 0.3 units by 2100 (IPCC 2007).

The two major forms of calcium carbonate (aragonite and calcite) have different dissolution properties. Increased acidity in the marine environment changes the dissolution rates for these two carbonate compounds making them less available (or under-saturated) for the marine organisms that need them to produce calcified shells and plates. Aragonite dissolves more readily than calcite and those species that use aragonite (e.g., corals and pteropods) are likely more vulnerable though any under-saturation of calcium carbonate could have pervasive effects on calcifying marine organisms such as mollusks, cnidarians, and echinoderms (Fabry et al. 2008, Doney et al. 2009). Figure F1 illustrates the chemical process and cascading biological implications.

Non-calcifying organisms may also be affected through indirect pathways ranging from cascading effects for species at higher trophic levels (e.g., fish, seabirds, marine mammals) resulting from reduced availability of plankton to reduced demersal egg adhesion or fertilization success of eggs broadcast into the ocean (Royal Society 2005). Elevated CO_2 concentrations can disturb the acid-base regulation, blood circulation, and respiration, as well as the nervous system of marine organisms, leading to long term effects such as reduced growth rates and reproduction (Portner et al. 2004). Further, even behavior changes of fish species have been linked to changes in pH (Munday et al. 2009).

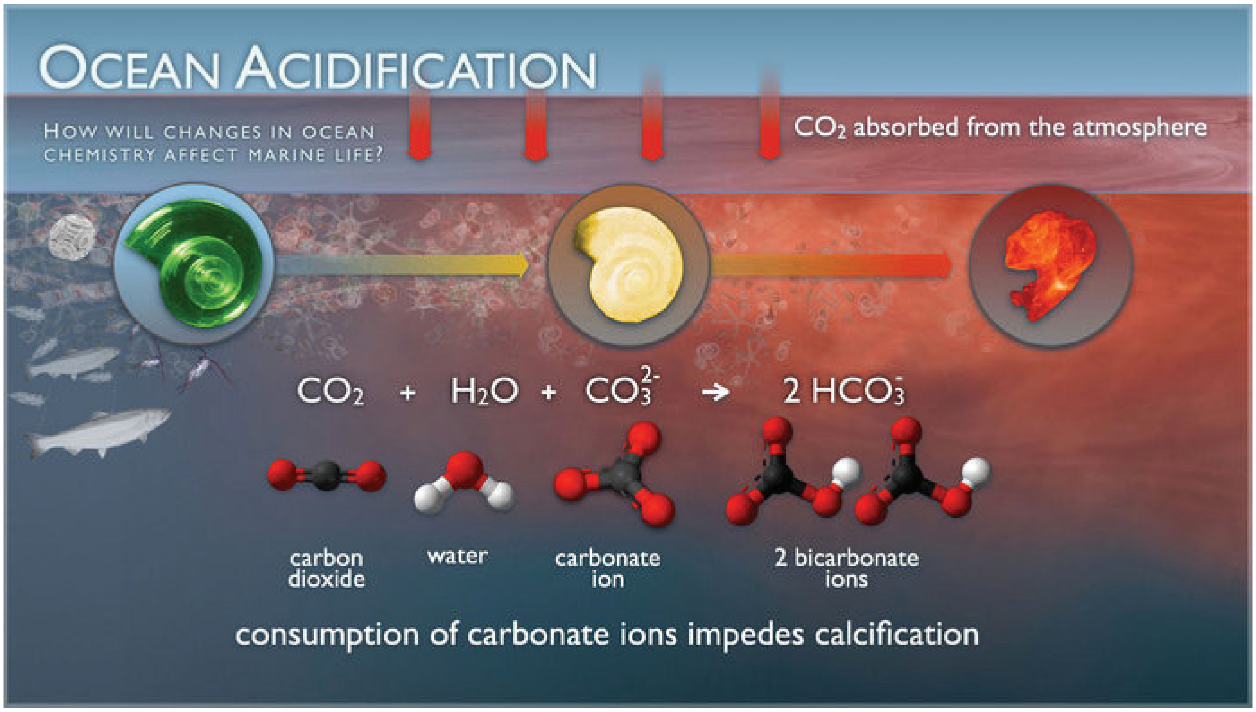

Figure F1. Schematic diagram of ocean acidification processes in the sea (NOAA Pacific Marine Environmental Laboratory Carbon Group).

The Arctic is considered to be a bell-weather or sentinel region for ocean acidification. Colder water is able to absorb increase amounts of dissolved gases and thus retains more carbon dioxide. In addition, because of its position at the end of the ocean's global circulation "conveyor belt", Northeast Pacific waters at depth have not recently interacted with the atmosphere and thus contain some of the world's lowest pH levels (Feely et al. 2008). The distribution of acidic water is more shallow in the North Pacific with the aragonite saturation horizon at <200 m in depth (Feely et al. 2008) compared to about 2,000 m in the North Atlantic Ocean (Feely et al. 2004). Since pre-industrial times, this saturation horizon has shifted upward in the water column between 30 and 100 m (Feely et al. 2004) and is projected to reach the surface during this century (Orr et al. 2005). At that point, virtually all North Pacific species will be exposed to increasingly corrosive waters.

