Impacts to Essential Fish Habitat from Non-fishing Activities in Alaska

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Executive Summary

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) is the primary law governing marine fisheries management in United States (U.S.) federal waters. First passed in 1976, the MSA fosters long-term biological and economic sustainability of our nation's marine fisheries out to 200 nautical miles (nm) from shore. In 1996, the U.S. Congress added new habitat conservation provisions to assist the fishery management councils (FMCs) in the description and identification of Essential Fish Habitat (EFH) in fishery management plans (FMPs); including adverse impacts on such habitat, and in the consideration of actions to ensure the conservation and enhancement of such habitat. The MSA also requires federal agencies to consult with the National Marine Fisheries Service (NMFS) on all actions or proposed actions that are permitted, funded, or undertaken by the agency that may adversely affect EFH. To specifically meet national standards, EFH descriptions and any conservation and management measures shall be based on the best scientific information available and allow for variations among, and contingencies in, fisheries, fishery resources, and catches. Previous iterations of this report *Impacts to Essential Fish Habitat from Non-fishing Activities in Alaska* addressed non-fishing activities requiring EFH consultations and activities that may adversely affect EFH and offered example conservation measures for a wide variety of non-fishing activities. In this recent update these activities are grouped into four broad environmental categories to which impacts usually occur: (1) wetlands and woodlands; (2) headwaters, streams, rivers, and lakes; (3) marine estuaries and nearshore zones; and (4) open water marine and offshore zones.

Alaska extends over Arctic, subarctic, and temperate climate zones. Four recognized Large Marine Ecosystems (LMEs) exist in these climate zones (NMFS 2010, NOAA 2012). A total of seventeen coastal zones are identified within the nearshore and coastal zones (Piatt and Springer 2007), eight terrestrial ecoregions are defined above the high tide line to interior Alaska (Nowacki et al. 2001). Water, the most important EFH feature, moves through all of these ecoregions and habitat types. This 2016 report introduces an ecosystem-based approach to this key feature, and presents the current understanding of the existing ecosystem processes within these regions and habitats that support EFH attributes[1] necessary for fish and invertebrate survival at different life stages. A new section also summarizes our current understanding of climate change and ocean acidification; presents the probable source and influence, current effects on marine EFH, discusses potential cumulative impacts in light of current emission scenarios, and suggests recommendations for improving our understanding and monitoring of climate change. Climate scientists, oceanographers, and fisheries biologists have identified significant change in our atmosphere, oceans, and regional weather patterns. An indicator in Alaska is the decline in the extent and duration of sea ice. Scientists at NMFS's Alaska Fisheries Science Center (AFSC) have suggested that changes to marine conditions have altered trophic dynamics and influenced the distribution and abundance of some commercial fish species in the Eastern Bering Sea (EBS). Furthermore, increasing sea surface temperatures (SSTs) in the Gulf of Alaska (GOA) may have a similar influence on fisheries distribution and abundance.

The NMFS Alaska Regional Division of Habitat Conservation offers this report to inform decision makers and the public on activities that may affect EFH and possible EFH Conservation Recommendations to conserve healthy fish stocks and their habitat.

[1] An EFH ***attribute*** is water and any quality or characteristic given to, or supported by water, related biology, chemistry, or geology that benefits aquatic or marine species and trophic levels at several possible life history stages.

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Acronyms and Abbreviations

AAF Act	Alaska Aquatic Farming Act
ac	acre(s)
ACC	Alaska Coastal Current
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
ADOT&PF	Alaska Department of Transportation and Public Facilities
AEA	Alaska Energy Authority
AFSC	Alaska Fisheries Science Center
AISWG	Alaska Invasive Species Working Group
AMAP	Arctic Monitoring and Assessment Programme
AMCC	Alaska Marine Conservation Council
AMD	acid mine drainage
AMSA	Arctic Marine Shipping Assessment
AOGA	Alaska Oil and Gas Association
ATTF	Alaska Timber Task Force
BEACH Act	Beaches Environmental Assessment and Coastal Health Act of 2000
BMP	Best Management Practice
BOD	biological oxygen demand
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
°C	degree Celsius
CFR	Code of Federal Regulations
CH_4	methane
cm	centimeter(s)
CO_2	carbon dioxide
CO_3^{2-}	carbonate
CPOM	coarse particular organic matter
CPW	central tropical Pacific warming
CSS	Center for Streamside Studies
CWA	Clean Water Act

CWP	Center for Watershed Protection
dB	decibel(s)
dB re 1µPa	decibel(s) at the reference level of one micropascal
DOM	dissolved organic matter
DoN	Department of the Navy
EBS	East/Eastern Bering Sea
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act
ENSO	El Niño Southern Oscillation
EPA	U.S. Environmental Protection Agency
EPW	eastern Pacific warming
ESA	Endangered Species Act
°F	degrees Fahrenheit
FAD	fish aggregation/attraction device
FERC	Federal Energy Regulatory Commission
FHWG	Fisheries Hydroacoustic Working Group
FL	fork length(s)
FMC	Fishery Management Council
FMP	Fishery Management Plan
FPOM	fine particular organic matter
FR	Federal Register
ft	feet
ft^3	cubic feet
FWCA	Fish and Wildlife Coordination Act
FWPCA	Federal Water Pollution Control Act
g	gram(s)
GHG	greenhouse gas(es)
GOA	Gulf of Alaska
GRS	Geographic Response Strategies

Gt	gigaton(nes)
ha	hectare(s)
HAPC	Habitat Areas of Particular Concern
HCO_3^-	bicarbonate
Hz	Hertz
in	inch(es)
IPCC	Intergovernmental Panel on Climate Change
ISF	instream flow
km	kilometer(s)
kph	kilometer(s) per hour
LME	Large Marine Ecosystem(s) or Large Marine Ecoregion(s)
LTF	log transfer facilities
LWD	large woody debris
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
MDN	marine-derived nutrients
mg	milligrams
mi	mile(s)
mm	millimeter(s)
MMS	Minerals Management Service
MSA	Magnuson-Stevens Fishery Conservation and Management Act
mph	mile(s) per hour
NEPA	National Enviornmental Policy Act
nm	nautical mile(s)
NMDMP	National Marine Debris Monitoring Program
NMFS	National Marine Fisheries Service
N_2O	nitrous oxide
NOAA	National Oceanic and Atmospheric Administration

NPDES	National Pollutant Discharge Elimination System
NPFMC	North Pacific Fishery Management Council
NRC	National Research Council
NSIDC	National Snow and Ice Data Center
OCS	outer continental shelf
ORPC	Ocean Renewable Power Company
oz	ounce(s)
PAH	polycyclic aromatic hydrocarbon
PDO	Pacific Decadal Oscillation
PFMC	Pacific Fishery Management Council.
POM	particulate organic matter
ppb	parts per billion
ppt	parts per trillion
psu	practical salinity units
REAP	Renewable Energy Alaska Project
rms	root-mean-square
ROW	right-of-way
SAFE	Stock Assessment and Fisheries Evaluation
SAV	submerged aquatic vegetation
MDN	salmon-derived nutrients
sec	second(s)
SEL	sound exposure level
SPL	sound pressure level
SST	sea surface temperature
TNC	The Nature Conservancy
TSS	total suspended solids
U.S.	United States
U.S.C.	United States Code
USACE	U.S. Army Corps of Engineers

USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VGP	Vessel General Permit
WDF	Washington Department of Fisheries
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WestGold	Western Gold Exploration and Mining Company
WWF	World Wildlife Fund
yd	yard(s)
yd^3	cubic yards
ZOD	zone of deposit

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Chapter 1 Introduction

1.1 Background on Essential Fish Habitat

Congress added the Essential Fish Habitat (EFH) provisions to the Magnuson-Stevens Fishery Conservation and Management Act (MSA); the federal law that governs United States (U.S.) marine fisheries management in 1996. The eight regional fishery management councils (FMCs) and the National Marine Fisheries Service (NMFS) subsequently identified EFH[2] for each of the species managed under the fishery management plans (FMPs) across the nation. The final rule implementing these provisions provided guidelines for FMCs to identify and conserve necessary habitats for fish as part of the FMPs. As revised, the MSA requires the Secretary of Commerce to assist FMCs in the identification of EFH for those fish stocks managed under an FMP. EFH is to be described in text and depicted on a map per the life history stage of each managed stock. In addition, EFH descriptions and any conservation and management measures shall be based on the best scientific information available and allow for variations among, and contingencies in, fisheries, fishery resources, and catches. The MSA also requires federal agencies to consult with NMFS on all actions or proposed actions permitted, funded, or undertaken by the agency that may adversely affect[3] EFH.

Federal agencies initiate consultation by preparing and submitting to NMFS a written EFH Assessment of any adverse effects of the proposed federal action on EFH. If a federal agency determines that the action will not adversely affect EFH, no consultation is required. To promote efficiency and avoid duplication, EFH consultation is usually integrated into existing environmental review procedures under other laws such as the National Environmental Policy Act (NEPA), Endangered Species Act (ESA), or Fish and Wildlife Coordination Act (FWCA).

The MSA requires NMFS to make conservation recommendations to federal and state agencies regarding actions that may adversely affect EFH. These EFH conservation recommendations are advisory, not mandatory, and may include measures to avoid, minimize, mitigate, or otherwise offset the potential adverse effects to EFH. Within 30 days of receiving NMFS's conservation recommendations, federal action agencies must provide a detailed response in writing. The response must include measures proposed for avoiding, mitigating, or offsetting the impact of a proposed activity on EFH. State agencies are not required to respond to EFH conservation recommendations. If a federal action agency chooses not to adopt NMFS' conservation recommendations, it must provide an explanation. Examples of federal action agencies that permit or undertake activities that may trigger EFH consultation include, but are not limited to, the U.S. Army Corps of Engineers (USACE), the Environmental Protection Agency (EPA), Bureau of Ocean Energy Management (BOEM), the Federal Energy Regulatory Commission

[2] EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." "Waters" include aquatic areas and their associated physical, chemical, and biological properties. "Substrate" includes sediment underlying the waters. "Necessary" means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem. "Spawning, breeding, feeding, or growth to maturity" covers habitat types utilized by a species throughout its life cycle (50 CFR 600.10).

[3] An adverse effect is any impact that reduces the quality and/or quantity of EFH. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species, and their habitat, as well as other ecosystem components. Adverse effects may be site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions (50 CFR 600.910[a]).

(FERC), and the Department of the Navy (DoN). FMCs are required to comment on proposed actions that may substantially affect habitat, including EFH, of an anadromous fishery resource under its authority.

Significance of Essential Fish Habitat

As Congress recognized in Section 2(a)(9) of the MSA, "one of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats." "Habitat considerations should receive increased attention for the
1.2 conservation and management of the fishery resources of the United States." EFH-designated waters and substrate are diverse, widely distributed, and closely interconnected with other aquatic and terrestrial environments.

Section 303(a)(7) of the MSA requires FMPs to describe and identify EFH, minimize the adverse effects of fishing on EFH to the extent practicable, and identify other actions to encourage the conservation and enhancement of EFH. FMCs conduct detailed analyses to evaluate the potential adverse effects of fishing on EFH and must act to address the potential effects to EFH that are more than minimal and not temporary in nature. FMPs must also identify activities other than fishing that may adversely affect EFH. For each of these activities, FMPs must describe the known and potential adverse effects to EFH and identify actions to encourage the conservation and enhancement of EFH.

This report addresses non-fishing activities that may adversely affect EFH. The scope of these activities are grouped into four broad categories: (1) wetlands and woodlands; (2) headwaters, streams, rivers, and lakes; (3) estuaries and nearshore zones; and (4) marine and offshore zones. This current review also addresses climate change and ocean acidification on large scale. In Alaska, four large marine ecosystems (LMEs) exist as: 1) the Gulf of Alaska (GOA); 2) the East Bering Sea (EBS) (including the Aleutian Islands); 3) the Chukchi Sea; and 4) the Beaufort Sea (Fautin et al. 2010).

Fish, fish habitat, and water are not delineated by distinct jurisdictional boundaries or policies. Therefore, EFH includes waters and nutrient dynamics that originate as groundwater, rainfall, and snowmelt. Water filters through wetland areas, recharges groundwater aquifers, and serves as surface waters in streams and rivers; eventually influencing estuaries, nearshore zones, and
1.3 marine waters. The complex interactions of water and nutrients as a habitat fuel nearshore fish nurseries which support Alaska's offshore fisheries.

Non-fishing Activities

Non-fishing activities discussed in this document are subject to a variety of regulations and restrictions designed to limit environmental impacts under federal, state, and local laws. Listing all applicable environmental laws and management practices is beyond the scope of the document. Moreover, coordination and consultation required by Section 305(b) of the MSA does not supersede the regulations, rights, interests, or jurisdictions of other federal or state agencies. NMFS may use the information in this document when developing conservation recommendations for specific actions under Section 305(b)(4)(A) of the MSA. NMFS will not recommend that state or federal agencies take actions beyond their statutory authority, and NMFS's EFH conservation recommendations are not binding.

Waters and substrates that comprise EFH are susceptible to a wide array of human activities unrelated to fishing. Broad categories of activities include, but are not limited to: mining, dredging, fill, water impoundment, non-point discharges, oil and gas development, transportation, water diversions, thermal additions, sedimentation and hazardous materials. The potential effects from larger un-manageable influences such as climate change and ocean acidification associated with human activities exists. Climate change may lead to habitat changes that alter trophic dynamics and shift the range and distribution of managed species. Warming ocean conditions may also allow for new shipping routes and new vectors may emerge introducing invasive or exotic species from ballast water exchanges (Raven et al. 2005).

1.4 Purpose of the Document

The general purpose of this document is to identify types of non-fishing activities that may adversely affect EFH and to provide example EFH Conservation Recommendations for specific types of activities to avoid or minimize adverse impacts to EFH. According to Section 303(a)(7) of the MSA, this information must be included in FMPs.

EFH Conservation Recommendations for each activity category are suggestions that the action agency or others can undertake to avoid, offset, or mitigate impacts to EFH. These conservation recommendations represent a cursory list of actions that can contribute to the conservation, enhancement, and proper function of EFH. Recommendations may or may not be applicable on a site-specific basis. For each site and proposed activity, recommendations may be amended based on the best and most current scientific information available before or during EFH consultations. Because many non-fishing activities have similar adverse effects on living marine resources, there is some redundancy in the impact descriptions and the accompanying conservation recommendations among sections in this document.

Importantly, this document serves to compliment other NOAA marine policy, directives and action plans. These plans share vision statements, themes, and objectives; collectively forwarding marine resource stewardship.

- NOAA Mission: Science, Service, and Stewardship

  NOAA Fisheries is responsible for the stewardship of the nation's ocean resources and their habitat. We are the federal agency entrusted by the public to ensure healthy fish remain a sustainable resource and are accessible to the public. We manage fish resources, including their habitat, using the latest and best science available while employing ecosystem-based management principles. This helps to ensure our fish stocks are available to markets, conserved or protected from adverse anthropogenic effects, and compliant with regulation.

- NOAA Strategic Plan:

  NOAA's Strategic Plan presents a commitment to address climate change[4] and associated effects to our nations coastline and marine resources, focusing on human welfare and sustain the Earth's oceans. This is a challenging task as the future will bring change, such as water allocation, water quality, and coastline resiliency to severe weather events, human population increase, as we become more and more dependent on our oceans for food, power, and health.

- NOAA Organizational Structure, Mission and Statutory Authority

  Simply, NOAA's Mission Statement is to "*Deploy best practices from enterprise performance and risk management, as well as social science integration to help decision makers achieve NOAA's Mission.*" Importantly, this statement puts in motion a science-based, organizational structure to manage the nation's coastlines, its oceans, its atmosphere, and its marine resources. Several line offices govern and research our natural resources and environment, such the fisheries, satellites, forecasting climate, marine mammals, oceanography, and scientific research platforms, such as vessels and aircraft. Together, these lines intertwine and lead us to better understand our oceans and skies and the relation between them.

- Alaska Fisheries Science Plan

  The Alaska Fisheries Science Center (AFSC) conducts the research to support NOAA Fisheries' stewardship mission on living marine resources and their habitats. Alaska spans nearly 1.5 million square miles and includes marine waters in the Gulf of Alaska, Bering Sea, Aleutian Islands, Chukchi Sea, and Beaufort Sea. These waters are habitat to enormous quantities of fish, and many species of marine mammals, some of which require; together these waters support some of the most important commercial fisheries in the world, are home to the largest marine mammal populations in the Nation, and support some of the most critically endangered marine mammal populations. Many of the nation's fisheries lead their industry in market value and offer wild-caught products

- AFSC Annual Guidance Memo

  Annually, the AFSC reviews its scientific programs and focuses on those platforms that meet or exceed NOAA Fisheries mission goals. The challenge is to provide the science necessary to promulgate healthy and sustainable marine resources, including conservation and protection of these resources. Simply, research is prioritized as fiscal

[4] Additional discussion on NOAA and NMFS climate change strategies can be found in the following reports: 1) Jason S. Link, Roger Griffis, Shallin Busch (Editors). 2015. NOAA Fisheries Climate Science Strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155, 70p., and 2) NMFS Draft Climate Science Action Plan, 2016; http://www.nmfs.noaa.gov/mediacenter/2016/02_February/03_02_draft_bering_sea_climate_science_plan.html

resources allow; the AFSC operates within fiscal limits. Importantly, the AFSC maintains the highest standard of science to best inform decision making and stakeholders.

- Alaska EFH Research Plan

  The NOAA Fisheries Alaska Regional Office (AKRO) coordinates the Alaska Essential Fish Habitat (EFH) Research Plan (Plan) with the Alaska Fisheries Science Center (AFSC) to directly fund research in support of EFH management needs. Specifically, the purpose of the Plan is to forecast, coordinate, and fund fisheries research in response to emerging fisheries management needs. The Plan furthers the role of EFH and provides guidance to prioritize research proposals through an internally-vetted request for funding of research proposals (RFP). The RFP cycle occurs early in each fiscal year to allow for budget forecasting. Proposals must be responsive to the Plan and its five priorities. Additionally, science and policy managers meet annually to identify any emphasis areas that may have emerged from recent discussions or are pressing issues. Proposals received undergo scientific review (scoring and ranking) by a diverse panel representing AFSC programs, known as the Habitat and Ecological Processes Research (HEPR) Program.

1.5 Brief History

In 2004, NMFS Alaska, Northwest and Southwest Regions completed a collaborative evaluation of non-fishing effects to EFH. In 2005, NMFS Alaska Region completed an Federal Environmental Impact Statement which updated this document to be Alaska specific (Appendix G of the EIS) (NMFS 2005a). This document was subsequently updated during the 2010 EFH 5 year review. EFH regulations state that FMCs and NMFS should review the EFH provisions of FMPs at least once every five years and that the EFH provisions should be revised or amended, as warranted, based on available information (50 CFR 600.815[a][10]). These regulations also state that the review should evaluate published scientific literature, unpublished scientific reports, information solicited from interested parties, and previously unavailable or inaccessible data. The NPFMC completed its most recent five-year review in April 2010, voted to revise the EFH sections of its FMPs, and completed those revisions in 2012 (NPFMC and NMFS 2012). This document will serve to update the information on non-fishing impacts to EFH and available to be included in the FMP’s as part of the 2015 EFH review.

1.6 Effect of the Recommendations on Non-fishing Activities

As previously stated, EFH Conservation Recommendations for non-fishing activities included in this document are nonbinding. They are intended to convey reasonable steps that could be taken to avoid or minimize adverse effects of categories of non-fishing activities on EFH. Their implementation is entirely at the discretion of the entities responsible for the activities and the agencies with applicable regulatory jurisdiction. NMFS fishery habitat biologists may use these recommendations as a starting point when consulting with federal action agencies on specific activities that may adversely affect EFH. NMFS develops EFH conservation recommendations for specific activities on a case-by-case basis based on individual circumstances. Therefore, recommendations in this document may or may not apply to any particular project. This information is also available to inform Federal action agencies undertaking EFH consultations with NMFS may use the information provided in this document, to assist in preparing EFH assessments.

Chapter 2 Climate Change and Ocean Acidification

2.1 Introduction

Scientists and policy makers may debate the level of change, reasons why or potential impacts; however, climate change is occurring despite our incomplete understanding of human or environmental influences, or consequences. Climate change is seen in easily measurable indicators such as glacial retreat and decreasing Arctic sea ice extent, the reduction in the mass of the Greenland Ice Sheet and changes in regional weather patterns (Dahl-Jensen et al. 2011, AMAP 2012). These visually measured indicators signal change and are difficult to dispute. Less visible indicators are also be measured (Table 1).

There is strong evidence to suggest that since the pre-industrial era, increased emissions of anthropogenic greenhouse gas (GHG) [carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)] have influenced changes in atmospheric and oceanic conditions, and weather patterns. Increased levels of atmospheric and oceanic CO_2 are measurable. Currently, the Intergovernmental Panel on Climate Change (IPCC) projects that emissions of GHG will continue to increase and further influence climate change into the foreseeable future (IPCC 2013, 2014). Ocean carbon chemistry is changing in response to increasing concentrations of atmospheric CO_2 (Caldeira and Wickett 2003, Feely et al. 2004, Ainsworth et al. 2011). Higher atmospheric CO_2 levels increase dissolved CO_2 and bicarbonate (HCO_3^-) ions in seawater, which subsequently leads to a decrease in seawater pH and carbonate (CO_3^{2-}) ions.[5] In general, a decrease in pH leads to a simultaneous increase in acidity. This phenomenon is collectively termed “ocean acidification” (Raven et al. 2005, Ainsworth et al. 2011).

Changes in seawater carbon chemistry may affect the marine biota through a variety of biochemical and subsequent physiological and physical processes. Decreasing pH (increasing acidity) alters the saturation state for calcium carbonate compounds, affecting calcification rates in many marine species (Feely et al. 2004, Doney et al. 2009, Feely et al. 2009). Since the industrial revolution, mean ocean pH has decreased to the lowest level in recorded history (Crowley and Berner 2001, Caldeira and Wickett 2003). Other measurable indicators such as ice cores and geologic samples suggest that recent measures of pH may be the lowest in millions of years. This trend in increasing CO_2 and declining pH is expected to continue (Caldeira and Wickett 2003, Feely et al. 2004, Sabine et al. 2004, Orr et al. 2005, 2013, IPCC 2014). Within this century, surface waters corrosive to Aragonite[6] are expected to first occur at high latitudes because of the inverse relationship with colder temperatures, and continued interactions between the atmosphere and global currents (Orr et al. 2005, Feely et al. 2009, Byrne et al. 2010).

Though subtle, there are many other measurable global indicators of climate change documented by the IPCC (IPCC 2013, 2014). The results in these reports are based on current global

[5] If CO_2 is added to seawater, the additional hydrogen ions react with CO_3^{2-} ions and convert them to HCO_3^-, reducing the capacity of seawater to buffer against acidic conditions.

[6] Aragonite is the stable form of calcium carbonate in high-latitude cold waters. Aragonite concentration and availability is essential to shell development in many marine invertebrate species. Seasonal declines in Aragonite concentrations in surface and shallow, subsurface waters of some northern polar seas have already been documented, and this declining trend is projected to continue into the middle of this century (Fabry et al. 2009).

measurements and analyses using several state-of-the-art global climate models that project future forecasts of the measured indices based on past and current conditions and projected future trends.

The IPCC concludes that anthropogenic GHG emissions since the pre-industrial era have driven large increases in atmospheric concentrations of CO_2, CH_4, and N_2O. Approximately 40 percent of these emissions have remained in the atmosphere while the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The oceans are estimated to have absorbed about 30 percent of the emitted anthropogenic CO_2. Total anthropogenic GHG emissions have continued to increase since 1970, with the larger absolute increases occurring between 2000 and 2010 despite a growing number of climate change mitigation policies (IPCC 2014).

Emissions of CO_2 from fossil fuel combustion and industrial processes contributed to approximately 78 percent of the total GHG emissions since 1970, with a similar percent increase occurring from 2000 to 2010. Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical over the previous three decades, whereas the contribution of economic growth has risen sharply. Global increases in the use of coal have reversed the long-standing trend of gradual de-carbonization of the world's energy supply (IPCC 2013, 2014).

2.1.1 Metrics

Visible evidence of climate change is easily measured with indicators such as sea ice decline, ice cap and glacial retreat, melting permafrost and shifts in long-standing regional weather patterns. Declines in multiyear sea ice, ice caps, and glacial retreat are particularly evident in Arctic and subarctic regions and have been receding at faster rates since 2000 than during any previous period recorded (Dahl-Jensen et al. 2011, AMAP 2012, NSIDC 2016). In March 2016, Arctic sea ice reached its annual maximum extent at 14.52 million km^2 (5.607 million mi^2), which is now the lowest extent in the satellite record (NSIDC 2016). The majority of ice caps and glaciers in the Northern Hemisphere have diminished during the last 100 years.[7] If current trends continue, it is projected that Arctic summer sea ice will disappear before the mid-century (Chapin et al. 2014).

The extent and duration of snow cover and freshwater ice have also decreased across Arctic and subarctic Alaska. Since 1966, the area of Arctic land mass covered by snow during early summer has decreased by 18 percent although the overall seasonal snowfall and depth has increased in other areas of Russia, North America, and Europe (AMAP 2012, NSIDC 2016). Freshwater ice cover on lakes and rivers in parts of the Northern Hemisphere is also breaking up earlier than ever previously observed (NSIDC 2016). Permafrost temperatures have risen by up to 2°C

[7] Loss in mass from the Greenland Ice Sheet (2.93 million km^3 surface area, by 3,000 m thick [0.70 million mi^3 by 9,843 ft]), combined with receding glaciers worldwide is important because of its potential contribution to sea level rise and reduction of salinity and density to marine surface waters, which could impact marine ecosystems and fisheries (Dahl-Jensen et al. 2011, AMAP 2012, NSIDC 2015).

(3.6°F) during the past two to three decades, and the southern limit of permafrost in the Arctic has shifted more northward in Russia and Canada (AMAP 2012).

Climate change is also evident by changes in regional weather patterns, particularly the increase in extreme weather events such as heavy precipitation, heat waves, coastal storms, erosion, fires, droughts, and floods (IPCC 2014). Total annual precipitation has increased in the U.S. and over land areas worldwide; precipitation has increased at an average rate of 3.8 millimeters (mm) (0.15 inches [in]) per decade in the contiguous 48 states since 1901 (EPA 2016b). Since 1950, there has been a 5 percent increase in Arctic precipitation over the land areas north of 55°N. Although this is a modest increase, the five wettest years have all occurred during the past decade (AMAP 2012). Increased heavy precipitation events are projected to continue in the U.S. (Walsh et al. 2014).

Winter storms and snow accumulation have increased in frequency and intensity in many regions since the 1950s. There has also been an increase in the frequency and intensity of damaging winds, hail and thunderstorms, and tornadoes (Walsh et al. 2014). Longer, ice-free seasons due to warming temperatures have affected the occurrence of coastal storms in Alaska (Stewart et al. 2013). For instance, an increase in the number of strong storms has been observed along Alaska's northern and northwestern coasts where protective sea ice cover is no longer present during spring, summer, and fall months. The loss of protective sea-ice barriers also intensifies flooding during storm surge and high-wind events. These storms have led to accelerated coastal erosion at rates of tens of feet (ft) per year in some areas of Alaska. In addition, rapid temperature increases during spring can lead to excessive glacial or snow melt at higher elevations, resulting in flooding (Stewart et al. 2013).

Cumulative impacts of decreasing snow and precipitation, and increasing temperatures have resulted in the increased frequency of extreme fire events in interior Alaska (Kasischke et al. 2010). These changes in temperature, precipitation, and frequency of fire events influence surface hydrology, increase sediment loads, and likely alter spawning and rearing habitats of anadromous species. During the 2000s, 17 percent of the landscape of interior Alaska was burned which is a 50 percent increase since the 1940s (Kasischke et al. 2010).

As discussed, there are many indicators of climate change. Although less visible than glacial retreat, storm events, and other metrics described above, the indicators listed in the table 1 below provide further evidence of a changing climate and measures of the rate of change.[8] These observed changes in the climate system include the warming of the atmosphere and ocean, diminishing amounts of snow and ice, and rising sea levels (IPCC 2014). The continuous warming of the Earth's surface over the last three decades exceeds the temperatures recorded since 1850. Most of this increased energy in the climate system is stored in the ocean which has also experienced acidification due to the uptake of CO_2 since the beginning of the industrial era. The warming has also contributed to the melting of glaciers which, together with ocean thermal expansion from warming, explain about 75 percent of the observed global mean sea level rise. Specific metrics describing these phenomena are listed below along with GHG emissions which

[8] The metrics presented in this table were compiled from IPCC (2013, 2014). Although these reports include many categories of measures and associated potential impacts, these listed represent what NOAA/NMFS/HCD/AKR concluded were some of the more important indicators related to EFH and associated fisheries in Alaska.

have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century (IPCC 2014).

Table 1
Atmosphere and Ocean
The globally averaged combined land and ocean surface temperature as calculated by a linear trend showed a warming of 0.85°C (1.53°F) from 1880 to 2012.
The total increase between the average of the 1850 to 1900 period and the 2003 to 2012 period is 0.78°C (1.4°F) based on the single longest dataset available.
On a global scale, ocean warming is greatest near the surface, and the upper 75 m (225 ft) warmed by 0.11°C (0.198°F) per decade between 1971 and 2010.
Cryosphere
The annual mean Arctic sea ice extent decreased from 1979 to 2012 at a rate of 3.5 to 4.1% per decade (0.73 to 1.07 million km^2 [0.28 to 0.41 million mi^2] per decade).
For the Arctic summer sea ice minimum, the decrease ranged from 9.4 to 13.6%per decade (0.73 to 1.07 million km^2 [0.28 to 0.41 million mi^2] per decade).
The annual mean sea ice extent for Antarctica increased between 1.2 and 1.8% per decade (0.13 to 0.20 million km^2 [0.05 to 7.72 million mi^2] per decade) between 1979 and 2012.
Snow cover in the Northern Hemisphere has decreased since the mid-20th century by 1.6 (0.8 to 2.4) % per decade for March and April and 11.7% per decade for June between 1967 and 2012.
The average rate of ice loss from the Greenland Ice Sheet increased from 34 gigatons (Gt) (40,000,000,000 metric tons) between 1992 and 2001 to 215 Gt (215,000,000,000 metric tons) between 2002 and 2011 (IPCC 2013).
Permafrost temperatures are also thought to have increased, causing permafrost melting although no numerical measures of change have currently been calculated or presented.
Sea Level
From 1901 to 2010, global mean sea level rose by 0.19 m (0.17 to 0.21 m) (0.62 ft [0.56 to 0.69]).
GHG Emissions
Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere totaled 2,040 ± 310 Gt (2,039,999,999,999 ± 310,000,000,000 metric tons).
Approximately 40% of anthropogenic CO_2 emissions remain in the atmosphere (880 ± 35 Gt [880,000,000,000 ± 35,000,000,000 metric tons] of). The remainder is absorbed on land and in the ocean.
The ocean absorbed approximately 37% of emitted anthropogenic CO_2[9].
General ocean circulation and data-constrained models suggest that the ocean absorbed approximately 37 Pg of anthropogenic carbon (Cant) between 1994 and 2010 (Talley et al. 2016).
Calculations of anthropogenic carbon at a global ocean inventory scale in 2010 indicate 155±31 Pg C (±20% uncertainty) (Khatiwala et al. 2013)[10].
Half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred during the last 40 years.
Atmospheric concentrations of anthropogenic CH_4 and N_2O have exceeded pre-industrial levels by approximately 150% (1,803 parts per billion [ppb]) and approximately 20% (324 ppb), respectively.

[9] Numerous oceanic processes act on aqueous CO_2 simultaneously influencing pH. Seasonal variability exists (diurnally, annually), temporally and spatially, especially near the sea surface. Currently, specific levels of dissolved CO_2 are difficult to unobtainable based on current sampling levels or associated analysis.

[10] One Petagram (Pg) = 1 trillion kilograms = 2.2 trillion lbs of anthropogenic carbon, abbreviated as Cant.

2.1.2 Large Marine Ecosystem

Alaska naturally experiences a wide range of extreme weather and climate events that affect ecosystem processes, human society, and supporting infrastructure. Recent evidence and analyses indicate that Alaska has warmed twice as fast as the rest of the U.S. and experienced significant changes in weather patterns. The state-wide average annual air temperature has risen by 1.7°C (3°F) and average winter temperature by 3.3°C (6°F) with substantial year-to-year and regional variability (Stewart et al. 2013).

2.1.2.1 *Gulf of Alaska*

Climate and ocean conditions in the North Pacific Ocean and Gulf of Alaska (GOA) have shifted between cool and warm periods or regimes, particularly over the past 90 years. For example, a "regime shift" occurred around 1976 and 1977, when ocean conditions shifted from a cold to a warm phase that has been correlated with the Pacific Decadal Oscillation (PDO). The majority of fisheries and oceanic scientists, and managers recognize this shift and have acknowledged that a complex suite of atmospheric and oceanic variables influenced this change.[11] In general, this shift in the GOA is thought to favor the production of some pelagic (upper water column) species in warm periods and some demersal (bottom dwelling) species in cold periods. An example is total Alaska salmon production (harvest), which generally inhabit the upper water column, is reported to be higher in warm regimes than in cool regimes (Mantua et al. 2009).

Potential mechanisms that led to this regime shift are presented in two proposed hypotheses. The first hypothesis suggests changes in the eastern North Pacific Ocean are driven largely by atmospheric pressure, related winds and water movements, and subsequent surface layer mixing and benthic upwelling all influence plankton production (Brodeur et al. 1996, Mantua et al. 1997, Francis et al. 1998). A second hypothesis suggests that strong recruitment of forage fish and invertebrates depends on emergence of their larvae at the same time plankton prey are available, commonly referred to as the "Match-Mismatch" hypothesis (Cushing 1990, Anderson and Piatt 1999). Collectively, climate-forced changes influenced atmospheric and ocean conditions altering the timing (phenology) and presence of larval and juvenile fish populations to available plankton prey and possibly exposed larval and juvenile fish populations to increased predation. A subsequent, weaker climate pulse occurred in 1989 but did not return the GOA or Eastern Bering Sea to pre-1976/1977 conditions (Hare and Mantua 2000). The prevailing reorganization of the marine ecosystem produced a dramatic decline in forage fish and invertebrate populations, and a predominance of groundfish which currently persists (Anderson et al. 1997, Anderson and Piatt 1999, Litzow 2006, Clark et al. 2010).

Anomalously warm water conditions currently continue in the GOA as a result of unusually quiet winter weather conditions, a weak Aleutian low weather system, and abnormally high sea level pressure off the coast of the Pacific Northwest. The resulting condition, termed the "warm blob," first appeared off Alaska's southern coast during the fall of 2013 and persists as of this review

[11] Multiple hypotheses are proposed on interactions and relationships of Pacific Decadal Oscillation (PDO), El Niño Southern Oscillation (ENSO), Eastern Pacific warming (EPW), and Central Pacific warming (CPW), all of which influence GOA oceanic conditions, trophic dynamics, and fisheries. However, these details are beyond the current scope of this report.

(Bond et al. 2015, Peterson et al. 2016, Yasumiishi and Zador 2016). This warm water mass is estimated to be nearly 2,000 km wide and 100 m deep (1,243 mi by 300 ft). Water temperatures between 1°C and 3°C (1.8°F and 5.4°F) are well above the long-term seasonal average (Bond et al. 2015, Peterson et al. 2016). The mass may be supported by cyclical weather patterns of high atmospheric pressure that dominates the weather pattern over western North America (Anderson et al. 2016). There is speculation that this atmospheric and oceanic influence is generated with corresponding conditions from the western North Pacific (Zador 2014, Kintisch 2015, Peterson et al. 2015).

The appearance of the warm blob coincided with a variety of unusual biological events, such as extremely low chlorophyll levels during late winter/spring of 2014, presumably due to suppressed nutrient transport into the mixed layer. Several fish species common to warmer southern waters have been sighted in the GOA and British Columbia. Humboldt squid (*Dosidicus gigas*) and skipjack tuna (*Katsuwonus pelamis*) were caught near the mouth of the Copper River in July of 2015. Ocean sunfish (*Mola mola*), and the common thresher shark (*Alopias vulpinus*) were documented off the coast of Southeast Alaska far north of their typical range. Pacific pomfret (*Brama japonica*) and Pacific saury (*Cololabis saira)* species associated with subtropical waters were also abundant in this northern region (Gallagher 2014, Medred 2014, Bond et al. 2015, Orsi 2016, Yasumiishi and Zador 2016). Record high numbers of Fraser River sockeye salmon (*Oncorhynchus nerka*) were also documented migrating around the northern side of Vancouver Island versus the traditional southern migration.

2.1.2.2 *Bering Sea*

Historically, the Bering Sea has always exhibited some inter-annual variability in air and sea surface temperature (SST) and sea ice extent. This seasonal variability has remained relatively consistent at decadal scales and largely dependent on the frequency and magnitude of low pressure atmospheric systems (Wyllie-Echeverria and Wooster 1998). Recent atmospheric, oceanic, and fisheries survey data and analyses indicate subtle changes in Arctic and subarctic weather patterns and ocean conditions. Stabeno et al. (2001) and Grebmeier et al. (2006b) identified that SSTs in the Bering Sea had warmed 0.23°C (0.41°F) per decade since 1954. Between 1972 and 1998, this gradual warming trend was also reflected in the southern extent and spatial distribution of sea ice. Although the later years in this broad time series reflected a slightly cooler leveling, SSTs never returned to previous historic lows, sea ice extent was never as far south, and sea ice residence time was shorter (Stabeno et al. 2001).

As Eisner et al. (2014) present, between 2000 and 2010, the Bering Sea experienced different multi-year climate shifts (Stabeno et al. 2012b) including above average SSTs and very low sea ice coverage (2000 to 2005) and a single transition year with average SSTs and sea ice extent (2006) followed by extremely cold years with extensive sea ice (2007 to 2009). In concurrence with this warming period (2000 to 2005), there was a decline in Bering Sea walleye pollock (*Gadus chalcogrammus*) recruitment which led to a 40 percent decline in the total allowable commercial harvest (Ianelli et al. 2013). Further data analysis strongly suggested that the decline in pollock recruitment and biomass during the warm years was a direct result of altered trophic dynamics from the changing ocean conditions (Farley and Trudel 2009, Coyle et al. 2011, Hunt et al. 2011, Heintz et al. 2013, Eisner et al. 2014). Simply, the decreased sea ice extent and early sea ice retreat changed ocean conditions and altered the timing of zooplankton blooms, leading to a decrease in the availability of large lipid-rich plankton, which are normally abundant during late sea ice retreat, and an increase in the availability of small lipid-poor plankton species. Pollock juveniles (age 0 to 1) had less prey available in both quality and quantity, experienced lower energy levels, and became susceptible to predation from other species and cannibalism. Consequently, the decreased prey availability led to reduced pollock recruitment numbers and reduced harvest levels (Ianelli et al. 2013).

Just as SST and sea ice extent signaled this extended warm pulse, benthic waters in the same region reflected a simultaneous warm pulse during the same years. Benthic fisheries and temperature data suggested a similar trend of increasing benthic temperatures (the cold pool) between 1982 and 2006 (Mueter and Litzow 2008). The cold pool is a recurrent benthic sea water zone with persistent temperatures of 0°C to 2°C (32°F to 35.6°F). Sea surface ice cover provides the character for this benthic zone which is formed as stratification isolates the deeper cold waters from warmer surface water exchanges. The extent of SST, sea ice cover, and the benthic character of the cold pool are directly correlated. Consequently, the cold pool had retreated north from its previous southern extent by approximately 230 km (143 mi), and subsequent shifts occurred in the distribution of some benthic fish species. Of the 40 taxa that were analyzed, 11 showed a linear response to shifting benthic temperatures and moved into the slightly warmer benthic zone previously occupied by the cold pool (Mueter and Litzow 2008). A similar study conducted by Kotwicki and Lauth (2013) assessed the spatio-temporal displacement of the same populations in multiple directions using data through 2010. Results also indicated a reduction in the extent of the cold pool and an increase in the ranges of many of the same benthic taxa. However, this analysis also introduced additional mechanisms, such as spatial distribution, nutrition, ontogeny, and spawning, into climate-forced change.

These climate-forced changes represented one of the first well documented occurrences where a multiyear climate-forced change altered trophic dynamics or influenced the range and distribution, and abundance of some Bering Sea taxa. Although this warming pattern or pulse was relatively brief (2000 to 2005) and immediately followed by characteristically cold weather patterns resuming from 2007 through 2012 (Sigler et al. 2011, Stabeno et al. 2012a, Stabeno et al. 2012b, Kotwicki and Lauth 2013), current indicators suggest a similar warming pattern may be occurring presently (2014 through 2016) (Farley 2016). If multiyear climate-forced warming patterns are more numerous and persistent in the future, projections indicate that there is a potential for changes in the range, distribution, and abundance of fisheries and increased uncertainty in modeling predictions and stock assessments (Mueter et al. 2011, Hollowed et al. 2013).

2.1.2.3 *Arctic*

The Arctic Ocean is the world’s smallest ocean and has limited exchange with other global oceans as it is surrounded by continental land masses, has relatively shallow shelves, and is often covered by ice (NPFMC 2009b). Alaska’s Arctic Ocean is divided into two regional adjacent seas: the Chukchi Sea and the Beaufort Sea. Generally, fisheries productivity in the Chukchi and Beaufort Seas is considered low due to extreme environmental conditions. The marine characteristics of both seas are strongly influenced by terrestrial freshwater runoff; 10 percent of worldwide runoff drains into 3 percent of its total oceanic area (NPFMC 2009b)[12]. Seasonally, limited sunlight and freezing Arctic conditions promote the formation of sea ice, which directly limits trophic interactions and the range and distribution of fish populations. Conversely, melting summer sea ice nourishes primary production as algae and nutrients are re-released, creating a highly productive and nutrient-rich, estuarine-like nearshore corridor.

The Chukchi and Beaufort seas are driven by different environmental, climate, nearshore, and terrestrial influences. Each exhibits different degrees of biological productivity and different EFH attributes. Comparatively, the Chukchi Sea is generally more productive than the Beaufort Sea as a result of nutrients and plankton flowing north from the Bering Sea (Woodgate and Aagaard 2005, NPFMC 2009b). There is also significant seasonal freshwater and nutrient influence from prevailing western ocean currents and the Yukon River discharge (Dittmar and Kattner 2003, Dittmar 2004, Woodgate and Aagaard 2005, Spencer et al. 2008, Letscher et al. 2013, McClelland et al. 2016). In the Beaufort during the summer, strong west winds may induce upwelling of cold, nutrient-rich nearshore waters. Benthic organisms move inshore and support nearshore fish and invertebrate populations. The McKenzie River plume also influences nutrients and trophic dynamics in nearshore Beaufort Sea fisheries (Dunton et al. 2006, Dunton et al. 2012, von Biela et al. 2013, Bell et al. 2016).

As Rand and Logerwell (2011) discuss, trends in ocean warming and declines in Arctic sea ice increase the potential for northward migrations of fish and invertebrate species from the Bering Sea and North Pacific (IASC 2004, Grebmeier et al. 2006a, Grebmeier et al. 2006b, Mueter and Litzow 2008, Mueter et al. 2009). As previously discussed, changes from Arctic to subarctic conditions have been observed in the Bering Sea with a shift from benthic to pelagic fish species (Overland et al. 2004, (Grebmeier et al. 2006a, Grebmeier et al. 2006b). Similar changes have been documented in Atlantic and North Sea fish communities (Beare et al. 2004, Perry et al. 2005). The effects of recent record-breaking ice recessions in the Arctic on marine fish communities are unknown because data are limited or nonexistent (Stroeve et al. 2007, Greene et al. 2008, Stroeve et al. 2008, Boé et al. 2009).

Currently, no federally managed commercial fishery exists in either the Chukchi or Beaufort Seas. Marine ecosystem processes that support EFH attributes, such as trophic interactions, primary and secondary production, and fisheries range and distribution have been assessed but are not entirely understood (Logerwell et al. 2011, Rand and Logerwell 2011). The seasonal influence of sea ice significantly limits the ability to access waters to achieve fisheries abundance and productivity data. Based on surveys conducted in 2010, fish comprised only 6 percent of the total weight even though 34 taxa of fish were identified. Invertebrate species comprised the remaining 94 percent of the catch. The majority of fish species that were identified were nearshore forage fish species that are not federally managed (Logerwell et al. 2011, Rand and Logerwell 2011) .

The impacts and stressors of climate change appear dramatic in Arctic ecosystems when considering ocean warming, continued loss of sea ice, and potential ocean acidification (ACIA 2005). However, weather conditions and seasonal sea ice still limit access to prolonged marine

[12] Some variability exists in the literature on the volume of freshwater discharge into the Arctic ocean and the total continental shelf area. For example, Lammers et al. (2001) imply that 11 percent of the world's freshwater discharge enters 1 percent of the world's volume in seawater. The Arctic ocean contains 25 percent of the world's continental shelf.

studies or commercial fisheries operations. Generally, little is known of marine fish distribution, abundance, diversity, or habitat use patterns in the winter (NPFMC 2009a, b). Climate change and uncertainty in resource availability exacerbate the challenges of predicting impacts or fishery development.

2.2 Cumulative Impacts of Climate Change to Marine Fisheries

Seasonal and decadal variability in climate patterns influence the range, distribution and abundance of marine fish species at some spatial or temporal scale. Scientists have some understanding of this influence, and subsequently fisheries scientists and managers account for some degree of variability in establishing sustainable harvest levels. The influence of climate change on Alaskan fisheries is presented in the previous examples; one from the Pollock fishery in the Bering Sea and the second in the changing distribution of southern fish species appearing in the north Pacific. These examples currently represent relatively short lived "pulse" events, over a couple years. On the other hand, it needs to be recognized that sea surface temperatures are predicted to increase in frequency and intensity. These persistent "press" events, in terms of decades, will exacerbate cumulative impacts subsequently decreasing the precision needed to implement appropriate fisheries management measures. Increasing frequency of rapid change complicates accurate assessment of the status of stocks and ability to forecast sustainable levels of harvest. Numerous subject matter experts have presented how increasing frequency and intensity of climate change will impact fisheries and fishery-dependent communities through a complex suite of linked processes and responses (Scavia et al. 2002, Harley et al. 2006, Brander et al. 2010, Hollowed et al. 2013)[13].

2.2.1 Impacts on Ecosystem Productivity and Habitat

If atmospheric CO_2 levels continue to increase, global physical models project increased sea temperatures in many regions, changes in locations and magnitudes of wind patterns and ocean currents, loss of sea ice in Polar Regions, and a rise in the sea level (IPCC 2014). The accumulation of CO_2 in the atmosphere and associated climate changes is expected to increase ocean acidification and expand oligotrophic gyres (Doney et al. 2012). These physical and chemical changes are expected to result in shifts in the timing, species composition, and magnitude of seasonal phytoplankton production (Cochrane et al. 2009, Wang and Overland 2009, Polovina et al. 2011, Doney et al. 2012). Changes in phytoplankton species composition may include population shifts to smaller sizes that could lengthen food chains and increase assimilation losses to higher trophic levels (Mora´n et al. 2010, Bode et al. 2011). These physical, and resulting biological, changes will occur at different spatial and temporal scales throughout the world's oceans (Burrows et al. 2011, Gnanadesikan et al. 2011, King et al. 2011). Changes in temperature, nutrient supply, mixing, light availability, pH, oxygen, and salinity are expected to affect the ecological functions and, consequently, the sustainable harvests available from the ocean's biological communities (Cochrane et al. 2009, Brander 2010, Denman et al. 2011, Doney et al. 2012). Exposure of marine organisms to ocean acidification and oxygen depletion will vary regionally, and other anthropogenic impacts (e. g., eutrophication) may also exacerbate impacts. The vulnerability of the species and a species response under these changes

[13] Hollowed *et al*. (2013), represents a consensus of international subject matter experts in climate change and marine fisheries. This publication addressing potential cumulative impacts of climate change across large marine ecosystems and associated fisheries represent potential similar impacts to Alaska's marine ecosystem processes, fisheries and communities, and was adopted for use in this report, with permission.

varies considerably (Whitney et al. 2007, Feely et al. 2008, Vaquer-Sunyer and Duarte 2008, Levin et al. 2009, Ries et al. 2009, Rabalais et al. 2010).