Further effects of climate change (see Appendix B) will likely increase the acidity of the North Pacific and Arctic Oceans. Coastal regions with high freshwater input from rivers and melting glaciers may also be more vulnerable to acidification because fresh water runoff is higher in dissolved carbon dioxide (NRC 2010). This may be of special importance to areas like the Bering Sea with huge freshwater inputs from the Yukon and Kuskokwim rivers (Fabry et al. 2008). Additionally, decreasing sea ice results in greater exposure of seawater to the atmosphere, allowing more exchange of carbon dioxide across the ocean-atmosphere interface. This combined with its increasingly rapid melt results in an additional source of fresh water input into northern marine waters (Yamamoto et al. 2012).

An recent analysis of oceanographic data collected during a 10-day storm event in the Beaufort Sea during 2011 indicated that coastal upwelling increased acidic conditions throughout the water column. Though such upwelling events are natural processes they have likely increased as a result of declining sea ice and changing atmosphere conditions in the region (Mathis et al.

2012). Similar increase in storm activity and intensity in the Bering Sea region could serve to compound threats from ocean acidity driven by changes in climate.

Recent modeling efforts have attempted to explore the interactions between climate change drivers and ocean acidification rates across different time horizons for marine waters of the Arctic and North Pacific Oceans. These efforts incorporate variation from emission scenarios and melting sea ice and make predictions about pH declining as much as 0.45 units which parallel recent transect observations in the Arctic suggesting that localized portions of Arctic waters will have reached acidity thresholds corrosive to aragonite within the decade (Steinacher et al 2009). Yamamoto et al (2012) suggest that the future reductions in pH could occur significantly faster than previously projected based on sea-ice reduction in the Arctic happening at a faster rate than had been estimated by the IPCC's Climate Change Fourth Assessment.

Key Data and Information Sources

Since its relatively recent description as a broad reaching global threat (Royal Society 2005) ocean acidification has garnered significant research attention. In Alaska where marine waters are thought to be especially vulnerable, substantial investments have been made by NOAA and the National Marine Fisheries Service's Alaska Fisheries Science Center (AFSC) and the Pacific Marine Ecology Lab (PMEL). Priorities for NOAA are guided by nationwide (Feely et al. 2010) and Alaska-specific research plans. The Ocean Acidification Research Center (OARC) at the University of Alaska, Fairbanks, newly established in the School of Fisheries and Ocean Sciences (SFOS) also works in close association with NOAA.

Alaska Fisheries Science Center

Beginning in 2008 the AFSC proposed a research plan targeted on focal species taxa based on their economic and ecological importance as well as their suspected vulnerability to ocean acidification (Sigler et al. 2008). A contemporary progress report on AFSC (2011) describes their priority species as:

- Shellfish: these economically valuable species are likely to suffer direct effects of reduced carbonate availability.
- Calcareous zooplankton: they are important prey species for commercially important fish (walleye pollock, Pacific salmon) and marine mammals.
- Coldwater corals: this highly diverse group of organisms provide structural habitat for a variety of benthic dwelling marine organisms, including commercial fishes.
- Commercially important fish: early life history stages may be especially vulnerable to ocean acidification.

A suite of research projects are currently being implemented by AFSC labs in Newport, Oregon and Kodiak which have established facilities for experimenting with ocean acidification effects on target species (AFSC 2011). Evaluations of pH at various thresholds have been implemented on survival on early life stages of crabs and walleye pollock as well as calcareous zooplankton was discontinued due to funding constraints but will be supplemented by efforts from the Northwest Fisheries Science Center. Research has also been conducted on the carbonate structure of coldwater corals and on modeling long-term king crab abundance into the future considering the exogenous effects from ocean acidification using scenarios to explore future crab fisheries. This suite of projects, as well as improvements in sampling techniques for ocean acidification, is ongoing in collaboration with other NOAA programs and universities (AFSC 2011).

Ocean Acidification Research Center

The School of Ocean and Fisheries Science at the University of Alaska Fairbanks established the OARC in 2010 to be a resource to resource managers, economic sectors and communities likely to be impacted by ocean acidification. Operations at OARC focus on two broad mandates:

- Conduct research into ocean acidification, particularly in Alaskan waters and determine the broader climate forcings leading to decreases in ocean pH and the impacts of these changes on commercial species.
- Maintain a central repository for the federal and state government, as well as the public and private sectors to access information relevant to ocean acidification and its impacts on fisheries and other economic resources.

Research at OARC focuses on long-term autonomous monitoring and modeling efforts, field observations in highly sensitive areas and quantifying physiological responses of vulnerable and commercially viable species. The center works closely with NOAA labs and is currently collaborating on a number of research efforts being conducted by the AFSC and PMEL Carbon Group. Examples of projects informing science in the ABSI region include an effort to deploy two mooring systems capable of making continuous ocean acidification observations through the year at fixed depths in the water column. This project will support the deployment of two mooring devices, one in the southern Bering Sea, and the other near Bering Strait. The OARC is completing a three-year effort in association with the Bering Ecosystem Study, to explore the biogeochemical impact of physical processes such as sea ice formation and melt on the cycling of carbon in the Bering Sea and an evaluation of the extent of ocean acidification.

Pacific Marine Environmental Laboratory Carbon Group

The NOAA-funded PMEL Carbon Group functions as an umbrella organization hosting and funding numerous research efforts aimed at understanding the ocean carbon cycle. Their research includes documenting the evolving state of the ocean carbon chemistry, studying processes controlling the role of the ocean in the global carbon cycle, and investigating how rising atmospheric carbon dioxide and climate change affect the chemistry of the oceans and its ecosystems. Oceanographic research cruises in the North Pacific over the past 15 years have confirmed significant upper ocean acidification that keeps pace with rising atmospheric carbon dioxide.

Monitoring by PMEL and others is needed to document and track changes, improve ocean biogeochemical models, guide integrated marine resource assessments, and inform management and policy decision making. The Arctic Ocean is seen by many as a sentinel region and PMEL and others are working to expand an observation network in Alaskan and the Arctic Basin (Figure G2). These efforts include supporting the mooring station efforts being implemented by OARC in Alaskan waters including the Bering Sea. They also support a Monitoring by Vessels of Opportunity program which includes NOAA ships and volunteer container ships that collect measurements to document the distributions and air-sea flux of carbon dioxide while transiting the Gulf of Alaska and Bering. They now include pH and oxygen saturation on selected ships in hopes of better understanding how physical forcing (e.g., sea-ice, nutrient supply, stratification,

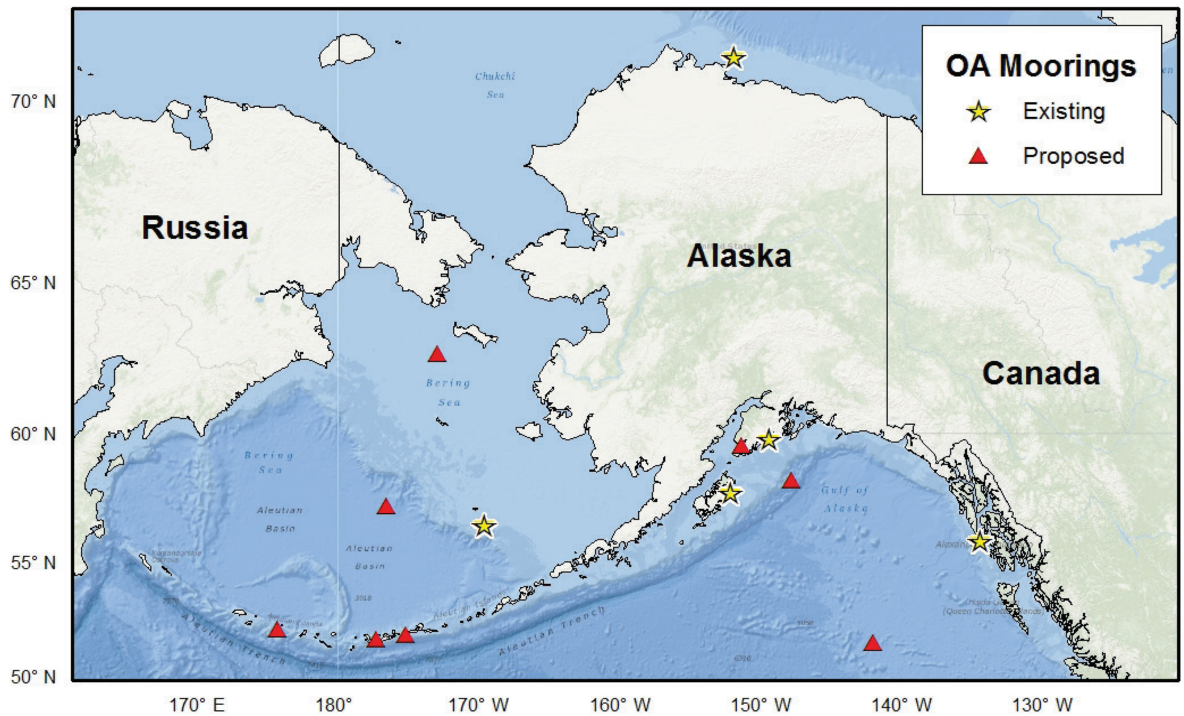

Figure G2. Locations of existing and proposed mooring buoys in the Alaska with ocean acidification monitoring capabilities. Sources: http://www.sfos.uaf.edu/oarc/ and Sigler et al. (2010).

etc.) and biological responses affect the marine carbon cycle and how these mechanisms may buffer or accelerate response to future climate change and ocean acidification.

The U.S. Geological Survey

The USGS initiated a new effort building from baseline data currently available for coastal Bering Sea Shelf and the Arctic Ocean. In 2010, 2011, and 2012 they collected water chemistry during during summer and fall cruises. Data from the cruises complement the previously available coastal data, but provide unique datasets helpful in testing numerous hypotheses associated with ocean acidification from coastal to open ocean at high latitudes. Flow-through and discrete water samples were collected on these cruises which represent some of the highest resolution and comprehensive datasets on carbonate chemistry in Arctic waters. The data were then used to calculate saturation state of the water to reflect whether carbonate minerals (ie., shells) could dissolve in order to provide insights on habitat responses to ocean acidification in the Bering Sea and Arctic Ocean (Robbins 2012).

Interagency Working Group on Ocean Acidification

In response to the Federal Ocean Acidification Research and Monitoring Act (FOARAM Act) passed by congress in 2009, several federal agencies are working to develop a collective approach to understand and address ocean acidification. The FOARAM Act established an Interagency Working Group on Ocean Acidification (IWG-OA) that developed a strategic research plan in March of 2012. This plan aims to guide “federal research and monitoring on ocean acidification that will provide for an assessment of the impacts of ocean acidification on marine organisms and marine ecosystems and the development of adaption and mitigation strategies to conserve marine organisms and marine ecosystems” (IWG-OA, 2012). The IWG-

OA is comprised of representatives from NOAA, National Science Foundation, Bureau of Ocean Energy Management, U.S. Department of State, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, National Aeronautics and Space Administration, U.S. Geological Survey, and the U.S. Navy. It is chaired by NOAA, and the vice-chair is from the National Science Foundation.