Regional differences in primary production are also anticipated. In mid-latitudes the mixed layer depth (MLD) is projected to shoal, which could decrease nutrient supply and ultimately primary production. For example, an inter-comparison study of 11 models projected that the ocean's MLD will change (decrease or shoal) in most regions of the North Pacific during the 21st century as the result of increased stratification resulting from warming and/or freshening of the ocean surface and changes in the winds (Jang et al. 2011). A study using four Earth System Models (ESMs) found a similar pattern in the North Atlantic (Steinacher et al. 2010). Capotondi et al. (2012) also provide a global treatment of stratification changes. Primary production in mid-latitudes is expected to be reduced by this MLD shoaling through decreased nutrient supply (Hashioka and Yamanaka 2007, Barange and Perry 2009). However, production may increase in higher latitudes especially in seasonally ice covered areas through increased light levels and a longer period of production and changes in the ice-edge bloom (Perrette et al. 2011). Increased stratification caused by sea surface freshening and/or warming is also a main driver of ocean deoxygenation through decreased ventilation (Whitney et al. 2007). Rykaczewski and Dunne (2010) hypothesized that decreased ventilation in upwelling zones may increase production due to increased residence times (the period where producers are retained in the high production zone) and nutrient remineralization; however, we note that these benefits could be offset by reduced nutrient supply. There remain important uncertainties regarding how physical and biological processes are incorporated into projection models (e.g. temperature response; Taucher and Oschlies 2011) and how these models represent coastal and shelf sea areas (e.g. Holt et al. 2012).

The responses of secondary production to climate change are not clear, partially because the data available for zooplankton are more limited and the mechanisms linking secondary production to ocean conditions are complex. In the North Atlantic, the total abundance of zooplankton changed with sea surface temperature (SST) change (Richardson and Schoeman 2004). However, this overall pattern masks important trends in the zooplankton community where the abundance of both herbivorous and carnivorous copepods increased with phytoplankton abundance but the abundance of neither group was directly correlated with SST. Several authors have recognized that the phenology of zooplankton may also be affected by a changing climate in both the Atlantic and Pacific (Chiba et al. 2004, Edwards and Richardson 2004, Mackas et al. 2007). Although climate change results in an earlier onset of production cycles, the actual timing and changes in the magnitude of production varied in direction and was influenced by different mechanisms among regions (Richardson, 2008). Our limited understanding of the trophodynamic linkages between phytoplankton and zooplankton adds considerable uncertainty to projections of the responses of these groups to global change (Ito et al. 2010).

2.2.2 Impacts on marine fish and shellfish

Climate-driven changes in the environment may affect the physiology, phenology, and behavior of marine fish and shellfish at any life-history stage, and any of these effects may drive population level changes in distribution and abundance (Loeng and Drinkwater 2007, Drinkwater et al. 2010, Jørgensen et al. 2012). Fish and shellfish will be exposed to a complex mix of changing abiotic (e.g. temperature, salinity, MLD, oxygen, acidification) and biotic (shifting distribution, species composition, and abundance of predators and prey) conditions making it more difficult to predict their responses. Climate-driven changes in ocean temperatures may shift population distributions causing predator–prey overlap, increasing predation mortality or potentially altering post-recruit abundance. Climate influenced change in the distribution of predator-prey relationships, for example the decrease in one species and the subsequent increase in an associated predator species, will lead to increasing levels of uncertainty in stock assessments (Mueter et al. 2013, Spencer et al. 2016).

Many climate-related changes have already been observed (Perry et al. 2005, Mueter and Litzow, 2008, Barange and Perry 2009, Nye et al. 2009). Kingsolver (2009) identified three types of potential responses of species to climate change: distribution changes in space and time, productivity changes, and adaptation. The extent of population-level changes may be mediated by the capacity for individual species/populations to adapt to changes in important abiotic and biotic factors through changes in the phenology of important life-history events (e.g. migration, spawning), or through changes in organismal physiology (e.g. thermal reaction norms of key traits such as growth; Portner 2010) and/or through acclimation (Donelson et al. 2011). Mismatches may occur when shifts in the environment lack consistent patterns or out-pace the species ability to adapt or acclimate to change (Burrows et al. 2011, Duarte et al. 2012).

Changes in life cycle dynamics will occur in concert with climate-induced expansion, contraction, and/or shifts in the quality and quantity of suitable habitat, and different life stages may be affected differently by changes in habitat characteristics (Petitgas et al. 2013). Moreover, in some regions, changes in temperature will be accompanied by changes in other abiotic factors. For example, expected regional changes in precipitation could lead to decreases or increases in local salinities which will have major impacts on distributions and productivities of fish species in coastal and estuarine areas. Thus, perhaps future thermal conditions may be suitable for new immigrant species, but shifts in salinities could make these waters uninhabitable, illustrating the challenges of projecting future trends in species richness of fish communities.

Hollowed et. al. (2013) present a summary of 30 recently published studies (2002-2013) providing evidence that climate change is influencing the spatial distribution of marine fish species. Although there are many accounts of temperate species moving to higher latitudes, presumably in response to warming (Beare et al. 2004, Perry et al. 2005), there is less evidence of contraction of ranges of boreal species (Genner et al. 2004, Rijnsdorp et al. 2010). The distributional changes may be the result of either active migration of living marine resources to higher latitudes or from differential productivity of local populations in lower and higher latitudes (Petitgas et al. 2012), and usually the causal factors are poorly documented. The sensitivity of fish and shellfish stocks to climate change may differ depending on whether the stock is at the leading, trailing or center of the species range (Beaugrand and Kirby, 2010). In some cases, latitudinal shifts will exacerbate mismatches due to concurrent changes in the light cycle and the duration of the growing season (Kristiansen et al. 2011, Shoji et al. 2011).

The aforementioned impact of climate change on MLD and ocean chemistry has been shown to exacerbate vertical habitat compression for some highly migratory species of billfish and tunas in the tropical Northeast Atlantic Ocean. Initial work demonstrated how the near-surface density of many high-oxygen demand species of pelagic fish was much higher in the eastern than in the western tropical Atlantic (Prince et al. 2010). Eastern boundary current conditions off the west coast of Africa create an oxygen minimum zone that is much closer to the surface than in the western tropical Atlantic. The habitat compression has led to higher vulnerabilities to surface fishing gear and artificially high indications of abundance. Stramma et al. (2011) reported that a decrease in the upper ocean layer dissolved oxygen occurred in the tropical Northeast Atlantic. This change equated to an annual habitat loss of approximately 15% over the period 1960–2010. Climate change is expected to further expand the Atlantic oxygen minimum zone due to increased ocean temperatures and decreased oxygen levels, potentially threatening the sustainability of the pelagic fisheries and their associated ecosystems.

Climate change may also influence recruitment success, which will impact population productivity (e.g. Hare et al. 2010, Mueter et al. 2011). The resilience to shifts in production may vary by region. In many regions, fish and shellfish have evolved within systems impacted by intermittent (1–2 years) or longer term events that occur on decadal or multidecadal timescales (Baumgartner et al. 1992, Hare and Mantua 2000, Greene and Pershing 2007, Di Lorenzo et al., 2008, Hatun et al. 2009, Overland et al. 2010, Alheit et al. 2012). These events will probably continue to occur in the future. It is unclear whether species and communities that have experienced such variability in the past will be better adapted to future climate change. In some well-documented cases, climate variability is thought to provide opportunities for dominance switching and ecosystem reorganization (Skud 1982, Southward et al. 1988, Anderson and Piatt 1999, Rice 2001, Stenseth et al. 2002, Chavez et al., 2003). Climate change may interrupt or accelerate these cycles of dominance switching with unknown implications for both dominant and subordinate species within each phase of a cycle.

The responses of individual marine species to climate change will vary by species and region resulting in a broad spectrum of potential shifts in geographic ranges, vertical distributions, phenologies, recruitment, growth, and survival. Thus, alterations in both the structure (i.e. assembly and connectivity) and function (i.e. productivity) of biological communities are expected. Large-scale losses and shifts in community structure, associated with disease, have been observed elsewhere and are thought to be unprecedented since the Holocene and Late Pleistocene (Aronson et al. 1998; Greenstein et al. 1998). Physical and chemical changes, and alterations in temperature influence carbonate saturation, and other climate-driven conditions increase vulnerability to disease in some fish and shellfish populations (Lafferty 2004, Harvell 2009, Burge 2014). Community responses are the most uncertain types of ecosystem responses to climate change because they involve more players (all the species in the community and the habitats that are used), their interactions, and direct as well as indirect effects of climate drivers (Stock et al. 2011), as well as the spatial and temporal complexity of responses (Burrows et al. 2011; Gnanadesikan et al. 2011). However, there is some evidence that community assemblages tend to move in concert based on retrospective studies of species spatial patterns and species richness (Hofstede et al. 2010, Lucey and Nye 2010).

2.2.3 Impacts on Fisheries and Fishery Dependent Communities

Fisheries and fishery-dependent communities have been subjected to fluctuations in fish stocks, extreme weather events, and natural changes in climate and sea-level throughout history. Coastal livelihoods have depended on the capacity to cope with such changes through the alteration of fishing practices or switching to alternative livelihoods (Allison et al. 2009, Perry et al. 2011). The capacity for human communities to respond to changes in the species composition, abundance, and availability of marine resources vary regionally (Daw et al. 2009). Climate change effects on fish and fisheries will occur within the context of existing and future human activities and pressures, as well as the combined effects of multiple stressors and natural agents of change acting directly and through feedback pathways (Ruckelshaus et al. 2013). In coastal ecosystems, pollution, eutrophication, species invasions, shoreline development, and fishing generally play more important roles as drivers of change than on the high seas.

It will be difficult to tease out the additional effect of climate change from other anthropogenic activities (such as fishing; Rogers et al. 2011). In some cases, where time-series are long enough or can be re-constructed, the relative importance of different forces can be quantified (e.g. Eero et al. 2011). Hare et al. (2010) examined the combined effects of fishing and climate in a modelling context and found that fishing likely remains the dominant pressure, especially at the historically high fishing levels. Other researchers found that it was difficult to separate the influence of anthropogenic climate change from decadal environmental variability and fishing even with a century of data (Engelhard et al. 2011, Hofstede and Rijnsdorp 2011), whereas others note that fisheries can amplify or moderate climate signals (Ottersen et al. 2006). Some promising alternative approaches to address these issues include: comparative studies, experiments, and opportunistic studies of major natural or anthropogenic events (Megrey et al. 2009, Murawski et al. 2010). Ainsworth et al. (2011) used five Ecopath with Ecosim models to simulate changes in primary production, species range shifts, zooplankton community size structure in response to ocean acidification, and/or ocean deoxygenation. Fishing pressure was also included as an additional perturbation to the modelled food web. Their study revealed that responses to the cumulative effects of climate change and fishing may result in different patterns than would have been predicted based on individual climate effects, indicating possible interactions.

The degree to which fisheries are managed sustainably varies globally (Worm and Branch, 2012). In many regions, efforts are underway to prevent overfishing, rebuild overfished stocks, and implement an ecosystem approach to management (Murawski, 2007). In the future, the detrimental effects of climate change on fish stocks may, to some extent, be buffered in stocks that have a large and productive spawning-stock biomass, a less truncated age structure, and sustainable exploitation rates (Costello et al. 2012). For example, cod have remained abundant with wide size/age structure in some areas (i.e. Øresund) where exploitation has been low, although temperatures have increased and while abundance has declined and age structure has narrowed in neighboring areas [North Sea, Baltic Sea (Lindegren et al. 2010)].

Natural scientists and economists are partnering to develop the projections of how fishers may respond to changes in fish distribution and abundance (Haynie and Pfeiffer 2012). It is unclear how complex management systems involving measures such as catch shares, bycatch limits, mixed species catch or effort limits, and spatial or temporal closures will perform as the species composition, distribution, and abundance of fish species change (Criddle 2012). An equally challenging issue is predicting how different nations will utilize the broad range of ecosystem services that marine ecosystems provide (Halpern et al. 2012). Multispecies management strategy evaluations can be used to evaluate the expected performance of management frameworks with respect to balancing these complex issues (Plaga´nyi et al. 2011). However, selecting the functional form of responses necessary to predict how fishers will respond to changes in marine resources will continue to be challenging.

The fish stocks, fisheries, and marine ecosystems that coastal communities depend on can be described as components of coupled marine social-ecological systems (Perry et al. 2011). This is a particularly useful representation when considering the policy goals of preserving the health of the marine ecosystem while maintaining the supply of desirable goods and services that support human livelihoods. The representation requires specifying the scale of the system, its properties (e.g. resilience, biodiversity, productivity, social capital), how it is, or can be, governed, and what structures and information are required for such governance. Management and governance approaches may need to be adapted to the available scientific and management capacity (including financial and social resources). While strengthening capacity may put extra demands on management agencies and stakeholders, it also brings with it greater sustainable benefits through reduced uncertainty (Cochrane et al. 2009 and 2011). Anthropogenic climate change is an increasingly influential driver of change in such social-ecological systems, added to an already complex set of natural and anthropogenic drivers. The impacts of climate drivers are manifested on time-scales that are generally longer than most other anthropogenic drivers to which these social-ecological systems routinely respond.

There is growing recognition of the need for much stronger integration of social and ecological sciences in developing adaptation options for industries and coastal communities (Allison et al. 2009, Daw et al. 2009, Miller et al. 2010, Gutierrez et al. 2011). In this context, there may be much to learn from the dynamics of small-scale fisheries in coastal communities. Institutions such as the FAO and Worldfish are active in working on climate change adaptation in such systems. Adaptation and mitigation depend on actions and behavioral choices by the communities who are exploiting the marine resources (whether for fisheries, tourism, or other goods and services), as well as a supportive wider governance environment to address threats and constraints to adaptation and mitigation that are outside the control of local communities. Resource users and communities, within the context of an integrated ecosystem approach, must have the capacity and the will to adapt and mitigate. Viable adaptation and mitigation actions require the identification of vulnerabilities at levels from the household to macroeconomic ability to diversify livelihoods for income and the availability of environmentally sustainable livelihoods and development options. For example, “co-benefits” of both adaptation and mitigation can arise from biodiversity conservation, and protection and restoration of mangroves, and other coastal vegetation (Ruckelshaus et al. 2013). Coastal resources governance can be encouraged to develop community-based disaster risk management and to integrate climate change issues into the local and national socio-economic development planning. These actions may help to prepare communities for climate change impacts on livelihoods that depend on marine resources.

2.2.4 Implications for Future Security of the Food Supply

The expansion of the world’s human population and current levels of hunger in many parts of the world have raised concerns over the security of the food supply in the future (OECD 2008, Godfray et al. 2010 and 2011). Fish currently provide essential nutrition to 4 billion people and at least 50% of the animal protein consumed by 400 million people (Laurenti 2007, FAO 2012), currently contributing 17 kg of fish per capita and year. Most of the expected increase in the human population to 2050 occurs in regions where fish provide most of the non-grain dietary protein (UN-DESA 2009, UN-WHO 2002). The extent to which marine fisheries will be able to provide fish for the world’s population in the future will depend on climate driven changes to the productivity of the world’s oceans and the performance of fisheries management systems (Bell et al. 2009, Worm et al. 2009, Costello et al. 2012). Several scientists have used outputs from IPCC global climate models to explore quantitatively or qualitatively the potential consequences of climate change on fish and fisheries production and the implications in terms of food security targets (e.g. Merino et al. 2012). These studies concluded that even with improved management, there is only a modest scope for increases in sustainable global yields for capture fisheries (Rice and Garcia 2011, Brander 2012). However, innovation in both large-scale and small-scale aquaculture may support a continued increase in production from marine and freshwater systems (FAO, 2008a, b, OECD 2008, Garcia and Rosenberg 2009, Rice and Garcia 2011, Merino et al., 2012). At present, global aquaculture production is very unevenly distributed with Asia accounting for 89% of world production (FAO, 2012). In addition, the effects of climate change on prospects for fisheries and aquaculture show strong regional differences (Merino et al. 2012). Substantial political and financial investment in aquaculture will be required in suitable climatic and environmental regions if it is to provide greater contributions to food security and meet the growing demand for fish and seafood products. Growing international trade in fish products and fishing fleet capacities is accentuating regional differences in potential fish consumption (OECD-FAO 2009, Kim 2010).

Hence, in addition to direct impacts of climate change on fish populations and communities, and thus food production, there can be indirect impacts through changes to the availability of alternative sources of protein, to the conditions suitable for intensive culture of fish and shellfish, and even to the complex interactions of climate on the global trade in food.

2.3 Potential Adverse Impacts

It is widely recognized that climate change has the potential to influence ecosystem processes at regional scales. Examples presented here (Section 2.1.2) of recent observations in the GOA, Bering Sea, and Arctic exemplify climate induced changes in Alaska’s fisheries. Alaska naturally experiences a wide range of extreme weather and climate conditions that influence fisheries. The added influence of climate induced change further complicates our understanding of the natural variability in these extreme conditions. Currently, it is very difficult to accurately predict the level of impact to EFH or FMP species.

Despite many of the currently anticipated impacts of climate change, there is no evidence that the physical oceanic circulation patterns and tides will be altered. Though the severity of an Arctic winter may decrease, there is no evidence that the length of winter and summer seasons, specifically the periods of light and darkness will be altered. However, climate change may influence larger weather patterns and associated seasonal precipitation and snow fall levels. Some regions may see significant increases in temperatures and water volumes while others regions may see significant decreases. There is a high level of uncertainty in how future changes will impact EFH attributes at regional and ecosystem scales.

At the watershed level, throughout Alaska changing seasonal or annual precipitation events may create more wetlands and wetland complexity. Changes in ground and surface water regimes may influence instream flows from headwater streams to larger river and estuarine processes. Precipitation patterns may alter water holding capacity of wetlands and watersheds. Increasing annual precipitation levels on an already saturated landform may increase flood events and scour river bottoms. Ice scour in watersheds may damage hyporheic substrates and may prove detrimental to some anadromous salmon species in their embryonic phase. On the other hand, warming climate patterns may prove beneficial to many fish species that no longer endure freezing winter conditions. Rising ground and surface water regimes in other regions may provide increased instream flow or temperatures and prove beneficial to some anadromous salmon species by minimizing freezing winter conditions under the ice.

In estuarine and nearshore zones, EFH may experience further decreases in the extent and duration of seasonal ice presence in Arctic and sub-Arctic seas. This may expose entire regions of Alaska's coast to continued shoreline erosion. Decreasing sea ice may increase the frequency and severity of coastal storms and subsequent shoreline erosion. Increased coastal erosion may alter natural sediment processes and substrate composition, changing trophic dynamics and further influencing the range and distribution of larval and juvenile fish species in nursery grounds that represent adults seen later in marine commercial fisheries. As discussed, decreasing sea ice extent has been shown to impact marine trophic levels and alter abundance and recruitment of economically valuable marine fish species.

Decreases in sea ice extent allow for increased vessel traffic, and in recent years, the length of the summer vessel transit season has been longer (Mellgren 2007, Reiss 2008, NPFMC 2009b). The Arctic Council's Arctic Marine Shipping Assessment presents an evaluation of impacts due to increased Arctic shipping activities (Arctic Council 2009, Fretheim et al. 2011). Shipping and vessel traffic through the Arctic is projected to increase should climate change further reduce the extent and duration of Arctic sea ice. Expansion of Arctic natural resource development is also projected; however, that expansion is highly dependent on a multitude of economic influences. With the exception of northern Norway and northwest Russia, a significant lack of critical infrastructure limits Arctic marine operations. Extensive gaps in hydrographic, oceanographic, and meteorological data exist for significant portions of the primary shipping routes, which are critical for supporting safe navigation. Subsequently, there is an increased potential to introduce additional anthropogenic stressors, such as the release of oil through accidental or illegal discharge, ship strikes to marine mammals, increased noise and sonic disruption, and the introduction of invasive species. Indigenous cultures have expressed concern for the social, cultural, and environmental impacts of such commercial expansion (ACIA 2005, Arctic Council 2009). Despite potential for increases from climate forced stress in Arctic processes, the winter season will remain devoid of sun light and remain relatively cold when the suns elevation declines each winter (Sigler et al. 2011). This in itself may minimize some forms of marine operations. Additional information on increasing vessel traffic can be found in section 6.4.1.

Continued declines in sea ice may further alter trophic dynamics from primary and secondary production through apex marine predators. While these impacts may negatively alter one species range and distribution, it could also prove beneficial to other species increasing their abundance. Those changes in one species abundance may create additional unseen impacts to other fish species as a result of predator-prey interactions. Increasing atmospheric temperatures have already influenced the range, duration and thickness of Arctic sea ice. The continued decline in the presence of Arctic sea ice may actually accelerate additional decline and may further influence seasonal weather patterns in Arctic and sub-arctic regions of Alaska.

The continued melting of established tundra permafrost wetlands in the Arctic may increase the release of greenhouse gases into the atmosphere and may liberate concentrations of terrestrial carbon, nitrates and phosphates into watersheds and marine systems. These releases may further exacerbate impacts of climate change in ways we do not currently understand or predict. These cumulative impacts to freshwater and marine ecosystem processes may be detrimental to some

EFH and FMP fish species while having completely beneficial impacts to other species. It is highly uncertain how the cumulative impacts of so many influences could impact regional ecosystems.

Climate change may introduce increasing variability in ecosystem processes and species biodiversity, but it could also stimulate additional development throughout the Arctic. As permafrost thaws and economic activity in a region expands, the risks associated with engineering and operations may also increase. Decreasing severity of winter weather patterns may improve transportation opportunities, infrastructure and shipping logistics, which in turn may increase opportunities to expand both terrestrial and marine mining (Bankes 2010). A survey conducted by Jackson (2014) suggests that of the 485 mining industry representatives that responded to surveys, Alaska ranked in the top 10 of 112 jurisdictions that were favorable and attractive for future investment.

With increased potential of development comes certain probability of development challenges associated infrastructure and engineering in the Arctic. In regions where warming or thawing permafrost have occurred, there is also increased occurrence of compromised foundations and structural instability of buildings, roads and railways. Thawing permafrost is structurally weak, resulting in settling that damages infrastructure (Schaefer et al. 2011, Schaefer et al. 2012). Constructing and maintaining roads, railways, and building structural foundations on unstable, thawing permafrost is poorly understood (Ljunggren and Rocha 2011). The integrity of manmade structures and pipelines built on thawing permafrost could collapse and increase the likelihood of accidents like oil and chemical spills.

2.4 Recommended Conservation Measures

NOAA is responsible for applying an "ecosystem approach to sustainable fisheries management[14]". Federally managed species designated with fisheries management plans (FMPs), must be managed in a manner that ensures long term sustainable yields. To this goal, species distribution and abundance data is collected and evaluated; spanning diverse habitat conditions and for various life history stages. Stock assessments are conducted to determine future sustainable harvest. Many of these indicators are presented in the Ecosystem Considerations Chapter found within the annual Stock Assessment and Fisheries Evaluation (SAFE) report (Zador 2015) (NPFMC 2015a, b, e). The report summarizes recent analysis and highlights trends and changing conditions, that may inadvertently guide future fisheries data collection and analysis.

As identified in several papers cited in this section, the expanding influence of climate change has the potential to introduce increasing variability in accurately predicting the condition of fisheries in the future. Should these currently identified trends continue or intensify, they

[14] NOAA Fisheries is responsible for the stewardship of the nation's living marine resources, habitats, interactions and ecosystems, under mandates derived from numerous key statutes including the: 1) Magnuson-Stevens Fishery Conservation and Management Act, 2) Endangered Species Act, 3) Marine Mammal Protection Act, 4) National Aquaculture Act, and 5) National Environmental Protection Act. An ecosystem approach was adopted to address all these mandates simultaneously and also consider cumulative effects of management decisions and human influences (Executive Order 13547 of July 19th 2010; Ocean Research Advisory Panel 2013).

threaten sustainable management of marine fisheries. Adding to the difficulty, the best indicators of climate change and ocean acidification (e.g., temperature, salinity, oxygen, and carbonate chemistry) are not currently collected at spatial and temporal scales that accurately represent Alaska's LME's and subsequent fisheries. A common theme from subject matter experts in marine fisheries under the influence of climate change, is the need to identify and address key "data and information gaps" (Griffis et al. 2008, Osgood 2008, NOAA Ocean Acidification Steering Committee 2010). Without robust and targeted data collection and analysis of key ecosystem indicators, accurate assessment of change in the fisheries can be increasingly difficult to identify and consider in management actions.

It is widely recognized that human influences to ecosystem processes in freshwater systems influence downstream marine estuaries, and nearshore and coastal zones. These potential impacts are likely further exacerbated by the prevailing influence of climate change. A growing body of literature identifies many post project marine monitoring programs are chronically under sampled and limited historical time-series do not provide statistically defensible analysis of change, or provide the ability to implement adaptive EFH management measures (Bernhardt et al. 2005 and 2007, Palmer and Febria 2010). Our ability to measure and discern between climate changes and anthropogenic impacts becomes more possible with targeted data collection and analysis of marine systems over longer periods.

Functional ecosystem processes (headwater streams through marine systems) provide water quality and support species biodiversity, abundance and sustainable fisheries. Ecosystem variables can be measured and monitored to assess marine conditions, such as the physical, chemical, or biological components of habitats or the presence, abundance, or distribution of these habitats. Long term measuring and monitoring of marine habitats and their associated species should be employed to discern between project impacts and climate change.

General Recommendations

- Conduct pre-project, systematic sampling of a projects impacted region to establish a baseline to discern between climate driven change or project driven impacts.
- Baseline data collection and post-project monitoring efforts should be commensurate with the project size, level of effect, and expected project life. A longer timeframe may be needed should the project affect habitats that are less resilient to recover.
- Select habitat attributes that represent physical, chemical, and biological components, including the presence, absence, abundance, or distribution of EFH species over time.
- Mitigation measures and reasonable alternatives should consider impacts to EFH with attention to any long-term influences from climate change.
- Projects that will have decadal-scale effects should consult with or brief NMFS and the NPFMC for interpretation as to whether or not the activity will adversely affect any federally managed fishery resource.

- Projects should include design alternatives to account for the potential of changing weather patterns, water levels, increased storm activity (buffering techniques), and exposure to higher energy environments.
- Action agencies should hold combined meetings with local and regional biological resource managers and communities to detail climate change uncertainties, include communities and their resources at risk.

Chapter 3 Wetlands and Woodlands

3.1 Introduction – Current Condition

Whether hydrologically confined or connected to surface and groundwater aquifers, wetland and woodland complexes are extensive throughout Alaska. The ecosystem processes and functions provided by these biomes are integral components of water quality, the condition of watersheds and ultimately support fisheries sustainability. Wetlands typically occur in topographic settings where surface water collects or groundwater discharges, making the area wet for extended periods of time (Tiner 1996). Wetlands also exist within and between aquatic and woodland habitats and typically are influenced by both habitats (Welsch et al. 1995). Wetland and woodland complexes can be characterized as hydrologically connected or confined (disconnected) to other ground or surface waters (Naiman and Bilby 1998, Northcote and Hartman 2004, Furniss et al. 2010). Connected watersheds (open waters in riparian areas and floodplains) have both bidirectional and unidirectional hydrologic exchanges with riverine systems. Bidirectional flows (i.e., from wetlands or woodlands to streams/rivers and vice versa) occur through the lateral movement of surface water and groundwater between the channel and riparian/floodplain areas. In contrast, unidirectional flows (i.e., from wetlands to rivers/streams but not vice versa) occur in up-gradient areas (e.g., hillslopes and nearby uplands) outside the floodplains. Confined wetlands (e.g., isolated wetlands in basins, broad flats, or slopes) have the potential for only unidirectional hydrologic flows from wetlands to the river network through precipitation or flooding events but have no groundwater connection or influence (EPA 2015). Confined wetlands are influenced by climate and geography, and occur across various hydrologic gradients; from wetlands having permanent connections with perennial channels to isolated wetlands having little to no ground or surface water connections (Tiner et al. 2002, EPA 2015).

3.2 Alaska Metrics

3.2.1 Wetlands

Snowmelt and rainfall saturate the Alaskan landscape, forming extensive freshwater wetland areas ranging from lowlands and depressions to hillsides and slopes (Hall et al. 1994). Alaska's wetlands occupy approximately 43 percent or 690,000 km^2 (266,410 mi^2) of the state's 1.7 million km^2 (663,267 mi^2) surface area (Dahl 1990). The majority of Alaska’s wetlands are in the interior, Arctic, and western regions of the state. Interior Alaska encompasses 28.7 million hectares (ha) (71 million acres [ac]), and the Arctic and western regions contain a total of 37.6 million ha (93 million ac) of wetlands. According to the U.S. Fish and Wildlife Service (2013), only 43 percent of Alaska's wetlands are mapped with 36 percent available digitally via the internet.

Due to the expansive terrestrial landscape, Alaskan wetland ecosystem types vary considerably across geographic regions and climatic zones. Treeless expanses of moist and wet tundra underlain by permafrost occur in most of the Arctic and northwestern portions of Alaska, while the interior region contains millions of acres of black spruce (*Picea marina*), muskeg, and floodplain wetlands dominated by deciduous shrubs and emergents. At least two-thirds of Alaska's wetlands are comprised of Palustrine scrub/shrub (Hall et al. 1994). Shrub and herbaceous bogs dominate much of the landscape. Wetlands are also abundant in the valleys and basins associated with large river systems such as the Yukon, Kuskokwim, Porcupine, Tanana, and Koyukuk Rivers (Hall et al. 1994).

Predominant freshwater wetland types include bogs, grass wetlands, and sedge wetlands. Occurring throughout Alaska, bog habitats include shrub-bog and forested-bog types. Shrub-bogs are characterized by spongy peat deposits, tannic acidic waters, and an overlying vegetative layer of thick sphagnum moss. Evergreens and shrubs are the most abundant woody plants found in forested-bog habitats. Alaska's grass wetland communities are classified as mesic graminoid herbaceous which are dominated by water-tolerant grass species that occur in clumps or tussocks and may be intermixed with pure stands of sedges. Sedge wetlands are dominated by tall sedges, cottonwood grasses, rushes, or bulrushes and are typically inundated with water. These wetlands occur in very wet areas of floodplains; in the slow-flowing margins of ponds, lakes, streams, and sloughs; and in depressions of upland areas (Viereck et al. 1992, ADF&G 2006, Walker et al. 2009).

3.2.2 **Woodlands**

Alaska's woodlands are extensive; there are approximately 48.6 million ha (120 million ac) of forestland with >10 percent tree cover in the state. Alaska's old-growth coastal temperate rainforest can be subdivided into different habitat types based on the relative mix of species which, in turn, is a function of soil type and drainage, elevation, and latitude (Viereck et al. 1992, Gallant et al. 1995). The cooler temperatures, low sun angles, and shorter growing seasons in high-latitude forests favor dominance by conifers. Old-growth coastal temperate rainforest first emerges in regions of south central Alaska such Resurrection Bay or in Cook Inlet. However, this vegetation type dominates Alaska's coastal zone from Prince William Sound through Southeast Alaska to the Pacific Northwest. The major coastal temperate rainforests include western hemlock (Tsuga heterophylla) (46 percent), mixed hemlock/spruce (26 percent), Sitka spruce (17 percent), cedar (5 percent), and hardwood/deciduous (4 percent) (ADF&G 2006).

Most of this forestland is found in interior Alaska which stretches from the Kenai Peninsula to the south slope of the Brooks Range and is classified as "boreal forest." The boreal forest occupies over 60 percent of the total forest area of Canada and Alaska. About 5.3 million ha (13 million ac) of forest occurs along Alaska's southeast coast and is classified as coastal temperate rainforest. Over 95 percent of this coastal temperate rainforest lies within the Tongass and Chugach National Forests (ADF&G 2006, Albert and Schoen 2007). Boreal forests are dominated by coniferous trees; species may vary regionally depending on soil conditions and variations in the microclimate. Broadleaved trees occur in pure stands or are mixed with conifers. Needleleaf, broadleaf, and mixed forest communities occur in the interior forested lowland and upland areas across a variety of sites, such as floodplain terraces, streambanks, lake margins, and highlands; on burned or otherwise disturbed areas; and near timberline. These forests are dominated by white (*P. glauca*) and black spruces. Deciduous forests of balsam poplar (*Populus balsamifera*), quaking aspens (*P. tremuloides*), or a mix of these two species develop on floodplains of meandering rivers and bottomlands (Viereck et al. 1992, Gallant et al. 1995).

The Cook Inlet Transition Zone is defined as a region between the interior boreal and coastal temperate rain forests, generally ranging from south of the Alaska Range surrounding Cook Inlet and stretching northward into the Susitna River Valley. This zone has the mildest climate in the boreal region and is generally free from permafrost (ADF&G 2006). Tall scrub communities dominated by alder and willow form thickets on streambanks, floodplains, and drainage ways. Coniferous forests include white, black, and Sitka (P. sitchensis) spruces, while deciduous forests are dominated by quaking aspen (Populus tremuloides), paper birch (Betula papyrifera), and black cottonwood (P. trichocarpa). Mixed forest types may contain spruce in combination with any of these other common broadleaf species (Viereck et al. 1992, Gallant et al. 1995).

Alaska's high latitude Arctic tundra occurs from the crest of the Brooks Range northward to the Arctic Ocean and is known as the Arctic Slope. The Arctic Slope includes the northern side of the mountains, the northern foothills, and the flat coastal plain. It is the only true Arctic biogeographic province in the U.S. The dominant plant species of tundra habitats are sedges, low and dwarf shrubs, and graminoids interspersed with forbs as well as mat- and cushion-forming plants and scattered nonvascular bryophytes (ADF&G 2006). Trees are generally unable to establish in Arctic tundra habitats due to an underlying impermeable permafrost layer complemented by thin soils (Viereck et al. 1992). Above tree line elevations in the Alaska, Brooks, and Chugach Mountain Ranges alpine tundra also occurs. Maritime tundra also is present along the coastal areas of southwestern Alaska and the western Alaska Bering Sea Islands (ADF&G 2006).

3.3 Physical, Biological, and Chemical Processes

3.3.1 Wetlands

Ecosystem functions and bio-chemical processes in Alaska's wetland types vary widely depending on regional climate patterns, topography, geology, hydrology, and vegetation (Quinton et al. 2003, King et al. 2012, Walker et al. 2012, Harms et al. 2016). Recent studies conducted in Alaska indicate wetland processes increase biological productivity supporting EFH and associated fisheries. These processes regulate water quality and provide refuge to dependent aquatic species (Wipfli et al. 2007, Whigham et al. 2012). Decomposed plant matter and detritus form the foundation of nutrient sources and trophic dynamics for many species of freshwater invertebrates and fish (Fellman et al. 2009, Shaftel et al. 2011, Dekar et al. 2012, King et al. 2012, Walker et al. 2012). Wetlands facilitate natural biochemical processes that facilitate hydrologic equilibrium throughout watersheds and provide the foundation for several EFH attributes.

Generally, wetlands regulate surface and groundwater recharge and discharge, maintain water balance, and in stream flow (Carter 1996, Bullock and Acreman 2003). Many wetlands primarily serve as discharge areas releasing water to tributaries. Wetlands connected to tributaries provide temporary storage of water which decreases runoff velocity, reduces flood peaks, and distributes storm flows over an extended period of time. This natural water level mitigation reduces in stream erosion and scour of benthic substrates in the stream beds. Wetlands improve water quality by effectively sequestering, filtering and removing suspended sediments, heavy metals and pesticides. Through these natural processes wetlands convert anthropogenic constituents into useful and beneficial organic forms. (Carter 1996, Callahan et al. 2015). Wetlands provide habitats, including breeding and nesting grounds, for a variety of fish and wildlife species.

3.3.2 Woodlands

The ecosystem functions and processes of Alaska's woodland types also vary considerably depending on regional climate patterns, topography, geology, hydrology, and species of vegetation (Oakley et al. 1985). Generally, riparian forests are functionally defined as three-dimensional ecotones of interaction that include both terrestrial and aquatic components, providing decomposition and recomposition of the existing fauna/flora. These ecotones extend vertically down into groundwater regimes and above the canopy, and horizontally across floodplains and the broader terrestrial landscape (Everest and Reeves 2007). Similar to wetlands, woodlands also provide a variety of biotic functions. Forest canopies regulate water temperature by providing shade to watersheds. Woodlands provide large volumes of leaf litter fueling primary and secondary production and aquatic trophic dynamics. Beneficial to freshwater fisheries, trees deposit large woody debris (LWD) and root wades, creating instream habitat, promoting lateral channel meander, pools and riffles, and providing organic nutrient (Everest and Reeves 2007).

Woodland vegetation influences stream water chemistry through processes including direct chemical uptake and indirect influences such as supplying organic matter to soils and channels, modifying water movement, and stabilizing soils (Dosskey et al. 2010). Woodlands also play a critical role in nutrient cycling between terrestrial and aquatic habitats. Nutrient retention, especially in regulating denitrification by microbial flora/fauna, and organic input (dead plant material) directly influence the food availability and growth rates of fish in both upstream and floodplain habitats (ADF&G 2006). Woodland trees also serve as an important food source for juvenile salmon rearing in watersheds. Aquatic and terrestrial invertebrates that thrive in woodland watersheds comprise a substantial biomass of organic nutrients (Broadmeadow and Nisbet 2004, Dekar et al. 2012). Both diversity and density of aquatic invertebrates is higher in lakes and streams with abundant woodland areas (ADF&G 2006). Trees also influence fish habitat by providing inputs of LWD, promote channel structure and complexity and maintain stream bank stability (NRC 2002, Dekar et al. 2012).

3.4 Source of Potential Impacts

3.4.1 Upland Activities

Upland activities can impact EFH through both point source and nonpoint source pollution. Nonpoint source impacts are discussed here. Technically, the term “nonpoint source” means anything that does not meet the legal definition of point source in Section 502(14) of the Clean Water Act (CWA); which refers to discernible, confined, and discrete conveyance from which pollutants are or may be discharged. Land runoff, precipitation, atmospheric deposition, seepage, and hydrologic modification (generally driven by anthropogenic development), are the major contributors to nonpoint source pollution (ADEC 2013a). The major sources of nonpoint pollution discussed in detail in this document include those listed below.

- Silviculture/Timber Harvest (Section 3.2.2)
- Pesticides (Section 3.2.3)
- Urban and Suburban Development (Section 3.2.4)
- Road Building and Maintenance (Section 3.2.5)
- Flood Control/Shoreline Protection (Section 5.2.11)

Nonpoint source pollution is usually lower in intensity than an acute point source event but may be more damaging to fish habitat in the long term. Deegan and Buchsbaum (2005) place human impacts to marine habitats into three categories: (1) permanent loss, (2) degradation, and (3) periodic disturbance. Nonpoint source pollution may be a periodic disturbance that creates a situation of degradation and leads to permanent loss. It may affect sensitive life stages and processes, is often difficult to detect, and have impacts that go unnoticed for a long time. When population impacts are detected, they may not be tied to any one event or source and may be difficult to correct, clean up, or mitigate.

The impacts of nonpoint source pollution on EFH may not necessarily represent a serious, widespread threat to all species and life history stages. The severity of the threat of any specific pollutant to aquatic organisms depends on the pollutant type and concentration and the length of time a particular species and its life history stages are exposed to the pollutant. For example, species that spawn in areas that are relatively deep with strong currents and well-mixed water may not be as susceptible to pollution as species that inhabit shallow, inshore areas near or within enclosed bays and estuaries. Similarly, species whose egg, larval, and juvenile life history stages utilize shallow, inshore waters and rivers may be more prone to coastal pollution than species whose early life history stages develop in offshore, pelagic waters (Baker et al. 2011).

3.4.2 Silviculture/Timber Harvest

Recent revisions to federal and state timber harvest regulations in Alaska and best management practices (BMPs) have resulted in increased protection of EFH on federal, state, and private timber lands (USDA 2015a). These revised regulations include forest management practices, when fully implemented and effective, may prevent or minimize adverse effects to EFH. However, if these management practices are ineffective or not fully implemented, timber harvest could have both short- and long-term impacts on EFH throughout many coastal watersheds and estuaries. Historically, timber harvests in Alaska were not conducted under the current protective standards, and these past practices may have degraded EFH in some watersheds.

3.4.2.1 *Potential Adverse Impacts*

In both small and large watersheds, there are many complex and important interactions between fish and forests (Northcote and Hartman 2004). If appropriate environmental standards are not followed, forest conditions after harvest may result in altered or impaired instream habitat structure and watershed function. However, when implemented modern forestry practices prevent or minimize most of the potential effects on EFH. Potential impacts to EFH have been greatly reduced by the adoption of BMPs designed to protect fish and habitat.

There are five major categories of silviculture activities that may adversely affect EFH if appropriate forestry practices are not followed: 1) construction of logging roads, 2) creation of fish migration barriers, 3) removal of watershed and streamside vegetation, 4) hydrologic changes and increased sedimentation, and 5) disturbance associated with log transfer facilities (LTFs) and in-water log storage (Section 5.2.12). Possible effects to EFH include the following (Trombulak and Frissell 2000, Northcote and Hartman 2004, EPA 2005, Frissell and Shaftel 2014):

- Removal of the dominant vegetation and conversion of mature and old-growth upland and riparian forests to tree stands or forests of early seral stage;
- Reduction of soil permeability and increase in the area of impervious surfaces;
- Increase in erosion and sedimentation due to surface runoff and mass wasting processes, which potentially also affect riparian areas;
- Impaired fish passages because of inadequate design, construction, and/or maintenance of stream crossings;
- Altered hydrologic regimes resulting in inadequate or excessive surface and stream flows, increased streambank and streambed erosion, and loss of complex instream habitats;
- Changes in benthic macroinvertebrate populations;
- Loss of instream and riparian cover resulting in increased water temperatures;
- Increase in surface runoff with associated inorganic and organic contaminants (e.g., herbicides, fertilizers, heavy metals, dicing salts, and fine sediments) and higher temperatures;
- Alterations in the supply of LWD and sediment which can have negative effects on the formation and persistence of instream habitat features; and
- Excess debris in the form of small pieces of wood and silt which can cover benthic habitat and reduce dissolved oxygen levels.

Construction of Logging Roads

Improperly engineered, constructed, or maintained logging roads and the use of these roads can destabilize slopes and increase erosion and sedimentation (as discussed above). Two major types of erosion may occur: mass wasting and surface erosion. Mass wasting, such as landslides, debris slides, slumps, earthflows, debris avalanches, and debris flows, can be directly or indirectly caused or exacerbated by timber harvest and road building on high-hazard soils and unstable slopes (Spence et al. 1996). Thus, accelerated erosion rates from roads, because of debris slides, may range from 30 to 300 times the natural rate in forested areas. However, this varies with terrain in the Pacific Northwest (Sidle et al. 1985). Erosion from roadways is most severe when construction practices do not include properly located, sized, and installed culverts; proper ditching; and ditch blocker water bars (Furniss et al. 1991). Contributing up to 90 percent of the total sediment production, roads are generally considered to be the major source of sediment to water bodies adjacent to harvested forest lands (EPA 2005). The eroded sediment, such as rill erosion and channelized flow or sheet erosion or overland flow, delivery to downslope waterways reduces habitat quality and availability for aquatic macroinvertebrates on which salmon feed and reduces the exchange of oxygenated water in spawning gravels, decreasing the survival time of salmon eggs and embryos (Murphy 1995). BMPs included in current federal and state forest practices require the avoidance of hazardous slopes or the development of site-specific hazard management plans (EPA 2005, USDA 2008).

Creation of Fish Migration Barriers

Stream crossings (bridges and culverts) on forest roads; that are inadequately designed, installed, or maintained, can alter the existing waterway through changes to the physical habitat structure, hydrology, and water quality. This can potentially lead to species loss and altered ecosystem communities. In addition, it can result in full or partial barriers to both upstream and downstream fish migration, eliminating or reducing access to spawning sites and fragmenting habitat patches (Daigle 2010, Maitland et al. 2016). For example, in two watersheds in northwestern Washington, impassable culverts reduced juvenile coho salmon (*O. kisutch*) rearing capacity by 30 to 58 percent (Roni et al. 2002, Pess et al. 2003). Currently, 36 percent of the stream crossing structures in the Tongass National Forest meet juvenile fish passage standards for upstream migration (USDA 2015a). Forest Plan standards stipulate that juvenile fish will have unrestricted upstream passage within a defined range of stream flows (USDA 2015a). Current fish passage standards on the Tongass National Forest stipulate that juvenile fish be able to successfully swim through culverts during approximately 98 percent of the year (USDA 2015a).

Perched and undersized culverts can accelerate stream flows so that these structures become velocity barriers for migrating fish. However, perched culverts are prohibited under current BMPs, and all culverts are now subject to sizing requirements designed to allow for the passage of fish and significant flood events.

Blocked culverts result from undersized designs or inadequate maintenance of removed debris. When a culvert is blocked, it can result in displacement of the stream from the downstream channel to the roadway or roadside ditch, resulting in dewatering of the downstream channel and increased erosion of the roadway. Under modern BMPs, however; culverts must be properly sized and maintained.

Culverts and bridges deteriorate structurally over time. Failure to replace or remove them at the end of their useful life may cause partial or total fish passage blockage. Current BMPs require the removal of culverts upon road closure unless other measures are warranted. Channel incision can often occur downstream of a culvert and generally moves upstream. An existing culvert can act as a grade control, halting the upstream progression of a head cut and causing further channel regrade (Castro 2003); therefore, caution should be used when removing culverts since the unchecked upstream progression of a head cut can cause further damage to EFH. Additional information on culverts is available in the Alaska Department of Fish and Game (ADF&G) and Alaska Department of Transportation and Public Facilities (ADOT&PF) Memorandum of Agreement for the Design, Permitting, and Construction of Culverts for Fish Passage (ADF&G and ADOT&PF 2001), NMFS Northwest Region’s Anadromous Salmonid Passage Facility Design (NMFS 2011), and ADF&G’s Guide to the Procedures and Techniques used to Inventory and Assess Stream Crossings 2009-2014 (Eisenman and O’Doherty 2014).

Removal of Watershed and Streamside Vegetation

Timber harvest activities that remove streamside vegetation increases the amount of solar radiation reaching the stream and can result in warmer water temperatures, especially in small, shallow streams of low velocity. In southeastern Alaska, Meehan (1969) found that the maximum temperatures of logged streams without riparian buffers exceeded that of unlogged streams by up to 2.3ºC (36.1ºF) but did not reach lethal temperatures. In cold climates, the removal of riparian vegetation can result in lower water temperatures during winter, increasing the formation of ice, damaging, and delaying the development of incubating fish eggs and alevins.