Their strategic plan calls for the establishment of a "National Ocean Acidification Program" to lead U.S. coordination of ocean acidification activities between the Federal agencies as well as with academic institutions, industry, private sector and international partners. They recommend that the location and leadership model for the proposed program be determined by the participating agencies with a focus on leveraging assets of existing Federal programs. The future of these recommendations is not completely clear, neither are the implications for potential additional new resources for ocean acidification research.

Threats to Resources and Ecosystem Services

Specific threats to resources and ecosystem services form this emerging stressor are broadly summarized by researchers as uncertain (e.g., Royal Society 2005, NRC 2010). There are very clear biological implications for the ABSI region based on biogeochemical measurements and modeling (e.g., Ainsworth et al 2011) as well as some limited field observations from other parts of the globe showing ocean acidification currently affecting calcareous marine organisms (e.g., Moy et al. 2009). Experimental manipulations of pH demonstrate more pronounced and severe effects (e.g., Arnold et al 2009). Prioritizing resources most at risk is confounded by uncertainty in the science as well as balancing potential cascading trophic effects predicted for top level predators (fish, seabirds and marine mammals) with effects already being observed at those lower trophic levels. AFSC's Alaska-specific model (Sigler et al. 2008) for prioritizing research starts with species most important to society and with the greatest likelihood of vulnerability. An alternative and equally valid approach might start with the ecosystem services of commercial fisheries and subsistence but would likely still result in targeting resources in the order presented here.

Invertebrates/Shellfish

There appears to be substantial energetic cost involved with increased CO_2 on developmental processes for shellfish. This may come in part as a result of decreased calcification or shell dissolution in order to maintain internal chemistry (Gazeau et al., 2007; Michaelidis et al., 2005), or increase muscle wastage in order to maintain skeletal integrity (Wood et al., 2008). A net decline in calcification, along with a reduced shell mass of developing larvae was demonstrated during experiments on early life stages of European lobsters (Arnold et al. 2009). A similar evaluation for larval Tanner and Dungeness crabs is being implemented by OARC with results available in spring of 2013 (R. Descoteaux pers. comm.). An evaluation of the effects of varying pH levels on red king crab larvae (Long et al. 2013) has been expanded upon by the AFSC's Kodiak lab to include evaluations at various life stages. Preliminary results suggest that red king crabs and tanner crabs experienced reduced growth and survival during both larval and juvenile stages. The researchers suggest that ocean acidification could affect crab stocks in the near future (Long et al. 2013). These efforts by AFSC are ongoing and now include bioeconomic modeling efforts to look at economic implications for king crab fisheries in the Bering Sea (AFSC 2011).

Trophic Function

Planktonic calcifiers may be particularly susceptible to increases in acidity. In experiments their shells, which protect them from small predators and acts as a ballast for daily vertical migrations grew more slowly in more acidic water (Comeau et al. 2009) and seem to be readily damaged by pitting, peeling and partial dissolution when placed into acidified sea water (Orr et al. 2005). Increased acidification can now be measured and biological responses have been demonstrated for pterpods in high latitude southern oceans (Moy et al., 2009). Pteropods like Limacina helicina are a foundational food source for pelagic fish in subarctic and arctic regions (Orr et al. 2005) and may contribute substantially to Arctic cod and other forage fish diets in the eastern Bering Sea. For example, during the fall Bering Aleutian Salmon International Survey (BASIS), Limacina helicina comprised up to 25% of prey wet weight for juvenile walleye pollock in waters that move through the Aleutian passes into the southeastern Bering Sea (Sigler et al. 2008). Predicted effects of climate change on pink salmon growth in the Gulf of Alaska link a 10% decrease in pteropod production to a 20% drop in mature salmon body weight (Aydin et al. 2005). More recent evaluations of variability in salmon diets have called these results into some question (Armstrong et al. 2008).

Fishes

Fish are thought primarily to be vulnerable to ocean acidification resulting from changes in the quantity or composition of the food available based on impacts to lower trophic levels (e.g., Royal Society 2005). However there may also be direct physiological effects on some fish species and these are thought to most likely impact growth and survival of early life stages --eggs, larvae, and juveniles (NRC 2010). There could be direct physiological stress associated with low pH environments that manifest as reduced rates of growth and survival (Michaelidis et al. 2007) or that may affect behavior as evidenced by a study showing impaired olfactory discrimination and loss of homing ability in orange clownfish larvae (Munday et al., 2009).

Mortality rates at early life stages are intrinsically high for fish and even minor changes in survival rates can result in order of magnitude responses in recruitment rates. Slight reductions in growth and development prolong the time that fish stay in these vulnerable stages thereby increasing mortality.

Research focused on early life stages has yielded mixed results. For example Franke and Clemmesen (2011) found that decreased pH didn't affect embryogenesis or the hatch rate for Atlantic herring and there was no relationship between pH and total length, dry weight, yolk sac area and otolith area of the newly hatched larvae. However they did find that pH can negatively impact the metabolism of herring embryos. Recently completed research by the AFCS on juvenile walleye pollock found no overall response to experimental manipulation of pH as measured by indicators of stress (blood cortisol, cortisol secretion, blood glucose, hematocrit), tissue damage, body condition or growth rates). The research concluded Walleye pollock early life stages appear resilient to direct physiological effects of ocean acidification including reductions that are well beyond thresholds expected in the next 100 years (Hurst et al. 2012 and Hurst et al. 2013).

Coldwater Corals

Coral reefs are the most biologically diverse habitats on Earth and provide food, resources and coastal protection to hundreds of millions of people. They are under significant and sustained threat from a number of anthropogenic threats including ocean acidification (Hoegh-Guldberg 2007). Researchers estimate that by 2100 70% of coldwater corals could be exposed to corrosive waters which may disrupt these important ecosystems (Guinotte et al., 2006). Deep-sea corals are widespread including the continental shelf and upper slope but the Aleutian Islands have the highest diversity of deep corals in Alaska and possibly in the North Pacific Ocean. They include at least 50 endemic species or subspecies. In the Aleutian Islands, they form high density "coral gardens" that are similar in structural complexity to shallow tropical reefs and are characterized by a rigid framework, high topographic relief, and high taxonomic diversity (Stone 2006). In recent years the diversity of these gardens has been documented, as has their importance as habitat structure for commercially valuable species (Stone 2005). Concern has been expressed about potential impacts already occurring as a result of commercial fishing (see Appendix C) in the region (Stone 2006, Heifetz et al. 2007) and ocean acidification could bring compounding effects.

Alaskan coldwater corals satisfy all of their nutritional requirements by suspension feeding presumably on small zooplankton and phytoplankton. The specific skeletal composition has been determined for only a few Alaskan coral species but many Alaskan corals use calcite to build their skeletons (Cairns and Macintyre 1992). According to Sigler et al. (2008) effects of ocean acidification on deep-sea corals will be direct relative to their structural composition and indirect due to changes in food supply. Both could result in decreased growth and recruitment ultimately affecting the structural habitat for other species. Octocorals, stylasterids, and pennatulaceans are identified as important structure-forming components of benthic ecosystems in Alaskan waters and Sigler et al. (2008) suggests these species could experience decreased growth and recruitment rates and ultimately changes to their distribution that will trigger cascading effects to the ecosystems they support. Current research implemented by AFSC is focused on better understanding the skeletal composition of coldwater corals in order to determine which species may be most at risk to corrosion resulting from increasing pH. This research will be coupled with information about species distribution and projected aragonite and calcite saturation horizons to complete a risk assessment for coldwater corals in Alaska. The AFSC (2011) expects this work to be completed in late 2013.

Commercial and Subsistence Fisheries

Ocean acidification may affect marine fisheries directly by altering the growth or survival of target species, and indirectly through changes in species' ecosystems, such as predator and prey abundance or important habitats. This could result in changes in abundance or size-at-age and ultimately change sustainable harvest levels (NRC 2010). Shellfish fisheries are particularly vulnerable to ocean acidification because of the effect on shell formation especially during early life stages (Kurihara, 2008). Similarly, plankton species are calcifiers, and their decline or collapse could adversely affect higher trophic commercial species that feed on them. Fisheries could also be affected by changes in habitat resulting from disruption or degradation of habitat structures formed by marine calcifiers (Guinotte and Fabry, 2009). According to the OARC the seafood industry has an estimated annual value of $5.8 billion and creates the largest private sector employer in Alaska and ocean acidification has the potential to disrupt this industry from top to bottom with coupled direct/indirect effects. Though specific effects on resource availability are unclear a recent effort by the Alaska Marine Conservation Council documented substantial concerns of economic and lifestyle impacts resulting from ocean acidification in coastal communities of Dillingham, Kodiak and Homer. Those engaged in finfish harvest balanced their concerns about ocean acidification with other economic drivers which they felt had greater known implications for their industry This analysis found that shellfish producers and consumers from these communities had the highest level of concern in part due to recent declines in availability of oyster larvae theorized to be linked to ocean acidification in the Pacific

Northwest (Donkersloot 2012). This same concern recently launched, $1.8 million dollar ocean acidification research center at the University of Washington which aims to detect potential harmful pH changes at coastal shellfish farms.

Strategic Opportunities and Information Needs

With its relatively recent emergence as an issue during the last decade and research and monitoring efforts only having been initiated in Alaska in the past five years, there are limited clear opportunities for additional LCC staff research, analysis or data synthesis to further define this stressor. However, LCC staff can more closely monitor the efforts by AFSC and OARC in order to detect implications for the ABSI Region. The ABSI LCC should seek regular engagement with the AFSC or OARC. Through these engagements we could seek out potential niche-roles that the ABSI LCC could play in supporting research and communicating the latest scientific results to managers and stakeholders of our region. Given potential implications for a number of the participating federal agencies the Steering Committee members for ABSI LCC should also attempt to stay abreast of the proceedings of the interagency working group commissioned by the FOARAM Act. Monitoring this group's efforts would alert us to emerging research priorities and opportunities that might acted upon by ABSI LCC.

University of Maine

Researchers from the University of Maine have been awarded a National Science Foundation to determine if a globally unique and widespread calcareous alga in Alaska's Aleutian archipelago is threatened with extinction due to the combined effects of ocean acidification and food web alterations. Their research effort begins in 2014 and will be the first in situ example exploring how ocean acidification is affecting the physiology of long-lived, carbonate producing organisms in the subarctic North Pacific. It will also be one of the first studies attempting to document potential interactions between ocean acidification, ocean warming and food web changes to ecological processes. The ABSI LCC may wish to seek potential collaborations that leverage and extend this work as well as efforts to share these results with managers and stakeholders in the region.