Adverse effects on Pacific salmon from warm-water temperatures include: (1) delayed or blockage of adult migration; (2) increased adult mortality and reduced spawning success, including gamete survival during pre-spawning holding; (3) reduced growth of alevins/ juveniles; (4) reduced competitive success relative to other fishes; (5) out-migration from unsuitable habitats and truncation of spatial distribution; (6) increased disease virulence with reduced disease resistance; and (7) potentially harmful interactions occurring with other habitat stressors (Dunham et al. 2001, Materna 2001, McCullough et al. 2001, Sauter et al. 2001, Marine and Cech 2004). Current BMPs require the retention of riparian buffers for shade which should limit changes in water temperature and dissolved oxygen.

By removing watershed or streamside vegetation, timber harvest reduces transpiration losses from the landscape and decreases the absorptive capability of the groundcover. These changes can result in increased surface runoff during periods of high precipitation and decreased base flows during dry periods (Myren and Ellis 1984, Heifetz et al. 1986). Reduced soil strength can result in destabilized slopes and increased sediment and debris input to streams (Swanston 1974). Sediment deposition in streams can reduce benthic community production (Culp and Davies 1983) with fine sediment causing mortality of incubating salmon eggs and cap sediment causing the emergence of alevins (Koski 1981, EPA 2005), thus reducing the amount of habitat available for juvenile salmon (Heifetz et al. 1986). Cumulative sedimentation from logging activities can significantly reduce the egg-to-fry survival of coho and chum salmon (*O. keta*) (Cederholm and Reid 1987). Reductions in the supply of LWD also result when old-growth forests are removed, thus, causing a loss of habitat complexity which is critical for successful salmonid spawning and rearing (Bisson et al. 1988, Murphy and Koski 1989). These effects occur when vegetation is removed within a stream's watershed but are intensified when streamside vegetation is removed. Current riparian buffer standards and BMPs are being implemented in most instances (USDA 2008), and long-term effectiveness studies are being conducted to determine if timber harvest has any effect on habitat condition (Martin and Grotefendt 2001, Martin 2009).

Hydrologic Changes and Increased Sedimentation

According to the Tongass Land Management Plan Revision (USDA 2015c), forest management activities affect water quality and quantity and the timing of water flows through changes in soil and watershed conditions. Most watersheds are in a state of dynamic equilibrium where changes occur naturally because of changes in weather patterns. Because of the overriding influence of climate and basin resiliency, changes in streamflow and sediment delivery resulting from management activities (e.g., timber harvest) are difficult to measure.

Sediment is water-transported earth material; it may be transported as either a suspended load or a bedload. A suspended load is carried within the water column, while bedload material moves (rolls or bounces) along the bottom of the stream or riverbed. Suspended load causes water to have a turbid or murky appearance. Under natural conditions, the majority of suspended load and bedload transport occurs during storm runoff events (USDA 2003).

The mass wasting of soil, streams cutting new channels, and bank erosion are the main natural processes creating sediment. Landslides cause large but temporary increases in suspended and bedload sediments. Stream and riverbed or bank erosion may contribute to sedimentation over long periods of time. Steep terrain and large amounts of rainfall make the land sensitive to natural sediment production and to sediment produced by road construction and timber-harvesting activities.

Forest management activities that have the greatest potential to affect soil erosion, including sheet rill, gully, or mass wasting erosion, are associated with timber harvest and include road and log-landing construction, rock pit development, and some yarding methods. Road construction increases soil erosion because of the destabilizing effect of cuts, fills, and drainage alteration and the lack of protective vegetation cover on road surfaces and other disturbed areas. The actual amount of erosion caused by roads is not known or reliably quantifiable (USDA 2003).

Sediment that settles on or penetrates into the stream bed is of more concern than suspended sediment and can lead to long-term deleterious changes to fish and invertebrate populations. Soil mass wasting constitutes the most potentially damaging type of erosion and is thought to be the major cause of accelerated erosion resulting from silviculture activities. Although mass wasting has the potential positive effect of providing new sources of woody debris and gravel, it also negatively affects aquatic habitats by destroying viable eggs via smothering and bed load overturn and by destroying habitat elements (e.g., pools, riffles, and log discharge) for fish (USDA 2003). Standards and guides, BMPs, and other relevant mitigation measures are applied to minimize these potential adverse effects.

3.4.2.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of silviculture/timber harvest on EFH and to promote the conservation, enhancement, and proper functioning of EFH. The references listed below apply to all conservation recommendations.

- For all potential adverse impacts to EFH from silviculture/timber harvest, the current standards and guidelines for the Tongass National Forest in southeast Alaska can be found at https://fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5367422.pdf. This Forest Plan is currently being amended; the newly proposed plan (USDA 2015c) is available at http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd480655.pdf.
- The current standards and guidelines for the Chugach National Forest, including soils and fish, water, and riparian areas, can be found at http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm8_028736.pdf. This Forest Plan

is currently being revised; the newly proposed plan (USDA 2015b) is available at http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd486944.pdf.

- The Forest Service Region 10 Best Management Practices Policy, Soil and Water Conservation Handbook, FSH 2509.22 can be found at http://www.fs.usda.gov/wps/portal/fsinternet/!ut/p/c4/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gjAwhwtDDw9_AI8zPyhQoY6BdkOyoCAGixyPg!/?ss=1110&navtype=BROWSEBYSUBJECT&cid=fsbdev2_038796&navid=160000000000000&pnavid=null&position=Not Yet Determined.Html&ttype=detail&pname=Region 10- Land & Resource Management.
- The Alaska Division of Forestry's booklet on implementing BMPs for timber harvest operations (ADNR 2011) includes BMP compliance descriptions and guidance for compliance monitoring and can be found at http://forestry.alaska.gov/Assets/uploads/DNRPublic/forestry/pdfs/forestpractices/FRPA_fieldbook_final_5-11_2.pdf.
- The State of Alaska Forest Resources & Practices Regulations (ADNR 2013a, ADNR 2013b) can be found at http://forestry.alaska.gov/Assets/uploads/DNRPublic/forestry/pdfs/forestpractices/PDF_Forest_Resources_and_Practices_Act_text-May_2013_update.pdf.
- The State of Alaska riparian management standards can be found at http://forestry.alaska.gov/Assets/uploads/DNRPublic/forestry/pdfs/forestpractices/STREAMCLASSIFICATIONMATRIX.pdf.

Stream Buffers

Timber operations in watersheds with EFH should adhere to modern forest management practices and BMPs, including the maintenance of vegetated buffers along all streams to the extent practicable to reduce sedimentation and supply large wood. In Alaska, buffer width is site-specific and varies by stream class (Class I, II, III, IV, and Non-streams), stream process groups (flood plain, glacial outwash, alluvial fan, low gradient contained, moderate gradient/mixed control, moderate gradient contained, high gradient contained, palustrine, and estuarine), channel type and stream gradient and is dependent on the use by anadromous and resident fish. Riparian management standards differ on public and private lands. Riparian buffers required on federal lands can be found in the Tongass and Chugach National Forests Resource Management Plans (USDA 2015c, USDA 2015b). Riparian management on the Tongass National Forest is also performed in accordance with the Tongass Timber Reform Act; which does not allow commercial harvesting within 30.5 meters (m) (100 ft) on either side (horizontal distance) of Class I streams and Class II streams that flow directly into a Class I stream. Riparian buffers required on other lands must comply with the State of Alaska Forest Resources & Practices Regulations (ADNR 2013a, ADNR 2013b). See the references listed in the previous section for more details.

Estuary and Beach Fringe

For timber operations adjacent to estuaries or beaches, vegetated buffers should be maintained, as needed, to protect EFH. Estuaries are ecological systems at the mouths of streams where fresh and salt water mix and where salt marshes and intertidal mudflats are present. The landward extent of an estuary is the limit of salt-tolerant vegetation (not including the tidally influenced stream or river channel incised into the forested uplands), and the seaward extent is a stream's delta at mean low water. The estuary fringe is an area of approximately 305 m (1,000 ft) slope distance around all identified estuaries and should be maintained as unmodified forest. The beach fringe is an area of approximately 305 m (1,000 ft) slope distance inland from mean high tide around all marine coastlines. The beach fringe should be maintained as mostly undisturbed forest that contributes to the maintenance of the ecological integrity of the biologically rich tidal and intertidal zones (USDA 2015c).

Watershed Analysis

A watershed analysis is a procedure for assessing important riparian and aquatic values and processes in a watershed context. It is designed to:

- Help set the stage for project-level planning and decisions,
- Strengthen NEPA analyses and decisions, and
- Focus interdisciplinary discussions on key watershed resources (USDA 2008).

The scope and intensity of the watershed analysis should be commensurate with the level of risk associated with the NEPA decision and the information necessary to support that decision. Watershed analyses require site-specific, field-based site evaluations and include the following methods: field inventory of all affected stream reaches to verify fish presence, stream classes, and channel types; consideration of cumulative effects of past, present, and future timber sales within the watershed; assessment of current condition; and additional analyses. A watershed analysis should be incorporated into timber and silviculture projects when possible (Nichols et al. 2013).

Forest Roads

The development of forest roads can be a major cause of increased sedimentation in streams, and road culverts can block or inhibit upstream fish passage. Roads need to be designed to minimize sediment transport problems and to avoid fish passage problems. Recommended conservation measures for forest roads include, but are not limited to, those listed below.

- Incorporate erosion control and stabilization measures in project plans for stabilizing all human-caused soil disturbances. Stabilization measures include treating unstable soils with effective and appropriate erosion control measures to prevent or minimize sedimentation and erosion of unstable soils.
- Improve engineering, construction, and maintenance of logging roads to reduce landslides. Avoid construction on highly unstable, uplifted marine sediment and on slopes in excess of the soil's internal angle of friction. Avoid locating roads and landings

on a slope greater than 67 percent, on an unstable slope, or in a slide-prone area. Seed, mulch, develop terraces, or combine treatments to control erosion after logging road construction.

- Avoid construction of roads across alluvial floodplains, mass wastage areas, and braided bottom lands.
- Seek road locations that avoid fish streams; cross streams only when other locations are not feasible and fish habitat can be protected. Where roads are located near fish streams, avoid the introduction of sediment and debris during clearing, construction, and operation activities. Restrict logging road density or traffic during the wet season and possibly close logging roads to manage sediment runoff. Excess excavation material must not encroach upon the stream course; deposit all excess material in a suitable, stabilized upland site. Leave as much undisturbed ground cover between the road and the stream as feasible. Require complete end haul of excess excavation where there is the probability of downhill movement of that material into the stream. To prevent introducing debris into a stream in sufficient quantity to degrade water quality, fall trees away from all fish-bearing waters, standing waters, and other surface waters.
- Meet fish passage direction at locations where roads cross fish streams. Specify permissible uses of heavy machinery and the timing of road construction activities.
- Design roads so that drainage structures intercept and carry runoff from the hillside and inside portions of a crowned road surface for forest roads utilizing through-cuts or partial/full bench road construction.
- Install and space drainage structures as necessary to accommodate peak flows or to ensure adequate drainage of unstable soils. Slope drainage ditches along the roadbed to the nearest relief culvert. Discharge from road ditches should be cross drained to filter on natural forest floor rather than flowing directly into streams.
- Avoid the introduction or spread of invasive species during road construction, reconstruction, and maintenance.

3.4.3 Pesticides

Pesticides are a diverse group of chemical substances intended to prevent, destroy, control, repel, kill, or regulate the growth of undesirable biological organisms in agriculture and a range of non-agricultural uses (e.g., forestry, irrigation ditches, stagnant water, etc.). They include insecticides, herbicides, fungicides, nematicides, molluscicides, rodenticides, repellents, fumigants, disinfectants, wood preservatives, antifoulants, and others. Over 900 different active pesticide ingredients are currently registered for use in the U.S. and are formulated with a variety of other inert ingredients that may also be toxic to aquatic life. Legal mandates regulating pesticides include the CWA and the Federal Insecticide, Fungicide, and Rodenticide Act. Water quality criteria for the protection of aquatic life have only been developed for a few of the currently used ingredients (EPA, Office of Pesticide Programs). In Alaska, the Pesticide Control Program is administered by the Alaska Department of Environmental Conservation's (ADEC) Division of Environmental Health (http://www.dec.state.ak.us/EH/pest/index.htm). Nationwide, the most comprehensive environmental monitoring efforts have been conducted by the U.S. Geological Survey (USGS) as part of the National Water Quality Assessment Program.

While agricultural runoff is a major source of pesticide pollution in the lower 48 states (Ryberg et al. 2014, Stone et al. 2014), the most common sources of pesticides in Alaska are from other human activities, such as fire suppression on forested lands, forest site preparation, noxious weed control, right-of-way (ROW) maintenance (e.g., roads, railroads, power lines), algae control in lakes and irrigation canals, riparian habitat restoration, and urban and residential pest control (ADEC 2015a).

Pesticides are frequently detected in freshwater and estuarine systems that provide EFH. Pesticides can enter the aquatic environment as single chemicals or as complex mixtures. Direct applications, surface runoff, spray drift, agricultural return flows, and groundwater intrusions are all examples of transport processes that deliver pesticides to aquatic ecosystems. Habitat alteration from pesticides is different from more conventional water quality parameters because, unlike temperature or dissolved oxygen, the presence of pesticides can be difficult to detect due to limitations in proven methodologies. This monitoring may also be expensive. As analytical methodologies have improved in recent years, the number of pesticides documented in fish and their habitats has increased. In addition, pesticides may bioaccumulate in the ecosystem by retention in sediments and detritus which are ingested by macroinvertebrates which, in turn, are eaten by larger invertebrates and fish, the process of bio-accumulation and bio-magnification (Howell et al. 1992).

3.4.3.1 *Potential Adverse Impacts*

There are three basic ways that pesticides can adversely affect EFH: (1) a direct, lethal, or sublethal toxicological impact on the health or performance of exposed fish; (2) an indirect impairment of aquatic ecosystem structure and function; and (3) a loss of aquatic macroinvertebrates that are prey for fish and aquatic vegetation which provides physical shelter for fish.

Fish kills are generally rare when pesticides are used according to their labels. Most effects of pesticide exposures to fish are sublethal. This is a concern if they impair the physiological or behavioral performance of individual animals in ways that will decrease their growth or survival, alter migratory behavior, or reduce reproductive success. In addition to early development and growth, many pesticides have been shown to impair fish endocrine, immune, nervous, and reproductive systems (Moore and Waring 2001). Historically, sublethal impacts of pesticides on fish health were rarely addressed and, therefore, are poorly understood. Over the past few years, the study of acetylcholinesterase-inhibiting insecticides has shown that sublethal exposures affect the fitness of exposed salmonids and, ultimately, may result in population-level consequences (Johnson et al. 2008, Baldwin et al. 2009, NMFS 2009).

Understanding the consequences of sublethal impacts to fish remains a focus of recent and ongoing NMFS research (Scholz et al. 2000, Sandahl et al. 2005, Laetz et al. 2009). Between 2008 and 2015, NMFS submitted seven biological opinions to the EPA on the registration of 31 active pesticides whose ingredients can have their own toxic properties that may result in adverse effects on salmon or their prey. Many of these pesticides can produce severe effects on individuals as well as populations of Pacific salmonids under NMFS jurisdiction (http://www.nmfs.noaa.gov/pr/consulation/pesticides.htm).

The effects of pesticides on ecosystem structure and function can be key factors in determining the cascading impacts of those chemicals on fish and other aquatic organisms at higher trophic levels (Preston 2002). These factors include impacts on primary producers (Hoagland et al. 1996), aquatic microorganisms (DeLorenzo et al. 2001), and macroinvertebrates that are prey species for fish. For example, many pesticides are specifically designed to kill insects. Not surprisingly, these chemicals are toxic to insects and crustaceans that inhabit river systems and estuaries. Overall, pesticides will have an adverse impact on fish habitat if they reduce the productivity of aquatic ecosystems.

Some herbicides are actually toxic to aquatic plants that provide shelter for various fish species. A loss of aquatic vegetation could damage nursery habitat or other sensitive habitats, such as eelgrass beds and emergent marshes.

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and
3.4.3.2 minimize potential adverse impacts of pesticides on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Incorporate integrated pest management plans and BMPs as part of the authorization or permitting process to ensure the reduction of pesticide contamination in EFH (Fulton et al. 1999). If pesticides must be applied, consider area, terrain, weather, droplet size, pesticide characteristics, and other conditions to avoid or reduce effects to EFH.
- Carefully review labels and ensure that application is consistent with the product's directions. Follow local, supplemental instructions such as state-use bulletins, if available.
- Avoid the use of pesticides within 150 m (500 ft; linear) and/or 305 m (1,000 ft; aerial) of anadromous fish bearing streams.
- For forestry vegetation management projects, follow the ADEC measures that establish a 11-m (35-ft) pesticide-free protective area from any surface or marine water body and require that pesticides not be applied within 61 m (200 ft) of a public water source (ADEC 2013a).
- Consider current and recent meteorological conditions. Rain events may increase pesticide runoff into adjacent water bodies. Saturated soils may inhibit pesticide penetration.
- Do not apply pesticides when wind speeds exceed 16 kilometers per hour (kph) (10 miles
3.4.4 per hour [mph]).
- Begin the application of pesticide products nearest to the aquatic habitat boundary and proceed away from the aquatic habitat; do not apply pesticides toward a water body.

Urban and Suburban Development

Urban and suburban development is a major (cumulative) threat to EFH (NMFS 1998a, b). Urban and suburban development and the corresponding infrastructure result in four broad categories of impacts to aquatic ecosystems: hydrological, physical, water quality, and biological (CWP 2003).

3.4.4.1 *Potential Adverse Impacts*

Direct impacts of general urban and suburban development on EFH are discussed below and are related to the watershed effects of land development, including stormwater runoff. Other development-related impacts, including dredging (Section 5.4.1), discharge of fill material (Section 5.4.4), and flood control and shoreline protection (Section 5.4.11), are discussed in later sections of this document.

Development activities within watersheds and in coastal marine areas can impact EFH during both long- and short-term timeframes. The Center for Watershed Protection (CWP) conducted a comprehensive review of the impacts associated with impervious cover and urban development and found a negative relationship between watershed development and 26 stream quality indicators (CWP 2003). The primary impacts identified include: (1) the loss of hyporheic zones (the region beneath and next to streams where surface and groundwater mix) and riparian and shoreline habitat and vegetation and (2) runoff. Removal of riparian and upland vegetation has been shown to increase stream water temperatures, reduce supplies of LWD, and reduce sources of prey and nutrients to the water system. An increase in impervious surfaces in a watershed, such as the addition of new roads, buildings, bridges, and parking facilities, results in a decreased infiltration to groundwater and increased runoff volumes. These impacts can adversely affect water quality and the shape of the hydrograph in downstream water bodies (i.e., estuaries and coastal waters) (EPA 2007).

The loss of hyporheic zones and riparian and shoreline habitat and vegetation can increase water temperatures and remove sources of cover. Such impacts can alter the structure of benthic and fish (i.e., salmon) communities. Shoreline stabilization projects (Section 5.2.5) that alter reflective wave energy can impede or accelerate natural movements of shoreline substrates, thereby affecting intertidal and subtidal habitats. The channelization of rivers causes a loss of floodplain connectivity and a simplification of habitat. The resulting sediment runoff can also restrict tidal flows and elevations, resulting in losses of important fauna and flora (e.g., submerged aquatic vegetation [SAV]).

Runoff from impervious surfaces (e.g., buildings, rooftops, sidewalks, parking lots, roads, gutters, storm drains, and drainage ditches) is the most widespread source of pollution into the nation's waterways (EPA 1995). Runoff from urban development is an emerging threat, particularly to ecosystems along all coastal margins of the U.S. (McCarthy et al. 2008, Weiss et al. 2008) since urban and suburban development in the U.S. continues to expand in coastal areas at a rate approximately four times greater than inland areas. Impacts from urban and suburban development are generally difficult to control because of the intermittent nature of rainfall and runoff, the large variety of pollutant source types, and the variable nature of source loadings (Safavi 1996). Runoff includes pollutants such as construction sediments, oil from vehicles, road salts, bacteria from failing septic systems, and inorganic and organic contaminants (i.e., heavy metals). The 2000 National Water Quality Inventory (EPA 2002) reported that runoff from urban areas is the leading source of impairment in surveyed estuaries and the third largest source of impairment in surveyed lakes. While our understanding of the individual, cumulative, and synergistic effects of all contaminants on the coastal ecosystem are incomplete, pollution discharges may cause organisms to be more susceptible to disease; impair reproductive success; and cause acute, chronic, and sublethal effects in aquatic species (EPA 2005). Urban areas can have a chronic and insidious pollution potential that one-time events, such as oil spills, do not.

Salmonids and other anadromous fish appear to be particularly impacted by the proportion of impervious cover in a watershed (CWP 2003). In a study in the Pacific Northwest, coho salmon were seldom found in watersheds with above 10 or 15 percent of impervious cover (Luchetti and Feurstenburg 1993). Other studies have shown that impacts to stream quality can be expected when a watershed exceeds 10 percent impervious cover (CWP 2003). Key stressors in urban streams, such as higher peak flows, reductions in habitat complexity (e.g., fewer pools, LWD, and hiding places), and changes in water quality, are believed to change salmon species composition, favoring cutthroat trout (*O. clarkii*) populations over the natural coho populations (May et al. 1997, Livingston et al. 1999).

Stormwater management systems are often built to move water quickly away from roads, resulting in increased velocities and higher peak volumes of water in streams. Uncontrolled higher velocities and higher peak flow volumes of urban stormwater have a greater erosive capacity than stormwater from a forested watershed. Higher velocities and flow volumes erode streambanks and increase stream sediment loads. In a simulation model comparing an urban watershed with a forested watershed, Corbett et al. (1997) demonstrated that runoff from an urban watershed had 5.5 times greater volume and sediment than runoff from a forested watershed. Additionally, reduced canopy cover can often cause higher stream temperatures. Literature reviews and ongoing research illustrate the adverse impacts of urban stormwater discharge and growing communities on fresh water and marine invertebrate, fish, and marine mammal populations (Beach 2002, Neff 2002, LaLiberte and Ewing 2006, Weiss et al. 2008).

Urban stormwater also discharges nonpoint pollutants to soil and water, leading to their eventual bioaccumulation in aquatic species. Polycyclic aromatic hydrocarbons (PAHs) are among the most toxic to aquatic life and can persist for decades (Short 2003). Waterborne PAH levels are often significantly higher in urbanized than nonurbanized watersheds (Fulton et al. 1993). Petroleum-based contaminants contain PAHs which can cause acute toxicity to managed species and their prey at low concentrations when released into the environment through spill, combustion, and atmospheric deposition; some PAHs are known carcinogens and mutagens (Neff 1985).

Sublethal effects of fish exposure to many chemical and metal pollutants often associated with urban stormwater over time may prove more deleterious than concentrations that are immediately lethal. Subtle sublethal effects on fish may include changes in behavior, feeding habits, and reproductive success (Murty 1986). Stormwater contaminants have been shown to negatively alter cellular function and biochemical machinery in many aquatic organisms. These impacts may lead to increased mortality in fish species via carcinogenesis through oxidized metabolites, interference with DNA repair mechanisms, and/or initiation of teratogenesis (prenatal toxicity that causes structural or functional defects in the developing embryo or fetus). Some stormwater contaminants disrupt neurotoxic and olfactory responses that maintain normal homing, predator avoidance, and spawning behavior. They can weaken immune system response and inadvertently increase susceptibility and mortality from diseases. These conclusions are well documented in a variety of fish species (Neff 1985, Muir et al. 1988, Dethloff et al. 1999, Hansen et al. 1999a, Hansen et al. 1999b, Baldwin et al. 2003, Sandahl et al. 2007).

Failing septic systems and combined sewer overflows are an outgrowth of urban development. The EPA estimates that 10 to 25 percent of all individual septic systems are failing at any one time, introducing excrement, detergents, chlorine, and other chemicals into the environment. Even treated wastewater from urban areas can alter the physiology of intertidal organisms (Moles and Hale 2003). Sewage discharge is a major source of coastal pollution, contributing 41, 16, 41, and 6 percent of the total pollutant load for nutrients, bacteria, oils, and toxic metals, respectively (Kennish 1998). Nutrients such as phosphorus concentrations are particularly indicative of urban stormwater runoff (Holler 1990) and may lead to algal blooms, eutrophication, loss of biodiversity, and the expansion of invasive species. Sewage wastes may also contain significant amounts of organic matter that exert a biochemical oxygen demand (Kennish 1998). Organic contamination contained within urban runoff can also cause immunosuppression and increased susceptibility to diseases in juvenile salmon (Arkoosh et al. 1998, Arkoosh et al. 2001).

3.4.4.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of urban and suburban development on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Implement BMPs for sediment control during construction and maintenance operations (EPA 1993). These BMPs may include: (1) avoiding ground-disturbing activities during the wet season; (2) minimizing exposure time of disturbed lands; (3) using erosion prevention and sediment control methods; (4) minimizing the spatial extent of vegetation disturbance; (5) maintaining buffers of vegetation around wetlands, streams, and drainage ways; and (6) avoiding building activities in areas with steep slopes and areas prone to mass wasting events with highly erodible soils. Structural BMPs are also recommended and may include sediment ponds, sediment traps, vegetated swales, or other facilities designed to slow water runoff and trap sediment and nutrients.
- Avoid using hard engineering structures for shoreline stabilization and channelization when possible. Use bioengineering approaches (i.e., approaches with principles of geomorphology, ecology, and hydrology) to protect shorelines and riverbanks. For example, use native vegetation for soil stabilization. Naturally stable shorelines and river banks should not be altered.
- Encourage comprehensive planning for watershed protection and avoid or minimize filling and building in coastal and riparian areas affecting EFH. Development sites should be planned to minimize clearing and grading, cut-and-fill, and new impervious surfaces.
- Where feasible, remove obsolete impervious surfaces, such as abandoned parking lots and buildings, from riparian and shoreline areas and reestablish water regime, wetlands, and native vegetation.

- Protect and restore vegetated buffer zones of appropriate width along streams, lakes, and wetlands that include or influence EFH.
- Manage stormwater to replicate the natural hydrologic cycle, maintaining natural infiltration and runoff rates to the maximum extent practicable.
- Where Instream Flows (ISF) are insufficient to maintain the water quality and quantity needed for EFH, establish conservation guidelines for water use permits and encourage the purchase or lease of water rights and the use of water to conserve or augment ISFs in accordance with state and federal water laws.
- Use the best available technologies in upgrading wastewater systems to avoid combined sewer overflow problems and chlorinated sewage discharges into rivers, estuaries, and the ocean.
- Design and install proper wastewater treatment systems away from open waters, wetlands, and floodplains.
- Where vegetated swales are not feasible, install oil/water separators to treat runoff from impervious surfaces in areas adjacent to marine or anadromous waters. Ensure that oil/water separators are regularly maintained such that they do not become clogged and function properly on a continuing basis.

3.4.5 Road Building and Maintenance

Roads and trails have always been part of man’s impact on his environment (Luce and Crowe 2001). Federal, state, and local transportation departments devote huge budgets to the construction and maintenance of roads. In Alaska, roads play an important part in access and, thus, are vital to the economy (Conner 2007). The potential impacts to EFH associated with the building and maintenance of paved and unpaved roads are discussed in the following section.

3.4.5.1 *Potential Adverse Impacts*

Current road design construction and management practices are a vast improvement from previous methods. However, roads still have a negative effect on the biotic integrity of both terrestrial and aquatic ecosystems (Trombulak and Frissell 2000), and the effects of roads on aquatic habitat can be profound (Daigle 2010). Potential adverse impacts to aquatic habitats resulting from the existence of roads in watersheds include: (1) increased surface erosion, including mass wasting events and deposition of fine sediments; (2) changes in water temperature; (3) elimination or introduction of migration barriers such as culverts; (4) changes in streamflow; (5) introduction of invasive species; (6) changes in channel configuration; and (7) the concentration and introduction of PAHs, heavy metals (e.g., copper, lead, zinc), and other pollutants.

Road building and maintenance can affect aquatic habitats by increasing rates of natural disturbances, such as landslides and sedimentation, and even properly designed and constructed roads can become sources of landslides and sedimentation if they are not maintained. Streams, wetlands, or other sensitive areas located near roads may experience increased sedimentation from general road maintenance and use, storms, and snowmelt events. Poorly surfaced or unpaved roads can substantially increase surface erosion. The rate of erosion is primarily a function of storm intensity, surfacing material, road slope, and traffic levels. This surface erosion results in an increase in fine sediment deposition (Cederholm and Reid 1987, Bilby et al. 1989, MacDonald et al. 2001), which has been linked to decreased fry emergence and juvenile densities, loss of winter carrying capacity, and increased predation of fishes in stream gravels. Increased fine sediments can reduce benthic production or alter the composition of the benthic community. For example, embryo-to-emergent fry survival of incubating salmonids is negatively affected by increases in fine sediments in spawning gravels (Koski 1981, Everest et al. 1987, Chapman 1988, Scrivener and Brownlee 1989, Young et al. 1991, Weaver and Fraley 1993). Road crossings also affect benthic communities of stream invertebrates. Additionally, studies show that populations of noninsect invertebrates tend to increase the farther away they are from a road (Luce and Crowe 2001).

Beschta et al. (1987) and Hicks et al. (1991) document some of the negative effects of road construction on fish habitat, including the elevation of stream temperatures beyond the range of preferred rearing where vegetation has been removed, inhibition of upstream migrations, increased disease susceptibility, reduced metabolic efficiency, and shifts in species assemblages. Roads built adjacent to streams can result in changes in water temperature due to increased sunlight reaching the stream if vegetation is removed and/or altered in composition. Roads can also degrade aquatic habitat through improperly placed culverts at road-stream crossings that reduce or eliminate fish passages (Evans and Johnston 1980, Belford and Gould 1989, Clancy and Reichmuth 1990, Furniss et al. 1991).

Roads have three primary effects on hydrologic processes and, therefore, streamflow. First, they intercept rainfall directly on the road surface, in road cutbanks, and as subsurface water moving down the hillslope. Second, they concentrate flow either on the road surfaces or in adjacent ditches or channels. Third, they divert or reroute water from flow paths that would otherwise be taken if the road was not present (Furniss et al. 1991). Another possible consequence of road construction on hydrologic processes is the destabilization of the stream channel by intercepting groundwater flow and channeling water directly into the stream, thus, increasing the frequency and volume of floods as well as erosion and other associated natural processes. Erosion is most severe when poor construction practices are allowed and combined with inadequate attention to proper road drainage and maintenance practices.

Roads can also serve as vectors for introducing nonnative species to a watershed by creating suitable habitat for invasive species, planting invasive species along roadsides for erosion control, and serving as a route for the accidental introduction from vehicular or other traffic traveling along the road system (Trombulak and Frissell 2000).

Pavement and many paving compounds used in road construction, surfacing, and resurfacing and especially pavement sealing and repair products contain high levels of PAHs (Grosenheider et al. 2005, Mahler et al. 2005, Barsh et al. 2007, Teaf 2008). The friction between road and tire surfaces erodes and liberates asphalt, rubber material, and chemical compounds. Further contributions of automotive fluids, fuel, and brake linings concentrate on or near road surfaces and eventually reach streams and the ocean (Grosenheider et al. 2005, Simon and Sobieraj 2006, Weiss et al. 2008). PAHs and heavy metals are toxic to aquatic wildlife, particularly fish and invertebrate populations (Rand 1995, Logan 2007) and accumulate in estuarine, nearshore, and marine fish and invertebrates (Kennish 1997, Johnson et al. 2002, Kennish 2002).

Recommended Conservation Measures

The following conservation measures should be viewed as options to prevent and minimize adverse impacts of road building and maintenance to EFH and to promote the conservation, enhancement, and proper functioning of EFH (EPA 1993).

3.4.5.2

- Roads should be sited to avoid sensitive areas, such as streams, wetlands, and steep slopes, to the maximum extent possible.
- Build bridges rather than culverts for stream crossings when possible. If culverts are to be used, they should be sized, constructed, and maintained to match the gradient and width of the stream to accommodate design flood flows, and they should be large enough to provide for migratory passage of adult and juvenile fishes. If appropriate, use the NMFS Northwest Region's Anadromous Salmonid Passage Facility Design (NMFS 2011) or the culvert guidelines contained in the ADF&G and the ADOT&PF Fish Pass Memorandum of Agreement (ADF&G and ADOT&PF 2001).
- Design bridge abutments to minimize disturbances to stream banks, and place abutments outside of the floodplain whenever possible.
- Specify erosion control measures in road construction plans.
- Avoid side casting of road materials on native surfaces and into streams.
- Use only native vegetation in stabilization plantings.
- Use seasonal restrictions to avoid impacts to habitat during species critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Properly maintain roadway and associated stormwater collection systems.
- Limit roadway sanding and the use of deicing chemicals during the winter to minimize sedimentation and the introduction of contaminants into nearby aquatic habitats. Snow-melt disposal areas should be silt-fenced and include a collection basin. Roads should be swept after break up to reduce sediment loading in streams and wetlands.
- Plan development sites to minimize clearing and grading and cut-and-fill activities.
- Protect existing riparian buffer zones, and wherever practicable, establish new riparian buffer zones of appropriate width on all permanent and ephemeral streams that include or influence EFH. Establish buffers wide enough to support shading, LWD input, leaf litter inputs, sediment and nutrient control, and bank stabilization functions.

Chapter 4 Headwaters, Streams, Rivers and Lakes

4.1 Introduction – Current Condition

Streams, rivers, and lakes are all essential components of complex aquatic ecosystems. The majority of Alaska's water resources are generally pristine due to Alaska's size, remoteness, and sparse population. It has the fewest impaired water bodies and the greatest number of unimpaired water bodies in the country (ADEC 2013b, 2015b). Alaska's vast watersheds are influenced by complex geomorphology, regional climate and seasonal weather patterns, and terrestrial vegetation at enormous spatial and temporal scales. Flowing surface waters directed by these interactions are also supported by three-dimensional subsurface groundwater regimes. Groundwater regimes support surface waters providing the foundation for habitat complexity, ISF, biochemical processes, ecosystem function, and abundant fisheries. According to Sophocleous (2002), surface and groundwater ecosystems are viewed as linked components of a hydrological continuum. These hydrologic processes provide the foundation for EFH, associated biogeochemical processes and sustainable fisheries.

In Alaska, landscape and associated vegetation and hydrologic processes are generally characterized within eight ecoregion descriptions: Arctic tundra in the north, intermontane and boreal predominant regions in the southcentral region, Bering coastal tundra and taiga, Aleutian Island meadows, two other distinct mountain transition zones in the Southcentral region, and the temperate coastal rainforests of the GOA and Southeast Alaska (Nowacki et al. 2001). Within these terrestrial complexes, a multitude of watershed interactions afford an infinite range of variations in stream, river, and lake habitats, all of which provide some measure of ecosystem process or function to EFH associated with anadromous Pacific salmon, the only anadromous species recognized within FMPs in Alaska. However, although anadromous salmon maybe found within all these regional descriptions, the species is not well established in the Arctic tundra ecoregion north of the Brooks Range.

4.2 Alaskan Metrics

Alaska includes 44,659 km^2 (17,243 mi^2) of inland waterways which consist of 12,000 rivers; thousands of streams and creeks; over three million lakes greater than 2 ha (5 ac); and an estimated 100,000 glaciers (Glass 1996, ADF&G 2006, NMFS 2015). Approximately three-fourths of all freshwater resources in Alaska are stored as glacial ice covering about 5 percent of the state (ADF&G 2006). Alpine glaciers and ice fields, glacial and clearwater rivers and streams connect many interior water sheds to Alaska's marine estuarine ecosystem (ADF&G 2006). Over 18,000 Alaskan lakes, rivers, or streams are identified as important habitat for anadromous fish. Southeastern Alaska contains over 5,200 anadromous salmon streams totaling 40,000 kilometer (km) (24,855 miles [mi]) in length (Halupka et al. 2000). Over 20,000 water bodies used by anadromous fish have not yet been catalogued or documented in the Anadromous Fish Catalogue (Anadromous Fish Act [16.05.087(a)]).

Alaska has approximately 563,270 km (350,000 mi) of primary rivers; however the majority of secondary and smaller headwaters streams have not been mapped (ADF&G 2016). There remain thousands of miles of headwater streams and EFH that play an important role in emerging and rearing salmon that have not been surveyed. For example, fisheries surveys recently conducted by the Southwest Salmon Habitat Partnership, in areas not previously surveyed (Nushagak and Kvichak River drainages) documented salmon in the majority of headwater streams (Woody and O'Neal 2010). Of the 168 km (104.3 mi) of headwater streams surveyed, anadromous salmon were present and documented in 74 percent of head water tributaries. These data support the hypothesis that nearly every stream in many headwaters with less than 10 percent gradient may contain rearing salmon species in some life history stage (7 out of 10 streams).

Alaska's regional watersheds extend from the interior of the state to the Arctic, northwest, and southern coasts (NMFS 2015). Thousands of rivers and streams enter the GOA from southcentral to southeastern Alaska, while numerous rivers and streams enter the Bering Sea from western Alaska and the Alaskan Peninsula. The Yukon River, the longest river in Alaska and the third longest in the U.S. (Brabets et al. 2000), drains a watershed of over 855,000 km^2 (330,117 mi^2) and flows for 3,187 km (1,980 mi) from its headwaters in Canada to the Bering Sea (NMFS 2015). Other large salmon rivers include the Kuskokwim, Stikine, and Copper (Augerot 2005, ADF&G 2006). The Arctic region is crossed by many northward flowing streams, the largest of which is the Colville River. This region also contains continuous permafrost, tundra, and numerous small lakes and ponds (NMFS 2015). Lake Iliamna is Alaska's largest lake with a volume of 115 km^3 (15,968 ft^3) encompassing an area of approximately 2,590 km^2 (1,000 mi^2). Other large lakes include Clark, Becharof, Naknek, Ugashik, Teshekpuk, Tustumena, Kenai, and Wood-Tikchik (Augerot 2005, ADF&G 2006).

Alaska's Harding Icefield (777 km^2 [300 mi^2]), located in the Kenai Peninsula, is the largest in North America and one of only four remaining icefields in the U.S. Thirty-five of Alaska's glaciers stem from the Harding Icefield. These glaciers feed and influence nearly all major riverine systems in Alaska and provide the headwaters to some of the state's largest rivers, including the Copper, Susitna, and Tanana (ADF&G 2006). Alaska's freshwater ecosystems range from the temperate coastal rainforest of the southeast region with maritime climate and dense riparian vegetation, to the boreal forest of interior Alaska with continental climate and modest riparian vegetation, and the Arctic tundra of the North Slope with sparse riparian vegetation (ADF&G 2006).

4.3 Physical, Biological, and Chemical Processes

The MSA defines EFH as waters and substrates necessary for fish. EFH not only includes visible surface water and hard substrate but also habitat attributes and ecosystem processes that provide water quality, quantity, and nutrient resources essential for survival. For anadromous Pacific salmon, these waterways provide migratory corridors for both outbound fry and inbound adults, water quality and quantity over spawning and rearing substrates, protection from freezing winter conditions as embryos in hyporheic gravel substrates (wet substrates beneath and adjacent to streams) and nutrient availability during spring emergence and rearing (Scheuerell et al. 2007). Salmon require cool waters in sufficient quantities to allow for migration and successful spawning. Relevant geomorphic stream characteristics include channel width, depth and slope, substrate composition, and pool and riffle sequences. Organic inputs come from canopy leaf litters and riparian grasses that provide nutrient subsidies. LWD provides shelter, nutrient as well as promotes lateral channel meander and geomorphic complexity (Scheuerell et al. 2007).

Salmon themselves inadvertently provide nutrient subsidies to watersheds, numerous aquatic and terrestrial species of flora and fauna, as well as their own progeny. All these biochemical and geomorphic influences are the ecosystem processes within watersheds that directly influence the sustainability of salmon populations at numerous life history stages (Boulton et al. 1998, Gende et al. 2004).

<u>Hyporheic Zone</u>

The hyporheic zone is the interactive ecotone between surface water and groundwater beneath and alongside rivers and streams (Stanford and Ward 1988, 1993, Brunke and Gonser 1997,
4.5.1 Boulton et al. 1998). It is the gravel substrate where adult salmon deposit eggs and the salmon embryos develop over the winter. The condition of that substrate and the water moving through that substrate plays an integral role in embryo development and over winter survival. Three major types of hyporheic zones have been characterized: wetted channel, parafluvial, and floodplain scale (Naiman et al. 2000). Interactions within these hydrologic regimes is regionally based on geology and riverine topography and is often temporal in response to ISFs and seasonal influences (Winter et al. 1998, Naiman et al. 2000, Sophocleous 2002, Malcolm et al. 2004, Youngson et al. 2004). The relative contribution of groundwater and surface water to this zone also varies spatially according to local channel morphology, riparian-stream linkages, and hydrology. The hyporheic zone influences various watershed ecosystem processes such as nutrient cycling, vital gaseous exchange, thermal regimes, and even pollutant buffering (Dahm et al. 1998, O'Keefe and Edwards 2002, Pinay et al. 2002, Battin et al. 2003, Hancock et al. 2005, Mulholland and Webster 2010).

Depending on the region, watershed, species, or even individual run, salmon eggs and embryos can be deposited throughout summer and fall months (Schindler et al. 2010). The embryos reside there until the following spring when they emerge as fry. The hyporheic zone subsequently supports salmon egg and embryo survival and development through Alaska’s often harsh winters under freezing conditions (Cunjak and Power 1986, Cunjak 1988, 1996). In Japan, Urabe et al. (2014) reported that channel morphology via hyporheic flow was a significant determinant in maintaining population diversity in chum salmon. Salmon spawning activity is usually observed in gravel substrate with favorable hydraulic properties water gradients and associated
4.5.2 temperature (Power et al. 1999, Geist 2000, Geist et al. 2002, Garland et al. 2003, Schindler et al. 2003, Malcolm et al. 2005, Smith 2005, Huusko et al. 2007).

<u>Headwater Streams</u>

The watershed network can be partitioned into headwater and network systems based on hydrologic (e.g., precipitation, heat dynamics), geomorphic (e.g., channel reach type, woody debris), and biological (e.g., organic matter, energy input) process characteristics. These systems are important sources of sediments, water, nutrients and organic matter for downstream reaches (Gomi et al. 2002). Four topographic units compose headwater streams: hillslopes (divergent or straight contour lines, typically no channelized flow), zero-order basins (an unchannelized hollow with convergent contour lines), transitional channels (temporary or ephemeral channels emerging from zero-order basins), and first- (upper-most, unbranched channels with perennial or sustained intermittent flows) and second- (headwaters) stream channels. The complex interaction of geomorphic and hydrologic processes affects the biological process at various temporal/spatial scales. The frequency, intensity, and duration of these spatio-temporal scales are important factors altering the responses and recovery time of riparian vegetation, channel morphology, and biological communities (Gomi et al. 2002, Freeman et al. 2007).

Headwater streams are abundant and unique aquatic systems that amongst several other attributes provide habitat complexity, increased prey availability and simultaneous refuge from predation (Meyer et al. 2007, Whigham et al. 2012). In Alaska, headwater streams are abundant and can be an important spawning and rearing habitat for juvenile salmonids (Woody and O'Neal 2010, Copeland et al. 2014). Unlike higher-order stream reaches that receive large volumes of Marine Derived Nutrient (MDN)[15] from salmon carcasses, food webs in headwater reaches are more reliant on terrestrial subsidies from invertebrates, riparian areas, and instream nutrients (Piccolo and Wipfli 2002, Wipfli and Gregovich 2002, Wipfli et al. 2007, Dekar et al. 2012, Shaftel et al. 2012, Walker et al. 2012).

Not all Pacific salmon emerge from substrate and emigrate to the sea. Depending on the region, watershed, species, habitat conditions, and forage opportunities some salmon species, such as coho and chinook (*O. tshawytscha*), disperse into small and non-natal streams to take advantage of rearing and prey opportunities (Bradford et al. 2001, Ebersole et al. 2006, Daum and Flannery 2011, Copeland et al. 2014). Armstrong et al. (2013) recently documented the freshwater phase juvenile coho salmon moving considerable distances (350 to 1,300 m [1,148 to 4,265 ft]), up and down stream, daily between warmer and colder water habitats to take advantage of abundant prey opportunities. Freshwater phase coho exhibiting these feeding migrations had accelerated their metabolism and digestion, grew faster, and were better prepared for their marine phase. Levings and Lauzier (1991) identified juvenile chinook salmon using the main stem river to over winter. Suitable overwinter habitat is also provided to rearing juvenile salmonid as a result of hyporheic water processes (e.g., groundwater influence, high levels of dissolved oxygen, low-flow velocities, instream cover LWD, and even anchor ice) (Heifetz et al. 1986, Cunjak 1996, Reynolds 1997, Mouw 2004, Roussel et al. 2004, Smith 2005, Huusko et al. 2007, Brown et al. 2011, Huusko et al. 2013).

4.3.3 Organic Matter

Organic matter, particularly Dissolved Organic Matter (DOM), and decomposition are important sources of nutrients for primary production in freshwater ecosystems. Organic matter is incorporated into stream ecosystems through autotrophic (macrophytes, periphyton, phytoplankton) and heterotrophic (protozoans, bacteria, macroinvertebrates, aquatic vertebrates) pathways. Heterotrophic organisms derive energy from DOM, fine and coarse particular organic matter. These organic inputs usually come from outside the aquatic ecosystem; naturally falling into waters or forced during storm events, rain fall, periods of spring flooding and snowmelt. The majority of these sources arrive in the form of needles and leaf litter, grasses and LWD (Vannote et al. 1980, Bisson and Bilby 1998). Nutrient subsides are also delivered by adult salmon in anadromous watersheds (see Marine-Derived Nutrients section below). These organic matter

[15] The terms Marine Derived Nutrients (MDN) and Salmon Derived Nutrients (MDN) are used synonymously throughout the current literature depending on the source, discipline or topic. For simplicity, MDN will be used throughout this report to signify nutrient derived from any life stage of salmon.

sources provide the foundation for primary and secondary production in watersheds. Energy flows out of net production through shredding, grazing and decomposition of Particulate Organic Matter (POM) and gradual excretion of DOM. Of these, the main energy flow from producers is through direct grazing of living tissues and detritus from external sources (Murphy 1998).

Primary production in Alaskan riverine ecosystems is predominantly by benthic algae found within a complex assemblage of algae, bacteria, fungi, and periphyton (biofilm) (Verspoor et al. 2010). This energy dynamic changes predictably in response to trends in geomorphology and fluvial processes (Vannote et al. 1980). Export and retention of organic matter into a stream channel largely determine the contribution of aquatic primary producers to a stream ecosystem. Both organic matter and nutrients undergo a cycling process called spiraling (Murphy 1998), which occurs where nutrients are assimilated by living organisms; returned to the stream by decomposition, respiration, or excretion; and eventually reincorporated farther downstream (Bisson and Bilby 1998). Streams with short spirals have high retention capacity and efficiently utilize organic matter and nutrients (Murphy 1998).

In diverse stream environments, macroinvertebrates have an important influence on nutrient cycles, primary production, decomposition, and translocation of materials. Benthic invertebrates graze periphyton from mineral and organic substrates; reduce decomposing vascular plant tissue; feed directly on living vascular macrophytes, decomposing wood, FPOM, and animal tissue acting as sieves to remove particulate matter from suspension (Mulholland 1992, Wallace and Jackson 1996). The linkages between flow parameters, resource availability, respiratory/thermal requirements, and biotic interactions (e.g., competition and predation) influence the structure and function of these diverse benthic stream ecosystems. Secondary production within these stream ecosystems includes a combination of features such as abundance, biomass, growth, reproduction, survivorship, and generation time (Wallace and Jackson 1996). Estimated production of macroinvertebrate prey and predators in first and second-order low-gradient streams indicated that invertebrate predators represented 25 to 35 percent of macroinvertebrate production (Wallace and Jackson 1996, Piccolo and Wipfli 2002, Wipfli and Gregovich 2002, Wipfli et al. 2007, Wipfli and Baxter 2010).

Tundra and grassland areas have similar physical, chemical, and biological linkages. The Alaskan tundra is a cold-climate landscape that has vegetation but is devoid of trees (ADF&G 2006), while dry grassland communities occur across boreal regions of Alaska on dry, south-facing slopes or well-drained lowland sites (Viereck et al. 1992). The overall annual productivity of these freshwater ecosystems generally consists of low nutrient input levels, low temperatures, prolonged periods of ice presence, and short growing seasons. Spring-fed streams with stable environments exhibit a greater diversity in primary producers. Tundra streams tend to be ephemeral and low in pH and nutrients with corresponding low productivity. Medium-sized rivers that drain lakes typically have moderate to high levels of productivity and associated diversity in invertebrate fauna (Wrona et al. 2005).

4.3.4 Marine-Derived Nutrients

Pacific salmon accumulate up to 99 percent of carbon, nitrogen, and phosphorous (among other nutrients) in their body mass during their ocean phase growth. The salmon spawning migrations transport large volumes of these MDN back into watersheds. These nutrients cross traditional ecosystem boundaries, providing nutrient subsidies to other aquatic species (invertebrates and fish) and terrestrial species (e.g., bears, wolves, and passerine birds) and fertilize a variety of riparian vegetation (Willson and Halupka 1995, Cederholm et al. 1999, Gende et al. 2002, Naiman et al. 2002, Hilderbrand et al. 2004, Quinn 2005, Rüegg 2011). MDN increase stream and river productivity both immediately after spawning and during the following spring. Studies indicate that these nutrient subsidies introduced during the summer and fall of one year persist in hyporheic substrates through the following year, providing nutrient sources to resident fish and invertebrate populations and inadvertently increasing prey abundance for emerging salmon fry the following spring (Bilby et al. 1998, Hilderbrand et al. 1999, O'Keefe and Edwards 2002, Hocking et al. 2009, Rinella et al. 2013).

This process influences food webs through bottom-up effects of increased primary and secondary production (Schindler et al. 2003, Verspoor et al. 2010, Verspoor et al. 2011) or when consumers switch their diets to salmon (Gende et al. 2001, Scheuerell et al. 2007, Swain and Reynolds 2015). Salmon also liberate and export nutrient from streams through spawning activities (Moore et al. 2007). Salmon disturb stream beds during nest digging, thereby suspending nutrient-laden sediments into the water column (Moore 2006). Salmon smolts also transfer nutrients during their migration to the ocean (Moore and Schindler 2004, Scheuerell et al. 2005). Salmon are net importers of nutrients to stream and riparian habitats by evidence of nutrient export (Janetski et al. 2009, Holtgrieve and Schindler 2011). The assimilation of MDN into riparian ecosystems via these pathways (e.g., hyporheic flowpaths, epilithon layer) varies over time and among different areas (Mitchell and Lamberti 2005, Helfield and Naiman 2006, Cak et al. 2008, Albers 2010). Once in the riparian zone, MDN’s are incorporated into a variety of pools including soil organic matter, vegetation, microbial biomass, and roots (Ben-David et al. 1998, Bilby et al. 2003, Bartz and Naiman 2005, Wilkinson et al. 2005, Gende et al. 2007, Fellman et al. 2008). Nutrients not immediately assimilated into watershed processes are transported downstream from headwater streams to estuaries and nearshore zones (see Estuaries and Nearshore sections).

4.3.5 Riparian Zones

Rivers, streams, and terrestrial ecosystems (i.e., forested or vegetated hillslopes) are strongly linked. The riparian zone transitions from aquatic vegetation at the wetted edge to terrestrial vegetation of the upslope forest. The surrounding riparian vegetation affects stream processes (e.g., radiation inputs and outputs, supply and storage of organic matter [wood and litter]) and the structure of stream banks (Richardson et al. 2005). Retention and routing of allochthonous organic matter (e.g., riparian/lateral input of leaf litter and LWD) are important factors affecting the biological processes in headwater streams (Gomi et al. 2002). Riparian zones are connected to lotic systems (e.g., small headwater streams to large braided rivers) via the exchange of materials and organisms. Aquatic food webs derive energy from both in-stream and terrestrial sources (Vannote et al. 1980). The basic components of food webs (e.g., nutrients, detritus, and organisms) cross spatial boundaries (Polis et al. 1997). Terrestrial subsidies (e.g., invertebrates, coniferous needles, deciduous leaves, and woody materials) act as basal resources for many aquatic organisms (Gutierrez 2011). For instance, terrestrial invertebrates are an import food source for salmon in headwater and small streams; they account for 50 percent of the prey consumed by juvenile salmon (Allan et al. 2003).

4.3.6 Hydrology

The hydrology and geology of freshwater ecosystems influence the physical and chemical characteristics of rivers and streams. For instance, the quality of surface water and groundwater is strongly affected by ground strata and bedrock geology (Brabets et al. 2000). Land cover influences a number of hydrologic factors, such as snow accumulation, soil moisture depletion, surface runoff, infiltration, and erosion. These factors, in turn, can affect the water quality of a particular stream or river. The composition of certain types of vegetation may also affect water quality. In addition, land cover directly influences the permafrost because of the thermal properties that determine the quantity of heat entering and leaving the underlying ground where the permafrost occurs (Brabets et al. 2000). Streamflow quantity and variability also have considerable influence on the quality of surface water. The quantity of water in a stream or river influences its ability to support aquatic communities, to assimilate or dilute waste discharges, and to carry suspended sediment and geochemical weathering products (Brabets et al. 2000)

Instream flow dynamics, shoreline and benthic deposition and erosion, and sediment transport in woodland river and stream ecosystems is largely influenced by the presence of LWD. The persistence of LWD influences channel dynamics by stabilizing banks and substrate material and by providing subsequent succession of riparian vegetation cover for terrestrial predators. LWD also promotes the formation of pool habitats and provides spawning bed integrity and habitat for aquatic invertebrates, elevating in-stream productivity. LWD groundings often lead to the formation of downstream islands, bars, and slough habitats in large rivers, whereas in smaller streams, lakes, and ponds, LWD plays an important role in habitat creation immediately adjacent to the input point. Decaying terrestrial debris often accumulates near LWD, providing a food source for aquatic invertebrates (Naiman et al. 2000, Gurnell et al. 2002, ADF&G 2006).

4.3.7 Surface and Groundwater Regimes

Surface water regimes support ISF dynamics which supply the primary medium and energy source for the movement of water, sediment, organic material, nutrients, and thermal energy (Ziemer and Lisle 1998). Important hydrologic pathways include subsurface, overland, and Hortonian overland flows. Subsurface flow accounts for nearly all the water that is delivered to stream channels from undisturbed forested hillslopes. In channels and floodplains, subsurface flow is very important to benthic and hyporheic organisms. Surface water flows occur where the ground strata and soils become fully saturated, consequently forcing subsurface waters to emerge as flowing surface water regimes. The tendency of water to flow horizontally across land surfaces when rainfall has exceeded infiltration and storage capacity is Hortonian overland flow. Increased areas of Hortonian overland flow directly contribute to stream peak flows during storms in headwater channels and have a greater capacity to erode and transport sediment.

In contrast to hillslope runoff, stream flow pertains only to surface flow in the channel (Ziemer and Lisle 1998). The surface water/groundwater interface is a crucial point for lateral nutrient fluxes between uplands and aquatic ecosystems and for upstream/downstream (longitudinal) processes in lotic systems (Sophocleous 2002). Annual winter and spring floods distribute sediment and organic debris through the stream system, scour the bed, and remove newly established vegetation in the active channel. These floods can cause mortality of certain benthic invertebrates, altering food webs which affect the trophic structure of these communities.

Through erosion, scour and deposition, extreme floods can create new surfaces that renew dynamic processes of both aquatic and riparian ecosystems. Recessional spring and early summer flows, punctuated by peak flows, control the success of riparian plant seeds to germinate on stream banks and floodplains. Summer low flows allow the settlement of sediments, clearer water, and low-energy habitats to expand (Ziemer and Lisle 1998).

Channel Morphology

Stream channels are important avenues of sediment transport that deliver eroded material from freshwater ecosystems to the ocean. Channels ranging in size from small ephemeral streams to
4.3.8 large rivers exhibit a wide variety of morphologies but share a number of basic processes (Montgomery and Buffington 1998). Channel morphology is influenced by local, systematic downstream variations in sediment input from upslope sources (frequency, volume, and size of sediment supply), the ability of the channel to transport these loads to downslope reaches (frequency, magnitude, and duration of discharge/valley gradient), and the effects of vegetation on channel processes (bank strength, in-channel size, rate of delivery/decay, and orientation/position). Potential channel adjustments to altered discharge and sediment load include changes in width, depth, velocity, bed slope, roughness, and sediment size (Montgomery and Buffington 1998). Spatial variability in sediment supply may govern channel morphology in different portions of a drainage network (Montgomery and Buffington 1998). Positions within a stream network and differences between the transport capacity to sediment supply ratios allow segregation of channel reaches into source, transport, and response segments. Source segments are headwater colluvial channels that act as transport-limited sediment storage sites subject to intermittent debris flow scour. Transport segments are composed of morphologically resilient, supply-limited reaches (bedrock, cascade, and step-pool) that rapidly convey increased sediment inputs. Response segments consist of lower-gradient, more transport-limited reaches (plane-bed, pool-riffle, and dune-ripple) in which significant morphological adjustments occur in response to the increased sediment supply. The distribution of these segment types defines watershed-scale patterns of sensitivity to altered discharge and sediment supply (Montgomery and Buffington
4.4 1998).

4.4.1 Source of Potential Impacts

Mining

Mining within riverine habitats may result in direct and indirect chemical, biological, and physical impacts to habitats within the mining site and surrounding areas during all stages of operations. On-site mining activities include exploration, site preparation, mining and milling, waste management, decommissioning or reclamation, and abandonment (NMFS Starnes and Gasper 2000, 2005b). Mining and its associated activities from exploration to post-operation have the potential to cause adverse effects to EFH by reducing or altering fish habitats or populations in affected watersheds (E&E 2010). The operation of metal, coal, rock quarry, and gravel pit mining in upland and riverine areas has caused environmental damage in urban, suburban, and rural areas. Some of the most severe damage, however, occurs in remote areas where some of the most productive fish habitat is often located (Sengupta 1993). In Alaska, existing regulations promulgated and enforced by other federal and state agencies are designed to control and manage these changes to the landscape to prevent and minimize impacts. However, while environmental regulations may avoid, limit, control, or offset many potential impacts, mining will, to some degree, always alter landscapes, ground and surface water regimes, and environmental resources (NRC 1999).

4.4.2 Mineral Mining

Mining and mineral extraction activities take many forms, such as commercial and recreational suction dredging; placer, open pit, and surface mining; and contour operations. The process for mineral extraction involves exploration, mine development, mining (extraction), processing, and reclamation.

4.4.2.1 *Potential Adverse Impacts*

The potential adverse effects of mineral mining on fish populations and their habitat are well documented (Goldstein et al. 1999, Brix et al. 2001, Hansen et al. 2002, Farag et al. 2003) and depend on the type, extent, and location of the mining activities. Recreational gold mining with equipment such as pans, motorized or nonmotorized sluice boxes, concentrators, rockerboxes, and dredges can adversely affect EFH on a local level. Commercial mining is likely to involve activities on a larger scale, resulting in even greater disturbances (Williamson et al. 1995).

Impacts associated with the extraction of material from within or near a stream or river bed may include: (1) alteration in channel morphology, hydraulics, lateral migration, and natural channel meanders; (2) increases in channel incision and bed degradation; (3) disruption in pre-existing balance of suspended sediment transport and turbidity; (4) direct impacts to fish spawning and nesting habitats (redds), juveniles, and prey items; (5) simplification of in-channel fluvial processes and LWD deposition; (6) altered surface and groundwater regimes and hydro-geomorphic and hyporheic processes; and (7) destruction of the riparian zone during extraction operations. Loss of stream habitat, in particular, is thought to be the single biggest cause of declines of anadromous salmonids in general (Nehlsen et al. 1991, Reeves and Sedell 1992). In addition to the potential loss or alteration of habitat of aquatic waterways, mineral mining effects may include direct and indirect chemical stressors such as mining-related pollution, acid mine drainage (AMD), altered temperature regimes, reduction in oxygen concentration, and the release of toxic materials (e.g., cadmium, copper, zinc) (Johnson et al. 2008, E&E 2010). Many of these impacts have been previously discussed in this document. The discussion below summarizes the impacts that have not been previously addressed.

Scientific literature has many examples of spawning substrate selection by salmonid species being influenced by chemical and physical variables such as instream and inter-substrate flow (hyporheic zone), dissolved gases, nutrient exchange, and temperature. Mining activities may disrupt these physical and geochemical systems initiating and promulgating mineral dissolution or precipitation reactions that can alter pre-mining groundwater quality and chemistry in ways that may be difficult to predict (Lewis-Russ 1997).

Recent studies suggest that diffuse mining-related pollution in rivers may significantly contribute to the loading of metals, principally because mine water contribution may be influenced by altered water tables (Younger 2000). Minerals and metals liberated from rock and soil substrates interact with atmospheric oxygen and water (Jennings et al. 2000, Younger et al. 2002, Jennings et al. 2008). The introduction of this metal and mineral rich runoff or AMD into the aquatic ecosystem can have adverse impacts on the ecology of entire watersheds. Once started, AMD is difficult to stop or reverse. This acidic drainage can dissolve metals and metalloids, causing them to leach from the mined rock into the environment potentially in toxic levels. AMD also lowers pH (increases acidity); salmon populations are adversely impacted by acute and chronic exposure. Salmon are particularly vulnerable to low pH when undergoing the physiological changes that occur during smolts' transition from freshwater to salt water and adult spawners' transition from salt water to freshwater (Chambers et al. 2012). AMD is known to be toxic to fish, algae, zooplankton, and aquatic invertebrate populations at the ecosystem, metabolic, and cellular levels (Buhl and Hamilton 1991, Saiki et al. 1995, West et al. 1995, Barry et al. 2000, Hansen et al. 2002, Peplow and Edmonds 2005, Levit 2010). For example, the release of cadmium via AMD can cause salmon mortality, and chronic exposure to cadmium can cause pronounced sublethal effects such as decreased growth, inhibited reproduction, and population alterations (Levit 2010). The hyporheic zone is especially vulnerable since this zone supports salmon spawning and incubating eggs as well as production of aquatic insects and aquatic vegetation. Groundwater may enter the hyporheic zone in an undiluted condition, leading to injury and mortality of aquatic organisms (including fish) prior to benefiting from the dilution effects of the overlying streamflow (Brunke and Gonser 1997, Gandy et al. 2007).

Metal contamination and exposure has been shown to influence simple migratory behavior and avoidance mechanisms in fish populations (e.g., Goldstein et al. 1999, Hansen et al. 1999a, Brix et al. 2001, Farag et al. 2003, Sandahl et al. 2004). Numerous studies have shown how exposure to toxic contaminants in surface waters can impact fish olfaction which is critical for behaviors such as mating, locating prey, and avoiding predators (see Tierney et al. 2010). Copper contamination in surface waters is common in watersheds with mining activities. McIntyre et al. (2012) recently evaluated the effects of copper exposure on juvenile coho salmon predator avoidance behaviors and found that the exposed juveniles were unresponsive to their chemosensory environment, unprepared to evade nearby predators, and less likely to survive an attack sequence. Additional studies indicate that salmonids exposed to sublethal levels of metals are susceptible to increasing levels of fish pathogens due to stressed immune responses and metabolisms (Jacobson et al. 2003, Peplow and Edmonds 2005, Spromberg and Meador 2005).

The ability to treat or neutralize AMD is very site specific and often unpredictable. Mine waste will be exposed to the natural elements of weathering over a long period of time (CSS 2002). Studies on rivers recovering from metal and mineral contamination concluded that despite efforts to remediate surface water pollution, community recovery in the hyporheic zone may take longer than surface macroinvertebrate recovery due to the continued release of metals by reductive dissolution and exposure to AMD. Depending on the scale of the mining operation and associated topography and hydrogeomorphic processes, active treatment to neutralize AMD may need to last in perpetuity to be effective (Kuipers 2000, Jennings et al. 2008).

The creation of waste dumps, tailings impoundments, mine pits, and other facilities that become permanent physical features of the post-mining landscape can cause fundamental changes in the physical characteristics of a watershed (O'Hearn 1997). Mining and the placement of spoils in riparian areas can cause the loss of riparian vegetation and changes in heat exchange, leading to higher summer temperatures and lower winter stream temperatures (Spence et al. 1996). Bank instability can also lead to altered width-to-depth ratios which further influence temperature (Spence et al. 1996). Mining efforts can also bury productive habitats near mine sites. Although reclamation efforts and mitigation practices may restore topographic land forms to mine sites, these efforts generally fail to restore natural hydrogeomorphic and aquatic functions and associated water quantity and quality within measurable time frames (Kilmartin 1989, Mutz 1998). Additionally, commercial operations may involve road building (Section 3.2.5), tailings disposal, and leaching of extraction chemicals which may affect EFH.

In accessing mineral and ore deposits, many mining methods require withdrawals from groundwater aquifers. These naturally occurring and often saturated groundwater aquifers sustain ISFs. Altered water regimes may change instream channel morphologies, stream gradients, and bank and benthic substrates and disrupt the equilibrium between flow and sediment transport in tributaries (Johnson et al. 1999, Sophocleous 2002). Often these impacts are seen many miles upstream and downstream of the actual mine site, thus, impacting EFH and anadromous species by limiting access to migratory corridors and reducing available spawning and rearing habitat.

4.4.2.2 *Recommended Conservation Measures*

The following measures are adapted from recommendations in Spence et al. (1996), NMFS (2005a), and Washington Department of Fish and Wildlife (2009). These conservation recommendations should be viewed as options to prevent and minimize adverse impacts to EFH due to mineral mining and promote the conservation, enhancement, and proper functioning of EFH.

- To the extent practicable, avoid mineral mining in waters, water sources and watersheds, riparian areas, hyporheic zones, and floodplains providing habitat for federally managed species.
- Schedule necessary in-water activities when the fewest species/least vulnerable life stages of federally managed species will be present.
- Minimize spillage of dirt, fuel, oil, toxic materials, and other contaminants into EFH. Prepare a spill prevention plan, if appropriate.
- Treat wastewater (acid neutralization, sulfide precipitation, reverse osmosis, electrochemical, or biological treatments) and recycle on site to minimize discharge to streams. Test wastewater before discharge for compliance with federal and state clean water standards.
- Minimize the effects of sedimentation on fish habitat. Use methods such as contouring, mulching, and construction of settling ponds to control sediment transport. Additionally, use methods such as sediment curtains to limit the spread of suspended sediments. Monitor turbidity during operations and cease operations if turbidity exceeds predetermined threshold levels.
- If possible, reclaim rather than bury mine waste that contains heavy metals, acid materials, or other toxic compounds to limit the possibility of leachate entering groundwater.

- Restore natural contours and use native vegetation to stabilize and restore habitat function to the extent practicable. Monitor the site for an appropriate time to evaluate performance and implement corrective measures, if necessary.
- Minimize the aerial extent of ground disturbance (e.g., through phasing of operations) and stabilize disturbed lands to reduce erosion.
- For large scale mining operations, stochastic models (as tools for estimating probability distributions of potential outcomes) should be employed to make predictions of ground and surface hydrologic impacts and acid-generating potential in mine pits and tailing impoundments. Supporting model information should describe how the data were collected and included in the model and summarize the governing equations and defense of assumptions made with a sensitivity analysis.

4.4.3 Sand and Gravel Mining

In Alaska, riverine sand and gravel mining is extensive and can involve several methods including wet-pit mining (i.e., removal of material from below the water table); dry-pit mining on beaches, exposed bars, and ephemeral streambeds; and subtidal mining.

4.4.3.1 *Potential Adverse Impacts*

Primary impacts associated with riverine sand and gravel mining activities include: the creation of turbidity plumes and re-suspension of sediment and nutrients, the removal of spawning habitat, and the alteration of channel morphology. These primary impacts often lead to the following secondary impacts: (1) alteration of migration patterns, (2) creation of physical and thermal barriers to upstream and downstream migration, (3) increased fluctuation in water temperature, (4) decreases in dissolved oxygen, (5) high mortality of early life stages, (6) increased susceptibility to predation, (7) loss of suitable habitat (NMFS 2005a), (8) decreased nutrients (from loss of floodplain connection and riparian vegetation), and (9) decreased food production (loss of invertebrates) (Spence et al. 1996).

Turbidity plumes can cause spawning habitat to be moved several kilometers downstream. Reduction in water clarity by sediment plumes can also have behavioral and physiological impacts to fish species. Behavioral impacts may include the avoidance of turbid waters and temporary impacts on the feeding efficiency of fish that rely on visual cues to detect prey. In addition, fish gills can become clogged or damaged by elevated, persistent suspended-solid concentrations (CSA 1993) and lead to suffocation, increased energy demands, and other negative consequences (Michel et al. 2013). Sand and gravel mining in riverine, estuarine, and coastal environments can also suspend materials at the mining sites. Sedimentation may be delayed because gravel removal typically occurs at low flow when the stream has the least capacity to transport fine sediments out of the system. Another delayed sedimentation effect results when freshets inundate extraction areas that are less stable than they were before the activity occurred. In addition, for species such as salmon, gravel operations can interfere with migrations past the site if they create physical or thermal changes either at or downstream from the work site (Williamson et al. 1995).

Extraction of sand and gravel in riverine ecosystems can reduce or eliminate spawning gravels if the extraction rate exceeds the deposition rate of new gravel in the system, reduces gravel depth, or exposes bedrock (Spence et al. 1996). Gravel excavation also reduces the local supply of gravel to downstream habitats. In addition, mechanical disturbance of spawning habitat by mining equipment can lead to high mortality rates in early life stages. Mining can alter channel morphology by making the stream channel wider and shallower. Consequently, the suitability of stream reaches as rearing habitat for federally managed species may be decreased, especially during summer low-flow periods when deeper waters are important for survival. Similarly, a reduction in pool frequency may adversely affect migrating adults that require holding pools (Spence et al. 1996). Changes in the frequency and extent of bed load movement and increased erosion and turbidity can also remove spawning substrates, scour redds (resulting in a direct loss of eggs and young), or reduce their quality by deposition of increased amounts of fine sediments. Deep pools created by the material removal in streams appear to attract migrating adult salmon for holding. These concentrations of fish may result in high losses as a result of increased natural predation or recreational fishing activities in the deep pools. Examples of using gravel removal to improve habitat and water quality are limited and isolated (Williamson et al. 1995).

4.4.3.2 *Recommended Conservation Measures*

The following recommended conservation measures for sand and gravel mining are adapted from the Federal Interagency Working Group (2006), NMFS (2005a), and Williamson et al. (1995). They should be viewed as options to prevent and minimize adverse impacts of sand and gravel mining to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- To the extent practicable, avoid sand/gravel mining in waters, water sources and watersheds, riparian areas, hyporheic zones, and floodplains the serve as habitat for federally managed species.
- Identify upland or off-channel (where the channel will not be captured) gravel extraction sites as alternatives to gravel mining sites in or adjacent to EFH, if possible.
- If operations in EFH cannot be avoided, design, manage, and monitor sand and gravel mining operations to minimize potential direct and indirect impacts to living marine resources and habitat. For example, minimize the areal extent and depth of extraction.
- Include restoration, mitigation, and monitoring plans, as appropriate, in sand/gravel extraction plans.
- Implement seasonal restrictions to avoid impacts to habitat during species' critical life history stages (e.g., spawning season/egg and larval development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

4.4.4 Organic and Inorganic Debris

Organic and inorganic debris and its impacts to EFH extend beyond riverine systems into estuarine coastal and marine systems. Therefore, this topic is discussed here and also addresses impacts of debris to other systems.

Naturally occurring flotsam[16], such as LWD and macrophyte wrack (i.e., kelp), plays an important role in aquatic ecosystems and EFH. LWD and wrack promote habitat complexity and provide structure to various aquatic and shoreline habitats (PFMC and NMFS 2014). The natural deposition of LWD creates habitat complexity by altering local hydrologic conditions, nutrient availability, sediment deposition, turbidity, and other structural habitat conditions. In riverine systems, the physical structure of LWD provides cover for managed species, promotes the formation of habitats and microhabitats (e.g., pools, riffles, undercut banks, and side channels), provides spawning bed integrity and habitat for aquatic invertebrates (elevates in-stream productivity), retains gravel, and helps maintain underlying channel structure (Ralph et al. 1994, Montgomery et al. 1995, Abbe and Montgomery 1996, Spence et al. 1996, Naiman et al. 2000, Gurnell et al. 2002, ADF&G 2006). LWD also plays similar role in salt marsh habitats (Maser and Sedell 1994). In benthic ocean habitats, LWD enriches local nutrient availability as deep-sea wood borers convert the wood to fecal matter, providing terrestrially based carbon to the ocean food chain (Maser and Sedell 1994). When deposited on coastal shorelines, macrophyte wrack creates microhabitats and provides a food source for aquatic and terrestrial organisms, such as isopods and amphipods, which play an important role in marine food webs.

Conversely, inorganic flotsam and jetsam[17] debris can negatively impact EFH. Inorganic marine debris is a problem along much of the coastal U.S. and consists of a wide variety of man-made materials, including general litter, plastics, hazardous wastes, and discarded or lost fishing gear. Marine debris litters shorelines, fouls estuaries, entangles fish and wildlife, and creates hazards in the open ocean. The debris enters waterbodies indirectly through rivers and storm water outfalls and directly via ocean dumping and accidental release. Although laws and regulatory programs exist to prevent or control these issues, marine debris continues to affect aquatic resources.

4.4.5 Organic Debris Removal

Naturally occurring flotsam, such as LWD and macrophyte wrack (i.e., kelp), is sometimes intentionally removed from streams, estuaries, and coastal shores due to dam operations, aesthetic concerns, and commercial and recreational purposes (e.g. active beach log harvests, garden mulch, and fertilizer). However, the presence of organic debris is important for maintaining aquatic habitat structure and function.

4.4.5.1 *Potential Adverse Impacts*

The removal of organic debris from natural systems may adversely impact habitat quality by reducing habitat function. For example, the reduction of LWD inputs to estuaries in the Pacific Northwest has reduced the number of spatially complex and diverse channel systems that provide productive salmon habitat (NRC 1996). Reductions in LWD inputs to estuaries may also affect the ecological balance of estuarine systems by altering rates and patterns of nutrient transport, sediment deposition, and the availability of in-water cover for larval and juvenile fish. In rivers and streams of the Pacific Northwest, the historic practice of removing LWD to

[16] Flotsam is defined as marine debris not deliberately discharged or thrown overboard from a vessel.
[17] Jetsam is defined as marine debris deliberately discharged or thrown overboard from a vessel such as to lighten the ship.

improve navigability and facilitate log transport has altered channel morphology and reduced habitat complexity, thereby negatively affecting habitat quality for spawning and rearing salmonids (Sedell and Luchessa 1982, Koski 1992).

Beach grooming and wrack removal can substantially alter the macrofaunal community structure of exposed sand beaches (Dugan et al. 2000). The species richness, abundance, and biomass of macrofauna associated with beach wrack (e.g., sand crabs [*Emerita analoga*], isopods, amphipods, and polychaetes) are higher on ungroomed beaches (Dugan et al. 2000). The input and maintenance of wrack can strongly influence the structure of macrofaunal communities, including the abundance of sand crabs (Dugan et al. 2000), an important prey species for some managed fish species.

4.4.5.2 *Recommended Conservation Measures*

The recommended conservation measures for organic debris removal are listed below. They should be viewed as options to prevent and minimize adverse impacts of organic debris removal to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Encourage the preservation of LWD whenever possible. Remove it only when it presents a threat to life or property.
- Encourage appropriate federal, state, and local agencies to aid in the downstream movement of LWD around dams, culverts, and bridges wherever possible rather than removing it from the system.
- Educate landowners and recreationalists about the benefits of maintaining LWD.
- Localize and minimize beach grooming practices whenever possible.
- Advise gardeners to only harvest dislodged, dead kelp and leave live, growing kelp (whether dislodged or not). (See ADF&G brochure “Harvesting Kelp and other Aquatic Plants in Southcentral Alaska” http://www.adfg.alaska.gov/static-sf/region2/pdfpubs/kelp.pdf).

4.4.6 Inorganic Debris

Inorganic debris is a chronic problem along much of the U.S. coast and results in littered shorelines and estuaries with varying degrees of negative effects to coastal ecosystems. Nationally, land-based sources of marine debris account for about 80 percent of the marine debris found on beaches and in U.S. waters. Debris can originate from combined sewer overflows and storm drains; stormwater runoff; landfills; solid waste disposals; poorly maintained garbage bins; floating structures; and the littering of beaches, rivers, and open waters. It generally enters waterways indirectly through rivers and storm drains or by direct ocean dumping. Ocean-based sources of debris, including discarded or lost fishing gear (Johnson et al. 2008) and galley waste and trash from commercial merchant, fishing, military, and other vessels, also create problems for managed species.

Congress has passed numerous laws intended to prevent the disposal of marine debris in U.S. ocean waters. The Marine Protection, Research, and Sanctuaries Act, Titles I and II (also known as the Ocean Dumping Act), implements the International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention) commonly known as the MARPOL Annex V (33 CFR 151) for the United States. The MARPOL Annex V is intended to protect the marine environment from various types of garbage by preventing ocean dumping if the ship is less than 46.3 km (25 nautical miles [nm]) from shore. Dumping of unground food waste and other garbage is prohibited within 22.2 km (12 nm) from shore, and ground non-plastic or food waste may not be dumped within 5.6 km (3 nm) from shore.

Laws and regulations that address land-based sources of inorganic debris include the Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act), the Shore Protection Act of 1988, and the CWA. The BEACH Act authorizes the EPA to fund state, territorial, Tribal, and local government programs to test and monitor coastal recreational waters near public access sites for microbial contaminants and to assess and monitor floatable debris. The Shore Protection Act contains provisions to ensure that municipal and commercial solid wastes are not deposited in coastal waters during vessel transport from the source to the waste-receiving station. The CWA regulates discharges of pollutants into U.S. waters. The basis of the CWA, originally the Federal Water Pollution Control Act (FWPCA), was enacted in 1948, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1977. In accordance with the CWA, the EPA implements pollution control programs, such as setting wastewater standards for industry and water quality standards for all contaminants in surface waters. Laws and regulatory programs also prevent or control debris disposal from ocean sources, including commercial merchant vessels (e.g., galley waste and other trash), recreational boaters and fishermen, offshore oil and gas exploration activities, development and production facilities, military and research vessels, and commercial fishing vessels (Johnson et al. 2008).

Despite these laws and regulations, marine debris continues to adversely impact our waters. The National Marine Debris Monitoring Program (NMDMP) was a five-year study (2001-2006) designed to provide statistically valid estimates of marine debris affecting the entire U.S. coastline and to determine the main sources of the debris. Study results indicate that marine debris continues to plague the U.S., and certain regions face larger problems than others (Sheavly 2007, EPA 2011). Alaska was not included in the results of the study because an insufficient number of surveys meeting the sampling criteria were conducted. Hawaii was the only location to demonstrate a significant decrease in all debris. In 2008, Alaska conducted a workshop addressing marine debris problems and potential prevention methods (Williams and Ammann 2009). Generally, marine debris from both ocean- and land-based activities increased across the U.S. by over 5 percent each year during the study period. The most abundant debris items surveyed nationally were straws, plastic beverage bottles, and plastic bags.

4.4.6.1 *Potential Adverse Impacts*

Land- and ocean-sourced inorganic marine debris is a very diverse problem, and adverse effects to EFH are varied. Floating or suspended debris can directly affect managed species via consumption or entanglement which may lead to subsequent starvation, suffocation, and increased vulnerability to predation (Kennish 2002). Floating debris, particularly plastics, will likely increase substantially in estuaries by 2025 due to the continued increase coastal populations and recreational uses (Kennish 2002). Microplastics, which are defined as less than 5 mm (0.2 in) in size, are an emerging marine pollutant, having accumulated in the oceans and sediments in recent years (Lusher 2015). They can resemble the prey species of some commercially important fish species; fish may directly ingest microplastics or ingest lower trophic organisms that have fed on microplastics (Wright et al. 2013). Some species will not only ingest microplastics but also draw plastics into the gill cavity due to their ventilation mechanisms (e.g., shore crab [*Carcinus maenas*]) (Watts et al. 2014). Nanometer-sized microplastics can actually pass through cell membranes, thus, effecting organisms at the cellular level (Lusher 2015).

The potential effects of plastic marine debris ingestion by North Pacific and Bering Sea juvenile salmon and steelhead have been reported to cause direct mortality (e.g., mechanical injury, starvation, or toxicity) or indirect mortality (e.g., biomagnification/bioaccumulation of toxic chemicals and transgenerational epigenetic effects on physiology and behavior) (Myers et al. 2013). The ingestion of microplastics by North Pacific zooplankton suggests that these species (copepods and euphausiids) at the lower trophic levels of the marine food web are mistaking plastic for food which raises the potential risk to higher trophic level species, such as salmon (Desforges et al. 2015).

Toxic substances in plastics can kill or impair fish and invertebrates that use the habitats polluted by these materials (Vegter et al. 2014). In addition, the chemicals that leach from plastics can persist in the environment and bioaccumulate through the food web. Plastics are also subject to fouling; harmful algal bloom species are known to thrive on floating plastics (Masó et al. 2003). Because plastics essentially do not fully degrade in these environments, they pose a long-term pollution hazard (Kennish 2002).

Once floatable debris settles to the bottom of estuaries, nearshore areas, and the open ocean, it can continue to cause environmental problems. Plastics and other materials with a large surface area can cover and suffocate immobile animals and plants, creating large spaces devoid of life. Currents can carry suspended debris to underwater reef habitats where the debris can become snagged, damaging these sensitive habitats. The typical floatable debris from combined sewer overflows includes street litter, sewage containing viral and bacterial pathogens, pharmaceutical byproducts from human excretion, and pet wastes. Pathogens can also contaminate shellfish beds and reefs.

4.4.6.2 *Recommended Conservation Measures*

Pollution prevention and improved waste management can occur through regulatory controls and BMPs as reviewed by Lippiatt et al. (2013). The recommended conservation measures listed in the section below should be viewed as options to prevent and minimize adverse impacts of inorganic debris to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Encourage proper trash disposal, particularly in coastal and ocean settings, and participate in coastal cleanup activities.

- Advocate for local, state, and national legislation that rewards proper disposal of debris (e.g., implementation of a deposit on all plastic bottles).
- Encourage enforcement of regulations addressing marine debris pollution and proper disposal.
- Provide resources and technical guidance for the development of studies and solutions to address marine debris issues.
- Educate the public on the impact of marine debris and provide guidance on how to reduce or eliminate the release of debris into the environment.
- Implement structural controls, such as trash racks, mesh nets, bar screens, and trash booms, to collect and remove trash before it enters nearby waterways. Concentrate floating debris and trash and prevent it from traveling downstream.
- Consider the use of centrifugal separation to physically separate solids and floatables from the water in combined sewer outflows by increasing the settling time of trash and particles.
- Encourage the development of incentives and funding mechanisms to recover lost fishing gear.
- Require all existing and new commercial construction projects near the coast (e.g., marinas and ferry terminals, recreational facilities, and boat building and repair facilities) to develop and implement refuse disposal plans.

4.4.7 Dam Construction and Operation

Dams provide sources of hydropower, water storage, and flood control. The construction and operation of dams may affect basic hydrologic and geomorphic functions including the alteration of physical, biological, and chemical processes that, in turn, may affect water quality, timing, and quantity and alter sediment transport [Adapted from (EPA 2007, Johnson et al. 2008)].

4.4.7.1 *Potential Adverse Impacts*

The potential effects of dam construction and operation on fish and aquatic habitats include: (1) complete or partial upstream and downstream migratory impediment; (2) alterations to water quality and flow patterns; (3) alterations to the distribution and function of ice, sediment, and nutrient budgets; (4) alterations to the floodplain, including riparian and coastal wetland systems and associated functions and values; (5) thermal impacts; and, (6) alterations to downstream estuaries. Salmonids, in particular, face impacts from heavy dam obstruction (Liermann et al. 2012).

Dam construction and operations can impede or block anadromous fish passage and other aquatic species migration in streams and rivers. Unless proper fish passage structures or devices are operational, dams may prevent access to productive upstream spawning and rearing habitats or can alter downstream juvenile migration. Turbines, spillways, bypass systems, and fish ladders also affect the quality and quantity of EFH available for salmon passage in streams and rivers (PFMC and NMFS 2014). The construction of a dam can fragment habitat, resulting in alterations to both upstream and downstream biogeochemical processes.

An understanding of the hydrologic system, including the timing and annual variation of flows and long-term trends in hydrology and climate, is necessary to determine how changes may alter habitat, habitat flow needs, and project operations. Dam operations alter downstream water velocities and change discharge patterns. Water-level fluctuations, altered seasonal and daily flow regimes, and reduced water velocities may affect the migratory behavior of juvenile salmonids and reduce the availability of shelter and foraging habitat (PFMC and NMFS 2014). These modifications can also increase migration times (Raymond 1979). Dam operation effects include pulse-type flows which are sudden changes in flow over relatively short periods of time. These flows most often occur in regulated rivers associated with hydroelectric operations and water resource needs. Based on flow magnitude and various combinations of frequency and duration, hydropower operations may affect flow, water temperature, turbidity, riparian/organic matter, and nutrients which, in turn, may affect fish communities and benthic macroinvertebrates. The effects on anadromous fish can include stranding/trapping of fry and juvenile fish, isolation of habitat features, loss of productive habitat, disruption of spawning, dewatering of redds, scour and flushing of redds, and food chain disruption (Reiser 2005, Reiser et al. 2008).

Many dams have multiple functions including flood control and water storage. Dams that are used for flood control are designed to suppress peak flows; dams that are designed for water storage use the reservoir capacity to store peak flows to increase water supply during normally low-flow periods, thus, dampening flow variation throughout the year (Waples et al. 2009). The result of flood control and water storage is a reduction in the range of flows in the river, which can result in a loss of hydrologic and geomorphic functions and reduce the complexity of salmon rearing habitats. Large floods create new channels and recruit wood from the floodplain. Bank protection to stop river movements across floodplains also reduces habitat. In addition, inhibiting channel movement reduces wood recruitment from floodplains and shifts floodplain forest composition to older age classes over time (Waples et al. 2009). Each of these impacts reduces salmon habitat diversity in the river landscape and, consequently, leads to reduced salmon life history diversity because the habitat types necessary for the expression of certain life history variants are lost (Beechie et al. 2006). These reductions in life history diversity lead to a reduced resilience of salmon populations (Waples et al. 2009).

The effects on the migratory behavior of anadromous species are additionally complicated by the development of reservoirs associated with dams. Reservoir affects include impediments to migration (e.g., increased migration times), thermal barriers, increased predation, and loss of riparian habitat due to the large range of water level fluctuation.

Changes to the natural flow regime have effects on sediment and LWD transport as well as on seasonal icing. Ice formation and breakup are important to flood hazards, fluvial morphology, and fish habitat. An understanding of the relationship between the natural flow regime and ice development and function is necessary to assess how dam operations will affect these processes. An understanding of sediment and LWD transport, geomorphic influence, and an overall sediment budget is also import to understand dam effects. Dam operation can limit the natural processes associated with flooding and ice breakup and can limit or alter natural sediment and LWD transport processes by impeding the high flows needed to scour fine sediments and move gravel and woody debris downstream (PFMC and NMFS 2014). Floods transport sediments, such as silt, sand, gravel, and aquatic plants and animals, leafy debris, and LWD. Curtailing these resources will affect the availability of spawning gravels and simplify channel morphology (Spence et al. 1996).

Changes to the timing and quantity of flow in rivers may result in the loss of riparian wetlands when water levels increase upstream and result in flow alterations downstream of the dam. In general, the greater the storage capacity of a dam the more extensive the downstream geomorphologic and biological impacts (The Heinz Center 2002). Lost wetlands result in a loss of floodplain and flood storage capacity and, thus, a reduced ability to provide flood control during storm events (Johnson et al. 2008).

Dams may affect the thermal regimes of streams by raising or lowering water temperatures. Reductions in river water temperatures are common below dams if the intake of the water is from lower levels of the reservoir. Stratification of reservoir water not only affects temperature but can create oxygen-poor conditions in deeper areas and, if these waters are released, can degrade the water quality of the downstream areas (Johnson et al. 2008). Below a dam, nitrogen supersaturation may also negatively affect migration, as well as incubation or rearing, salmon by causing gas-bubble disease.

Dams may also affect the health and extent of downstream estuaries by altering seasonal flow patterns and reducing the transport of average sediment supply of detritus and nutrients. This can lead to increased competition with nonnative species, influence the success of predators and competitors, and influence the virulence of disease organisms (e.g., bacteria, viruses, and protozoa) (PFMC and NMFS 2014).

4.4.7.2 *Recommended Conservation Measures*

The following conservation recommendations should be viewed as options to prevent and minimize adverse impacts of dams to EFH and to promote the conservation, enhancement, and proper functioning of EFH [Adapted from (EPA 2007, Johnson et al. 2008)].

- Avoid the construction of new dam facilities, where possible.
- Construct and design facilities with efficient and functional upstream and downstream fish passage which ensures the safe, effective, and timely passage of juveniles and adults.
- Retrofit existing dams with efficient and functional upstream and downstream fish passage structures.
- Develop and implement monitoring protocols for fish passage.
- Operate dams within the natural flow fluctuation rates and timing, mimic the natural hydrography, allow for sediment and wood transport, and consider and allow for natural ice function. A run-of-river dam operation in which the volume of water entering an impoundment exits the impoundment with minimal change in storage is optimal and is the preferred mode of operation for fishery and aquatic resource interests. Water-flow monitoring equipment should be installed upstream and downstream of the facility. Reservoir-level fluctuation should also be monitored.

- Understand longer term climatic and hydrologic patterns and how they affect habitat; plan project design and operation to minimize or mitigate for these changes.
- Use seasonal restrictions for the construction, maintenance, and operation of dams to avoid impacts to habitat during species' critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Construct dam facilities with the lowest hydraulic head practicable for the project. Develop the project at a location where dam height can be reduced.
- Downstream passage should prevent adults and juveniles from passing through the turbines and provide sufficient water downstream for safe passage.
- Coordinate maintenance and operations that require drawdown of the impoundment with state and federal resource agencies to minimize impacts to aquatic resources.
- Develop water and energy conservation guidelines for integration into dam operation plans and into regional and watershed-based water resource plans.
- Encourage the preservation of LWD, whenever possible. If possible, relocate debris as opposed to removing it completely. Remove LWD only to prevent damage to property or threats to human health and safety.

  Develop a sediment transport and geomorphic maintenance plan to allow for peak flow mimicking that will result in sediment pulses through the reservoir/dam system and allow for high-flow geomorphic processes.

4.4.8 Commercial and Domestic Water Use

An increasing demand for potable water combined with the inefficient use of freshwater resources and natural events (e.g., droughts) have led to serious ecological damage worldwide (Deegan and Buchsbaum 2005). Because human populations are expected to continue to increase in Alaska, water use, including water impoundments and diversion, is also assumed to increase (Gregory and Bisson 1997). Groundwater supplies 83 percent of Alaska's 1,602 public drinking water systems. Ninety percent of the private drinking water supplies are groundwater. Roughly 1,500,210 cubic m (m^3) (330 million gallons) of water per day from aquifers, which directly support riverine systems, are used for domestic, commercial (including aquaculture), industrial, and agricultural purposes in Alaska (ADEC 2008). Surface water sources serve a large number of people from a small number of public water systems (e.g., Anchorage and several southeastern communities).

4.4.8.1 *Potential Adverse Impacts*

The diversion of freshwater for domestic and commercial uses can adversely affect EFH by (1) altering natural flows and the process associated with flow rates, (2) altering riparian habitats by removing water or by submersion of riparian areas, (3) removing the amount and altering the distribution of prey bases, (4) affecting water quality, and (5) entrapping fishes. Water diversions can involve either withdrawals (reduced flow) or discharges (increased flow).

Water withdrawal alters natural flow, stream velocity, and channel depth and width. Water withdrawal can also change sediment and nutrient transport characteristics (Christie et al. 1993, Fajen and Layzer 1993), increase the deposition of sediments, reduce water depth, and accentuate diel temperature patterns (Zale et al. 1993). Loss of vegetation along streambanks and coastlines due to fluctuating water levels can decrease the availability of fish cover and food and reduce bank stability (Christie et al. 1993). Changes in the quantity and timing of stream flow alters the velocity of streams which, in turn, affects the composition and abundance of both insect and fish populations (Spence et al. 1996). Returning irrigation water to a stream, lake, or estuary can substantially alter and degrade habitat (NRC 1989). Problems associated with return flows include increased water temperature, increased salinity, the introduction of pathogens, decreased dissolved oxygen, increased toxic contaminants from pesticides and fertilizers, and increased sedimentation (Northwest Power Planning Council 1986). Diversions can also physically divert or entrap EFH-managed species.

Water withdrawn from freshwater lakes during construction projects can result in low dissolved oxygen levels due to fluctuating water levels, which stress fish and/or cause mortality (Cott et al. 2008). Fish are particularly susceptible to decreased oxygen levels from water withdrawals during the winter months when lakes are covered by ice; the ice limits the amount of available habitat for overwintering fish when compared with open-water periods (Cott et al. 2008). Water level fluctuations can be especially influential on the natural dispersion of larval and juvenile fish to rearing areas. Aquatic invertebrates can also be significantly impacted by water level variations outside normal seasonal conditions (Cott et al. 2008).

Responsible water utilization can help reduce domestic and commercial water usage (Flowers 2004) which minimizes the effects to EFH. During 1990, industry, mining, and power (23 percent) was the major commercial water use category in Alaska (ADEC 2008). Prudent planning and water usage at the commercial scale also has the advantage of being cost effective.

4.4.8.2 *Recommended Conservation Measures*

The conservation measures listed below should be viewed as options to prevent and minimize adverse impacts of commercial and domestic water use to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Design water diversion and impoundment projects to create flow conditions that provide for adequate fish passage, particularly during critical life history stages. Avoid low water levels that strand juveniles and dewater redds. Incorporate juvenile and adult fish passage facilities on all water diversion projects (e.g., fish bypass systems). Install screens at water diversions on fish-bearing streams, as needed.
- Maintain the water quality necessary to support fish populations by monitoring and adjusting water temperature, sediment loads, and pollution levels.
- Maintain appropriate flow velocity and water levels to support continued stream functions. Maintain and restore channel, floodplain, riparian, and estuarine conditions.

- Where practicable, ensure that mitigation is provided for unavoidable impacts to fish and their habitat. Mitigation can include water conservation measures that reduce the volume of water diverted or impounded.

Chapter 5

Estuaries and Nearshore Zones

Introduction - Current Condition

Coastal zones comprise some of the world's most ecologically productive and biologically diverse marine ecosystems (Sheaves et al. 2015). This interface between land and sea provides a complex and dynamic exchange of energy, water, nutrients, sediments, and organisms (Beck et
5.1 al. 2001, Beck et al. 2003, Sheaves 2009, Gleason et al. 2011). Studies conducted in Alaska suggest comparable productivity in estuarine and nearshore zones although ecosystem processes and functions differ considerably from temperate climates.