If the ABSI LCC aims to understand affects to key resources and services relative to ocean acidification an integrated species vulnerability assessment ideally in partnership with AFSC or OARC might be a first step. One approach could be a review of key food webs in the region and assessment of risk to species and trophic function with implications for human communities to further identify information needs and science priorities. A key aspect of such an effort could include implications for climate change to exacerbate effects of ocean acidification.

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Appendix H. Partnership Community Online Results

Beginning in March 2013 the staff of the ABSI LCC launched an online survey tool to collect input from researchers, managers, and stakeholders, also known as the "Partnership Community." We advertised the survey broadly to all individuals who attended our 2013 workshop, Alaska Native tribal and other local government representatives, the EPA's environmental coordinators in the region, our general e-mail list, and key research experts identified by our Steering Committee. In all instances recipients were encouraged to share the survey with their network of contacts to maximize survey response.

Respondents were asked to rank the conservation threats posed to seven resource categories and four ecosystem services by each landscape-level stressor in a process similar to that which was completed by the Steering Committee and core staff (Burn and Poe 2013). The average threat scores for each stressor by resource/service interaction were summarized and compared to those returned by the Steering Committee and core staff. We also requested narrative input similar to that asked of our 2013 workshop participants (i.e. key management issues and their associated science needs for each stressor).

Respondents were asked to identify themselves across the following categories of profession (research, manager, or other) and by organizational affiliation (Federal, State, Tribal, University, Non-governmental, or other). Respondents were also asked to rate their overall level of knowledge of the six landscape-scale stressors and 11 categories of resources and ecosystem services using a 5-point Likert scale ranging from low to high.

During a two-month open period we received 20 completed survey responses. The majority were from respondents who identified themselves as federal employees (n=15) with two respondents each from university and tribal entities, and one from a non-governmental organization. Respondents were almost evenly split with eight managers, ten researchers and two reporting as "other." The self-identified level of expertise for respondents is described by average value across resource and ecosystem service in Figure H1. Respondents reported having the greatest expertise with Seabirds, Marine Mammals, and Fisheries, and the lowest expertise with Human Community Sustainability, Cultural Artifacts/Sites, Coldwater Corals and Invertebrates/Shellfish. With respect to the six landscape-scale stressors, respondents reported having the greatest level of knowledge about Climate Variability and Change and the least about Ocean Acidification (Figure H2).

The average concerns about conservation threats from stressors were similar to those identified by the Steering Committee and core staff for climate change and variation, commercial fishing, and invasive and introduced species (Table H1). Respondents from the partnership community had somewhat less overall concern for threats from marine shipping. The greatest differences were observed for ocean acidification and pollutants and contaminants, respectively. Both were evaluated as having a higher overall conservation threat to resources and ecosystem services in the ABSI Region. The greater concern for ocean acidification and contaminants and pollutants may come from respondents having less understanding of these stressors and equating that to a greater threat. This may differ from judgments about ocean acidification made by Steering Committee and core staff given our bias toward threats where clear applied management needs were discernible.