Alaska’s rugged and extensive coastline provides countless shoreline and nearshore substrate types from sheltered bays to exposed bedrock outcrops. An infinite combination of substrate compositions exist including amalgams of muds, sands, pebbles, gravels, and cobble and boulder beaches. In some regions there are extensive micro- and macro-algal beds, eelgrass meadows, and kelp forests. In contrast, other regions under the seasonal influence of ice scour have little evidence of benthic vegetation with the exception of microalgae beds. In the Arctic sea ice plays a fundamental role in the bio-chemical, and physical processes. Spring sea ice melt releases trapped algae and nutrient nourishing primary production in nearshore and estuarine zones providing essential nutrition anadromous and amphidromous fish and invertebrate species (Loeng 2005, NPFMC 2009b).

Water is the primary medium moving all nutrients, detritus, and organisms back and forth through estuarine-nearshore-offshore ecosystems. The flow of water, both vertically (e.g., upwelling) and horizontally (i.e., currents, tidal movements), is a key determinant of estuarine and nearshore productivity and consequent food webs. The temporal dynamics of flow (e.g., frequency, duration, magnitude, timing, and rate of change) within and among these zones vary in time and space and influence the physical, chemical, and biological connectivity between these ecosystems. The physical connection (depth and velocity) of water flow through the estuary and nearshore zones largely forms the foundation for all chemical and biological
5.2 connections (Polis et al. 1997, McClelland et al. 2012, EPA 2015).

Alaska Metrics

In Alaska, large coastal watersheds and rivers provide significant volumes of terrestrially-derived nutrients and sediments, which in turn provide complexity and support biodiversity in estuaries and nearshore zones (Hall 1988). Of the 30 coastal and nearshore zones identified in Alaska (Piatt and Springer 2007), 17 are distinctly associated with estuarine complexes within Arctic, subarctic, and temperate climate and oceanic influences. Compared to the coastline of the lower 48 states, Alaska’s estuaries and nearshore zones are the most expansive, convoluted, and complex. Although estuaries and nearshore zones undoubtedly play a significant role in supporting the most productive fisheries in North America, the associated nearshore ecosystem processes, functions and bio-chemical interactions, though known to exist remain relatively unstudied (Emmett et al. 2000).

Alaska's coastline is estimated at over 70,000 km (44,000 mi)[18]. Within this context, nearshore EFH is generally defined as waters from the 20 m (60 ft) contour to the high tide line and is characterized as supratidal, intertidal, and subtidal habitats. The surface area of coastal bays and estuaries in Alaska is approximately 53,448 km^2 (33,211 mi^2), nearly three times the estuarine area found in the lower 48 states (Saupe et al. 2005). These estuarine and nearshore zones have highly variable water conditions, oceanography and salinity, diverse geomorphology and substrate types, and complex trophic dynamics, all of which are subject to significant seasonal climatic and environmental influences (Baker et al. 2011). Marine- and terrestrial-driven influences fuel the rich biodiversity within these coastal zones (Caddy and Bakun 1995, NMFS 2013).

5.2.1 Regional Coastal Ecosystems

5.2.1.1 *Southeast and Gulf of Alaska*

In southeast Alaska, the Alexander Archipelago (>100 ha [247 ac]) has over 2,900 estuaries encompassing a total surface area of 30,721 km^2 (11,861 mi^2). At 1,181 ha (2,900 ac), the Stikine River Delta is the largest of these estuaries (Albert and Schoen 2007). The GOA includes two large estuary systems: Cook Inlet, which is 370 km^2 (230 mi^2) long with the second largest tidal range (12 m [39 ft]) in North America, and Prince William Sound, a nearly enclosed glacially carved embayment covering over 9,000 km^2 (5,600 mi^2). Prince William Sound has a convoluted shoreline that is approximately 4,500 km (2,800 mi) in length (Saupe et al. 2005). From southeastern Alaska to the end of the Alaska Peninsula, there are thousands of miles of shoreline inside sheltered and semi-enclosed bays. The ten largest estuaries of the Alexander Archipelago encompass 30,985 ha (76,747 ac) of habitat supporting salt marsh, mudflat, and algal bed communities (Carstensen 2007). The extensive 48,000 km (29,800 mi) of coastline provides ideal habitat for seaweeds (e.g., canopy and understory kelp communities), which occur on shores from the splash zone to approximately 30 m (90 ft) into the subtidal zone (Lindstrom 2009). Alaskan eelgrass (*Zostera marina*) beds are distributed along sheltered portions of the coastline from southeast Alaska to the Seward Peninsula (ADF&G 2006).

In the southcentral GOA, the Copper River Delta, encompassing 500 km^2 (311 mi^2) of intertidal mudflats, serves as feeding grounds for a variety of migratory (salmonids and seabirds) and resident demersal (e.g., Dungeness crabs [*Cancer magister*]) species (Powers et al. 2002). The Copper River provides the largest source of freshwater, sediment load and terrestrial nutrient to the delta. Brabets (1997) reported the delivery of 62 million metric tons (69 million tons) of suspended sediments annually to the delta from the 63,000 km^2 (24,324 mi^2) drainage basin of the Copper River.

5.2.1.2 *Aleutian Islands*

The Aleutian Islands lie in a long, porous arc consisting of over 300 small, volcanic islands extending for 2,260 km (1,404 mi). This arc has a narrow continental shelf with steep slopes separated by deep-water passes. The bathymetry changes dramatically from benthic depths of the Aleutian Trench to a sea level rise in a distance of <150 km (<93.2 mi), providing dramatic

[18] Estimates of the size of Alaska's coastline are known to vary among different sources and methods of measure.

variety between oceanic-shelf to nearshore habitats (NPFMC 2007, 2015c). The north-south width of the shelf also varies from east to west, from 4 km (2.5 mi) to >80 km (49.7 mi) occurring east of Samalga Pass (NPFMC 2007, 2015c). This continental shelf/slope is composed of a complex mixture of substrates ranging from boulders to sand (NPFMC 2015c). Bedrock covered by such coarsely fragmented substrates dominate and provide habitat structure in many of the passes (Fautin et al. 2010). These geologic features influence mixing of ebb and flood tides between shallow, colder Bering Sea and deep, warmer Pacific Ocean to the South. This mixing of waters (deep and shallow, warm and cold) provides marine nutrients to fuel complex food chains that support rich marine biodiversity. Corals and sponge communities are dominant features of benthic communities on the steep rocky slopes and provide important habitats for a variety of fish and invertebrate species (Heifetz et al. 2005, Stone 2014). A species and diversity habitat gradient appears in local food webs along the Aleutian chain with Atka mackerel (*Pleurogrammus monopterygius*), Pacific cod (*Gadus macrocephalus*), and neritic zooplankton being prominent to the west of the deeper passes and walleye pollock and oceanic zooplankton being more frequent to the east (Hunt and Stabeno 2005, Logerwell et al. 2005, Neidetcher et al. 2014).

5.2.1.3 *Bering Sea*

According to Piatt and Springer (2007), the nearshore coastal region from Unimak Island in the south to Point Hope in the north, defines one relatively distinct coastal zone. That coastal expanse represents approximately 6,532.7 km (3,527.4 nm) of nearshore habitat (Lewis 2016). The Bering Sea is one of the most biologically diverse marine ecosystems in the world and supports the world's largest fisheries, there is currently little information on nearshore and estuary processes north of Cape Newenham. However, similar estuarine bio-chemical processes documented in arctic and sub-arctic regions, to the North and South, provide similar fish nursery functions discussed later in the report (Sections 5.3.1 and 5.3.2).

North of Nunivak Island seasonal ice cover in the northern Bering Sea begins in November and often increases to greater than 80 percent coverage of the Continental Shelf during its maximum extent in March. Shallow water nearshore zones exposed to seasonal influence of sea ice can be heavily scoured and may provide little beneficial habitat to larval and juvenile life stages of fish and invertebrates. Much of the nearshore coastline of the northern Bering Sea, with the exception of part of the Seward Peninsula, is mostly shallow with offshore bars and lagoons. Sand and silt are the primary components over most of the seafloor of the Bering Sea, with sand predominating in waters at a depth of less than 60 m (197 ft) (NMFS 2004, 2005a). Generally, despite seasonality, benthic substrates deeper than the impact of ice scour is likely EFH to some species of fish or invertebrates in larval or juvenile life stages.

The dominant circulation pattern of nearshore Bering sea waters begins with the flow of North Pacific water (the Alaska Stream) into the EBS through the major passes in the Aleutian Islands. There is net gain in water transport eastward and northward along the north side of the Alaska Peninsula, eventually flowing northward into Bristol Bay, and around Cape Newenham toward Nunavak Island, Norton Sound and the Bering Strait (NMFS 2013).

The largest embayments in the Bering Sea are Norton Sound and Bristol Bay which themselves consist of many smaller estuaries. There are a mutiltude of smaller estuarine embayments draining coastal watersheds such as the Kuskokwim and Hazen Bays. One of the largest Alaskan riverine deltas, the Yukon, flows into Norton Sound, whereas the second largest river, the Kuskokwim, flows into Kuskokwim Bay (Kammerer 1990, Brabets et al. 2000). The Nushagak, Kvichak, and Wood Rivers are three of the largest rivers draining into Bristol Bay (WWF and TNC 1999, NMFS 2013). The largest salt marsh complex, the Yukon-Kuskokwim Delta in the Bering Sea, encompasses over 40,469 km^2 (15,625 mi^2) (Glass 1996). On the Alaska Peninsula in the southern Bering Sea, the Izembek Lagoon contains the largest eelgrass bed (160 km^2 [62 mi^2]) in the world (Tippery 2013). Eelgrass cover dominates approximately 31,000 ha (76,600 ac) or 91 percent of the SAV on the lower Alaska Peninsula (Hogrefe et al. 2014).

Because of economic value, the southeastern Bering sea fisheries and marine processes are extensively studied. A nearshore ecosystem component of that larger marine system is Bristol Bay, which is comprised of numerous smaller bay and estuary complexes. Notable complexes are Nushagak and Kvichak Bays, Togiak and Kulukak Bays in the north, Egegik and Ugashik Bays in the south, and numerous other semi-enclosed bays along the Alaska Peninsula shoreline (NMFS 2013). Bristol Bay benthic sediments represent a wide range of grain sized muds, clays and silts, sands, and gravels. Gravels and sands tend to dominate nearshore zones while finer grained sands, silts and muds tend to dominate as depth and distance increases from the inner bay influences of tides and river outwelling. This grading is particularly noticeable in Bristol Bay and immediately westward. The condition occurs because settling velocity of particles decreases with particle size (Stokes Law), as does the minimum energy necessary to resuspend or tumble them (Smith and McConnaughey 1999, NPFMC 2015a, NPFMC 2015b, NPFMC 2015e).

5.2.1.4 *Arctic*

In the Arctic Ocean, numerous estuaries also exist where freshwater streams enter the Chukchi and Beaufort Seas. In the Chukchi Sea, Kasegaluk Lagoon is over 190 km (120 mi) long and 8 km (5 mi) wide, and Kotzebue Sound is 160 km (100 mi) long and 110 km (70 mi) wide. In the Beaufort Sea, the Colville River Delta near Prudhoe Bay spans over 40 km (25 mi) in width with its shallow waters (<3 m [10 ft]) extending 16 km (10 mi) or more offshore (NMFS 2015). The adjacent Canadian Mackenzie River Delta (12,170 km [7,562 mi] long) also provides a vast majority of the freshwater input (~300 km/year [186 mi/year) to the Beaufort Sea (Dunton et al. 2012, Casper et al. 2015).

In northern regions of Alaska, the seasonal influence of ice, tides, currents, storm surge, and wave energy severely limits suitable shallow nearshore habitat. This is evident along Arctic and subarctic coastlines and seasonally as far south as Bristol Bay (Weingartner et al. 1998, Gutt 2001). Survival of any life stage of marine species is greatly reduced under these conditions. In contrast, deeper nearshore habitats below the influence of ice scour remain unaffected along with the vast majority of Alaska’s coastline and sheltered bays in subarctic zones and farther south.

5.3 Physical, Chemical, and Biological Processes

5.3.1 Nearshore Fish Nurseries

A growing body of literature identifies Alaska's nearshore marine zones as some of the most biologically productive in North America (Robards et al. 1999, Abookire et al. 2000, Dean et al. 2000, Arimitsu et al. 2003, Abookire and Piatt 2005, Arimitsu and Piatt 2008, Johnson et al. 2012). Many species that inhabit nearshore zones and estuaries contribute to Alaska's economy. From 2000 to 2004, approximately 15 percent of the total landed weight (25 billion pounds) and 32 percent of the total dollar value ($4.7 billion) of commercial landings in Alaska were directly attributed to estuarine and nearshore fish and shellfish species harvests (Lellis-Dibble et al. 2008).

In an extended series of nearshore surveys across multiple marine ecoregions in Alaska, approximately 718,345 fish representing 121 species from 29 families were captured in beach seines (Johnson et al. 2012). Four commercially important FMP species accounted for 55 percent of that total catch: walleye pollock, Pacific herring (*Culpea pallasii*), pink salmon, and chum salmon. Although species assemblages, abundance, and richness vary considerably within seasons, nearshore zones and regions surveyed, the majority of species caught were in larval or juvenile life stages. Ecologically important forage fish species (e.g., Pacific sand lance, Pacific herring, Pacific sandfish [*Trichodon trichodon*], and capelin [*Mallotus villosus*]) were also well represented in these nearshore surveys. Pacific herring and Pacific sandfish, capelin (97 percent) and sand lance (83 percent) were also captured in juvenile life stages. Based on estimated sizes at maturity, juvenile life stages dominated catches for most species, particularly those represented in federal FMPs for Alaska (Johnson et al. 2012).

Very recent nearshore surveys of the GOA further emphasize the importance of these nearshore zones as fish nurseries (Ormseth et al. 2016). As Ormseth et al. (2016) describe, the most notable feature seen in these nearshore fish communities was the strong seasonal (summer) changes in abundance and species composition that were driven by the arrival of age-0 fishes such as Pacific cod, walleye pollock, saffron cod, and *Hexagrammos* spp. Age-0 herring were strongly represented despite the season, and sand lance were also occasionally in high abundance. Species specific growth rates were also documented; age-0 Pacific cod, pollock, and saffron cod appeared in the summer at 50-70 mm length and by fall had grown to 80-110 mm. The research conducted during these surveys contributed a great deal of new information regarding the nearshore environment of the GOA. These surveys provided substantial evidence for the importance of nearshore areas as refuges for fish, particularly early juveniles, because these areas provide suitable physical habitats and abundant nutrition. Analyses are also being conducted to further develop habitat suitability models of similar nearshore EFH important to juvenile stages of offshore FMP groundfish species although these efforts are in their infancy (Pirtle et al. In prep, Pirtle et al. In review).

Adult stages of many commercially important species (i.e., flatfishes) spawn in offshore waters; however, their eggs, larvae and juvenile stages are found in nearshore zones. Ocean currents transport and distribute (through advection) eggs, larval and juvenile stages to nearshore zones (Nichol 1998, Coyle and Pinchuk 2002, Wilderbuer et al. 2002, Dew and McConnaughey 2005, Norcross and Holladay 2005, Lanksbury et al. 2007, Cooper et al. 2014, Hurst et al. 2015). These early life stages settle in a variety of rearing substrates and habitat types that provide increased refuge, forage, and rearing opportunities. Depending on the species range, distribution and region, larval and juvenile life stages found in nearshore zones gradually move offshore and are seen as adults in commercial fisheries (Gillanders et al. 2003, Able 2005, Brown 2006, Lanksbury et al. 2007, Laurel et al. 2007, Hurst et al. 2015). Assemblages of groundfish, forage fish, invertebrates, and anadromous species are well represented in a variety of different habitat and substrate types and water conditions in nearshore habitats (Johnson et al. 2012, NMFS 2013, Ormseth et al. 2016).

Although commercially important FMP species inhabit these nearshore zones at earlier life stages, less is known about the specific EFH attributes supporting their abundance (Thayer et al. 1978, Beck et al. 2003, Johnson et al. 2012). The survival and abundance of these early life stages is apparently the result of increased nutrient and refuge availability and subsequent decreased predation. A growing body of evidence also suggests that terrestrial influences play a role, especially those nearshore zones influenced by estuaries. Estuaries are recognized as critical links that transfer DOM and nutrients between terrestrial and coastal marine ecosystems, having some of the highest areal rates of heterotrophic bacterial production in aquatic ecosystems. The mixing behavior of terrigenous DOM in estuaries is quite variable and changes seasonally with riverine discharge. The terrestrial ecosystem processes that alter the timing, magnitude, and lability of DOM delivery to estuaries have the potential to influence biogeochemical cycling in nearshore marine ecosystems (Fellman et al. 2010).

5.3.2 Estuarine Processes – Terrestrial Influence

Many of Alaska's estuaries are allochthonous[19] in nature (turbid) with some nearshore waters often dominated by seasonal freshwater runoff (outwelling) from snowmelt and summer rains. Coastal watersheds drain to the ocean transporting riverine sediment and nutrients to marine estuaries and nearshore zones (Milliman and Meade 1983, Milliman and Farnsworth 2011, Day et al. 2012). Anthropogenic impacts to watersheds, estuaries, and nearshore zones are well documented (Caddy and Bakun 1995, Hopkinson and Vallino 1995, Jonsson and Jonsson 2003, Kennish 2016). However, little attention is focused on understanding the natural processes in pristine systems that link watersheds, nearshore zones and associated fisheries.

Outwelling[20] nutrients in the form of detritus, DOM, and POM influence estuarine and nearshore zones. In regions of Alaska where salmon remain abundant, MDN also contribute to an ecosystem's productivity (NMFS 2013). Sediments entrained in outwelling river plumes dictate the composition of benthic substrates in estuaries. All of these components influence everything from trophic dynamics to distribution, abundance, and growth of nearshore larval and juvenile marine species. The turbidity observed in many of these estuaries and nearshore river plumes also provide refuge for a multitude of marine fish and invertebrate species. This frontal, or

[19] In aquatic or marine ecology, allochthonous materials are mobile DOM from leaves and wood, detritus or sediments. Often these mobile DOM's and nutrients (C, N, and P) comprise foundational elements of secondary production and food chains.

[20] Terrestrial freshwater runoff from large river systems and watersheds drains into marine estuaries. In referenced literature, this runoff is often referred to as "outflow" or "outwelling." Outwelling freshwater chemistry, temperature, and nutrient plumes influence marine estuary chemistry and productivity. One analysis estimates 20 billion tons of dissolved sediments and organic material if transported to the global ocean annually (Milliman and Farnsworth). Current total estimates specific to Alaska do not exist.

mixing zone between plume and ocean waters is characterized by strong physical (e.g., hydrodynamic convergence) and biological processes (Grimes and Kingsford 1996).

The influence coastal rivers have on estuaries and nearshore zones is a function of the size of the watershed, terrestrial geology, landform and vegetation, and coastal processes. These factors determine the composition of the detritus entering a marine estuary. The Columbia River is an example of a well-studied coastal river which contributes substantial quantities of terrestrial derived (terrigenous)[21] and allochthonous material into nearshore zones (approximately 7,501 m^3/second [sec] [264,900 ft^3/sec]) (Kudela et al. 2010, Litz et al. 2014). Generally, lighter river water plumes override heavier ocean water creating frontal and convergence zones. Large aggregations of terrigenous detritus and sediments provide nutrient and refuge to phytoplankton, zooplankton, ichthyoplankton, forage fish, juvenile salmon, and fish predators in nearshore zones (Litz et al. 2014).

During high flow periods, outwelling river plumes modify regional coastal circulation patterns, frequently becoming bidirectional throughout an ocean driven upwelling season depending on prevailing wind stress, Coriolis Effect and Ekman Transport[22]. River plume re-circulation provides a biological refuge during weak or absent upwelling and promotes trophic transfer of carbon and nitrogen to higher trophic levels. Providing refuge increases residence times, increases growth rates and biomass, and collectively enhances biological production and diversity (Kudela et al. 2010). Litz et al. (2014) reported that abundant numbers of forage and anadromous fish species sought refuge from predators and took advantage of ample feeding opportunities in the river plume. Campbell et al. (2011) identified similar seasonal productivity occurring in the Copper River plume and coastal GOA, that occurred in the Columbia River plume.

In Alaska, variable freshwater discharges from several watersheds and river systems share similar characteristics and contribute to estuarine and nearshore marine systems in a comparable manner. In the GOA, the greater Alexander Archipelago provides significant freshwater flows (approximately 25,500 m^3/sec [1 million ft^3/sec]) to southeastern Alaska marine waters (Baker et al. 2011). The discharge from the Copper River is approximately 1,600 m^3/sec (56,500 ft^3/sec). In southcentral Alaska, the Kenai River discharges water at 168 m^3/sec (5,922 ft^3/sec). In Bristol Bay, the collective discharge from the Nushagak, Kvichak, and Wood Rivers contribute 1,312 m^3/sec (46,323 ft^3/sec). More comparable in scale to the Columbia River, the Yukon River provides 6,428 m^3/sec (227,000 ft^3/sec). In the Arctic, the Mackenzie River provides freshwater volumes of approximately 9,911 m^3/sec (350,000 ft^3/sec).

Turbidity in some estuaries may minimize photosynthesis, associated algal blooms, and primary production. To the contrary, outwelling nutrients in the form of detritus, DOM, POM, and MDN provide the foundation of energy-transfer (secondary production) supporting assemblages of

[21] Terrigenous sediments are those sediments derived from terrestrial sources such as rocks, sands, muds and silts. Because DOM comprise elements of muds and silts, they can also be composed of terrestrial plant and organic sources.

[22] Though Wind Stress, Coriolis Effect and Ekman Transport all influence marine ecosystem processes and productivity, a detailed understanding or each is currently beyond the scope of this report. Additional information is provided at (http://oceanmotion.org/html/background/ocean-in-motion.htm).

minute bacteria, fungi, and algae through larval stages of plankton, invertebrates, juvenile groundfish, and anadromous species. Surveys of allochthonous Alaskan estuaries have revealed abundant invertebrate populations. Recognized species found in the estuaries of Bristol Bay and Cook Inlet include euphausiids, hyperiids, amphipods, copepods, pteropods, chaetognaths, and polychaetes (Turek et al. 1987, Moulton 1997, Radenbaugh 2010, 2011, 2012, Hartwell et al. 2016). Abundant prey availability at these trophic levels is essential to the fitness and survival of larval and juvenile fish (Beamish and Mahnken 2001, Beamish et al. 2004, Moss et al. 2005, Farley et al. 2007, Farley et al. 2011).

5.3.2.1 *Terrestrial Carbon – Plant Derived Nutrient*

The contribution of terrestrial detritus has been demonstrated in recent studies of estuarine and nearshore trophic and fisheries dynamics using stable isotopes (Darnaude 2005, Schlacher et al. 2009). Similarly, in the Arctic, the Mackenzie River Delta is a conduit through which large volumes of riverine DOM and POM are exported to the coastal marine environment (Walker 1998). In this system, the composition of terrestrial and riverine particulates is a mixture of freshwater bacteria, phytoplankton, and peaty detrital material distributed over shelf sediments and benthos (Casper et al. 2015). These DOM/POM nutrient sources have been shown to be more readily bioavailable to marine fish and invertebrate species in shorter food chains farther offshore (Dunton et al. 2006, Iken et al. 2010, Letscher et al. 2011, Vinagre et al. 2011, Dunton et al. 2012, Ortega-Retuerta et al. 2012, von Biela et al. 2013, Casper et al. 2015, Bell et al. 2016). Results strongly indicate that marine production in nearshore trophic dynamics in the Beaufort Sea is more closely linked to allochthonous riverine outwelling and terrestrial sources than previously recognized.

The estuarine Beaufort Sea and its inshore lagoons receive most freshwater from the Canadian Mackenzie River as well as numerous smaller American Arctic rivers (i.e., Colville River). In these nearshore sediments, 50 to 75 percent of the carbon deposited in these nearshore zones are of terrigenous origin (Dunton et al. 2012). The brackish band of water extending along 750 km (466 mi) of the Beaufort Sea coastline provides habitat for numerous anadromous and marine fishes (e.g., Arctic cisco/cod [*Coregonus autumnalis/Arctogadus glacialis*]) which feed exclusively on epibenthic fauna (e.g., polychaetes, mysids, and amphipods) that inhabit the various coastal bays and lagoons (Craig 1984).

5.3.2.2 *Terrestrial Nitrogen - Salmon-Derived Nutrient*

Despite continued declines in worldwide salmon populations, salmon in many regions of Alaska remain relatively abundant and exist at sustainable populations. The reasons for salmon declines have been well documented in countless studies and peer-reviewed literature. Lichatowich (2001), Gresh et al. (2000), and Montgomery (2004) provide well written summaries addressing the many reasons for these declines and in some cases extinctions.

Because of their cultural, commercial, and recreational importance Alaska's salmon species have been the focus of extensive research to gain a better understanding of their reliance on, and simultaneous contribution to trophic dynamics and ecosystem condition. Salmon represent a species that transects all types of EFH; from larval and juvenile rearing in headwater streams tributaries, and estuaries, with adult stages in the EBS, North Pacific, and the Arctic; and back again. Salmon are also recognized as a key indicator of ecosystem condition. In watersheds and estuarine systems heavily impacted by anthropogenic influences, declining salmonid abundance is often a direct reflection of these impacts.

Marine nearshore and estuarine habitats serve as transition zones and migratory pathways for juvenile salmon. They provide increased feeding and refuge opportunities and osmoregulatory adaptation between marine and freshwater zones. Salmonids not only take advantage of abundant feeding opportunities in estuarine and nearshore zones but have also demonstrated prolonged residence time, even seasonally, in estuaries (Murphy 1984, Heifetz et al. 1989, Johnson et al. 1992, Thedinga et al. 1993, Thedinga et al. 1998, Koski and Lorenz 1999, Halupka et al. 2003, Koski 2009, Hoem Neher et al. 2014). Hoem Neher et al. (2014) identified Alaskan juvenile coho salmon moving to and from marine and freshwater habitats taking advantage of abundant prey opportunities.

MDN have been shown to subsidize coastal watersheds with organic nutrients (e.g., carbon, nitrogen, and phosphorous) first in the form of whole carcasses and large solids and later as dissolved particulates (Willson et al. 1998, Cederholm et al. 1999, Gende et al. 2002, Naiman et al. 2002). Salmon carcasses contribute to biologic production in estuaries through seasonal pulses benefiting both marine estuaries and nearshore zones (Brickell and Goering 1970, Richey et al. 1975, Reimchen 1994, Bilby et al. 1996, Wipfli et al. 1998, Gende et al. 2004). These dissolved nutrients fuel estuarine productivity, and the associated bacteria and algae, in turn, increase the abundance of harpacticoid copepods that serve as primary prey for outbound juvenile salmon (Fujiwara and Highsmith 1997). Estimates generated from recent nutrient transport studies indicate that substantial amounts of MDN (46 to 60 percent) move directly back into the estuary (Mitchell and Lamberti 2005).

Salmon also contribute to estuarine and nearshore productivity in their early marine phase as smolt. Based on a recent assessment of the contribution of the Nushagak River and Kvichak River sockeye salmon to trophic dynamics of the EBS, sockeye salmon smolt ranked among the top ten forage groups and were comparable to Pacific herring or eulachon (*Thaleichthys pacificus*) as a nutritional source (Gaichas and Aydin 2010). These conclusions are similar to results from Moore and Schindler (2004) who found that outbound salmon smolt export substantial levels of nitrogen and phosphorus seaward. It takes hundreds of millions of outbound salmon smolt to produce tens of millions of returning inbound adults. Therefore, the trophic contribution of smolt to marine estuaries and nearshore zones is substantial.

5.4 Source of Potential Impacts

A large portion of Alaska's population resides near the state's 54,563-km (33,904-mi) coastline (NOAA 2010). Alaska's population centers are sparse, as most areas are not accessible or linked by a continuous road system. Further, communities 'boom and bust' as resource developments and their associated industries rise and fall. Historically, coastal features such as estuaries and embayments have been ideal for fishing, farming, and hunting and have provided sheltered waters with transportation access to rivers and the ocean. Nationally, urban development in coastal areas is growing at a rate of approximately five times that of other areas of the country, and over 50 percent of all Americans live within 80 km (50 mi) of the coast (Markham 2006). The expansion of port facilities, urbanization, filling of aquatic habitat and wetlands, and other forms of development surrounding estuaries and nearshore areas can have adverse impacts on fish habitat.

The dredging and filling of coastal wetlands for commercial, residential, port, and harbor development directly removes important coastal habitats and alters the habitat surrounding the developed area. Physical changes from shoreline construction can result in secondary impacts, such as increased suspended sediment loading, shading from piers and wharves, and the introduction of chemical contaminants from land-based human activities (Robinson and Pederson 2005). Even development projects that appear to have minimal individual impacts can have significant cumulative effects on the aquatic ecosystem (Johnson et al. 2008).

5.4.1 Dredging

The construction of ports, marinas, and harbors typically involves the dredging of sediments from intertidal and subtidal habitats to create navigational channels, turning basins, anchorages, and berthing docks. Additionally, periodic dredging is used to maintain the required depths after sediment is deposited into these facilities. Dredging is also used to create deepwater navigable channels and to maintain existing channels that periodically fill with sediments. Port expansion has become an almost continuous process due to economic growth, competition between ports, and significant increases in vessel sizes.

5.4.1.1 *Potential Adverse Impacts*

Dredging activities can adversely affect benthic and water column habitats. The potential environmental effects of dredging on managed species and their habitats include: (1) the direct removal/burial of organisms; (2) increased turbidity and siltation, including light attenuation from turbidity; (3) contaminant release and uptake, including nutrients, metals, and organics; (4) the release of oxygen-consuming substances (e.g., chemicals and bacteria); (5) entrainment; (6) noise disturbances; and (7) alterations to hydrodynamic regimes and physical habitat.

Many managed species forage on infaunal and bottom-dwelling organisms. Dredging may adversely affect these prey species by directly removing or burying them (Van Der Veer et al. 1985, Newell et al. 1998). Similarly, dredging may also force mobile animals such as fish to migrate out of the project area. Recolonization studies suggest that recovery may not be straightforward. Physical factors, including particle size, distribution, currents, and compaction/stabilization processes, can limit recovery after dredging events. The principal project-related factors that influence recovery rates include the composition of the beach fill sediments relative to those of the native beach and the timing of nourishment projects relative to spring benthic invertebrate larval recruitment periods (Wilber et al. 2009). Rates of recovery are known to range from several months for estuarine muds to up to two or three years for sands and gravels. Reported rates of recovery have been rapid when highly compatible beach fill sediments were used and spring larval recruitment periods were avoided. Conversely, longer recovery periods have been associated with the use of noncompatible fill and/or the occurrence of nourishment projects during larval recruitment periods (Wilber et al. 2009). Recolonization can take up to one to three years in areas with strong currents and five to 10 years in areas with weaker currents. Additionally, post-dredging recovery in cold waters at high latitudes may require additional time because these benthic communities can be composed of large, slow-growing species (Newell et al. 1998). Therefore, forage resources for benthic feeders may be substantially reduced in dredged areas. For example, the shallow subtidal macrobenthos at Port Valdez, Alaska, had not fully recovered 2.5 years after the dredging event (Blanchard and Feder 2003). Although macrobenthic communities may recover total abundance and biomass within a few month or years, their taxonomic composition and species diversity may remain different from pre-dredging to post-dredging for more than three to five years (Michel et al. 2013).

Certain types of dredging equipment can elevate levels of mineral particles or suspended sediment smaller than silt and organic matter in the water column. The associated turbidity plumes of suspended particulates may reduce light penetration and lower the rate of photosynthesis for subaquatic vegetation (Dennison 1987) and the primary productivity of an aquatic area if particulates remain suspended for extended periods of time (Cloern 1987). If suspended sediment loads remain high, fish may suffer reduced feeding ability (Benfield and Minello 1996) and be prone to gill injury (Nightingale and Simenstad 2001a). Prolonged sediment suspension and extensive turbidity plumes are primarily associated with the suspension of fine silt/clay particles that have relatively slow settling velocities, whereas sand and gravel that make up the coarse-grained sediment fraction resettle rapidly in the immediate vicinity of the dredge before they can be transported offsite (Schroeder 2009).

SAV beds and other sensitive habitats may also be directly and indirectly affected by dredging operations. Seagrasses provide key ecological services, including organic carbon production and export, nutrient cycling, sediment stabilization, enhanced biodiversity, and trophic transfers to adjacent habitats (Orth et al. 2006). Eelgrass beds, in particular, are critical to nearshore food web dynamics (Wyllie-Echeverria and Phillips 1994, Murphy et al. 2000). Studies have shown seagrass beds to be among the areas of highest primary productivity in the world (Herke and Rogers 1993, Hoss and Thayer 1993). This primary production provides high rates of secondary production in the form of fish (Good 1987, Sogard and Able 1991, Herke and Rogers 1993). Direct impacts of dredging include the physical removal or burial of the vegetation, while indirect impacts can result from increased sedimentation/turbidity (Erftemeijer and Lewis 2006). The suspension of disturbed sediments during the dredging process minimizes the light intensity that reaches SAV which depends on photosynthesis. Depending on the depth at which the vegetation occurs, high turbidity can cause a significant reduction in light availability leading to sublethal effects or death and, in turn, impact the aquatic wildlife which depends on this vegetation for nourishment and habitat (Erftemeijer and Lewis 2006).

Suspended material from dredging may react with dissolved oxygen in the water and result in short-term oxygen depletion to aquatic resources (Nightingale and Simenstad 2001a). Dredging can also disturb aquatic habitats by resuspending bottom sediments and releasing nutrients, toxic metals (e.g., lead, zinc, mercury, cadmium, copper), hydrocarbons (e.g., polyaromatics), hydrophobic organics (e.g., dioxins), pesticides, and pathogens into the water column (EPA 2000b, Erftemeijer and Lewis 2006). Toxic metals and organics, pathogenic microorganisms (i.e., bacteria and viruses), and parasites, notably helminthes and protozoa, may become biologically available to organisms either in the water column or through food chain processes.

Dredges have the potential to entrain fishes and invertebrates during all life cycle phases including adults, juveniles, larvae, and eggs. Entrainment is the direct uptake of aquatic organisms caused by the suction field generated by hydraulic dredges (e.g., hopper and cutterhead dredges). Benthic infauna is particularly vulnerable to entrainment by dredging (Reine and Clarke 1998) although some mobile epibenthic and demersal species, such as shrimp, crabs, and fish, can be susceptible to entrainment as well (McGraw and Armstrong 1990, Nightingale and Simenstad 2001a). Salmonids are frequently cited in studies of fish entrainment. For instance, in the Fraser River, Canada, juvenile salmonids and eulachon were the dominant taxa entrained during dredge operations, but nonanadromous estuarine and marine demersal species were the most frequently entrained at the mouth of the Columbia River and in Grays Harbor (Larson and Moehl 1990, McGraw and Armstrong 1990). Factors that contribute to higher entrainment rates include the dredge location and the degree of constriction of the waterway. The juvenile salmon and smelt in the Fraser River were distributed in closer proximately to the dredge, while the fish in the Columbia River and Grays Harbor were able to disperse over a greater area as they migrated due to the expansive mouth of this river and harbor (Reine and Clarke 1998).

Fish detect and respond to sounds for many life history requirements (Johnson et al. 2008). The noise generated by pumps, cranes, and the mechanical action of the dredge has the ability to alter the behavior of fish and other aquatic organisms. The noise levels and frequencies produced from dredging depend on the type of dredging equipment being used, the depth and thermal variations in the surrounding water, and the topography and composition of the surrounding sea floor (Nightingale and Simenstad 2001a, Stocker 2002). Several studies have indicated that dredge noise occurs in the low frequency range (< 1200 Hertz [Hz]) which is within the audible range of many species of fish (Reine et al. 2014b). According to a study by Clarke et al. (2003), cutterhead dredges produce peak sound levels in the range of 100 to 110 decibel (dB) re 1μPa root-mean-square (rms) with rapid attenuation occurring at short distances from the dredge and sound levels becoming essentially inaudible at a distance of ~500 m (~1,640 ft). Sound levels were recently recorded during hydraulic and mechanical dredging operations at depths of 3 and 9.1 m (9.8 and 29.9 ft) (Reine et al. 2014a). Source levels ranged from 170 to 175 dB re 1μPa rms during hydraulic cutterhead suction dredge operations and from 164 to 179 dB re 1μPa rms during backhoe dredge operations. The sound pressure levels (SPLs) measured in this study were below levels that would cause physical injury to any fish species in the study area (Reine et al. 2014a).

Due to the rapid attenuation of low frequencies in shallow water, dredge noise normally is undetectable underwater at ranges beyond 20 km (12.4 mi) to 25 km (15.5 mi) (Richardson et al. 1995). Established noise exposure thresholds for fishes are limited to interim criteria developed by the Fisheries Hydroacoustic Working Group (FHWG) for impulsive pile-driving noise, and, consequently, there are no specific criteria for evaluating the potential impacts of continuous dredging noise on marine fishes. It has been hypothesized that dredging-induced sound may block or delay the migration of anadromous fishes, interrupt or impair communication, or impact foraging behavior (Reine et al. 2014b), and dredging is known to elicit an avoidance response by marine fishes (Larson and Moehl 1990, McGraw and Armstrong 1990). However, very little is known about effects of anthropogenic sounds on fish and it is not yet possible to extrapolate from one experiment to other signal parameters of the same sound, to other types of sounds, to other effects, or to other species (Popper and Hastings 2009). While noise levels from large ships may exceed those from dredging, single ships usually do not produce strong noise in one area for a prolonged period of time (Richardson et al. 1995). However, noise from dredging may be continuous, thus, impacting fish for extended time periods (Nightingale and Simenstad 2001a).

Dredging and dredging equipment, such as pipelines, may physically alter, damage, or destroy spawning, nursery, and other sensitive habitats including eelgrass and kelp beds. Dredging may also affect hydrodynamic regimes by modifying current patterns and water circulation via alterations to substrate morphology. These alterations can cause changes in the direction or velocity of water flow, water circulation, or dimensions of the waterbody traditionally used by fish for food, shelter, or reproductive purposes. Altered hydrodynamics may affect estuarine circulation, including short-term (diel) and long-term (seasonal or annual) changes (Deegan and Buchsbaum 2005).

Recommended Conservation Measures

The recommended conservation measures for dredging are listed below. They should be viewed
5.4.1.2 as options to prevent and minimize adverse impacts of dredging operations to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Avoid dredging in sensitive habitat areas to the maximum extent practicable. Activities that would likely require dredging (e.g., placement of piers, docks, marinas) should instead be located in deeper water or designed to minimize the need for maintenance dredging.
- Reduce the area and volume of material to be dredged to the maximum extent practicable.
- Avoid dredging and the placement of dredging equipment in special aquatic sites and other high-value habitat areas (e.g., kelp beds, eelgrass beds, salt marshes).
- Implement seasonal restrictions to avoid impacts to habitat during species critical life history stages (e.g., spawning season, egg/larval development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Utilize BMPs to limit and control the amount and extent of turbidity and sedimentation. Standard BMPs may include silt fences, coffer dams, and operational modifications (e.g., use of hydraulic dredge instead of mechanical dredge).
- For new dredging projects, undertake multi-season and pre- and post-dredging biological surveys to assess the cumulative impacts to EFH and allow for implementation of adaptive management techniques.
- Prior to dredging, test the sediments to be dredged for contaminants as per EPA and USACE requirements.
- Provide appropriate compensation for significant impacts (short-term, long-term, and cumulative) to benthic environments resulting from dredging.
- Identify excess sedimentation in the watershed that prompts excessive maintenance dredging activities. Implement appropriate management actions, if possible, to curtail those causes.

- Determine a reasonable background turbidity level based on regular monitoring of ambient conditions. Establish turbidity limits (percent maximum allowable exceedance above the best estimates of background turbidity). Apply mitigation measures (e.g., temporary cessation or modification of dredging or disposal) if these limits are exceeded during dredge operations (see Erftemeijer and Lewis 2006).

Material Disposal and Filling Activities

Material disposal and filling activities can directly remove important habitat and alter the habitat surrounding the developed area. The expansion of navigable waterways is associated with economic growth and development and generally adversely affects benthic and water column
5.4.2 habitats. The discharge of dredged materials or the use of fill material in aquatic habitats can result in the covering or smothering existing submerged substrates, loss of habitat function, and adverse effects on benthic communities.

Disposal of Dredged Material

5.4.3 *Potential Adverse Impacts*

5.4.3.1 The disposal of dredged material can reduce the suitability of water bodies for managed species and their prey by (1) reducing floodwater retention in wetlands; (2) reducing nutrients uptake and release; (3) decreasing the amount of detrital input, an important food source for aquatic invertebrates (Mitsch and Gosselink 1993); (4) altering habitat by changing water depth or substrate type; (5) removing aquatic vegetation and preventing natural revegetation; (6) impeding physiological processes (e.g., photosynthesis, respiration) to aquatic organisms via increased turbidity and sedimentation (Arruda et al. 1983, Cloern 1987, Dennison 1987, Barr 1993, Benfield and Minello 1996, Nightingale and Simenstad 2001a); (7) directly eliminating sessile or semi-mobile aquatic organisms via entrainment or smothering (Larson and Moehl 1990, McGraw and Armstrong 1990, Barr 1993, Newell et al. 1998); (8) altering water quality parameters (i.e., temperature, oxygen concentration, and turbidity); and (9) releasing contaminants such as petroleum products, metals, and nutrients (EPA 2000b) [Adapted from
5.4.3.2 (EPA 2007, Johnson et al. 2008)].

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of dredged material disposal to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Avoid disposing of dredged material in wetlands, SAV, and other special aquatic sites whenever possible. Assess all options, including upland disposal sites, for the disposal of dredged materials and select disposal sites that minimize adverse effects to EFH.
- Test sediment compatibility for open-water disposal per EPA and USACE requirements for inshore and offshore, unconfined disposal.
- Ensure that disposal sites are properly managed (e.g., disposal site marking buoys, inspectors, the use of sediment capping and dredge sequencing) and monitored (e.g.,

chemical and toxicity testing, benthic recovery) to minimize impacts associated with dredged material.

- Acquire and maintain disposal sites for the entire project life when long-term maintenance dredging is anticipated.
- Encourage beneficial uses of dredged materials. Consider using dredged material for beach replenishment and construction. When dredging material is placed in open water, consider the possibilities for enhancing marine habitat.

5.4.4 Discharge of Fill Material

Like the discharge of dredged material, the discharge of fill material to create upland areas can remove productive habitat and eliminate important habitat functions. For example, the loss of wetland habitats reduces the production of detritus, an important food source for aquatic invertebrates; alters the uptake and release of nutrients to and from adjacent aquatic and terrestrial systems; reduces wetland vegetation, an important source of food for fish, invertebrates, and water fowl; hinders physiological processes in aquatic organisms (e.g., photosynthesis, respiration) because of degraded water quality and increased turbidity and sedimentation; alters hydrological dynamics, including flood control and groundwater recharge; reduces filtration and absorption of pollutants from uplands; and alters atmospheric functions, such as nitrogen and oxygen cycles (Mitsch and Gosselink 1993).

5.4.4.1 *Potential Adverse Impacts*

Adverse impacts to EFH from the introduction of fill material include the loss of habitat function and changes in hydrologic patterns. Aquatic habitats sustain remarkably high levels of productivity and support various life stages of fish species and their prey. These habitats are often used for multiple purposes, including spawning, breeding, feeding, and supporting growth to maturity. The introduction of fill material eliminates those functions and permanently removes the habitat from production.

Fill material can modify current patterns and water circulation by obstructing flow, changing the direction or velocity of water flow and circulation, or changing the dimensions of a water body. As a result, adverse changes can occur in the location, structure, and dynamics of aquatic communities; shoreline and substrate erosion and deposition rates; the deposition of suspended particulates; the rate and extent of mixing of dissolved and suspended components of the water body; and water stratification (NMFS 1998a).

In coastal waters, fill that causes the loss of low gradient habitat or native substrate will likely negatively affect salmon rearing in the area. Nearshore shallow slopes are important to juvenile salmonids because they provide optimal feeding habitat, shelter from high currents, and shelter from predators. Both the abundance and productivity of adult salmon and salmon prey are affected by habitat gradients (Celewycz and Wertheimer 1994). The abundance of food organisms for juvenile salmon appears to also be affected by habitat gradients (Sturdevant et al. 1994). In addition to salmon, fill in coastal waters may affect juvenile flatfish that rear in nearshore areas and have specific depth, slope, and substrate preferences (Moles and Norcross 1995) that limit their distribution and abundance. Nearshore juvenile flatfish habitat preferences vary by species, but those that rear in nearshore areas generally prefer intertidal to shallow subtidal areas with substrate conditions that allow the animal to easily bury itself.

Fill that causes a loss of circulation in the nearshore area may also diminish important food sources for juvenile salmon and other managed species. Pelagic zooplankton is an important food source for juvenile pink and chum salmon (Sturdevant et al. 1996). Zooplankton distribution and abundance depends on currents to transport the zooplankton from offshore areas to nearshore areas.

5.4.4.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts from the discharge of fill material on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Federal, state, and local resource management and permitting agencies should address the cumulative impacts of fill operations on EFH and consider them in the permitting process for individual projects.
- Minimize the areal extent of any fill in EFH or avoid it entirely. Mitigate all non-avoidable adverse impacts, as appropriate.
- Consider alternatives to the placement of fill in areas that support managed species. Identify and characterize EFH functions/services in the project areas so that appropriate mitigation can be determined, if necessary.
- Fill should be sloped to maintain shallow water, photic zone productivity; allow for unrestricted fish migration; and provide refuge for juvenile fish.
- In marine areas of kelp and other aquatic vegetation, fill (including artificial structure fill reefs) should be designed to maximize kelp colonization and provide areas for juvenile fish to shelter from high currents and predators.
- Fill materials should be tested and be within the neutral range of 7.5 to 8.4 pH. In marine waters, this pH range will maximize colonization of marine organisms. Excessively alkaline or acidic fill material should not be used.

5.4.5 Vessel Operations, Transportation, and Navigation

The demand for increased capacity of marine transportation vessels, facilities, and infrastructure is a global trend in response to the increase of human-based needs in coastal areas. As coastal areas grow, there are associated increases in vessel operations for cargo handling activities, water transportation services, and recreational opportunities (Johnson et al. 2008). In Alaska, the growth in coastal communities is placing demands on port districts to increase infrastructure to accommodate additional vessel operations for cargo handling and marine transportation. Port expansion has become an almost continuous process due to economic growth, competition between ports, and significant increases in vessel sizes. In addition, increased boat sales have led to additional pressures to improve and build new harbors, which is an important factor in Alaska because of the limited number of roads.

5.4.5.1 *Potential Adverse Impacts*

Activities associated with the expansion of port facilities, vessel/ferry operations, and recreational marinas can directly and indirectly impact EFH. Potential impacts include: (1) the loss and/or impairment of benthic, shoreline, and pelagic habitats; (2) altered light regimes and loss of SAV; (3) altered temperature regimes; (4) increased siltation, sedimentation, and turbidity; (5) the release of contaminants and debris (Section 4.2.6); (6) altered tidal, current, and hydrologic regimes; and (7) the introduction of invasive or nonnative species (Section 5.2.6).

Potential adverse impacts to EFH can occur during both construction and operation phases. One of the most obvious habitat impacts related to the construction of a port or marina facility is the alteration or loss of physical space taken up by the structures required for such a facility. In Alaska, open cell sheet pile dock faces with backfill are often used to construct or expand existing facilities. Such designs replace existing areas of shallow, slow moving water with deep, fast moving water across a sheer sheet pile face. The sheltered areas of slower moving water where juvenile fish tend to be more abundant are eliminated along with the clearer water microhabitats in the intertidal area that allow for visual feeding.

An increase in the number and size of operating vessels can cause more wave and surge effects on shorelines. Vessel wakes can cause a significant increase in shoreline erosion, affect wetland habitat, and increase water turbidity. Vessel prop wash can also damage aquatic vegetation and disturb sediments, which may increase turbidity and suspend contaminants (Klein 1997, Warrington 1999). When anchored in shallow nearshore waters, mooring buoys can drag the anchor chain across the bottom, destroying submerged vegetation and creating a circular scour hole (Walker et al. 1989).

The altered light regimes caused by these facilities and operations in coastal waters may affect primary production. Docks and piers block sunlight penetration, alter water flow, introduce chemicals, and restrict access and navigation. Piling density can also affect the amount of light attenuation created by dock structures. The height, width, and composition of the structures, as well as the orientation of the structure in relation to the sun, can influence how large a shade footprint an overwater structure may produce and how much of an adverse impact that shading effect may have on the localized habitat (Fresh 1997, Burdick and Short 1999, Fresh et al. 2001, Landry et al. 2008, Gladstone and Courtenay 2014).

Nearshore temperature regimes and biological communities can be altered via the construction of seawalls and bulkheads. Shorelines that have been modified invariably contain less vegetation than natural shorelines and can reduce natural shading and cause increases in water temperatures in the nearshore intertidal zone and in rivers. Conversely, seawalls and bulkheads constructed along north facing shorelines may unnaturally reduce light levels (and primary production rates) and reduce water temperatures in the water column adjacent to the structures (Johnson et al. 2008).

Changes in water quality due to increased siltation, sedimentation, and turbidity can also result from marina/port facility construction and operation. The inadequate flushing of marinas may cause changes in water quality (USACE 1993, Klein 1997). For instance, poor flushing in marinas can increase temperature and raise phytoplankton populations with nocturnal dissolved oxygen level declines, resulting in organism hypoxia and pollutant inputs (Cardwell et al. 1980). An exchange of at least 30 percent of the water in the marina during a tidal change should minimize temperature increases and dissolved oxygen problems (Cardwell et al. 1980). In addition, vessel operations pose a risk of accidental spills which would affect water quality and, in turn, the organisms and habitats (Michel et al. 2013). Diesel, the most commonly used fuel, is considered one of the most acutely toxic types of oil. Fish, invertebrates, and plants that come in direct contact with a diesel spill may be killed. Fish kills have been reported for small spills in confined, shallow waters. Crabs and bivalves can also be impacted from small diesel spills in shallow, nearshore areas. These organisms bioaccumulate the oil but will also depurate the oil, usually over a period of several weeks after exposure (Michel et al. 2013).

During port development, large sections of shoreline are typically replaced with impervious surfaces, such as concrete and asphalt. These surfaces exacerbate stormwater runoff and can increase the siltation and sedimentation loads and contaminants in estuarine and marine habitats. This increase in hard surfaces close to the marine environment also intensifies nonpoint surface discharges, adds debris, and reduces buffers between land use and the aquatic ecosystem which lead to direct, indirect, and cumulative impacts on a variety of habitats including shallow subtidal, deep subtidal, eelgrass bed, mudflat, sand shoal, rocky reef, and salt marsh habitats. Bulkheads, jetties, docks, and pilings can create water traps that accumulate contaminants or nutrients washed in from land-based sources, vessels, and facility structures. These conditions may create areas of low dissolved oxygen, dinoflagellate blooms, and elevated toxins (Johnson et al. 2008). Potential impacts would be site specific; structures generally interfere with longshore sediment transport processes resulting in altered substrate amalgamation, bathymetry, and geomorphology. Changes in the type and distribution of sediment may alter key plant and animal assemblages, starve nearshore detrital-based food webs, and disrupt the natural processes that build spits and beaches (Nightingale and Simenstad 2001b). In addition, the protected, low-energy nature of marinas and ports may alter fish behavior as juvenile fish show an affinity to structure and may congregate around breakwaters or bulkheads (Nightingale and Simenstad 2001b).

5.4.5.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of vessel operations, transportation infrastructure, and navigation to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Locate marinas in areas of low biological abundance and diversity. For example, when possible, avoid the disturbance of eelgrass or other SAV, including macroalgae, mudflats, and wetlands, as part of the project design. In situations where such impacts are unavoidable, consider mitigation as appropriate.
- When docks must be constructed over seagrass or other SAV, consider these measures to minimize impacts to the vegetation (Landry et al. 2008, Gladstone and Courtenay 2014).
    - Unless absolutely unavoidable, build docks so that they extend out into deep water for boating purposes to maintain the integrity of the shallow water seagrass beds between docks.

    - Use light transmitting docks (e.g., aluminum mesh decking instead of wooden decks) to reduce seagrass loss and bed fragmentation due to shading.
    - Minimize the effects of shading by minimizing the dock width, maximizing the dock height, and orienting the dock in a manner that decreases the area and time the space under the dock is left shaded during the day.

- Leave riparian buffers in place to help maintain water quality and nutrient input.
- Include low-wake vessel technology, appropriate routes, and BMPs for wave attenuation structures as part of the design and permit process. Vessels should be operated at sufficiently low speeds to reduce wake energy, and no-wake zones should be designated near sensitive habitats.
- Incorporate BMPs to prevent or minimize contamination from ship bilge waters, antifouling paints, shipboard accidents, shipyard work, maintenance dredging and disposal, and nonpoint source contaminants from upland facilities related to vessel operations and navigation.
- Locate mooring buoys in waters deep enough to avoid grounding and to minimize the effects of prop wash. Use subsurface floats or other methods to prevent contact of the anchor line with the substrate.
- Use catchment basins for collecting and storing surface runoff from upland repair facilities, parking lots, and other impervious surfaces to remove contaminants prior to delivery to any receiving waters.
- Locate facilities in areas with enough water velocity to maintain water quality levels within acceptable ranges.
- Locate marinas where they will not interfere with natural processes so as to affect adjacent habitats.
- To facilitate the movement of fish around breakwaters, breach gaps and construct shallow shelves to serve as "fish benches," as appropriate. Often benches are expanded shelf features used in common toe-slope stabilization transitions within the breakwater design. Benches need to provide for unrestricted fish movement throughout all tidal stages.
- Harbor facilities should be designed to include practical measures for reducing, containing, and cleaning up petroleum spills.
- Stage oil spill response equipment at several planned locations throughout the shipping route to facilitate any accidental spillage of vessel cargo or fuels.

5.4.6 Invasive Species

Based on Presidential Executive Order 13112, an invasive species is a species that is nonnative to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health. The introduction of aquatic invasive species into estuarine, riverine, and marine habitats has been well documented (Kohler and Courtenay 1986, Rosecchi et al. 1993, Spence et al. 1996) and can be intentional (e.g., for the purpose of stock or pest control) or unintentional (e.g., fouling organisms). Exotic fish, shellfish, pathogens, and plants can be spread via industrial and commercial shipping, recreational boating, aquaculture, biotechnology, and aquariums. The introduction of nonnative organisms to new environments can have many severe impacts on habitats (Omori et al. 1994).

Ballast water, water that is taken in or released by cargo vessels to compensate for changes in a ship's weight as cargo is loaded or unloaded or as fuel and supplies are consumed, is a major source of introducing invasive species into aquatic ecosystems.[23] When a vessel takes in ballast water, it also takes in aquatic organisms that may be carried from one port to another along the vessel's route. When ballast water is released, invasive species may be introduced into new environments where they can cause environmental harm. The EPA has historically exempted ballast water discharges and other discharges incidental to the normal operation of vessels ("incidental discharges") from the CWA National Pollutant Discharge Elimination System (NPDES) permit requirements. However, on December 18, 2008, the EPA signed the final Vessel General Permit (VGP) (73 FR 79473, December 29, 2009) which went into effect in Alaska on February 6, 2009 (74 FR 7042, February 12, 2009). Under the VGP, all vessels operating as a means of transportation and that discharge ballast water or other incidental discharges into U.S. waters require coverage except for (1) recreational vessels as defined in CWA § 502(25) and (2) vessels of the armed forces as defined in 40 CFR § 1700.3. In addition, as required by Pub. L. No. 110-299, commercial fishing vessels and nonrecreational vessels that are less than 24 m (79 ft) in length are not subject to this permit with the exception of ballast water discharges.

Invasive aquatic species that are considered high priority threats to Alaska's marine waters include: northern pike (*Esox lucius*), Atlantic salmon (*Salmo salar*), Chinese mitten crab (*Eriocheir sinensis*), signal crayfish (*Pacifastacus leniusculus*), zebra mussel (*Dreissena polymorpha*), New Zealand mudsnail (*Potamopyrgus antipodarum*), water thyme (*Hydrilla verticillata*), dotted duckweed (*Landoltia* [*Spirodela*] *punctata*), saltmarsh cordgrass (*Spartina alterniflora*), dense-flowered cordgrass (*S. densiflora*), purple loosestrife (*Lythrum salicaria*), Eurasian water-milfoiland (*Myriophyllum spicatum*), reed canary grass (*Phalaris arundinacea*), Japanese knotweed (*Polygonum cuspidatum*), swollen bladderwort (*Utricularia inflata*), and tunicates (*Botrylloides violaceus* and *Didemnum vexillum*) (ADF&G 2002).[24]

Relatively few aquatic invasive species have been documented in Alaska although a wide diversity of non-native taxonomic groups have colonized coastal ecosystems in other parts of the U.S. (McGee et al. 2006). Alaska's geographic isolation, harsh climate conditions, limited number of highly disturbed habitat areas, stringent plant and animal transportation laws, and small human population may explain the relative lack of invasion compared to more temperate sites in North America (ADF&G 2002, McGee et al. 2006). As economic activity and population size increase and the climate continues to change, the likelihood of aquatic invasive species establishing in Alaska will increase (Grebmeier et al. 2006b, McGee et al. 2006). According to ADF&G (2002), "potential introduction pathways include fish farms, the intentional movement of game or bait fish from one aquatic system to another, the movement of large ships and ballast water from the U.S. West Coast and Asia, fishing vessels docking at Alaska's busy commercial fishing ports, construction equipment, trade of live seafood, aquaculture, and contaminated sport angler gear brought to Alaska's world-renowned fishing sites."

[23] http://www.epa.gov/owow/invasive_species/ballastwaterFINAL.pdf

[24] http://www.adfg.alaska.gov/index.cfm?adfg=invasiveprofiles.didemnum_characteristics

The Alaska Invasive Species Working Group (AISWG) was formed in 2006 to minimize invasive species impacts in Alaska by facilitating collaboration, cooperation, and communication among AISWG members and the people of Alaska. The AISWG is composed of representatives from state, federal, university, citizen, native, conservation, and military organizations. Current information on invasive species in Alaska can be found at www.uaf.edu/ces/aiswg. The Alaska Aquatic Nuisance Species Management Plan (ADF&G 2002) focuses on prevention of invasions by the major invasive threats. The main goals of the plan are to coordinate with the public and with federal, state, local, and tribal governments for the prevention and monitoring of invasive species and the development of an effective public information program.

Invasive species pose a serious threat to Alaska's native flora and fauna. Long borders, long coastlines, busy shipping centers, and a large amount of imported goods give invasive species a variety of ways to enter Alaskan waters. Coordination and cooperation among Alaska's existing organizations and their available resources is critical to successfully control and prevent invasive species in Alaska (ADF&G 2002).

Potential Adverse Impacts

5.4.6.1 Invasive species can create five types of negative effects on EFH: (1) habitat alteration, (2) trophic alteration, (3) spatial alteration, (4) gene pool alteration, and (5) introduction of diseases.

Habitat alteration includes the excessive colonization by sessile invasive species, which precludes the growth of endemic organisms. Invasive species may alter community structure, particularly the trophic structure, by preying on native species and by increasing their own population levels. Introduced organisms may compete with indigenous species or prey on indigenous species which can reduce native fish and shellfish populations. For example, in freshwater lakes on Alaska's Kenai Peninsula, introduced northern pike have depleted local salmonid populations through rampant juvenile predation (ADF&G 2007). Spatial alteration occurs when territorial introduced species compete with and displace native species. The introduction of invasive organisms also threatens native biodiversity and could lead to changes in relative abundance of species and individuals that are of ecological and economic importance.

Long-term impacts from the introduction of nonindigenous species can include a decrease in the overall fitness and genetic diversity of natural stocks. Although hybridization is rare, it may occur between native and introduced species and can result in gene pool deterioration. Potential long-term impacts also include the spread of lethal diseases. The introduction of bacteria,
5.4.6.2 viruses, and parasites is a severe threat to EFH as it may reduce habitat quality. New pathogens or higher concentrations of disease can be spread throughout the environment, resulting in deleterious habitat conditions.

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of invasive species to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Uphold fish and game regulations of the Alaska Board of Fisheries (AS 16.05.251) and Board of Game (AS 16.05.255) which prohibit and regulate the live capture, possession, transport, or release of native or exotic fish or their eggs.
- Adhere to regulations and use BMPs outlined in the State of Alaska Aquatic Nuisance Species Management Plan (ADF&G 2002) and Management Plan for Invasive Northern Pike in Alaska (ADF&G 2007) .
- Encourage vessels to perform a ballast water exchange in marine waters (in accordance with the U.S. Coast Guard's voluntary regulations) to minimize the possibility of introducing invasive estuarine species into similar habitats. Ballast water taken on in the open ocean will contain fewer organisms, and these will be less likely to become invasive in estuarine conditions than species transported from other estuaries.
- Discourage vessels that have not performed a ballast water exchange from discharging their ballast water into estuarine-receiving waters.
- Require vessels brought from other areas over land via trailer to clean any surfaces (e.g., propellers, hulls, anchors, fenders) that may harbor non-native plant or animal species. Bilges should be emptied and cleaned thoroughly by using hot water or a mild bleach solution. These activities should be performed in an upland area to prevent the introduction of non-native species during the cleaning process.
- Treat effluent from public aquaria displays and laboratories and educational institutes using non-native species before discharge to prevent the introduction of viable animals, plants, reproductive material, pathogens, or parasites into the environment.
- Encourage the proper disposal of seaweeds and other plant materials used for packing purposes when shipping fish or other animals. These materials may harbor invasive species and pathogens and should be treated accordingly.
- Undertake a thorough scientific review and risk assessment before any non-native species are introduced into the environment.

5.4.7 Pile Installation and Removal

Pilings are an integral component of many overwater and in-water structures (Hanson et al. 2005). They support the decking of piers and docks, function as fenders and dolphins to protect structures, support navigation markers, and assist in breakwater and bulkhead construction. Materials used in pilings include steel, concrete, wood (both treated and untreated), plastic, or a combination of these materials (Hanson et al. 2005).

Impact or vibratory hammers are typically used to drive piles into the substrate (Hanson et al. 2005). Impact hammers consist of a heavy weight that is repeatedly dropped onto the top of the pile to drive the pile into the substrate. Vibratory hammers use a combination of a stationary, heavy weight and vibration in the plane perpendicular to the long axis of the pile to force the pile into the substrate. The type of hammer used depends on a variety of factors including pile material and substrate type. Impact hammers can be used to drive all types of piles, while vibratory hammers are generally most efficient at driving piles with a cutting edge (e.g., hollow steel pipe) and are less efficient at driving displacement piles (those without a cutting edge that must displace the substrate). Displacement piles include solid concrete, wood, and closed-end steel pipe (Hanson et al. 2005).

Pile Driving

Potential Adverse Impacts

Feist et al. (1996) reported that pile-driving operations affected the distribution and behavior of juvenile pink salmon and chum salmon. Fish may leave an area for more suitable spawning
5.4.8 grounds or may avoid a natural migration path because of noise disturbances. Pile driving can
5.4.8.1 generate intense underwater sound pressure waves that may adversely affect EFH. These pressure waves have been shown to injure and kill fish (CalTrans 2001, Longmuir and Lively 2001, Stotz and Colby 2001, Stadler 2002). Waves are much more likely to affect bottom-living fishes and invertebrates than those in the water column (Hawkins et al. 2014). Fish injuries associated directly with pile driving are poorly studied but include the rupture of the swim bladder and internal hemorrhaging (CalTrans 2001, Abbott and Bing-Sawyer 2002, Stadler 2002). However, we still know very little about the effects of anthropogenic sounds on fish, and the extrapolation of these findings to the same sounds under other conditions, to other fish species, or to wild animals from caged fish studies is not possible (Popper and Hastings 2009).

The underwater sounds produced by pile driving are typically characterized by multiple rapid increases and decreases in sound pressure over a very short period of time. The peak pressure is the highest absolute value of the measured waveform and can be a negative or positive pressure peak (Popper 2006). The type and intensity of the sounds produced during pile driving depend on a variety of factors, including the type and size of the pile, the firmness of the substrate into which the pile is being driven, the depth of water, and the type and size of the pile-driving hammer. SPLs are positively correlated with the size of the pile since more energy is required to drive larger piles. Wood and concrete piles appear to produce lower SPLs than hollow-steel piles of a similar size although it is unclear if the sounds produced by wood or concrete piles are harmful to fishes. Hollow steel piles with a diameter of 35.5 cm (14 in) in diameter have been shown to produce SPLs that can injure fish (Reyff 2003). Firmer substrates require more energy to drive piles and produce more intense SPLs. Sound attenuates more rapidly with distance from the source in shallow water than it does in deep water (Rogers and Cox 1988, CADoT 2009, CADoT 2015).

Driving large hollow steel piles with impact hammers produces intense, sharp spikes of sound that can easily reach injurious levels to fish. Vibratory hammers, on the other hand, produce sounds of lower intensity with a rapid repetition rate. A key difference between the sounds produced by impact hammers and those produced by vibratory hammers is the responses they evoke in fish. When exposed to sounds that are similar to those of a vibratory hammer, fish consistently displayed an avoidance response (Enger et al. 1993, Dolat 1997, Knudsen et al. 1997, Sand et al. 2000), and they did not habituate to the sound even after repeated exposures (Dolat 1997, Knudsen et al. 1997). Fish may respond to the first few strikes of an impact hammer with a startle response. After these initial strikes, the startle response wanes, and fish may remain within the field of a potentially harmful sound (Dolat 1997, NMFS 2001). The various responses to these sounds are due to the differences in the duration and frequency of the sounds.

When compared to impact hammers, the sounds produced by vibratory hammers are of longer duration (minutes versus milliseconds) and have more energy in the lower frequency range (15 to 26 Hz versus 100 to 800 Hz) (Würsig et al. 2000, Carlson et al. 2001). Studies have shown that fish respond to particle acceleration of 0.01 m/sec^2 at infrasound frequencies, that the response to infrasound is limited to the nearfield (less than 1 wavelength), and that the fish must be exposed to the sound for several seconds (Enger et al. 1993, Knudsen et al. 1994, Sand et al. 2000). Impact hammers, however, produce such short spikes of sound with little energy in the infrasound range that fish fail to respond to the particle motion (Carlson et al. 2001). Thus, impact hammers may be more harmful than vibratory hammers because they produce more intense pressure waves and because the sounds produced do not elicit an avoidance response in fishes.

The degree of damage is not related directly to the distance of the fish from the pile but to the received level and duration of the sound exposure (Hastings and Popper 2005). The degree to which an individual fish exposed to sound will be affected depends on a variety of variables including: (1) fish species, (2) fish size, (3) presence of a swim bladder, (4) physical condition of the fish, (5) peak sound pressure and frequency, (6) shape of the sound wave (rise time), (7) depth of the water around the pile, (8) depth of the fish in the water column, (9) amount of air in the water, (10) size and number of waves on the water surface, (11) bottom substrate composition and texture, (12) effectiveness of bubble curtains and other sound/pressure attenuation technology, (13) tidal currents, and (14) presence of predators. Depending on these factors, adverse effects on fish can range from behavioral changes to immediate mortality (Hastings and Popper 2005, Popper 2006).

Minimal data exist on the SPL required to injure fish. SPLs 100 decibels (dB) above the threshold for hearing may be sufficient to damage the auditory system in many fishes (Hastings 2002). SPLs of 155 dB re 1µPa may be sufficient to stun small fish. Stunned fish, while perhaps not physically injured, are more susceptible to predation. In 2008, the FHWG developed the Agreement in Principal for Interim Criteria for Injury to Fish from Pile Driving Activities. Based on this agreement, NMFS considers physical injury to begin when peak SPLs reach 206 dB re 1 µPa during a single strike and/or when the accumulated sound exposure level (SEL) from multiple strikes reaches 187 dB re 1 µPa for large fishes (≥ 2 grams [g] [0.07 ounces (oz)]) or 183 dB re 1 µPa for small fishes (< 2 g [0.07 oz]) (CADoT 2015). However, our knowledge on the sound levels at which mortality or injury may occur is limited for juvenile and adult fish and practically nonexistent for fish eggs and larvae (Popper and Hastings 2009). Fish larvae may suffer more from underwater sound than older life stages simply because juvenile and adult fish can actively swim away from a sound source, while planktonic larvae are passively transported by currents and, therefore, not capable of avoiding sound exposure (Bolle et al. 2012).

Short-term exposure to peak SPLs above 190 dB re 1µPa is thought to impose physical harm on fish (Hastings 2002). Ruggerone et al. (2008) studied the effects of pile-driving exposure on yearling coho salmon caged near (1.8 to 6.7 m [5.9 to 21.98 ft]) hollow steel piles. Although the SPLs reached 208 dB re 1 µPa (with cumulative SEL of 207 dB), no significant changes in behavior were observed during pile driving, and no fish were physically injured. However, researchers could not exclude all potential injuries to the test fish because researchers did not examine for potential injuries immediately after exposure or potential injuries to the auditory system, injuries that may have occurred at the cellular level, or stress caused by pile driving.

Small fish are more prone to injury by intense sound than are larger fish of the same species (Yelverton et al. 1975). For example, a number of surfperches (shiner [*Cymatogaster aggregate*] and striped [*Embiotoca lateralis*]) were killed during impact pile driving (Stadler 2002). Most of the dead fish were the smaller *C. aggregata* and similar-sized specimens of *E. lateralis* even though many larger *E. lateralis* were in the same area. Dissections revealed that the swim bladder of the smallest fish (80 mm [3.15 in] fork length [FL]) was completely destroyed, while that of the largest individual (170 mm [6.69 in] FL) was nearly intact, indicating a size-dependent effect. The SPLs that killed these fish are unknown. Of the reported fish kills associated with pile driving, all have occurred during use of an impact hammer on hollow-steel piles (Longmuir and Lively 2001, NMFS 2001, Stotz and Colby 2001, NMFS 2003).

Systems using air bubbles have been successfully designed to reduce the adverse effects of underwater SPLs of pile driving on fish. Both confined (i.e., metal or fabric sleeve) and unconfined air bubble systems have been shown to attenuate underwater sound pressures (Longmuir and Lively 2001, Christopherson and Wilson 2002, Reyff and Donovan 2003). When using an unconfined air bubble system in areas of strong currents, it is critical that the pile be fully contained within the bubble curtain. To accomplish this when designing the system, adequate air flow and ring spacing, both vertically and in terms of distance from the pile, are factors that should be considered.

5.4.8.2 *Recommended Conservation Measures*

Common measures to reduce the underwater sound generated by in-water pile driving include treatments to reduce the transmission of sound through the water and treatments to reduce the sound generated by the pile (CADoT 2015). The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of pile driving to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Install hollow steel piles with an impact hammer at a time of year when larval and juvenile stages of fish species with designated EFH are not present.

If this first measure is not possible, then the following measures regarding pile driving should be incorporated when practicable to minimize adverse effects:

- Drive piles during low tide when they are located in intertidal and shallow subtidal areas.
- Use a vibratory hammer when driving hollow steel piles. When impact hammers are required due to seismic stability or substrate type, drive the pile as deep as possible with a vibratory hammer first and then use the impact hammer to drive the pile to its final position.

Follow standard procedures to measure and analyze the underwater noise from pile driving (see CADoT 2015). Implement measures to attenuate the sound should levels exceed the interim criteria thresholds: when peak SPLs reach 206 dB re 1 μPa during a single strike and/or when the accumulated SEL from multiple strikes reaches 187 dB re 1 μPa for large fishes (≥ 2 g [0.07 oz]) or 183 dB re 1 μPa for small fishes (< 2 g [0.07 oz]). If sound levels are anticipated to exceed these acceptable limits, implement appropriate mitigation measures, when practicable. Methods to reduce the SPLs and SELs include, but are not limited to, the following:

- Surround the pile with an air bubble curtain system or air-filled coffer dam.
- Because the sound produced has a direct relationship to the force used to drive the pile, use a smaller hammer to reduce sound pressure.
- Use a hydraulic hammer if impact driving cannot be avoided. The force of the hammer blow can be controlled with hydraulic hammers; reducing the impact force will reduce the intensity of the resulting sound.
- Drive piles when the current is reduced (i.e., centered around slack current) in areas of strong current to minimize the number of fish exposed to adverse levels of underwater sound.

Pile Removal

5.4.9 *Potential Adverse Impacts*

5.4.9.1 The primary adverse effect of removing piles is the suspension of sediments which may result in harmful levels of turbidity and the release of contaminants contained in those sediments. The methods generally used for pile removal are vibratory removal, breaking or cutting below the mudline, direct pull, and use of a clamshell. Vibratory pile removal tends to cause the sediments to slough off at the mudline, resulting in relatively low levels of suspended sediments and contaminants. Vibratory removal of piles is gaining popularity because it can be used on all types of piles as long as they are structurally sound. Breaking or cutting the pile below the mudline may suspend only small amounts of sediment provided that the stub is left in place, and little digging is required to access the pile. Direct pull or use of a clamshell to remove broken piles may suspend large amounts of sediment and contaminants. When the piling is pulled from the substrate using these two methods, the sediments clinging to the piling slough off as it is raised through the water column, producing a potentially harmful plume of turbidity and/or releasing contaminants. Moreover, the use of a clamshell may suspend additional sediment if it penetrates the substrate while grabbing the piling.

While there is a potential to adversely affect EFH during the removal of piles, many of the piles removed in Alaska are old creosote-treated timber piles. The removal of these piles may provide
5.4.9.2 long-term benefits to EFH since chemicals from the piles can leach out, introducing toxins into the water column (Perkins 2009). Therefore, in some cases, removing a chronic source of contamination may outweigh the temporary adverse effects of increased turbidity.

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of pile removal to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Remove piles completely rather than cutting or breaking them off if they are structurally sound.
- Minimize the suspension of sediments and disturbance of the substrate when removing piles. Measures to help accomplish this include, but are not limited to, the following:
  - When practicable, remove piles with a vibratory hammer rather than using the direct pull or clamshell methods.
  - Remove the pile slowly to allow sediment to slough off at or near the mudline.
  - The operator should first hit or vibrate the pile to break the bond between the sediment and the pile to minimize the potential for the pile to break and to reduce the amount of sediment sloughing off the pile during removal.
  - Encircle the pile or piles with a silt curtain that extends from the surface of the water to the substrate to help contain the sedimentation.
- Complete each pass of the clamshell to minimize suspension of sediment if pile stubs are removed with a clamshell.
- Place piles on a barge equipped with a basin to contain attached sediment and runoff water after removal. Creosote-treated timber piles should be disposed of properly to prevent reuse in the marine environment, and all debris, including attached contaminated sediments, should be disposed of in an approved upland facility.
- Using a pile driver, drive broken/cut stubs far enough below the mudline to prevent the release of contaminants into the water column as an alternative to their removal.

5.4.10 **Overwater Structures**

Overwater structures include commercial and residential piers and docks, floating breakwaters, barges, rafts, booms, and mooring buoys. These structures are typically located in intertidal areas out to about 15 m (49 ft) below the area exposed by the mean lower low tide (i.e., the shallow subtidal zone) (Hanson et al. 2005).

5.4.10.1 *Potential Adverse Impacts*

Overwater structures can primarily adversely affect EFH via: (1) changes in ambient light conditions, (2) alterations of the wave and current energy regimes, (3) release of contaminants, and (4) activities associated with the use and operation of the overwater facilities (Nightingale and Simenstad 2001b). Although the effect of some individual overwater structures on EFH may be minimal, the overall impact may be substantial when considering cumulative effects of multiples structures in a given area.

Changes in ambient light conditions are caused by the shade that overwater structures can create which reduces the light levels below the structure. The size, shape, and intensity of the shadow cast by a particular structure depends upon its height, width, construction materials, and orientation. High, narrow piers and docks produce narrower, more diffuse shadows than low, wide structures. In addition, less light is reflected underneath structures built with light-absorbing materials (e.g., wood) than structures built with light-reflecting materials (e.g., concrete or steel) (Hanson et al. 2005). Light-transmitting decking (e.g., aluminum grating) also minimizes shading compared to non-grated material (e.g., wooden planks) (Landry et al. 2008). The preferred orientation for docks and other overwater structures depends on the orientation of the shoreline and angle of the sun at the site. Shade can be reduced by minimizing the width and maximizing the height of the structure and by orienting the structure in a manner that decreases the area and time the space under the structure is left shaded during the day (Landry et al. 2008, Gladstone and Courtenay 2014).

The shading caused an overwater structure affects the plant and animal communities below the structure. Distributions of plants, invertebrates, and fishes appear severely limited in under-dock environments when compared to adjacent, unshaded, vegetated habitats. Under-pier light levels can fall below threshold amounts for the photosynthesis of diatoms, benthic algae, eelgrass, and associated epiphytes. These photosynthesizers are an essential part of the nearshore habitat and the estuarine and nearshore food webs that support many species of marine and estuarine fishes. Eelgrass and other macrophytes can be reduced or eliminated through partial shading (Landry et al. 2008, Gladstone and Courtenay 2014).

Areas under large overwater structures like piers are suboptimal habitats not only for benthic fishes but also for many of the abundant pelagic fishes (Able et al. 2013). Shading can directly adversely affect fish which rely on visual cues for spatial orientation, prey capture, schooling, predator avoidance, and migration (Quinn 2005). The reduced-light conditions found under an overwater structure may limit the ability of fishes, especially juveniles and larvae, to perform these essential activities. For instance, several studies have shown that juvenile salmonids avoided swimming beneath overwater structures, suggesting that these structures may delay the out-migration of juvenile salmon and increase the risk of predation by exposing young salmon to larger fish (Toft et al. 2007, Munsch et al. 2014).

Shading from overwater structures may also indirectly affect fish by reducing prey abundance and habitat complexity via a decrease in aquatic vegetation and phytoplankton abundance (Kahler et al. 2000, Haas et al. 2002). Glasby (1999) found that epibiotic assemblages on pier pilings at marinas subject to shading were markedly different than in surrounding areas. Other studies have shown shaded epibenthos to be reduced relative to that in open areas. These factors are thought to be responsible for the observed reductions in juvenile fish populations found under piers and the reduced growth and survival of fishes held in cages under piers when compared to open habitats (Able et al. 1998, Duffy-Anderson and Able 1999).

The potential alterations of wave and current energy regimes from overwater structures can impact the nearshore detrital food web by altering the size, distribution, and abundance of substrate and detrital materials (Hanson et al. 2005). The structures can disrupt transport, thus altering substrate composition, and can act as barriers to natural processes which build spits and beaches and provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning (Hanson et al. 2005).

Treated wood used for pilings and docks releases contaminants into saltwater environments. PAHs are commonly released from creosote-treated wood. PAHs can cause a variety of deleterious effects (e.g., cancer, reproductive anomalies, immune dysfunction, and growth and development impairment) to exposed fish (Johnson et al. 1999, Johnson 2000, Stehr et al. 2000).

Wood also is commonly treated with other chemicals such as ammoniacal copper zinc arsenate and chromated copper arsenate (Poston 2001). These preservatives are known to leach into marine waters for a relatively short time after installation, but the rate of leaching varies considerably depending on many factors. Concrete and steel, on the other hand, are relatively inert and do not leach contaminants into the water.

The construction and maintenance of overwater structures often involve pile driving (Section 5.2.8) and dredging (Section 5.2.1); both of these activities may adversely affect EFH. Please see these previous sections for descriptions of potential adverse impacts to EFH.

5.4.10.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of overwater structures to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Use upland boat storage whenever possible to minimize the need for overwater structures.
- Develop overwater structures in deep enough waters to avoid intertidal and shade impacts, minimize or preclude dredging, minimize groundings, and avoid displacement of SAV as determined by a preconstruction survey.
- Design piers, docks, and floats to be multiuse facilities to reduce the overall number of such structures and to limit impacted nearshore habitat.
- Incorporate measures that increase the ambient light transmission under piers and docks. These measures include, but are not limited to, the following:
  - Maximize the height of the structure and minimize the width to decrease the shade footprint.
  - Use reflective materials (e.g., concrete or steel instead of materials that absorb light such as wood) on the underside of the dock to reflect ambient light.
  - Use light-transmitting materials (e.g., aluminum grating) instead of non-grated materials (e.g., wooden planks) (Landry et al. 2008).
  - Explore the use of artificial light to mitigate dock shading impacts (see Ono et al. 2010).
  - Use the fewest number of pilings necessary to support the structures to allow light into under-pier areas and minimize impacts to the substrate.
  - Align piers, docks, and floats in a north-south orientation to allow the arc of the sun to cross perpendicular to the structure to reduce the duration of light limitation.
- Use floating rather than fixed breakwaters whenever possible, and remove them during periods of low dock use. Encourage seasonal use of docks and off-season haul-out.
- Locate floats in deep water to avoid light limitation and grounding impacts to the intertidal or shallow subtidal zones.

- Maintain at least 0.30 m (1 ft) of water between the substrate and the bottom of the float at extreme low tide.
- Conduct in-water work when managed species and prey species are least likely to be impacted.
- To the extent practicable, avoid the use of treated wood timbers or pilings. If possible, use alternative materials such as untreated wood, concrete, or steel.
- Mitigate for unavoidable impacts to benthic habitats. Mitigation should be adequate, monitored, and adaptively managed.

5.4.11 Flood Control/Shoreline Protection

Structures placed along the shoreline to protect humans from flooding events include berms, breakwaters, jetties, dikes, levees, ditches, concrete or wood seawalls, rip-rap revetments (sloping piles of rock placed against the toe of the dune or bluff in danger of erosion from wave action), dynamic cobble revetments (natural cobble placed on an eroding beach to dissipate wave energy and prevent sand loss), vegetative plantings, and sandbags. These structures can cause changes in the physical, chemical, and biological characteristics of shoreline and riparian habitat and can have long-term adverse effects on tidal marsh and estuarine habitats (PFMC and NMFS 2014).

5.4.11.1 *Potential Adverse Impacts*

Although highly variable, tidal marshes typically have freshwater vegetation on the landward side, saltwater vegetation on the seaward side, and gradients of species in between that are in equilibrium with the prevailing climatic, hydrographic, geological, and biological features of the coast. These systems normally drain through tidal creeks that empty into bays or estuaries. Freshwater entering along the upper end of the marsh drains across the surface and enters the tidal creeks (PFMC and NMFS 2014). Dikes, levees, ditches, or other flood control structures at the upper end of a tidal marsh can cut off all tributaries feeding the marsh, preventing the flow of freshwater, annual renewal of sediments and nutrients, and the formation of new marshes. Water controls within the marsh can intercept and carry away freshwater drainage, thus blocking freshwater from flowing across seaward portions of the marsh or increasing the speed of runoff of freshwater to the bays or estuaries. These effects can lower the water table which may permit saltwater intrusion into the marsh and create migration barriers for aquatic species (PFMC and NMFS 2014).

In deeper channels where anoxic conditions prevail, large quantities of hydrogen sulfide may be produced that are toxic to marsh grasses and other aquatic life. Acid conditions of these channels may also result in the release of heavy metals from the sediments (PFMC and NMFS 2014). Contaminants may also be released into the environment via leaching of chemicals (e.g., creosote, chromated copper arsenate, and copper zinc arsenate) used on bulkheads or other wood materials. Potential impacts of these chemicals on salmon include increased mortality and adverse effects on behavior, development, navigation (Hecht et al. 2007, Sandahl et al. 2007, Baldwin et al. 2011, McIntyre et al. 2012).

Long-term effects of shoreline protection structures on tidal marshes include land subsidence (sometimes even submergence), soil compaction, conversion to terrestrial vegetation, greatly reduced invertebrate populations, and general loss of productive wetland characteristics (PFMC and NMFS 2014). Changes in the hydrology of coastal salt marshes can reduce estuarine productivity, restrict suitable habitat for aquatic species, and result in salinity extremes during droughts and floods (Johnson et al. 2008). Armoring shorelines to prevent erosion and to maintain or create shoreline real estate can reduce the amount of intertidal habitat and affect the nearshore processes and ecology of numerous species (Williams and Thom 2001). Potential hydraulic effects on the shoreline include increased energy seaward of the armoring, reflected wave energy, dry beach narrowing, substrate coarsening, beach steepening, changes in sediment storage capacity, loss of organic debris, and downdrift sediment starvation. The installation of breakwaters and jetties can change the local community via burial or removal of resident biota, changes in cover and preferred prey species, and predator attraction. Similar to armoring, breakwaters and jetties modify hydrology, nearshore sediment transport, and the movements of larval forms of numerous species (Williams and Thom 2001).

Restoration projects often use bank stabilization and in-stream structures to create new habitat; however, these projects often fail to consider the physical, chemical, and biological processes that drive the riverine ecosystem (Beechie et al. 2010).

5.4.11.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of flood control and shoreline protection on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Avoid or minimize the loss of coastal wetlands as much as possible; encourage coastal wetland habitat preservation.
- Do not dike or drain tidal marshlands or estuaries.
- Wherever possible, use soft approaches (e.g., beach nourishment, vegetative plantings, or placement of LWD) in lieu of “hard” shoreline stabilization and modifications (e.g., concrete bulkheads and seawalls or concrete or rock revetments).
- Ensure that the hydrodynamics and sedimentation patterns are properly modeled and that the structure design avoids erosion to adjacent properties when “hard” shoreline stabilization is deemed necessary.
- Include efforts to preserve and enhance fishery habitat to offset impacts. For example, provide new gravel for spawning or nursery habitats; remove barriers to natural fish passage; and use weirs, grade control structures, and low flow channels to provide the proper depth and velocity for fish.
- Avoid installing new water control structures in tidal marshes and freshwater streams. If the installation of new structures cannot be avoided, ensure that they are designed to allow for optimal fish passage and natural water circulation.
- Ensure water control structures are monitored for potential changes in water temperature, dissolved oxygen concentration, and other parameters.

- Use seasonal restrictions to avoid impacts to habitat during species critical life history stages (e.g., spawning and egg/larval development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in the review process for flood control and shoreline protection projects.
- Use an adaptive management plan with ecological indicators to oversee monitoring and to ensure that mitigation objectives are met. Take corrective action as needed.

5.4.12 Log Transfer Facilities/In-Water Log Storage

Rivers, estuaries, and bays were historically the primary means of transporting and storing logs in the Pacific Northwest (PFMC and NMFS 2014). In Alaska, the use of estuaries, bays, and nearby uplands for log storage is still common; most LTFs are in Southeast Alaska with a few in Prince William Sound. LTFs are constructed wholly or in part in waterways and used to transfer commercially harvested logs to or from a vessel or log raft or to consolidate logs for incorporation into log rafts (EPA 2000a). LTFs may use a crane, A-frame structure, conveyor, slide, or ramp to move logs from land into the water. Logs can also be placed in the water at the site by helicopters.

5.4.12.1 *Potential Adverse Impacts*

The potential physical adverse effects of LTFs on EFH are similar to the shading and other effects of floating docks and other overwater structures (see Section 5.2.10). However, the accumulation of bark debris is unique to LTFs (PFMC and NMFS 2014). Bark and wood debris may accumulate on the ocean floor of the waterway as a result of the abrasion of logs from transfer equipment during the process of bundling the logs into rafts and hooking them to a tug for shipment (PFMC and NMFS 2014). The debris can change the benthic habitat and degrade the water quality (Levings and Northcote 2004). The debris may smother clams, mussels, seaweed, kelp, and grasses (PFMC and NMFS 2014). These changes may be long term since the debris can sometimes remain in the area for decades. The accumulation of bark debris in shallow- and deep-water environments has been shown to decrease benthic species richness and abundance (Jackson 1986, Kirkpatrick et al. 1998) which can reduce the availability of food for some groundfish species and life stages (PFMC and NMFS 2014).

Log storage may cause adverse impacts via the leaching of soluble organic compounds from the stored logs. Log bark may affect groundfish habitat by significantly increasing oxygen demand within the area of accumulation (Pacific Northwest Pollution Control Council 1971). High oxygen demand can lead to an anaerobic zone within the bark pile where toxic sulfide compounds are generated, particularly in brackish and marine waters. Reduced oxygen levels, anaerobic conditions, and the presence of toxic sulfide compounds can reduce the production of salmon and their forage organisms as well as the available habitat (PFMC and NMFS 2014). In addition, soils at onshore facilities where logs are decked can become contaminated with gasoline, diesel fuel, solvents, and other pollutant from trucks and heavy equipment. These contaminants could leach into nearshore EFH (PFMC and NMFS 2014).

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of log transfer and storage facilities to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

5.4.12.2 Potential adverse physical, chemical, and biological effects of LTF operations can be substantially reduced by adhering to appropriate siting and operational constraints (PFMC and NMFS 2014). In 1985, the Alaska Timber Task Force (ATTF) developed guidelines to "delineate the physical requirements necessary to construct a log transfer and associated facilities, and in context with requirements of applicable law and regulations, methods to avoid or control potential impacts from these facilities on water quality, aquatic and other resources." Since 1985, the ATTF guidelines have been applied to new LTFs through the requirements of NPDES permits and other state and federal programs (EPA 1996). Adherence to the ATTF operational and siting guidelines and BMPs in the NPDES General Permit will reduce the amount of bark and wood debris that enters the marine and coastal environment, the potential for displacement or harm to aquatic species, and the accumulation of bark and wood debris on the ocean floor. The following conservation measures reflect those guidelines.

- Restrict or eliminate storage and handling of logs from waters where state and federal water quality standards cannot be met at all times outside of the authorized zone of deposition.
- Minimize potential impacts of log storage by employing effective bark and wood debris control, collection, and disposal methods at log dumps, raft building areas, and mill-side handling zones; avoiding free-fall dumping of logs; using easy let-down devices for placing logs in the water; and bundling logs before water storage (bundles should not be broken except on land and at mill-side zones).
- Do not store logs in the water if they will ground at any time or shade sensitive aquatic vegetation such as eelgrass.
- Avoid siting log-storage areas and LTFs in sensitive habitat and areas important for specified species as required by the ATTF guidelines.
- Site log storage areas and LTFs in areas with good currents and tidal exchanges.
- Use land-based storage sites, where possible, with the goal of eliminating the in-water
5.4.13 storage of logs.
- Also see the following link for LTF guidelines: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5445506.pdf.

<u>Utility Line, Cables, and Pipeline Installation</u>

With the continued development of coastal regions comes greater demand for the installation of cables. These include utility lines for power and other services; and pipelines for water, sewage, and other utilities. The installation of pipelines, utility lines, and cables can have direct and indirect impacts on the offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats. Many of the direct impacts occur during construction, such as ground disturbance in the clearing of the ROW, access roads, and equipment staging areas. Direct impacts may also be caused by dredging during the placement of pipe, cable, and utility lines. Indirect impacts may include increased turbidity, saltwater intrusion, accelerated erosion, and the introduction of urban and industrial pollutants due to ground clearing and construction (PFMC and NMFS 2014).

5.4.13.1 *Potential Adverse Impacts*

Potential adverse effects on EFH from the installation of pipelines, utility lines, and cables can occur through (1) the destruction of organisms and habitats, particularly vertically complex hard bottom habitats (e.g., hard corals and vegetated rocky reef); (2) turbidity impacts; (3) the resuspension and release of contaminants; and (4) changes in hydrology (Hanson et al. 2005). Shallow-water environments, rocky reefs, nearshore and offshore rises, wetlands, and estuaries are more likely to be adversely impacted than open-water habitats due to their higher sustained biomass and lower water volumes, which decrease their ability to dilute and disperse suspended sediments (Gowen 1978).

The destruction of organisms and habitats can occur in pipeline or cable ROW and can lead to long-term or permanent damage depending on the degree and type of habitat disturbance and the mitigation measures employed. Dredging and pipeline, utility line, and cable burials can alter bottom habitat by altering substrates used for feeding or shelter. Because vegetated coastal wetlands provide forage habitat for and protection of commercially important invertebrates and fish, marsh degradation due to plant mortality, soil erosion, or submergence will eventually decrease productivity. Vegetation loss and reduced soil elevation within pipeline construction corridors should be expected with the use of double-ditching techniques (Polasek 1997). Subsea pipelines that are placed on the substrate have the potential to create physical barriers to benthic invertebrates during migration and movement. Furthermore, erosion around buried pipelines and cables can lead to uncovering of the structure and the formation of escarpments. This, in turn, can interfere with the migratory patterns of benthic species (Johnson et al. 2008).

The increased turbidity resulting from the installation of pipelines, utility lines, and cables can cause a decrease in primary production (Hanson et al. 2005). Adverse impacts may be heightened during certain times of the year, such as during highly productive spring phytoplankton blooms or at times when organisms are already under stressed conditions. Changes in turbidity can temporarily alter phytoplankton communities. Depending on the severity of the turbidity, these changes in water clarity may affect the EFH habitat functions of species higher in the food chain.

The installation of pipelines, utility lines, and cables can also result in the resuspension and release of contaminants, such as heavy metals and pesticides from the sediment, which can have lethal effects (Gowen 1978). Spills of petroleum products, solvents, and other construction-related material can also adversely affect EFH.

Pipeline canals have the potential to change the hydrology of coastal areas facilitating rapid drainage of interior marshes during low tides or low precipitation, reducing or interrupting freshwater inflow and associated littoral sediments, and allowing saltwater to move farther inland during high tides (Chabreck 1972). This intrusion of saltwater intrusion into freshwater marshes often causes a loss of salt-intolerant emergent and submerged aquatic plants (Chabreck 1972, Pezeshki et al. 1987), erosion, and net loss of soil organic matter (Craig et al. 1979).

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of cable, pipeline, and utility line installation on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

5.4.13.2

- Align crossings along the least damaging route. Avoid known fished and sensitive areas such as deep sea corals, SAV, emergent marshes, and anadromous fish bearing streams.
- Use horizontal directional drilling where cables or pipelines would cross anadromous fish streams, salt marsh, vegetated intertidal zones, or steep erodible bluff areas adjacent to the intertidal zone.
- Store and contain excavated material on uplands. If storage in wetlands or waters cannot be avoided, use alternate stockpiles to allow continuation of sheet flow. Store stockpiled materials on construction cloth rather than bare marsh surfaces, seagrasses, or reefs.
- Backfill excavated wetlands with either the same or comparable material capable of supporting similar wetland vegetation. Restore original marsh elevations. Stockpile topsoil and organic surface material, such as root mats, separately and return it to the surface of the restored site. Use adequate material so that the proper pre-project elevation is attained following the settling and compaction of the material. After backfilling, implement erosion protection measures where needed.
- Use existing rights-of-way whenever possible to lessen overall encroachment and disturbance of wetlands.
- Bury pipelines and submerged cables where possible. Unburied pipelines or pipelines buried in areas where scouring or wave activity eventually exposes them run a much greater risk of damage leading to leaks or spills.
- Remove inactive pipelines and submerged cables unless they are located in sensitive areas (e.g., marsh, reefs, seagrass). If pipelines are allowed to remain in place, ensure that they are properly pigged, purged, filled with seawater, and capped.
- Use silt curtains or other barriers to reduce turbidity and sedimentation near the project site whenever possible.
- Limit access for equipment to the immediate project area. Tracked vehicles are preferred over wheeled vehicles. Consider using mats and boards to avoid sensitive areas. Caution equipment operators to avoid sensitive areas, and clearly mark sensitive areas to ensure that equipment operators do not traverse them.
- Limit construction equipment to the minimum size necessary to complete the work. Use shallow-draft equipment to minimize effects and to eliminate the necessity for temporary access channels. Use the push-ditch method in which the trench is immediately backfilled to minimize the impact duration when possible.
- Conduct construction during the time of year when it will have the least impact on sensitive habitats and species.