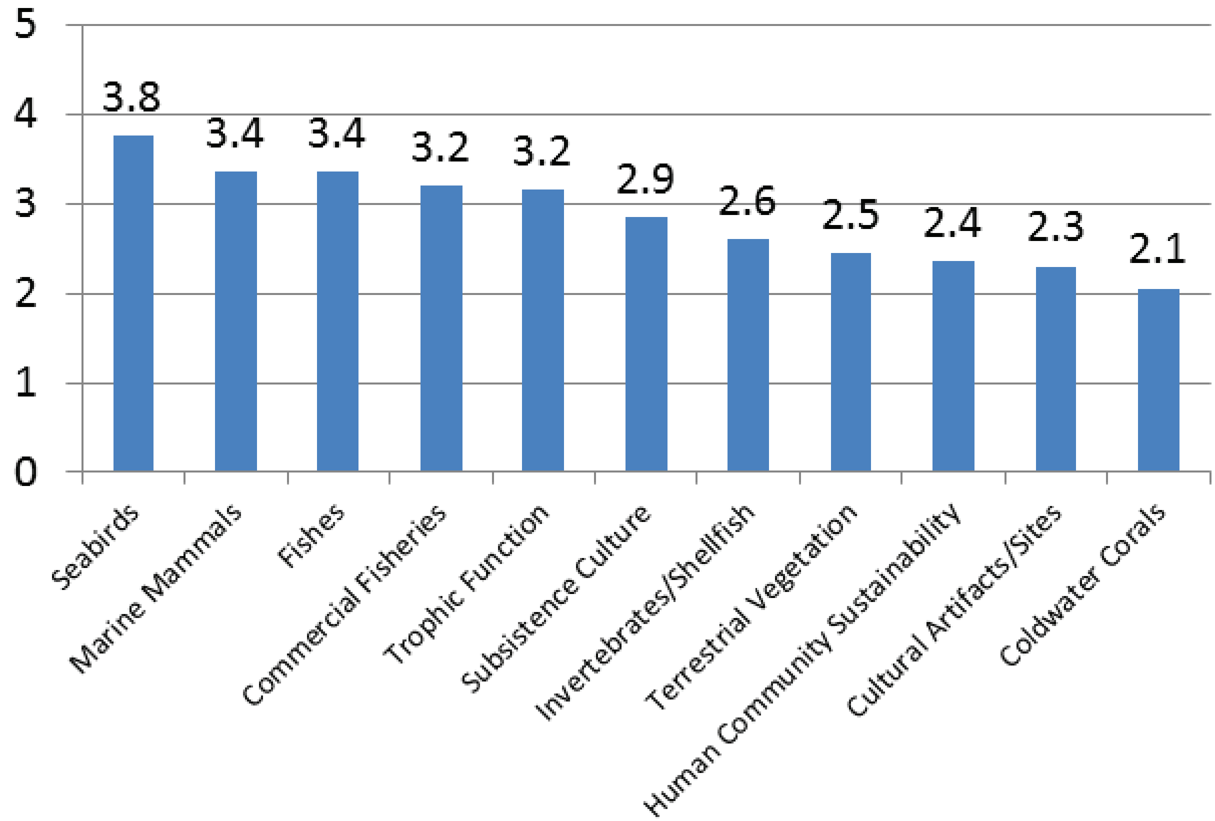


Figure H1. Self-identified expertise described by average rank for 20 respondents relative to key resources and ecosystem services at risk from landscape-scale stressors in the ABSI region.

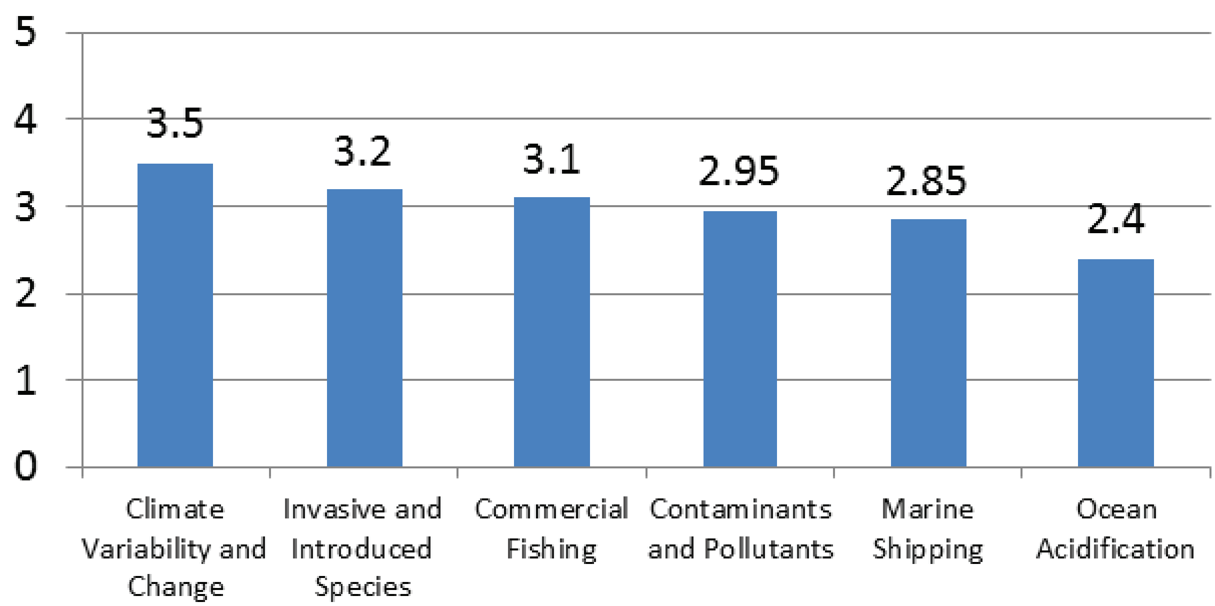


Figure H2. Self-identified expertise described by average rank for 20 respondents relative to six landscape-scale stressors in the ABSI region.

Table H1. Average threat assessments made by ABSI LCC Steering Committee and core staff compared to 20 survey respondents. Threat values are summarized for all 11 resources and ecosystems services across landscape-level environmental stressors in the ABSI region.

Stressor	Steering Committee	Survey Respondents	Difference
Climate Variability and Change	1.99	2.04	0.05
Commercial Fishing	1.51	1.61	0.10
Marine Shipping	1.31	1.16	-0.15
Invasive and Introduced Species	1.29	1.36	0.07
Contaminants and Pollutants	1.25	1.49	0.25
Ocean Acidification	1.18	1.59	0.41

An evaluation of average threat assessments made for individual resources and ecosystem services also revealed differences in respondents' perspective from the initial assessment made by the Steering Committee and core staff (Table 2). There were categorical differences in 27 of the 66 stressor-to-resource/ecosystem service evaluations (e.g., where respondents' average rank differs from Table 2 by a shift between one of the four threat categories of minimal, low, moderate, high; Table H2). The majority (2:1) of differences are from lower to higher categories of concern with none being shifts that are two-steps in nature (e.g., from minimal to moderate). The greatest disparity in assessment ranks occur within ocean acidification, contaminants and pollutants, and invasive and introduced species where partnership community respondents primarily noted heightened concern for a number of resources and ecosystem services. For marine shipping responses showed decreased concern across five resources and ecosystem services. The directional differences in threat ranks initially as assessed by the Steering Committee and core staff as compared to survey results are indicated by arrows in Table H2.

Respondents submitted a number of text comments specific to the conservation threats associated with each stressor. A tabulation of concepts expressed by respondents identified the most common management issues and their related science needs (Table H3).

The management issues and science needs offered by with survey respondents were similar to those identified during the January 2013 workshop. In both forums for feedback the understanding of interacting relationships among the stressors were described a key role that could be played by the ABSI LCC (e.g., how the biological availability of contaminants is changing as a result in changes in climate). We received feedback that cultural resource sites were vulnerable to impacts from climate change as well as invasive species and potentially as a result of looting activity.

These survey results are likely not completely representative of managers in the region given the relatively low response rate and small sample size (n=20). This is especially true for non-federal managers and researchers including community or tribal stakeholders. Our pool of respondents also leaned heavily toward expertise associated with seabirds, marine mammals and fishes and thus a bias of biological emphasis likely resulted. Subsequent prioritization efforts (e.g,. annual Implementation Plans) and future revisions of this plan will seek to have input from a broader array of stakeholders and expertise.

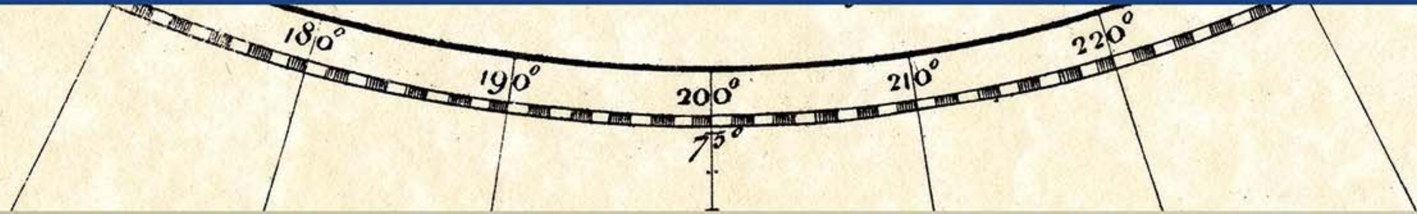
Table H2. Average threat assessments for resources and ecosystem services relative to six landscape-level environmental stressors made by 20 survey respondents. Directional arrows indicate a difference in threat category as compared to ranks made by the ABSI LCC Steering Committee and core staff.

Resource or Ecosystem Service	Climate Variability and Change	Commercial Fishing	Marine Shipping	Invasive and Introduced Species	Contaminants and Pollutants	Ocean Acidification
Seabirds	2.2	1.6	1.8 ↓	2.4	2.3 ↑	2.1 ↑
Marine Mammals	2.4	1.6	2.0 ↓	1.4	2.2	2.1 ↑
Fishes	2.1	2.5 ↑	1.3 ↓	1.6 ↑	2.0	1.9 ↑
Invertebrates/ Shellfish	2.1	1.6	1.2	1.6	2.0 ↑	2.3 ↑
Subsistence Culture	1.9	1.6 ↑	1.4 ↓	1.5 ↑	2.0	1.3 ↓
Commercial Fishing	2.0	2.2	1.2	1.5 ↑	1.4	1.7 ↑
Trophic Function	2.1 ↓	1.9	1.3	2.1 ↑	1.8 ↑	1.8
Human Community Sustainability	1.4 ↓	1.5	1.2	1.3	1.6 ↑	1.4
Coldwater Corals	1.9	1.5	0.8	1.1 ↑	1.2 ↑	2.1
Terrestrial Vegetation	1.8	0.2	0.3	2.2	1.1	0.4
Cultural Artifacts/Sites	1.4 ↓	0.6	0.5 ↓	1.1 ↑	0.6 ↓	0.4

Table H3. Most common management issues and science needs identified in text comments for each landscape-scale stressor.

Stressor	Management Issues	Science Needs
Climate Variability and Change	• How climate change will affect the marine ecosystem and food webs • Impacts to fihseries, subsistence users, infrastructure, communities, and cultural resources • Changes in weather patterns	• Climate, ecosystem, and food web models • Modeling and monitoring changes in seabirds, marine mammals, fish, and invertebrates • Better baseline information, including resource mapping
Commercial Fishing	• Overfishing • Physical damage to benthic habitat by trawl gear • Impacts to species either as bycatch or by competition for prey species	• Better understanding of bycatch of seabirds and marine mammals • Incorporating climate change into management decisions • Better understanding of trophic cascades in the ecosystem
Marine Vessel Traffic	• Impacts from oil spills and other hazardous materials • Introduction of non-native species, especially rats • Disturbance to marine mammals and birds with increased shipping in Bering Strait	• Better risk assessment to identify vulnerable areas and resources • Real-time monitoring of vessel traffic • Better oil spill prevention and response capabilities
Invasive and Introduced Species	• Impacts to native species (especially seabirds by rats), terrestrial vegetation, and archeological sites • Emphasize prevention and eradication • Aquatic invasive species transported in bilge water	• Inventory and monitoring • Improved eradication techniques • Risk assessment
Contaminants and Pollutants	• Oil spills as a source of contaminants • Cleanup of existing known sources of contamination • Understanding source(s) of contamination	• Long-term monitoring • Improved baseline information • Understanding impacts to subsistence users
Ocean Acidification	• Impacts to lower trophic levels that impact the entire food web • Impacts to shellfish and corals	• Long-term monitoring • Understanding impacts to food web • Many unknowns

The management issues and science needs identified during the January 2013 workshop were similar to those offered by with survey respondents. In both forums for feedback the understanding of interacting relationships among the stressors were described a key role that could be played by ABSI (e.g., how the biological availability of contaminants is changing as a result in changes in climate). A key gap in our consideration of vulnerabilities relative to cultural resources was identified in both engagement efforts. We received feedback that cultural resource sites were vulnerable to impacts from climate change as well as invasive species and potentially as a result of looting activity.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