- Suspend transmission lines beneath existing bridges or conduct directional boring under streams to reduce the environmental impact. If transmission lines span streams, site towers at least 61 m (200 ft) from streams.
- For activities on the continental shelf, implement the following measures to the extent practicable to avoid and minimize adverse impacts to managed species:
  - Shunt drill cuttings through a conduit and either discharge the cuttings near the sea floor or transport them ashore.
  - Locate drilling and production structures, including pipelines, at least 1.6 km (1 mi) from the base of a hardbottom habitat.
  - Bury pipelines at least 0.9 m (3 ft) beneath the sea floor whenever possible. Particular considerations (i.e., currents, ice scour) may require deeper burial or weighting to maintain adequate cover. Buried pipelines and cables should be examined periodically for maintenance of adequate cover.
  - Locate alignments along routes that will minimize damage to marine and estuarine habitat. Avoid laying cable over high-relief bottom habitat and across live bottom habitats such as corals and sponges.

5.4.14 Mariculture

Productive embayments are often used for commercial culturing and harvesting operations. These locations provide protected waters for geoduck (*Panopea generosa*), oyster, and mussel culturing. In 1988, Alaska passed the Alaska Aquatic Farming Act (AAF Act) which is designed to encourage the establishment and growth of an aquatic farming industry in the state. In order for the Alaska Department of Natural Resources (ADNR) to issue an aquatic farm permit, the AAF Act requires four criteria to be met, including the requirement that the farm may not significantly affect fisheries, wildlife, or other habitats in an adverse manner.

Shellfish culture in salmon EFH consists primarily of oyster culture although clams, mussels, and abalone are also harvested (PFMC and NMFS 2014). Shellfish aquaculture tends to have less impact on EFH than finfish aquaculture because the shellfish generally are not fed or treated with chemicals (OSPAR Commission 2009). There are several hundred public facilities (federal, tribal, and state-operated) producing Pacific salmonids for release into fresh and sea water salmon EFH (NRC 1996). In addition, hundreds of private hatcheries in salmon EFH commercially produce salmon, trout, catfish, and tilapia (PFMC and NMFS 2014).

5.4.14.1 *Potential Adverse Impacts*

Potential adverse impacts to EFH by mariculture operations include: (1) the risk of introducing undesirable species and disease, (2) the physical disturbance of intertidal and subtidal areas, and (3) impacts to estuarine food webs, including the disruption of eelgrass habitat (e.g., dumping of shell on eelgrass beds, repeated mechanical raking or trampling, and impacts from predator exclusion netting).

Mariculture includes the risk of introducing undesirable species and diseases into the natural environment. The artificial propagation of native and non-native fish in or adjacent to salmon

EFH has the potential to adversely affect that habitat by altering water quality, modifying physical habitat, and creating impediments to passage (PFMC and NMFS 2014). The escape of finfish, in particular, may adversely impact EFH. Introduced hatchery fish may prey on native fish, compete with native fish for food and habitat, spread diseases to wild populations, cause the release of chemicals into the natural habitat, and establish non-native populations of salmonids and non-salmonids (Fresh 1997, PFMC and NMFS 2014). Krkošek et al. (2007) reported that the recurrent outbreaks of parasitic sea lice from salmon farms typically killed over 80 percent of the wild pink salmon population runs along the central British Columbia coast.

Various methods of shellfish culture and harvest, such as mechanical harvest in eelgrass beds, harrowing, off-bottom culture, and raft and line culture, also have the potential to adversely impact salmon EFH. The greatest impacts are temporary and result from mechanical harvest or harrowing which involve physical disturbance of the benthic zone (PFMC and NMFS 2014). Hydraulic dredges used to harvest oysters in coastal bays can cause long-term adverse impacts to eelgrass beds by reducing or eliminating the beds (Phillips 1984). The use of chemicals to control burrowing organisms detrimental to oyster culture may also adversely affect EFH, and policies have been developed to regulate the use of chemicals in natural habitat and offset losses to eelgrass beds (WDF and WDOE 1992).

Concern has also been expressed about extensive shellfish culture in estuaries and its impact on estuarine food webs. Oysters are efficient filter feeders and reduce microalgae and zooplankton that are also food for salmon prey species. The extent to which this may adversely affect managed prey species is unknown. However, because bivalves remove suspended sediments and phytoplankton from the water column, mariculture may actually improve water quality in eutrophic areas and can assist in recycling nutrients from water column to the sediment (Emmett 2002).

Mariculture facilities can be attractive to bird and mammal species both as a food source and shelter/resting facilities. Seals, in particular, have been known to prey on shellfish in cages and use mariculture facilities as haul outs (OSPAR Commission 2009). This can result in economic loss to the facility, danger to employees, and possibly injury or death for the offending animal(s). Diving birds may also be attracted to the cages and have been known to become entangled. Increased boat traffic, human presence, and the use of scaring devices also may adversely affect resident bird and mammal species not directly utilizing the mariculture facilities.

5.4.14.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of mariculture facilities to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Aquaculture facilities rearing non-native species should be located upland and use closed-water circulation systems whenever possible.
- Site mariculture operations away from kelp or eelgrass beds. If mariculture operations are to be located adjacent to existing kelp or eelgrass beds, monitor these beds on an annual basis and resite the mariculture facility if monitoring reveals adverse effects.

- Do not enclose or impound tidally influenced wetlands for mariculture. Take into account the size of the facility, migratory patterns, competing uses, hydrographic conditions, and upstream uses when siting facilities.
- Undertake a thorough scientific review and risk assessment before any non-native species are introduced into the natural environment.
- Encourage development of harvesting methods to minimize impacts on plant communities and the loss of food and/or habitat to fish populations during harvesting operations.
- Provide appropriate mitigation for the unavoidable, extensive, or permanent loss of plant communities.
- Ensure that mariculture facilities, spat, and related items transported from other areas are free of nonindigenous species. For control of *Didemnum* tunicates, remove nets, floats, and other structures from salt water periodically and allow them to dry thoroughly and/or soak them in fresh water.

5.4.15 Alternative Energy Development

Alternative energy development projects are expanding in Alaska and include the following sources of renewable energy: biomass (e.g., wood, fish byproducts), geothermal, hydroelectric, solar, wind, and tidal and wave (AEA and REAP 2013). Of these potential sources of alternative energy that may impact EFH, tidal and wave energy development is assessed in this document because nearshore hydrokinetic technology is moving forward in Alaska (PFMC and NMFS 2014). Tidal energy projects have been proposed in Cook Inlet: one on the west side of Fire Island near Anchorage and another adjacent to the East Foreland in the vicinity of Nikiski on the Kenai Peninsula. These projects are currently in preliminary testing and environmental monitoring phases (ORPC 2013). Ocean thermal and offshore wind development are not discussed because they are not likely to be proposed off the west coast of the U.S. in the near future (PFMC and NMFS 2014).

Tidal and wave energy can be extracted via hydrokinetic devices which are placed directly in a river or tidal current and powered by the kinetic energy of the moving water (AEA and REAP 2013). Opposed to traditional hydropower facilities, hydrokinetic devices generate electricity from water without the need for dams and diversions (Cada et al. 2007). The Energy Independence and Security Act (EISA) of 2007 defines marine and hydrokinetic renewable energy as electrical energy from waves, tides, and currents in oceans, estuaries, and tidal areas; from free flowing water in rivers, lakes, and streams; from free flowing water in man-made channels; and from differentials in ocean temperature (ocean thermal energy conversion) (DoE 2009).

Hydrokinetic energy conversion devices can be categorized based on rotating machines and wave energy conversion devices (Bedard 2005). Rotating machines include a rotor which spins in response to the movements of river or ocean currents. Consisting of conventional propeller-type blades or helical blades, the rotor can be encased in a duct that channels the flow or open like a wind turbine. Wave energy converters harness the energy possessed by a body of water because of its elevation (i.e., head) relative to a reference point. Therefore, they oscillate based on changes in the height of ocean waves (head or elevation changes). All of these devices must be secured to the river or ocean bottom either via pilings driven into the sediments or via anchors and mooring cables (Cada et al. 2007).

Hydrokinetic energy development involves four phases of activities that can potentially affect EFH: preconstruction, construction, operation and maintenance, and decommissioning phases (DoE 2009, Boehlert and Gill 2010, Kramer et al. 2010). Pre-construction activities may include site evaluations and technology testing. Construction activities typically include horizontal directional drilling to land cables from the device to the shoreline, laying of subsea transmission cable, installation of foundations/moorings, and deployment and commissioning of device(s). Operation and maintenance activities include monitoring the mechanical functioning of the devices and appurtenances and inspecting and repairing equipment. Decommissioning at the end of the project (typically 5 to 30 years) involves the removal of all equipment in the water column and transmission cables and restoration of the site, if needed. Related activities that pertain to both the construction and operations phases include the installation and maintenance of navigation buoys to mark the deployment area and reliable port infrastructure to accommodate work vessels as well as the delivery and retrieval of large hydrokinetic devices to pier-side for repair and maintenance (PFMC and NMFS 2014).

5.4.15.1 *Potential Adverse Impacts*

Because most hydrokinetic energy projects have not yet been fully developed, there are few studies of their environmental effects. Potential effects on EFH are thought to result from the presence and operation of a wave energy convertor device or turbine (PFMC and NMFS 2014). Potential environmental impacts of a hydrokinetic facility and operations may result from the following: (1) alteration of river or ocean currents or waves, (2) alteration of bottom substrates and sediment transport/deposition, (3) alteration of bottom habitats, (4) impacts of noise, (5) effects of electromagnetic fields from electrical equipment and transmission lines, (6) release of contaminants, (7) interference with animal movements and migrations, including fish (prey and predators) and invertebrate attraction to subsurface components of devices, and (8) potential for injury to aquatic organisms from strike or impingement of rotors or blades (DoE 2009, Kramer et al. 2010).

Also there is a need to consider the principal factors that may impact fish populations and EFH from the development and construction of a wave energy facility. These include the introduction of noise; habitat alterations; entrainment, entrapment, or impingement of organisms; and the potential for spills of fuels or other hazardous materials (MMS 2007). Although this document summarizes these potential direct and indirect impacts to fish resources and EFH during hydrokinetic facility construction and operation, a detailed site-specific analysis would be needed since impacts can be influenced by site-specific conditions, such as water depth, currents, topography, and species and types of habitat present, as well as the anticipated spatial and temporal scales of a project (MMS 2007, Boehlert and Gill 2010). The potential cumulative effects of multiple devices in the water column also need to be evaluated (PFMC and NMFS 2014).

Both the construction and decommissioning of hydrokinetic energy facilities would lead to alterations in bottom substrates and habitats and increased sedimentation/turbidity (MMS 2007). Disturbances to the benthic habitat will occur during the temporary anchoring of construction vessels; the clearing, digging, and refilling of trenches for power cables; and the installation of permanent anchors, pilings, and other mooring devices. Prior to installation of a buried cable, debris is typically cleared from the cable route using a ship-towed grapnel (Carter et al. 2009). Cables are buried using a ship-mounted plow; buried cables are usually exposed and reburied using a water-jetting technique when needing repair (Carter et al. 2009). The placement/removal of transmission lines on the seafloor and foundation/mooring installation/removal would disturb the sediment, increase turbidity due to the suspension of sediments, and possibly alter the benthic habitat via the crushing/smothering of benthic organisms. The increased turbidity may decrease SAV due to the limited photosynthesis and in turn may reduce local primary productivity and the availability of other planktonic organisms that serve as a base of the food chain for fish resources. The loss of vegetation would also limit the forage and shelter habitats for fish (MMS 2007). The disturbance of sediments during the installation and removal of the foundations, anchors, and transmission cables may also mobilize contaminants which may impact fish and their prey and habitats. In addition, contaminants may be released via fuel spills as a result of vessel accidents or leaks during site construction or decommissioning (MMS 2007).

Noise associated with construction/decommissioning activities could disturb fish resources. Pilings may be required to anchor the devices; therefore, pile-driving operations may adversely affect EFH and the distribution and behavior of fish (MMS 2007). See Section 5.2.8 for more information about the potential impacts of pile-driving operations. Other noise disturbances during construction may result from the mooring of wave energy generators with other anchoring systems. However, these activities would likely generate less noise than pile driving, so the impacts to EFH and fish resources would be minimal. If pilings are installed during construction, they will need to be removed during decommissioning. The primary adverse effect of removing piles is not noise but the suspension of sediments which may result in harmful levels of turbidity and the release of contaminants contained in those sediments (see Section 5.2.9).

Once a hydrokinetic facility is operational, the presence of the structures themselves could potentially affect the migration and rearing habitat functions of juvenile and adult salmonids (DoE 2009). The floating and submerged structures, mooring lines, and transmission cables can create complex structural habitats that act as a fish aggregation/attraction device (FAD) provide substrate for attachment of invertebrates. Salmonids may be attracted to the physical structure itself and/or to the forage fish that are attracted to the structure (PFMC and NMFS 2014). Floating offshore wave energy facilities may also aggregate predators (e.g., fish, marine mammals, sea birds) which would threaten the safety of a salmon migration corridor via the increased predation risks to juvenile or adult salmonids. The quality of salmon migration routes may also be decreased due to captures from passive fishing gear that become entangled on mooring lines or the devices. The biological and chemical communities near the structures may also be altered due to the deposition of organic matter from biofouling and the new lighted, fixed surface structures (devices and navigation buoys marking the project area) which may attract prey and predators of juvenile and adult salmonids (PFMC and NMFS 2014).

The potential effects of noise associated with hydrokinetic energy operations are not well known due to the limited information on sound levels produced during the operation of ocean energy conversion devices (PFMC and NMFS 2014). Underwater noise would be produced by the hydraulic machinery associated with wave energy generation devices, but the sound levels are currently unknown (MMS 2007). Noise and vibrations associated with the operation of the generation units would be transmitted into the water column and possibly the sediment depending on the anchoring system used. Such noises could potentially disturb or displace some fish within surrounding areas or could mask sounds used by fish for communicating and detecting prey (MMS 2007). Depending on frequency, amplitude, and propagation, the operational sounds may also affect rearing and migration corridor habitats (PFMC and NMFS 2014).

Hydrokinetic operations may also impact aquatic organisms via entrainment, impingement, or entrapment. Depending on the design of the devices, there could be a potential for fish at various life stages to become impinged on screens, entrained through turbines, or trapped within water collection chambers. Planktonic organisms may also be prone to entrainment (MMS 2007). Collisions with fixed submerged structures (e.g., vertical or horizontal support piles, ducts and nacelles) are most likely in high-flow environments where fish avoidance or evasion response times are reduced due to flows that combine with swimming speeds to produce high approach velocities. Instead of swimming around these structures, fish may reach exhaustion by swimming in front of them and then be swept downstream towards them (Wilson et al. 2007). The greatest risk of collision for marine vertebrates is with rotating turbines since a fish struck by a rotor could be injured or killed (MMS 2007). Wilson et al. (2007) suggested that marine vertebrates may be able to detect and avoid devices at some distance. Hammar et al. (2013) tested a hydrokinetic turbine rotor (with rotational speeds up to 70 rotations per minute) and found that fish were able to avoid collision during daylight conditions. However, collision risk may increase at night when fish have a reduced possibility of visually detecting a rotor. Moreover, even if fish avoid collisions, the avoidance zone might be larger than the actual rotor and so multiple turbine systems may hinder fish migration. Large arrays comprising multiple turbines may restrict fish movements, particularly for large species, with possible effects on habitat connectivity if migration routes are exploited (Hammar et al. 2013).

Additional potential impacts from operations include the release of contaminants and the presence of electromagnetic fields (MMS 2007). Hazardous chemical substances may be introduced into the water column from the devices themselves or as a result of accidental releases or leaks from service vessels. Anti-fouling coatings inhibit the settling and growth of marine organisms, and chronic releases of dissolved metals or organic compounds could occur from these compounds (DoE 2009). In addition, the presence of electromagnetic fields associated with transmission cables has a potential to affect some fish species. During transmission of produced electricity, the matrix of vertical and horizontal cables will emit low-frequency electromagnetic fields. Migrating adult and juvenile salmonids may be exposed to these fields generated at a project site, which may affect the movement of salmon (PFMC and NMFS 2014). However, the electromagnetic fields associated with new marine and hydrokinetic energy designs have not been quantified There is some evidence that electric fields from submarine cables are detectable by some fish species and may result in attraction or avoidance (Gill 2005).

Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of hydrokinetic energy development and operation on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- 5.4.15.2 Locate and operate devices at sites and times of the year to avoid salmon migration routes and seasons, respectively.
- Schedule the noisiest activities (i.e., pile driving) at certain times of the year to minimize exposures to juvenile and adult salmon.
- Schedule transmission cable installation to minimize overlap with salmon migration seasons.
- Conduct pre-construction contaminant surveys of the sediment in excavation and scour areas.
- Minimize seafloor disturbance during installation of current energy generation units and during installation of underwater cables.
- To avoid the concentration of predators at the site, above-water structures could have design features to prevent or minimize pinnipeds hauling out and birds roosting.
- Sheath or armor the vertical transmission cable to reduce the transmission of electromagnetic fields into the water column.
- Bury transmission cables on the seafloor to minimize benthic and water column electromagnetic field exposure.
- Align transmission cables along the least environmentally damaging route. Avoid sensitive habitats (e.g., rocky reef, kelp beds) and critical migratory pathways.
- Use horizontal drilling where cables cross nearshore and intertidal zones to avoid disturbance of benthic and water column habitats.
- Design the mooring systems to minimize the footprint by reducing anchor size and cable/chain sweep.
- Develop and implement a device/array maintenance program to remove entangled, derelict fishing gear and other materials that may affect passage.
- Use nontoxic paints and lubricating fluids where feasible.
- Use practices and follow operating procedures that reduce the likelihood of vessel accidents and fuel spills.
- Limit the number of devices and size of projects until cumulative effects are better understood and minimization measures tested. If multiple devices must be used at a site, install them with gaps of several meters between to allow large fish to pass through (Hammar et al. 2013).
- When turbines are necessary, use brightly colored or fluorescent rotors which can be more easily visually detected in turbid waters (Hammar et al. 2013).

Marine and Offshore Zones

6.1 Introduction – Current Condition

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The marine and offshore zones of the LMEs in Alaska include the GOA in the eastern North Pacific, the EBS (which includes the Aleutian Islands), and the Arctic Ocean's Chukchi Sea and Beaufort Sea (NMFS 2010, NOAA 2012). These LMEs support very complex trophic dynamics and are some of the most productive marine ecosystems on earth (NMFS 2010). Primary and secondary production are considered to be key drivers of the overall ecological productivity and function in these fisheries. Phytoplankton and zooplankton transfer energy from inorganic nutrients using solar input and convert thermal and ultraviolet energy into useable organic forms of energy. These processes serve as the base for marine food webs through direct consumption by juvenile groundfish, invertebrates, anadromous salmon, and intermediates such as forage fish. The timing and magnitude of primary production are driven by natural physical forces that affect nutrient availability and metabolic activity both locally and in large regional patterns. Estuaries and nearshore zones are all part of a larger, interconnected oceanic system. Natural physical forces such as currents, upwelling, downwelling and nutrient outwelling all contribute to the primary productivity found on the continental shelfs.

Although the range and distribution of specific marine species or trophic interactions may be influenced by climatic or oceanic drivers, these LMEs generally influence the character of each other. The GOA, EBS (including the Aleutian Islands), Chukchi Sea, and Beaufort Sea are all linked by diurnal tides and seasonal sea circulation patterns. Ocean currents generally move in a counterclockwise flow around the GOA (Spies and Weingartner 2007). A portion of these waters cross through the Aleutian Islands and into the EBS (Schumacher et al. 1979, Reed and Stabeno 1994, Stabeno et al. 2002, Stabeno et al. 2005b, Weingartner et al. 2005, Aagaard et al. 2006). Currents carry some of these waters onto the EBS shelf and flow northward through the Bering Strait (Coachman et al. 1975, Stabeno et al. 1999, Woodgate et al. 2006). Eventually these waters circulate across the Chukchi Sea (Weingartner et al. 2005, Woodgate et al. 2005) and Beaufort Sea shelves and move farther into the North Atlantic (Aagaard and Carmack 1989). This transport represents an important component of larger global hydrologic cycles which move lower salinity water from the northern Bering Sea and Arctic Ocean to the higher salinity North Atlantic Ocean (Aagaard and Carmack 1989, Wijffels et al. 1992). The subsequent strength and temperature of this circulation pattern influences the stratification and ice cover of the Arctic Ocean as well as the seasonal sea ice extent into the Bering Strait and the EBS (Aagaard and Carmack 1989, Stabeno et al. 2010, Stabeno et al. 2012a).

6.2 Alaskan Metrics

6.2.1 Large Marine Ecosystems

LMEs are expansive areas of the ocean with distinct bathymetry, hydrography, and biological productivity features which link plant and animal populations together in the food chain (NOAA 2012). Of the 64 LMEs designated worldwide, four include Alaska's productive marine and offshore zones: (1) GOA, (2) EBS, including the Aleutian Islands, (3) Chukchi Sea, and (4) Beaufort Sea (Fautin et al. 2010). The high tide line to the U.S. Exclusive Economic Zone (EEZ) off Alaska is approximately 3,518,617 km^2 (1,358,675 mi^2) and includes over 70 percent of the total area of the continental shelf in the lower 48 states (NMFS 2015). Alaska’s coastline, including all known measured islands, is over 70,000 km (44,000 mi).

6.2.1.1 *Gulf of Alaska*

The GOA is a large, semicircular bight located in the eastern North Pacific Ocean off the southern coast of Alaska and the western coast of Canada. It spans both coastal and deepwater habitats and is characterized by a broad, deep continental shelf with several banks bisected by submarine canyons (i.e., troughs or valleys). The continental shelf encompasses approximately 160,000 km^2 (61,776 mi^2) of ocean floor and includes bottom depths ranging from 150 to 200 m (490 to 660 ft) (Mundy and Cooney 2005, DoN 2006, NPFMC 2015d). The upper slope varies in depth from approximately 200 to 3,000 m (660 to 9,843 ft), while the relatively flat abyssal plain is 3,000 to 5,000 m (9,843 to 16,000 ft) below sea level (Airamé et al. 2003, DoN 2011). In the eastern and central GOA between 270 and 465 km (168 and 289 mi) from shore, approximately 24 major seamounts are arranged in three chains extending perpendicular to the flow of the North Pacific Current (Maloney 2004, Stone and Shotwell 2007, NOAA 2016). These submerged volcanic mountains disrupt the monotony of the abyssal plain and rise above the sea floor from depths as great as 4,200 m (13,780 ft) to as shallow as 170 m (558 ft) (NMFS 2015). In the western GOA, bathymetry changes dramatically from the deep depths of the Aleutian Trench to sea level to volcanoes (>1,000 m [3,281 ft] high) in a distance of <150 km (490 ft) (NPFMC 2007, 2015c).

6.2.1.2 *East Bering Sea*

The Bering Sea is a semi-enclosed high-latitude sea that is bounded on the north and west by Russia, on the east by mainland Alaska, and on the south by the Aleutian Islands. Of its total area of 2.3 million km^2 (888,035 mi^2), 44 percent is over the continental shelf, 13 percent is over the continental slope, and 43 percent is over the deepwater basin with a maximum depth of 3,500 m (11,483 ft) (Stabeno et al. 1999, NMFS 2015). This relatively shallow sea is subdivided into southwestern deepwater and northeastern shallow water by the central slope (Katugin and Zuev 2007). At 1,200 km (246 mi) long by 500 km (311 mi) wide, the Bering Sea’s continental shelf is one of the largest in the world. The shelf is much broader in the EBS than in the West Bering Sea (<100 km [<62 mi]) (Stabeno et al. 1999). The continental shelf breaks at approximately 170 m (558 ft) in depth with seven major canyons, including three of the largest submarine canyons in the world (the Zhemchug, Navarinsky, and Bering Canyons), indenting the continental shelf (Carlson and Karl 1988, Stone and Shotwell 2007).

The EBS LME includes the Aleutian Islands which lie in a long porous arc that consist of over 300 small volcanic islands extending 2,260 km (1,404 mi) from the Alaska Peninsula to the Kamchatka Peninsula in Russia and form a partial geographic barrier separated by oceanic passes that connects the waters of the North Pacific with the EBS. The passes between the Aleutian Islands vary from narrow, shallow passes in the east to wide, deep passes in the west. The north-south width of the shelf also varies from east to west from 4 km (2.5 mi) to over 80 km (50 mi) east of Samalga Pass (NPFMC 2007, 2015c). Two unique features that lie east and west of the Aleutian Islands are the Aleutian Trench and Bowers Ridge. The Aleutian Trench runs along the shelf margin from the southern coastline of Alaska to waters off the northeastern coast of Siberia and is one of the deepest trenches in the eastern North Pacific. The trench is approximately 3,700 km (2,299 mi) in length with an average width of 50 km (31 mi) and a maximum depth of 7,700 m (25,262 ft) (Weingartner 2005). Bowers Ridge is a ~700-km (~435-mi) long submerged ridgeline north of Petrel Bank in the Aleutian Islands. This ridge spans depths from as shallow as 11 m (33 ft) to over 3,700 m (12,139 ft) and includes a number of pinnacles that rise close to the surface as well as submarine canyons and a deep-sea plateau (AMCC 2004, NMFS 2015).

6.2.1.3 *Chukchi Sea*

North of the EBS lies the Chukchi Sea which forms an ecological transition zone between the boreal-arctic Bering Sea and the high-arctic Beaufort Sea (Day et al. 2013). The Chukchi Sea is an embayment of the Arctic Ocean bounded on the west by the Siberian coast of Russia and on the east by the northwestern coast of Alaska. It is predominately a shallow sea covering an area of about 595,000 km^2 (229,731 mi^2) with a mean depth of 40 to 50 m (131 to 164 ft) (NPFMC 2009b). The continental shelf is broad (approximately 500 km [311 mi]) and shallow (58 m [190 ft] average depth) and extends roughly 800 km (494 mi) northward from the Bering Strait to the continental shelf break (Weingartner 2008). The wide, shallow Chukchi Sea shelf is classified as an inflow shelf to the Arctic Ocean because Bering Sea water flowing from the North Pacific Ocean influences its characteristics (NPFMC 2009b, Moore and Stabeno 2015). For instance, the peak of inflow during the summer provides fresh water, heat, nutrients, and plankton to the Chukchi Sea marine ecosystem (Moore and Stabeno 2015). Beyond the shelf break, water depths increase quickly beyond 1,000 m (3,281 ft). The western edge of the Chukchi Sea shelf extends to Herald Canyon, and the eastern edge is defined by Barrow Canyon which separates the Chukchi and Beaufort Seas (NOAA 2013). The Hanna and Herald Shoals rise to approximately 20 m (60 ft) below sea level (MMS and NOAA 2007), while water depths range from 50 to 200 m (160 to 660 ft) in the Barrow and Hanna Canyons (NOAA 2013).

6.2.1.4 *Beaufort Sea*

In contrast to the Chukchi Sea, the Beaufort Sea has a narrow shelf and steep slope culminating in the deep Canadian Basin (Moore and Stabeno 2015). It is a semi-enclosed basin located east of the Chukchi Sea off the northern Arctic coast of Alaska and extending generally from Point Barrow eastward to the end of Demarcation Bay (NPFMC 2009b). Covering an area of approximately 476,000 km^2 (183,785 mi^2), the Beaufort Sea’s narrow (100 km [60 mi]), shallow continental shelf has an average water depth of approximately 37 m (121 ft) and extends from 30 to 80 km (19 to 50 mi) from the coast (NOAA 2013). The narrow Beaufort Sea shelf is classified as an interior shelf which is mostly influenced by river inputs (NPFMC 2009b). Bottom depths on the shelf increase gradually to a depth of approximately 80 m (262 ft) and then increase rapidly along the shelf break and continental slope to a maximum depth of approximately 3,800 m (12,467 ft) (Weingartner 2008, NOAA 2013). Numerous narrow and low relief barrier island-lagoon systems within 1.6 to 32 km (1 to 20 mi) from the coast extend from the western Mackenzie River Delta to the Colville River (NPFMC 2009b).

Physical, Chemical and Biological Processes

Physical Oceanography

6.3 *Currents through LMEs and across Aleutians*

6.3.1 6.3.1.1 Pelagic and coastal currents thread all of the LMEs together, while the presence or absence of seasonal and permanent sea ice helps to differentiate them (Fautin et al. 2010). The ocean circulation in the GOA is dominated by the counter-clockwise motion of the North Pacific Subarctic Gyre (also referred to as the Alaska Gyre) and the Alaska Coastal Current (ACC). The ocean circulation in the interior of the GOA is an important mechanism for cross-shelf transport and is influenced by three major groupings of eddies (Haida, Sitka, and Yakutat) encompassing an area between 20,000 and 60,000 km^2 (7,722 and 23,166 mi^2). The Alaska Gyre is composed of the North Pacific Current flowing along the GOA's southern boundary; the Alaska Current, a northward-flowing, warm-water current offshore of the continental shelf; and the Alaska Stream, an extension of the Alaska Current flowing westward along the Alaska Peninsula and Aleutian Islands and forming the northern (westward) boundary current of the Alaska Gyre. Circulation patterns along the shelf divide the GOA inner shelf (ACC) from the mid and outer shelf including the shelf break. As the most prominent aspect of shelf circulation in the GOA, the ACC provides a large, ecologically important narrow zone (<40 km [<25 mi]) between the nearshore (within 35 km [22 mi] of the shore) and oceanic communities (Mundy and Spies 2005, Weingartner 2005). This "river in sea" is forced along by offshore winds and large freshwater runoff (Stabeno et al. 2004).

The Aleutian Islands are influenced by the ACC and Alaska Stream in the North Pacific and the Aleutian North Slope Current in the EBS (NPFMC 2007). Flowing along the south side of the Aleutian Islands, the ACC enters through the relatively shallow (<80 m [<263 ft]) and narrow (~30 km [~19 mi]) eastern Aleutian Unimak Pass, while the Alaska Stream flows through the central and western Aleutian passes connecting the GOA to the Aleutian Islands (Stabeno et al. 1999). Both the ACC and the Alaska Stream flow into the Aleutian North Slope Current which flows along the northern side of the Aleutian Islands before the steep continental slope forces much of the flow into the northwest-flowing cyclonic Bering Slope Current (Stabeno et al. 1999, Stone and Shotwell 2007). This current flows northwestward off the shelf break, and together with currents of the East Bering Shelf water from the south and the Anadyr water from the west, it flows northward through the Bering Strait into the Chukchi Sea (Stone and Shotwell 2007). Pacific water exits the Chukchi Sea shelf through the Barrow Canyon in the east and Herald Canyon in the west forming an eastward-directed shelf break boundary current that flows along the nearshore portions of the Alaskan Beaufort Sea shelf (Pickart and Stossmeister 2008). The ACC influences all of the LMEs and is forced mainly by a combination of coastal, wind-driven convergence and freshwater runoff from the surrounding land (Mundy 2005).

6.3.1.2 *Function of Shelf Breaks and Upwelling Nutrients*

The GOA shelf is predominately a downwelling system (Henson and Thomas 2008). Although downwelling dominates the GOA coastal regions throughout the year (seven to eight months), short reversals of wind during the summer can occur and lead to brief periods of intense upwelling (Stabeno et al. 2004). Water transport over submarine canyons, banks, and additional bathymetric features can also induce upwelling in localized regions along the GOA coast. Farther offshore, deep waters are upwelled along the continental shelf break and in the Alaska Gyre (Mundy and Spies 2005, Weingartner 2005). The open-ocean interior of the GOA is generally considered to be an upwelling region; however, this upwelling is weak (on the order of 1 m [3 ft] per day) (Sugimoto 1993, Xie and Hsieh 1995). In the Aleutian Islands, Swift and Aagaard (1976) reported upwelling of relatively saline water that is poor in oxygen and rich in nutrients from summer hydrographic data from the vicinity of Samalga Pass. Unusually low surface temperatures and shallow seasonal thermoclines in summer in the region have also contributed to upwelling.

In the EBS, the Zhemchug and Pribilof Canyons are located in the highly productive “Green Belt” habitat zone along the broad continental shelf (Springer et al. 1996). Physical processes on the shelf edge, such as intense tidal mixing, transverse circulation, and stationary mesoscale eddies in the Bering Slope Current, greatly enhance primary and secondary production through the upwelling and mixing of nutrient-rich waters into the euphoric zone (Mizobata and Saitoh 2004). In addition, upwelling along the shelf edge and the resultant high flux of phyto-detritus to the seafloor combined with the availability of hard substrates on canyon slopes also likely sustain high densities of corals and sponges (Miller et al. 2012). Nutrient-rich upwelling has also been documented in the West Bering Sea on the Koryak Shelf, west Gulf of Anadyr, and Chirikov Basin (Kivva and Chulchekov 2013).

In the Chukchi and Beaufort Seas, upwelling of warm, salty Atlantic water onto the continental shelf is common. This upwelling is particularly pronounced in the three major canyons that cut into these shelves: Herald and Barrow Canyons in the Chukchi Sea and Mackenzie Canyon in the Beaufort Sea (Pickart et al. 2009). Along the central Chukchi Sea near the shelf break, conditions are also favorable for upwelling, nutrient-rich Pacific winter water from the interior halocline onto the shelf when easterly or northeasterly winds are associated with Aleutian low storms to the south (Spall et al. 2014). In the eastern Chukchi Sea, an episodic wind-driven upwelling of deep, nutrient-rich layers along the canyons (e.g., Barrow) has been reported on the continental slope (Hunt et al. 2013). Shelf-break upwelling is observed in all seasons in both the Alaskan and Canadian Beaufort Seas. It is most common in the fall and winter months when the Aleutian low pressure systems passing to the south result in easterly winds along the northern slopes of Alaska and Canada. Under these conditions, the normally eastward-flowing Pacific water shelf-break jet reverses to the west, and water halocline is brought onto the shelf. As part of this wind-driven exchange, heat and freshwater are fluxed offshore in the surface layer, while nutrients and CO_2 are transported upwards and onshore (NOAA 2013).

6.3.1.3 *Role of Sea Ice*

Formed by the freezing of sea water, sea ice is a dominant feature of the Bering, Chukchi, and Beaufort Seas. Ice cover on the continental shelves forms seasonally and takes three major forms: immobile landfast ice, which is attached to the shore and extends to variable distances offshore; stamukhi, which is grounded, ridged sea ice; and freely-drifting offshore pack ice, which includes first-year and multi-year ice and moves under the influence of winds and currents (MMS and NOAA 2007). Ice alters physical relationships on the continental shelves and in the deep basin by altering tides, currents, mixing, and upwelling, as well as by absorbing and reflecting light. The cycle of ice formation and retention is important to resident and migratory wildlife and has very different patterns depending on the region (NOAA 2013). Sea ice controls the exchange of heat and other properties between the atmosphere and ocean and, together with snow cover, determines the penetration of light into the sea. Sea ice also provides a surface for particle and snow deposition and a habitat for plankton and contributes to stratification through ice melt. The zone seaward of the ice edge is important for plankton production and planktivorous fish.

In the EBS, seasonal ice forms as early as November and grows to cover over 80 percent of the continental shelf during its maximum extent in March (NMFS 2015). Ice cover on the northern shelf is consistently seasonal, while ice cover on the southern shelf is highly variable (Banas et al. In press). In contrast, the Chukchi Sea can vary from full ice cover to full open water annually with full ice cover typically extending for six months (approximately December to June). The southern Chukchi Sea is free of sea ice one to two months longer each year than the northern Chukchi Sea (MMS and NOAA 2007). In the Beaufort Sea, ice cover lasts 9 to 10 months from October through July. Over the shallow Chukchi shelf, annual ice from local freezing is most common. The Beaufort Sea shelf can be affected by perennial ice from the central Arctic following the circulation of the Beaufort Gyre along the shelf break, as well as annual ice formed locally over the shelf (Davis et al. 2014). In both the Chukchi and Beaufort Seas, remnants of annual landfast ice may remain near the coast during the summer even if offshore ice is gone. There are often areas of open water surrounded by sea ice (polynyas) during the winter and spring along the Alaskan Chukchi coast and in the Beaufort Sea. Landfast ice and polynyas alter physical characteristics by forming dense water and represent important areas of biological productivity during seasons with daylight (NPFMC 2009b).

6.3.1.4 *Temperature and Salinity*

The GOA is generally characterized by two SST regimes throughout the year. Relatively warm surface water occurs over the continental shelf, while colder water is found farther offshore beyond the shelf break (Royer and Muench 1977). Across the shelf, changes in SSTs are generally small (approximately 2°C [3.6°F]). The overall difference in annual temperatures diminishes with depth with annual SSTs being only 1°C (33.8°F) at depths greater than 150 m (492 ft) (Weingartner 2005). Freshwater entering the eastern North Pacific Ocean inhibits the development of deep water masses which affects oceanic heat transport. The annual average freshwater influx is approximately ~33,000 m^3/sec (1,165,384 ft^3/sec). This discharge accounts for nearly 40 percent of the freshwater flow into the GOA (Royer and Grosch 2007). The vertical salinity structure of the GOA and Alaska Gyre consists of a seasonally variable upper layer extending from the surface to approximately 100 m (330 ft) in depth. A halocline (strong, vertical salinity gradient) extending from 100 to 200m (330 to 660 ft) in depth with salinity increasing from 33 to 34 psu. A deep layer extending to approximately 1,000 m (3,300 ft) in depth where the salinity increases slowly to 34.4 psu. Beneath this deep layer, the salinity increases gradually to a maximum value of approximately 34.7 psu at the seafloor (Mundy 2005).

The patterns of temperature and salinity in the Aleutian Islands are very similar to the GOA. Temperature values at all depths decrease toward the west. Along the edge of the shelf in the Alaskan Stream current, a low salinity (>32 psu), tongue-like feature protrudes westward. On the south side of the central Aleutian Islands, nearshore salinities can reach as high as 33 psu as the higher saline EBS surface water occasionally mixes southward through the Aleutian Islands. Proceeding southward, a minimum of approximately 32.2 psu is usually present over the slope in the Alaskan Stream current; values then rise to above 32.6 psu in the offshore waters. Although surface salinity increases towards the west as the source of freshwater from the land decreases, salinity values near 1,500 m (4,921 ft) decrease slightly (NPFMC 2015c).

In the EBS, the year can be divided into two thermal periods based on large-scale features of SST distribution: winter (November through June) and summer (July through September). October is considered a transitional period between these two thermal conditions. To a large extent, the thermal regime in the EBS depends on water exchange with the Pacific Ocean. Seasonal temperature variations by depth are small and are as follows: 3 to 5°C (37 to 41°F) at 100 m (328 ft); difficult to discern variations at 200 m (656 ft); >0.3°C (33°F) at 500 to 1,000 m (1,640 to 3,281 ft); variable changes between 1.8 and 1.95°C (35.24 and 35.51°F) at 2,000 m (6,562 ft); and variable changes between 1.56 and 1.7°C (34.8 and 35°F) at 3,000 m (9,843 ft) (Luchin et al. 1999). The salinity in the upper water layer of the EBS depends on the advection of the Pacific Ocean water, the hydrological cycle between the surface layer and the atmosphere, continental drainage, ice formation, and the melting of sea ice. Salinity in the EBS increases with depth; however, during the period of ice formation, there may be a slight saline inversion in the surface layer. During the winter thermal period, daily salinity variations in the upper layer nearly disappear. In the EBS, the seasonal variability in salinity does not penetrate below 150 m (492 ft). The greatest range of salinity variation (4 to 7 psu) is observed in the surface layer, while the range of salinity variation is small (0.2 to 0.4 psu) below 150 m (492 ft) (Luchin et al. 1999).

Temperature and salinity in the Chukchi Sea vary seasonally and are influenced by sea ice formation and melting. During the spring (May through July), warm water (above 0°C [32°F]) appears in the southern Chukchi Sea due to a gradual increase in solar radiation and the warm water advected through the eastern Bering Strait. In the summer (August), deep waters of the Chukchi Sea can still be cold (0 to 3°C [32 to 37.4°F]) depending on the location on the shelf. However, SSTs can be above 9°C (48°F) in the southern Chukchi Sea. During the fall (September and October), SSTs of the southern Chukchi Sea cool but still remain relatively warm at 2 to 6°C (35.6 to 42.8°F). Radiative cooling causes the whole Chukchi Sea to fall below freezing during the winter (November through April) (Chu et al. 1999, NOAA 2013). During this time of year, shelf waters cool to the freezing point, and salinity increases during sea ice formation. As the ice melts and Bering Sea water moves onto the shelf during the spring and summer, the salinity decreases (Weingartner 2008).

In the Beaufort Sea, the temperature increases and salinity decreases throughout the summer due to surface warming and associated ice melting and freshwater input from the rivers. Following the removal of ice and the first significant wind-mixing event, salinities decrease rapidly in nearshore areas as a result of low-saline ice meltwater and freshwater input from rivers (Weingartner et al. 2009). SSTs increase to a maximum value near 8°C (46.4°F), and salinity varies from 14 to 32 psu with the lowest salinities observed immediately following the decay of landfast ice (Chu et al. 1999, Weingartner et al. 2009). During this time of year, the profiles of temperature and salinity show a multilayer structure with a shallow layer of warm, low-saline water overlying cool, high-saline deep layers. Temperatures decrease to around -1.7°C (-28.9°F) in the fall and remain near freezing until late June or early July. In October after ice formation, the salinity increases and ranges from 34 to 35 psu by January due to the expulsion of salt from growing sea ice. During the winter, the temperature decreases and salinity increases as freezing expels brine from sea ice. Salinities remain relatively constant through winter and spring and begin to decrease in June (Weingartner et al. 2009).

Marine Processes and Complexity of Trophic Dynamics

6.3.1.5 The four LMEs comprising the marine and offshore zones off Alaska are all considered Class II, moderately productive (150 to 300 grams of carbon per m^2 per year) ecosystems (Aquarone and Adams 2012a, b, Belkin et al. 2012, Heileman and Belkin 2012). The GOA's cold, nutrient-rich waters support one of the most productive marine ecosystems in the world with numerous interactions and food webs (Hoem Neher et al. 2015). Primary (phytoplankton) and secondary (zooplankton) production are considered to be key drivers of the overall ecological productivity and function in this region. These organisms transfer energy from inorganic nutrients and transfer thermal and ultraviolet energy into useable organic forms of energy that serve as the base for marine food webs through either direct consumption or intermediates such as forage fish. The timing and magnitude of primary production is driven by natural physical forces that affect nutrient availability, solar input, and metabolic activity (through thermal variability) both locally and regionally (Mundy 2005). The GOA watersheds, estuaries, fjords, and bays are part of a larger, interconnected offshore oceanic system (continental shelf, shelf break front, continental slope including submarine canyons, and abyssal plain intersected with seamounts) in which natural physical forces, such as currents (ACC and Alaska Gyre), upwelling, downwelling, precipitation, and freshwater runoff, all play important roles in determining regional primary productivity (Mundy 2005, Harwell et al. 2010). Species richness and diversity are the greatest along the shelf break and slope; species richness peaks at or just below the shelf break, and species diversity peaks deeper on the slope. In general, richness and diversity are higher in the eastern GOA compared to the western GOA (Zador 2015).

The marine environment of the Aleutian Islands is very dynamic; the islands are oriented east-west and form a porous boundary between the Bering Sea and the North Pacific Ocean. The islands are warmed by the North Pacific Ocean to the east and cooled by the Bering Sea to the west. Due to the dramatic bathymetry variations a very short distance from shore, the islands provide a variety of habitat coupling between onshore, nearshore, and offshore systems (NPFMC 2007). Many Aleutian environmental attributes change in the vicinity of Samalga Pass, suggesting that the marine ecosystem of the archipelago may be differentiated into multiple ecologically distinct regions. For example, the east side contains shallow, narrow passes;

Aleutian-Low-influenced weather; warm, fresh water; depleted nutrients; generally high chlorophyll concentrations; neritic zooplankton; and abundant forage fish/flatfish. In contrast, the west side contains deep, wide passes; Asian-influenced weather; cold, salty water; abundant nutrients; generally low chlorophyll concentrations; oceanic zooplankton; and food webs of demersal fishes (NPFMC 2007).

The combination of a broad continental shelf, extensive winter sea ice coverage, temperature and seasonal oscillations, and convergence of nutrient-rich current systems characterizes the Bering Sea as one of the most productive and biologically diverse marine ecosystems in the world (Loughlin et al. 1999, NMFS 2015). In the southern EBS, the broad continental shelf is differentiated into three bathymetrically fixed domains which are characterized by water column structure, currents, and biota. These domains include the coastal domain (depth <50 m [<164 ft]) with a weak stratification, the middle shelf domain (depth 50 to 100 m [164 to 328 ft] with a wind-mixed surface layer abutting a tidally mixed bottom layer, and the outer shelf domain (depth 100 to 180 m [328 to 591 ft]) with mixed upper and lower layers separated by a layer with slowly increasing density. The domains are separated by the following fronts or transitional zones: a narrow (5 to 30 km [3 to 19 mi]), inner structural front separates the well-mixed coastal waters and the two-layered middle shelf domain; the middle transition zone lies between the middle and outer shelf domain; and the outer front domain shelf break separates the outer shelf from slope waters (Macklin and Hunt 2004, Stabeno et al. 2005a). The balance of wind and tidal energy plays a major role in shaping the vertical structure of the coastal and middle shelf domains. These domains provide unique habitats for biota; for example, the mesozooplankton community is dominated by small-medium copepods in the two shallower domains, while the outer shelf and oceanic region are dominated by large copepods. The nearshore environment has little to no connection with the outer shelf or slope environment (NPFMC 2007). In the northern EBS, changes in topography, tidal energy, and river discharges (e.g., Yukon River) affect the location of the fronts with the inner front occurring in water depths of 30 m (98 ft) or less (Macklin and Hunt 2004, Stabeno et al. 2005a).

Detailed mass balanced food web models were constructed to compare ecosystem characteristics for the EBS, the Aleutian Islands, and the GOA. The results showed the EBS having a much larger benthic influence on its food web than either the GOA or the Aleutian Islands. Conversely, the Aleutian Islands ecosystem had the strongest pelagic influence on its food web relative to the other two systems. The GOA ecosystem appeared balanced between benthic and pelagic pathways, but this system has smaller fisheries than the other two systems and a high biomass of fish predators (Aydin et al. 2007).

In general, Arctic ecosystems are expected to have less biological productivity than lower latitude ecosystems due to seasonal darkness and cold weather; however, there is considerable variability between Arctic systems. The Chukchi and Beaufort Sea LMEs are physically and ecologically different (NPFMC 2009b). An Arctic climate along with major and annual changes in ocean climate, in particular the annual formation and deformation of sea ice, characterize the relatively shallow inflow shelf of the Chukchi Sea LME (Heileman and Belkin 2012). This LME remains ice-covered throughout the winter, is well mixed from fall through spring, and is stratified in the summer due to the input of relatively warm Alaska coastal waters (Wiese et al. 2013). The Chukchi Sea shelf is characterized by high productivity, rich benthic communities, and tight benthic-pelagic coupling which is due to a lack of significant grazing of the primary production in the water column, resulting in large amounts of organic material settling onto the seafloor (Iken et al. 2010). The strength of this pelagic-benthic coupling varies with a variety of factors, including the magnitude of primary production in sea ice and the water column, the timing of the seasonal sea ice cover, and the structure and trophic dynamics of the zooplankton community (1,300 mg/m^3 dominated by copepods) in relation to phytoplankton development (Iken et al. 2010, Heileman and Belkin 2012). During the open-water season, two ecosystems with different food-web structures located adjacent to each other are present in the northeastern Chukchi Sea. The pelagic-dominated ecosystem contains oceanic zooplankton, a higher percentage of sand and lower percentage of mud in sediments, lower densities and biomass of benthic macrofauna and megafauna, and higher densities and species richness of demersal fishes. In contrast, the benthic-dominated ecosystem has more neritic zooplankton, a lower percentage of sand and higher percentage of mud in sediments, higher densities and biomass of benthic macrofauna/megafauna, and lower densities and species richness of demersal fishes (Day et al. 2013). Faunal benthic diversity generally increases to the north in the Chukchi Sea where food availability in bottom water and surface sediments are greater and more heterogeneous and where finer grain sediments occur due to the northward flowing currents and strong wind-mixing upwelling (Wiese et al. 2013).

Like the Chukchi Sea LME, the Beaufort Sea LME exhibits an Arctic climate and extreme environment which is driven by major seasonal and annual changes in climate with ice coverage occurring for most of the year. In this oligotrophic sea, productivity is relatively high only in the summer after the ice melts (Belkin et al. 2012). The Beaufort Sea shelf remains ice covered throughout the winter, well-mixed from fall through spring, and stratified in the summer due to warm (~4°C [~39°F]) freshwater input form the Colville and Mackenzie Rivers, water intrusion from the clockwise flowing Beaufort Gyre, and wind/gyre-induced upwelling of deep Atlantic Water (Wiese et al. 2013). The Beaufort Sea continental shelf and slope waters generally have lower productivity and lower levels of benthic biomass than the northern EBS and Chukchi Sea (Audubon et al. n.d.). In the western portion, the mid shelf typically has higher benthic biomass levels than the eastern portion (Audubon et al. n.d.). On the narrow Beaufort Sea shelf, benthic communities are strongly influenced by freshwater inflow from the Mackenzie River and smaller Alaskan rivers that carry terrestrial, mostly recalcitrant carbon, large sediment loads and inorganic nutrients within them (Bell In review-in press). These conditions result in generally lower infaunal biomass (<10 g/m^2). Epifaunal biomass is higher on the upper Beaufort Sea slope near Barrow Canyon than on the Beaufort Sea shelf due to the upwelled, comparatively warm, Atlantic Water along the slope providing nutrients and Arctic zooplankton onto the shelf and the nutrient-rich outflow from Barrow Canyon at depth which gets deflected to the east (Pickart et al. 2009, Bluhm et al. 2013).

Productivity and production at lower trophic levels can shape Arctic ecosystems, especially considering the relatively short food chains that occur in the Arctic. Primary production is ultimately the foundation of these Arctic ecosystem food webs which are supported by ice algae that grow on the underside of and within the sea ice itself and phytoplankton which occurs in the water column and near the ice edge. In the Chukchi and Beaufort Sea ecosystems, a greater proportion of primary productivity moves through the benthic portion of the food web compared to more southern regions, such as the southern EBS. This makes productivity of seafloor communities particularly important (Audubon et al. n.d.). Light-limitation, low temperatures, the timing of ice melt, and the nature of zooplankton advection result in the export of the majority of the primary/secondary production to the benthos (Wiese et al. 2013). Detailed mass balance food web models were constructed to compare ecosystem characteristics for the EBS, eastern Chukchi Sea, and Beaufort Sea. Results indicated that the EBS had the highest benthic biomass, which was nearly equaled by the eastern Chukchi Sea, while the Beaufort Sea had the lowest benthic biomass compared to the other two ecosystems (Whitehouse 2012, Wiese et al. 2013)

6.4 Source of Potential Impacts

6.4.1 Increasing Vessel Traffic

The Bering Sea is a highly productive ecosystem and currently supports the largest sustainable fisheries in the world. To the north, the Bering Strait connects the Bering Sea to the Chukchi and Beaufort Seas, and the Arctic Ocean. The coastlines of the Beaufort and Chukchi seas, from the Canadian Border to Point Hope is approximately 4,057.4 km (2,521.7 miles). The Bering Sea coastline from Point Hope south to the end of Unimak Island in the Bering Sea is approximately 6,532.7km (3,527.4 miles). The combined linear length of that coast line and nearshore zones is 10,590.1 km (6,049.1 miles)[25] (USCTI 2016). Though marine surface circulation flows north from the Bering Sea into the Chukchi, and east into the Beaufort Sea, seasonal winter sea ice builds and moves in the opposite direction, from the Beaufort and Chukchi seas south through the Bering Strait, into the Bering Sea. This counter current movement of sea ice is the result of several simultaneous influences; the rapid expansion of new sea ice, displacement of old sea ice, rapidly expanding sea ice reduces the north and west circulation pattern, subsequently allowing the prevailing weather pattern to dominant sea ice migration.

Historically, the Arctic's Beaufort and Chukchi seas remain frozen for well over half a year obstructing maritime shipping from October through June. Conversely, recent warming trends and continually diminished sea ice conditions are extending the navigable open water season during summer months. Arctic sea ice reached its lowest extent ever previously recorded in September 2012, representing the longest Arctic navigation season on record (NSIDC 2017). In the years between 2012 and 2015, the Arctic sea ice minimum extent was the lowest in the satellite record (1979-2015), and in January 2017, a new record low for winter sea ice extent was established (ARC 2017, NSIDC 2017).

6.4.1.1 *Bering Sea – Vessel Activity*

A variety of vessel types operate in the Bering Sea, south of the Bering Strait. Bering Sea shipping is currently dominated by traffic through the Aleutian Islands between North America and East Asia, the Great Circle Route (Fletcher 2016). Year round, commercial fishing vessels are also very common throughout the Bering Sea. Numerous other vessel types include fuel tankers, container and refrigerated cargo ships, and the U.S. Coast Guard. Smaller tankers, cargo ships, and barges also move throughout the eastern Bering Sea serving coastal and inland communities with goods, supplies and fuel. Cargo ships supporting industrial activities and

[25] Adding the length of the Aleutian Islands, from Unimak Island in the east to the far western Island of Attu, the Aleutian Islands add approximately 1,800km (1,100 miles) to this linear measure to total 12,390.1 km of coastal and nearshore zone. Dutch Harbor, in the Aleutian Islands is the only deep draft port within the entire expanse that can currently support oil response capabilities.

resource extraction in the region also comprise a significant volume of vessel traffic (Fletcher 2016). Seasonally, the Alaska Marine Highway ferry also serves communities of the Aleutian Islands archipelago and the Alaskan Peninsula. Other seasonal vessel operations include government vessels and research ships, some pleasure craft and more recently cruise ships. Overall, fishing vessels are most common, tankers and bulk carriers comprise the majority of deep draft vessels, and ocean going tugs are prevalent due to the extensive use of tow barges to serve Alaskan communities.

6.4.1.2 *Bering Strait and Arctic - Vessel Activity*

Vessel traffic through the Bering Strait has always increased in the summer as seasonal winter sea ice recedes. The primary incentive for the potential increase in shipping through the Bering Strait and Arctic shipping routes is to save time and reduce shipping expenses between the north Pacific and north Atlantic ports (Masters, 2013). Accounting for the increased vessel activity is variable depending upon periods examined, vessel type and size, and tracking mechanism. In 2009, roughly 150 large commercial vessels transited the Bering Strait during the open water period from July to October (AMSA 2009, Hartsig 2012). Approximately twenty-five were bulk carriers moving supplies or commodities into or from mining operations near Kivalina, south of Point Hope. Russian bulk carriers supported communities in the Russian far northeast. The remaining large vessels comprised fuel barges serving coastal communities, and industry or government research and survey vessels involved in different phases of marine science or oil and gas exploration. One report concluded that between 2011 and 2013, transits through the Bering Strait increased from 410 to 440, and transits through the Northern Sea Route increased from 36 to 71, as compared to only 4 in 2010 (USCMTS 2016). Respectively, a 30 and a 35 vessel trip increase. Transit statistics reported in another report indicate that during the 2015 season 300 unique vessels accounted for 540 vessel transits through the Bering Strait (NSRIO 2015). These reports both clearly indicate some degree of increase in vessel traffic.

6.4.1.3 *Arctic Port Facilities*

The current trend of diminishing sea ice and predictions of continued decline have stimulated discussions of new international trade routes through the Arctic. Historically, vessels had very limited access to the region. There has previously never been a need for a modern Marine Transportation System (MTS) (CMTS 2016). Nearshore zones are typically very shallow with poor approaches. Navigation aids such as buoy's could never be deployed in seas with such shallow depths, shifting shorelines and heavy seasonal ice scour. Nearshore nautical charts remain dated. Less than two percent of navigationally significant U.S. Arctic waters have never been surveyed using current technology and standards (USCTI 2016). Marine transportation in the Arctic remains hazardous do to extreme weather conditions and unpredictable sea ice extent. Emergency communications, and response and rescue capabilities are limited further challenging already difficult and potentially dangerous operations (CMTS 2013). Though vessel activity and transits through the Arctic may continue to increase, the rise in coastal resource extraction and associated development is speculative. Currently, there are no firm economic incentives or justification for investment or development of port facilities in the Arctic. On land, thawing permafrost provides an unstable construction foundation for buildings, structures, or road and rail infrastructure (Mellgren 2007, Reiss 2008). Mobilizing manpower and construction material to remote Arctic areas by air remains extremely expensive.

6.4.1.4 *Introduced Environmental Risk*

Despite challenges of coastal infrastructure development, shipping through these northern routes may increase significantly introducing a different suite of risks. Projections of vessel traffic based on recent industry surveys suggest the region will see further increases in all types of vessel traffic (CMTS 2013, Lloyd's 2013). All vessels carry some form of oil products on board as fuel or lubricating oils. Tankers vary in size but all carry large volumes of oil as cargo (Fletcher 2016). Some ocean going barges carry more oil cargo than small tankers. The first luxury cruise ship to transit the North West Passage (Seward Alaska to New York City N.Y.) had a fuel capacity of 20,600 bbl. This volume of fuel is currently larger than many bulk cargo carriers or tankers transiting these waters.

Based on vessel operations and purpose, the estimated overall oil exposure risk was identified for each vessel type (Fletcher 2016). Tankers dominated overall potential oil spill exposure due to the volume of oil and fuel carried. Currently, at least on the U.S. side, oil cargo is all "nonpersistent" (Types 1 and 2) oil carried for use in communities or industrial activity in the region. Most large ships currently use heavy fuel oil for their own propulsion. This "persistent" oil (Types 3 and 4) typically lasts longer in the environment if spilled than a non-persistent type. There are currently no reports or analysis that clearly confirm or address tankers are transporting large volumes of raw crude oil or bitumen. The extraction and refining of bitumen from tar sands is so recent that bitumen has not been classified into any group of oil regarding persistence in the environment.

Generally, vessels carry less volume of oil for their own fuel than tankers, however the largest of the bulk carriers in the analysis had more than 30,000 bbl fuel capacity, which is more than most tank barges currently carry and more than one third the cargo capacity of the smallest tankers (Fletcher 2016). To consider the proportionate contribution of different vessel types to oil exposure in the regions, total exposure was estimated based on persistent or non-persistent oils; tankers account for 90% of non-persistent oil exposure, bulk carriers represent 38% of persistent oil exposure, then other cargo vessels are at 36% and tankers were 25%. When exposure for both oil types is combined, the persistent oil volume accounted for the longer duration of persistent oil in the environment and thus greater potential impact (Fletcher 2016).

6.4.1.5 *Recommended Conservation Measures*

Vessel Operations

- Vessel operations and shipping activities should be familiar with Alaska's Geographic Response Strategies (GRSs), which detail environmentally sensitive areas of Alaska's coastline. Currently, GRSs exist for many different regions and areas including southeast Alaska, southcentral Alaska, Kodiak Island, Prince William Sound, Cook Inlet, Bristol Bay, Northwest Arctic, North Slope, and the Aleutian Islands (see http://www.dec.state.ak.us/spar/perp/grs/home.htm).

- Coordinate with other federal and state agencies to access and identify commercial activities and major infrastructure gaps that promote safe and sustainable Arctic communities.

- Coordinate with other federal and state agencies to develop safe harbor facilities for ships in need of assistance.
- Coordinate with existing data-sharing frameworks, such as Data.gov, the Alaska Regional Response Team Ocean.gov, and AOOS to facilitate waterways planning and emergency response.
- Continue international collaboration on the Bering Strait Port Access Route Study; consider appropriate ship routes for the Bering Strait and U.S. Arctic.
- Collaboration with international, federal, state and local authorities to ensure readiness of Arctic maritime and aviation infrastructure for emergency response management.
- Support Pan-Arctic response equipment database development, best practices and information sharing for continued oil spill response planning in the Arctic.
- Develop plans to transport critical response equipment from the contiguous United States (lower 48) into the Arctic.
- Evaluate facilities currently available on the north slope for use as seasonal staging areas for response exercises or research platforms.
- Continue scientific support for oil spill response and research directives in the Oil Pollution Act of 1990 (OPA90).
- Develop on-shore facilities for oil spill response (e.g. hazardous/oily waste disposal, wildlife response, responder housing).

Introduction of Invasive Species

- Encourage vessels to perform a ballast water exchange in offshore marine waters (in accordance with the U.S. Coast Guard's voluntary regulations) to minimize the possibility of introducing invasive estuarine species into similar habitats.
- Discourage vessels that have to not perform a ballast water exchange into nearshore and estuarine-receiving waters.
- Adhere to regulations and use BMPs outlined in the State of Alaska Aquatic Nuisance Species Management Plan (ADF&G 2002) and Management Plan for Invasive Northern Pike in Alaska (ADF&G 2007).

6.4.2 Point-Source Discharges

Contaminants enter waterways through point and nonpoint sources. Nonpoint source pollutants typically enter aquatic systems as relatively diffuse contaminant streams primarily from atmospheric and terrestrial sources. (See Section 3.2.1 for the discussion on nonpoint source pollution.) In contrast, point source pollutants are generally introduced via a pipe, culvert, or similar outfall structure. These discharge facilities are often associated with domestic or industrial activities or in conjunction with collected runoff from roadways and other developed portions of the coastal landscape. Waste streams from sewage treatment facilities and watershed runoff may be combined in a single discharge. Both point source and nonpoint source discharges introduce inorganic (Section 4.2.6) and organic (Section 4.2.5) contaminants into aquatic habitats where they may become bioavailable to living marine resources (Johnson et al. 2008).

The practice of disposing of waste materials into rivers, estuaries, and marine waters is not a modern phenomenon; it has been used as a preferred method since the beginning of human civilization (Ludwig and Gould 1988, Shahidul Islam and Tanaka 2004). Nevertheless, when the full spectrum of emissions from land-based activities is taken into account, the use of coastal waters as a repository for anthropogenic waste has not previously been practiced on as large or intense a global scale as in recent decades (Williams 1996). Identifying the sources and effects of anthropogenic contaminants in near-coastal areas of the U.S. is an ongoing scientific effort (EPA 1999).

6.4.2.1 *Potential Adverse Impacts*

While the NPDES program has led to ecological improvements in U.S. waters, point sources continue to introduce pollutants into the aquatic environment, albeit at reduced levels (Johnson et al. 2008). The CWA includes important provisions to address acute or chronic water pollution emanating from point source discharges. Currently under the NPDES program, individual state governments have assumed primacy and authority of each states own water quality standards or discharge levels. In Alaska, the ADEC has the authority to regulate pollutant discharges from domestic, industrial, oil and gas facilities; seafood; storm water; mining; and other sources into surface waters of the U.S. that are within Alaska or which occur in its territorial seas (within 4.82 km [3 mi] of shore). That program is recognized as the Alaska Pollution Discharge Elimination Program (APDES). For many states, the EPA may remain in an oversight role of many standards, but still retains authority and regulates discharges from some facilities within Alaska, including those located in Denali National Park and Preserve and in Indian Country, and retains oversight responsibility for ADEC-regulated discharges (ADEC 2013c).

Determining the fate and effect of natural and synthetic contaminants in the environment requires an interdisciplinary approach to identify and evaluate all processes sensitive to pollutants, which is critical since adverse effects may be manifested at the biochemical level in organisms (Luoma 1996) in a manner particular to the species or life stage exposed. Exposure to pollutants can inhibit the following: (1) basic detoxification mechanisms (e.g., production of metallothioneins or antioxidant enzymes); (2) disease resistance; (3) the ability of individuals or populations to counteract pollutant-induced metabolic stress; (4) reproductive processes, including gamete development and embryonic viability; (5) the growth and successful development through early life stages; (6) normal processes, including feeding, respiration, osmoregulation; and (7) overall Darwinian fitness (Capuzzo and Sassner 1977, Widdows et al. 1990, Nelson et al. 1991, Stiles et al. 1991, Luoma 1996, Thurberg and Gould 2005).

The nature and extent of a pollutant's dispersal depends on a variety of factors including site-specific ecological conditions, the physical state of the contaminant introduced into the aquatic environment, and the inherent chemical properties of the substance. Soluble or miscible substances usually enter waterways in an aqueous phase, ultimately becoming adsorbed onto organic and inorganic particles (Wu et al. 2005). However, contaminants also enter aquatic systems as either particle-borne suspensions or solutes (Bishop 1984, Turner and Millward 2002). Physical factors, such as the presence of significant currents or a strong thermocline or pycnocline, influence the spatial extent of contaminant dispersal. In particular, turbulent mixing or diffusion disperses contaminant patches in coastal waters which results in larger, comparatively diluted contaminant distributions farther away from the initial point source—the mixing zone (Bishop 1984). Subsequent biological activity and geochemical processes intercede and typically result in contaminant partitioning between the aqueous and particulate phases (Turner and Millward 2002).

Physical dispersion, biological activity, and other ecological factors play significant roles in the distribution of contaminants in aquatic habitats; however, the partitioning of contaminants is largely governed by certain ambient environmental conditions, notably salinity, pH, and the physical nature of local sediments (Turekian 1978, McElroy et al. 1989, Turner and Millward 2002, Leppard and Droppo 2003, Wu et al. 2005). Typically, highly reactive suspended particles serve as important carriers of aquatic contaminants and are largely responsible for their bioavailability, transport, and ecological fate as they disperse into receiving waters (Turner and Millward 2002). Additionally, hyporheic exchange between overlying water and groundwater can alter salinity, dissolved oxygen concentration, and other water chemistry aspects in ways that can influence the affinity of local sediment types for particular contaminants or otherwise affect contaminant behavior (Ren and Packman 2002).

If located improperly, discharge sites may modify habitat by creating adverse impacts to sensitive areas such as freshwater shorelines and wetlands, emergent marshes, seagrasses, and kelp beds. Extreme discharge velocities of effluent may cause scouring at the discharge site and may also entrain particulates and, thus, create turbidity plumes. These turbidity plumes of suspended particulates can reduce light penetration and lower the rate of photosynthesis and the primary productivity of an area while elevated turbidity persists. The contents of the suspended material can react with the dissolved oxygen in the water and result in oxygen depletion or smother SAV, including eelgrass beds and kelp beds. Accumulation of outfall sediments may also alter the composition and abundance of infaunal or epibenthic invertebrate communities (Ferraro et al. 1991). Many benthic organisms are quite sensitive to grain size, and accumulation of sediments can also submerge food organisms.

The introduction of pollutants through direct discharges into EFH can create lethal/sublethal habitat conditions to salmon and their prey. For example, fish kills may be due to a pesticide runoff event or an increase in water temperatures or when algae blooms caused by excess nutrients deplete the oxygen content in the receiving water. Pollutant and water quality impacts can also have chronic effects that are detrimental to fish survival. Contaminants can assimilate into fish tissues by absorption across the gills or through bioaccumulation through consuming contaminated prey. Pollutants either suspended in the water column (e.g., nitrogen, contaminants, and fine sediments) or settled on the bottom (through food chain effects) can also affect salmon. Many heavy metals and persistent organic compounds (e.g., pesticides and polychlorinated biphenyls) tend to adhere to solid particles. When these solid particles are deposited, the heavy metals, persistent organic compounds, or their degradation products can bioaccumulate in benthic organisms at much higher concentrations than in the surrounding waters (Good et al. 1987, Stein et al. 1995).

6.4.2.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of point source discharges to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Locate discharge points in coastal waters well away from shellfish beds, seagrass beds, corals, and other similar fragile and productive habitats.
- Monitor water quality discharges following NPDES/APDES permit requirements from all discharge points, including municipal stormwater systems, and actively reduce the size of mixing zones that discharge to coastal areas and watersheds.
- Reduce potentially high velocities by diffusing effluent to acceptable velocities.
- Determine baseline benthic productivity by sampling before any construction activity related to the installation of new outfalls to facilitate monitoring of environmental changes.
- Provide for mitigation when degradation or loss of habitat occurs from placement and operation of the outfall structure and pipeline.
- Institute source-control programs that effectively reduce noxious materials to avoid introducing these materials into the waste stream.
- Ensure compliance with pollutant discharge permits which set effluent limitations and/or specify operation procedures, performance standards, or BMPs. These efforts rely on the implementation of BMPs to control polluted runoff (EPA 1993).
- Establish and update, as necessary, pollution prevention plans, spill control practices, and spill control equipment for the handling or transporting of toxic substances in EFH.
- Treat discharges to the maximum extent practicable including up-to-date methodologies for reducing discharges of biocides (e.g., chlorine) and other toxic substances (e.g., dissolved copper).
- Use land-treatment and upland disposal/storage techniques where possible. Limit the use of vegetated wetlands as natural filters and pollutant assimilators for large-scale discharges to those instances when other less damaging alternatives are not available.
- Avoid siting pipelines and treatment facilities in wetlands and streams.

6.4.3 Seafood Processing Waste—Shoreside and Vessel Operation

Seafood processing is conducted throughout much of coastal Alaska. Processing facilities may be onshore or on vessels (ADEC 2010b). Seafood processing includes any activity that modifies the physical condition of a fishery resource (ADEC 2010a). The Alaskan fishing industry produces over one million metric tons of by-product and waste annually. There are over 200 fish-processing plants in Alaska with fish waste processing occurring at only 10 of the largest shore-based plants. These plants process 400 metric tons of waste per day or more (DoA 2009). With the exception of fresh market fish, some form of processing involving butchering, evisceration, precooking, or cooking is necessary to bring the catch to market. Precooking or blanching facilitates the removal of skin, bones, shells, gills, and other materials. Seafood processing facilities generally consist of mechanisms to offload the harvest from fishing boats; tanks to hold the seafood until the processing lines are ready to accept them; processing lines, process water, and waste collection systems; treatment and discharge facilities; processed seafood storage areas; and necessary support facilities such as electrical generators, boilers, retorts, water desalinators, offices, and living quarters. In addition, recreational fish cleaning at marinas and small harbors can produce a large quantity of fish waste.

Pollutants of concern from seafood processing wastewater are primarily components of the biological wastes generated by processing raw seafood into a marketable form, the chemicals used to maintain sanitary conditions for processing equipment and fish containment structures, and refrigerants (ammonia and freon) that may leak from the refrigeration systems used to preserve seafood (ADEC 2010a). Biological waste includes fish parts (heads, fins, bones, and entrails) and chemicals which are primarily disinfectants that must be used in accordance with EPA specifications. The EPA is currently developing an amendment to the Effluent Limitation Guidelines and Standards, national wastewater discharge standards, for the Canned and Preserved Seafood Category (Seafood Processing, 40 CFR Part 408). The EPA plans to issue a final rule covering the Alaskan seafood processing subcategories in 2016 (EPA 2016a).

6.4.3.1 *Potential Adverse Impacts*

Seafood processing operations have the potential to adversely affect EFH through the discharge of nutrients, chemicals, fish byproducts, and “stickwater” (water and entrained organics originating from the draining or pressing of steam-cooked fish products). EPA investigations illustrate that receiving water quality is directly influenced by the effluent discharge. In areas with strong currents and high tidal ranges, waste materials disperse rapidly. In areas of quieter waters, waste materials can accumulate and result in shell banks, sludge piles, dissolved oxygen depressions, and associated aesthetic problems (Stewart and Tangarone 1977). If adequate disposal technology is not available or employed in processing facilities that generate large quantities of nutrient rich fish waste, there is a potential to saturate designated mixing zones (EPA 1993, LaLiberte and Ewing 2006). Recent research results also suggest that if marine conditions support the approach grinding fish waste may not be the best approach (Thorne et al. 2006, Tech 2008). Investigations should be conducted to accuaractly assess and account for the volume of fish waste disgarded on a seasonal basis, as well as tidal volumes, velocities and effluent dilution. Factors such as tidal return or reflux also need to be considered.

The chronic increase in accumulating nutrient load can eventually cause eutrophication and create anoxic and hypoxic conditions. The impacts and effects of hypoxic conditions are well documented in coastal benthos and estuarine habitats (Brandt et al. 2005, Breitburg et al. 2009, Levin et al. 2009, Rose et al. 2009). Seafood processing discharges influence nutrient loading, eutrophication, and anoxic and hypoxic conditions, significantly influencing marine species diversity and water quality (Lotze et al. 2003, Roy Consultants Ltd. et al. 2003, Thériault et al. 2006). Ammonia, sulfides, and micro-toxin levels are also shown to be amplified in these habitats (Lalonde et al. 2008). The impacts to marine water carrying capacity resulting from the decomposition rate are further influenced by seasonal changes in water temperature as well as water depth (Ahumada et al. 2004, Verity et al. 2006).

Processors discharging fish waste are required to obtain permits. Various water quality standards, including those for biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform bacteria, oil and grease, pH, and temperature, are all considerations in the issuance of such permits. Although fish waste is biodegradable, fish parts that are ground to fine particles may remain suspended for some time, thereby overburdening habitats with particle suspension (NMFS 2005a). Localized effects depend on the differences in habitats and seafood processing methods.

In Alaska, seafood processors are allowed to deposit fish parts in a zone of deposit (ZOD) (EPA 2001) which can alter benthic habitat, reduce locally associated invertebrate populations via smothering, and lower dissolved oxygen levels in overlying waters. Impacts from accumulated processing wastes are not limited to the ZOD; severe anoxic and reducing conditions occur adjacent to effluent piles which undergo periodic gas eruptions, sending large mats of waste to the surface and releasing toxic noxious gases (EPA 1982, 2013). Examples of localized damage to benthic environment include several acres of bottom-driven anoxic piles of decomposing waste up to 7.9 m (26 ft) deep. Juvenile and adult stages of flatfish are drawn to these areas for food sources. This attraction may lead to increased predation on juvenile fish species by other flatfishes, diving seabirds, and marine mammals drawn to the food source (NMFS 2005a). However, due to the difficulty in monitoring these areas, impacts to species can go undetected.

Scum and foam from seafood waste deposits can also occur on the water surface and/or increase turbidity. Turbidity decreases light penetration into the water column, reducing primary production. Reduced primary production decreases the amount of food available for consumption by higher trophic level organisms. In addition, stickwater takes the form of a fine gel or slime that can concentrate on surface waters and move onshore to cover intertidal areas.

6.4.3.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of fish processing waste to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- In developing water quality standards for effluent mixing zones, accurate volumes of discharge and waste must be represented when assessing potential impacts.

- When considering potential environmental mechanisms influencing water quality standards in mixing zones, tidal return and reflex need consideration.
- To the maximum extent practicable, base effluent limitations on site-specific water quality concerns.
- Encourage the use of secondary or wastewater treatment systems where possible.
- Do not allow designation of new ZODs for fish processing waste. Instead, seek disposal options that avoid an accumulation of waste. Explore options to eliminate or reduce ZODs at existing facilities.
- Promote sound recreational fish waste management through a combination of fish-cleaning restrictions, public education, and proper disposal of fish waste.
- Encourage alternative uses of fish processing wastes (e.g., fertilizer for agriculture and animal feed).
- Explore options for additional research. Some improvements in waste processing have occurred, but the technology-based effluent guidelines have not changed in 20 years.
- Monitor biological and chemical changes to the site of seafood processing waste discharges.
- Locate waste outfall in areas with adequate natural flushing or exposed to higher currents.

6.4.4 Water Intake Structures/Discharge Plumes

Withdrawals of riverine, estuarine, and marine waters are common for a variety of uses, such as to cool power-generating stations and create temporary ice roads and ice ponds. In the case of power plants, the subsequent discharge of heated and/or chemically treated discharge water can also occur (Johnson et al. 2008).

6.4.4.1 *Potential Adverse Impacts*

Water intake structures and effluent discharges can interfere with or disrupt EFH functions in the source or receiving waters via impacts related to: (1) entrainment, (2) impingement, (3) degrading water quality, (4) operation and maintenance, and (5) construction.

As discussed in Section 5.2.1, entrainment is the direct uptake of aquatic organisms. With the use of intake structures, aquatic organisms may be entrained along with the cooling water into the cooling system. These organisms are usually the egg and larval stages of aquatic species including managed species and their prey. Entrainment can subject these life stages to adverse conditions resulting from the effects of increased heat, antifouling chemicals, physical abrasion, rapid pressure changes, and other detrimental effects. Long-term water withdrawal may adversely affect fish and shellfish populations by adding another source of mortality to the early life stage, which often determines recruitment and year-class strength (Travnichek et al. 1993). Pink salmon are likely to be more susceptible to entrainment because they typically enter estuarine and marine habitats immediately after emergence and are, therefore, much smaller. Based on entrainment studies conducted at power plants located in coastal areas, a large percentage of entrained larvae are composed of resident fishes that serve as a forage base for other species, such as salmon. Power plants located in open coastal environments have far less potential for population-level effects on fish populations than power plants located in coastal bays (EPRI 2007).

Impingement occurs when organisms that are too large to pass through in-plant screening devices become stuck against the screening device or remain in the forebay sections of the system until they are removed by other means (Grimes 1975, Hanson et al. 1977, Langford et al. 1978, Moazzam and Niaz Rizvi 1980, Helvey 1985, Helvey and Dorn 1987). The organisms cannot escape due to the water flow that either pushes them against the screen or prevents them from exiting the intake tunnel. Similar to entrainment, the withdrawal of water can trap particular species, especially when visual acuity is reduced (Helvey 1985).

Thermal effluents in riverine and inshore habitats can cause severe problems by directly altering benthic communities or killing organisms, especially ichthyoplankton. Temperature influences biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of these organisms (Blaxter 1969). Power plants may use once-through cooling biocides, such as sodium hypochlorite and sodium bisulfate which are extremely toxic to aquatic life, to periodically clean the intake and discharge structures.

6.4.4.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of water intake and discharge to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Locate facilities that rely on surface waters for cooling in areas other than estuaries, inlets, heads of submarine canyons, rock reefs, or small coastal embayments where managed species or their prey concentrate. Locate discharge points in areas with low concentrations of living marine resources. Incorporate cooling towers at discharge points to control temperature, and use safeguards to ensure against release of pollutants into the aquatic environment in concentrations that reduce the quality of EFH.
- Design intake structures to minimize entrainment or impingement. Use velocity caps that produce horizontal intake/discharge currents and ensure that intake velocities across the intake screen do not exceed 0.15 m/sec (0.5 ft/sec).
- Design power plant cooling structures to meet the best available technology requirements as developed pursuant to Section 316(b) of the CWA. Use alternative cooling strategies, such as closed cooling systems, to completely avoid entrainment or impingement impacts in all industries that require cooling water. When alternative cooling strategies are not feasible, other options may include fish diversion or avoidance systems; fish return systems that convey organisms away from the intake; mechanical screen systems that prevent organisms from entering the intake system; and, if impacts are unavoidable, habitat restoration measures to mitigate for expected losses of juvenile fish, larvae, and eggs.

- Regulate discharge temperatures (both heated and cooled effluent) so they do not appreciably alter the ambient temperature to an extent that could cause a change in species assemblages and ecosystem function in the receiving waters. Implement technologies to diffuse heated effluent.
- Avoid the use of biocides (e.g., chlorine) to prevent fouling where possible. Implement the least damaging antifouling alternatives.
- Treat all discharge water from outfall structures to meet state water quality standards at the terminus of the pipe. Ensure that pipes extend a substantial distance offshore and are buried deep enough not to affect shoreline processes. Set buildings and associated structures far enough back from the shoreline to preclude the need for bank armoring.

6.4.5 Oil and Gas Exploration, Development, and Production

The Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE)[26], are responsible for regulating oil and gas operations on the U.S. Outer Continental Shelf (OCS). The OCS Lands Act directs BOEM and BSEE to oversee the "expeditious and orderly development [of OCS resources] subject to environmental safeguards" (43 U.S.C. §§ 1332[3], [6], 1334[a][7]). BOEM is responsible for leasing, plan administration, environmental studies, NEPA analyses, resource evaluations, and economic analyses. BSEE is responsible for all field operations, including permitting and research, inspections, offshore regulatory programs, oil spill response, and training and environmental compliance functions. The ADNR Division of Oil and Gas exercises similar authority over Alaska's state waters (ADNR 1999). Offshore petroleum exploration, development, and production activities have been conducted in Alaskan waters or on the Alaska OCS since the late 1950s (AOGA 2015). Offshore exploration, development, and production of natural gas and oil reserves are important aspects of the U.S. economy. As the demand for energy resources grows, efforts to balance oil and gas development and the protection of the environment will continue.

6.4.5.1 *Potential Adverse Impacts*

Offshore oil and gas operations can be classified into exploration, development, and production activities (which includes transportation). These activities occur at different depths in a variety of habitats and can cause various physical, chemical, and biological disturbances (Helvey 2002, NMFS 2005a). Some of these disturbances are summarized below. However, not all of the potential disturbances in this section apply to each activity.

- Noise from seismic surveys, vessel operations, and the construction of drilling platforms or islands

As discussed in Section 5.2.8 (Pile Driving), noise generates sound pressures that may disrupt or damage marine life. The range of potential effects to fish from intense sound sources varies and is primarily influenced by the level of sound exposure. Direct effects such as hearing damage or loss, tissue damage, or death can occur. However, indirect effects that modify fish behavior are

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[26] Both the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE), were formed from the restricting of the Minerals Management Service (MMS).

much more common and likely (NOAA 2011). Oil and gas activities generate noise from drilling activities, construction, production facility operations, seismic exploration, and vessels (including baseline levels of noise when under power and icebreaking noise during in-ice surveys). The effects of the noise generated from seismic surveys and exploratory drilling are a primary concern to fish and EFH and are followed by concerns of the impacts of noise generated from regular vessel operations and icebreaking activities (NOAA 2011).

Seismic surveys direct sound waves at and into the seafloor and use the reflected waves to map the geology of the earth's subsurface. The energy emitted by a typical airgun shot during seismic surveys ranges in frequency from 10 Hz to 120 Hz which is within the hearing range of most fish. Moreover, the sound level can be as high as 255 dB which is well above those levels known to impact fish (NOAA 2011). Research suggests that the noise from seismic surveys may cause fish to exhibit behavioral changes including moving away from the acoustic pulse, displaying alarm responses, changing schooling patterns, changing swimming speeds and position in the water column, and interruption of feeding and reproduction (Fewtrell and McCauley 2012) affecting both fish distribution and catch rates (Engås et al. 1996). However, while there is agreement that noise from seismic surveys affects the behavior of fish, there are differences of opinion regarding the magnitude of those effects (Wardle et al. 2001, Gausland 2003, McCauley et al. 2003). In addition, few studies have investigated the effects of seismic surveys specifically on salmonids. Sverdrup et al. (1994) exposed Atlantic salmon to a simulated airgun blast and found that the exposed salmon showed signs of injury within 30 minutes of exposure and experienced short-term changes in stress hormone levels. Studies have also found temporary auditory threshold shifts in adult northern pike and lake chub (*Couesius plumbeus*) after exposure to 5 to 20 airgun blasts with a cumulative SEL of 185 to 191 dB but no threshold shifts in broad whitefish (*Coregonus nasus*) exposed to 5 airgun blasts with a cumulative SEL of 187 dB (Popper et al. 2005). Unfortunately, the study did not include detailed necropsies so it is unknown if the exposed fishes incurred any internal damage. Varying results of the effects of seismic noise on salmonids and non-salmonids reinforces the need for caution when extrapolating the effects of seismic airguns on one species to the effects on another species (PFMC and NMFS 2014). Seismic surveys may also impact fish eggs and larvae which cannot move away from the sound source to escape exposure; airgun noise would likely need to pass within meters of the eggs or larvae to cause any detrimental effects (NOAA 2011).

In contrast to seismic surveys, the noise generated from exploratory drilling is less intense but more stationary and persistent. A drilling operation consists of loud mechanical noises emitted over a range of frequencies and intensities from a single, fixed source for up to 90 days at a time. A stationary zone of displacement can be created around the drilling site and could negatively impact fish if this zone is near important spawning, fish-rearing, or feeding habitats (NOAA 2011).

Baseline vessel noise comes from engines, generators, propellers, and pumps. Some of this noise falls within the range of fish sensory perception, and fish have been shown to exhibit avoidance behaviors when confronted with noisy vessels (Mitson and Knudsen 2003). The noise levels from icebreaking operations vary depending on ice thickness, ice condition, the vessel used, and vessel speed. Operations can reach peak levels of 190 dB and are typically continuous in nature (Roth and Schmidt 2010). This sound level is above the threshold to initiate avoidance behavior in fish; however the operations are transient so long-term displacement of fish is not likely (NOAA 2011).

- Physical alterations to habitat from the construction, presence, and eventual decommissioning and removal of facilities such as islands or platforms; storage and production facilities; and pipelines to onshore common carrier pipelines, storage facilities, or refineries

Activities such as vessel anchoring, platform or artificial island construction, pipeline laying, dredging, and pipeline burial can temporarily or permanently change bottom habitat by altering substrates used for feeding or shelter. The associated epifaunal communities, which may provide feeding or predator escape habitats, may also be disturbed by these activities. Benthic organisms, especially prey species, may avoid recolonizing disturbed areas if the substrate composition is changed or if facilities are left in place after production ends (NOAA 2011). Dredging, trenching, and pipe laying generate spoils that may be disposed of on land or in the marine environment where sedimentation may smother benthic habitat and organisms. Most activities associated with oil and gas operations are, however, conducted under permits and regulations that require companies to minimize impacts or to avoid construction or other disturbances in sensitive marine habitats.

- Waste discharges, including well drilling fluids, produced waters, surface runoff and deck drainage, domestic waste waters generated from the offshore facility, solid waste from wells (drilling muds and cuttings), and other trash and debris from human activities associated with the facility

The EPA and the State of Alaska issue permits for discharge of drilling muds and cuttings to ensure the activities meet Alaska's water quality standards. The discharge of muds and cuttings from exploratory and construction activities may change the seafloor and suspend fine-grained mineral particles in the water column. These alterations may affect feeding, nursery, and shelter habitat for various life stages of managed species. Drilling muds and cuttings may adversely affect bottom-dwelling organisms at the site by covering immobile forms or forcing mobile forms to migrate. Suspended particulates may reduce light penetration and lower the rate of photosynthesis and the primary productivity of the aquatic area, especially if suspended for long intervals. High levels of suspended particulates may reduce feeding ability for groundfish and other fish species, leading to limited growth. The contents of the suspended material may react with the dissolved oxygen in the water and result in oxygen depletion. In addition, the discharge of oil drilling muds can change the chemical and physical characteristics of benthic sediments at the disposal site by introducing toxic chemical constituents. Changes in water clarity and the addition of contaminants may reduce or eliminate the suitability of water bodies as habitat for fish species and their prey (NMFS 1998a, b).

- Oil spills

Oil, gas, and associated contaminants can enter EFH from several natural and man-made sources. The chronic release of oil from anthropogenic sources is responsible for the majority of petroleum hydrocarbon input to both North American waters and the world's oceans. Estimates of crude-oil seepage demonstrate that 47 percent of oil entering the marine environment is from natural seeps, whereas 53 percent results from leaks and spills during the extraction, transportation, refining, storage, and utilization of petroleum (Kvenvolden and Cooper 2003). The chronic release of oil from natural seeps into long-term receiving bodies has different environmental transport, fate, and impacts than those associated with the man-made discharges described in this document (NAS 2003).

Accidental discharge of oil can occur during almost any stage of exploration, development, or production on the outer continental shelf or in nearshore coastal areas. Sources include equipment malfunction, ship collisions, pipeline breaks, other human error (e.g., loss of well control), or severe storms. Support activities associated with product recovery and transportation may also contribute to oil spills (NMFS 2005a). Federal and state laws and regulations require numerous oil spill prevention and cleanup response measures. However, spills from oil and gas development remain a potential source of contamination to the marine environment. Although major spills (e.g., 50,000 barrels or more) do occur (e.g., the *Exxon Valdez* in March 1989 and the *Deepwater Horizon* in April 2010), smaller spills occur more frequently. From 1995 to 2012, 85 percent of the oil spills in Alaska involved less than one barrel, 99.9 percent of the spills involved less than 50 barrels, and only 0.1 percent involved more than 500 barrels. Although large catastrophic oil spills can have adverse impacts on EFH, small spills and chronic releases can also affect EFH.

There is potential for hydrocarbons to adversely impact EFH between the release of the oil and the complete biodegradation of the oil. Once in the environment, petroleum products can be weathered and transformed through physical, chemical, and biological processes (Hazen et al. 2010). Many factors determine the degree of damage from a spill including the type of oil, spill size and duration, the geographic location, and the season. Oil is not a single substance; there are many different kinds of oil. When spilled, the various types of oil can affect the environment in different ways. Oils also differ in how difficult they are to clean up. Oil types differ based on viscosity, volatility, and toxicity. Viscosity refers to an oil's resistance to flow. Volatility is how quickly the oil evaporates into the air. Toxicity refers to how toxic or poisonous the oil is to either people or other organisms. Spill responders group oil into four basic types which are listed below along with a general summary of how each type can affect EFH.

Very Light Oils (Jet Fuels, Gasoline)

- Highly volatile (should evaporate within 1 to 2 days)
- High concentrations of toxic (soluble) compounds
- Localized, severe impacts to water column and intertidal resources
- No cleanup possible

Light Oils (Diesel, No. 2 Fuel Oil, Light Crudes)

- Moderately volatile; will leave residue (up to one-third of spill amount) after a few days
- Moderate concentrations of toxic (soluble) compounds
- Will "oil" intertidal resources with long-term contamination potential
- Cleanup can be very effective

Medium Oils (Most Crude Oils)

- About one-third evaporates within 24 hours
- Oil contamination of intertidal areas can be severe and long-term
- Oil impacts to waterfowl and fur-bearing mammals can be severe
- Cleanup most effective if conducted quickly

Heavy Oils (Heavy Crude Oils, No. 6 Fuel Oil, Bunker C)

- Little or no evaporation or dissolution
- Heavy contamination of intertidal areas likely
- Severe impacts to waterfowl and fur-bearing mammals (coating and ingestion)
- Long-term contamination of sediments possible
- Weathers very slowly
- Shoreline cleanup difficult under all conditions

The toxic effects of oil on EFH vary among the various types of oil. Generally, crude oil spills are well documented and tend to act in predictable ways in the marine environment. Diesel spills are more common in Alaska than crude oils spills. As noted above, diesel spills evaporate faster than heavier oils like bunker and crude oil; however, diesel and lighter oils have a higher acute toxicity that can kill fish and cause mass die-offs.

Despite measures taken to prevent leakage during the production and shipping of various types of petroleum hydrocarbons, some are released into the marine environment. Although the biodegradation of hydrocarbons by marine organisms has been occurring for millennia, hydrocarbons released during an oil spill can affect marine organisms including fish that are dependent on EFH. Hydrocarbons released during an oil spill supply plentiful energy resources to certain marine organisms; however, elements like nitrogen and phosphorus can limit the rate at which microorganism can breakdown hydrocarbons or bio-remediate. For example, some coastal areas inundated by crude oil during the *Exxon Valdez* spill likely exhausted the local supply of essential nutrients, resulting in a decreased rate of hydrocarbon biodegradation (Lindstrom et al. 1991, Prince and Bragg 1997).

The impacts of the potential energy contained in hydrocarbons on the marine food webs differ based on the environment in which the oil is released (e.g. coastal sublittoral, deep water, temperature etc.). The degradation of oil can have negative effects on marine organisms and EFH (e.g., algae blooms, eutrophication, smothering) (Joye et al. 2011). Moreover, oil can kill marine organisms (acute toxicity), cause delayed mortality, reduce their fitness through sublethal effects (chronic toxicity), and disrupt the structure and function of the marine ecosystem (NRC 2003). The contaminants contained in the spilled oil can persist in that environment for long periods of time (e.g., the *Exxon Valdez* spill impacted coastal areas for a decade or more), causing both acute and chronic toxic effects on individuals and populations (Peterson et al. 2003, Almeda et al. 2013a, Almeda et al. 2013b, Fodrie et al. 2014). Similarly, spilled oil can cause acute and chronic effects to kelp and other marine plants that provide food, spawning habitat, and nursery habitat for managed species like herring, salmon, and groundfish (BOEM 2012).

Diluted bitumen (dilbit) (e.g., Athabasca oil sands Alberta, Canada) is a petroleum product that has a greater potential to have adverse effects on EFH and Habitat Areas of Particular Concern (HAPC) than crude oil or diesel. Dilbit is a petroleum product mixture that is denser than crude oil because it is an asphaltic-dominated petroleum residue. Unlike conventional crude oil, dilbit floats briefly in water and then sinks as the light components evaporate. The remaining bitumen can make cleaning up a dilbit spill more difficult than a conventional oil spill, particularly if dredging is considered too ecologically damaging. Therefore, bitumen spills could result in a different set of ecological exposure and effects to consider during the assessment of natural resource injuries under the Oil Pollution Act of 1990. The 2010 dilbit spill on the Kalamazoo River showed that certain types of petroleum products can increase the likelihood of adverse impacts to the benthos when released in the environment.

- Polycyclic Aromatic Hydrocarbons (PAH's)

Characterized as petroleum and any derivatives, oil can be a major stressor to fish habitats. Both large and small quantities of oil can affect habitats and living marine resources. Oil can be toxic to all marine organisms, but certain species and life history stages are more sensitive than others. Oil is toxic to fishes and other marine organisms even at low concentrations (parts per trillion [ppt]) (Incardona et al. 2015). In general, the early life stages (eggs and larvae) are the most sensitive, juveniles are less sensitive, and adults are the least sensitive (Rice et al. 2000). Impacts include acute and delayed mortality and interference with the reproduction, cardiac development, immune function, growth, and behavior (e.g., spawning and feeding) of fishes, especially from early life stage exposures (Gould et al. 1994). Fish, like herring, exposed to PAHs in the embryonic or larval stages cause chronic cardiac defects that can be found in adult fish years after a spill occurs (Incardona et al. 2015).

PAHs are considered to be the most toxic components of crude oil (Almeda et al. 2013a, Almeda et al. 2013b). PAHs elicit a range of toxic effects depending on their chemical structure and can persist in marine habitats for many years, creating pathways for biological exposure to lingering oil and associate adverse effects. Studies conducted following the *Exxon Valdez* oil spill described toxicity in eggs, larvae, and juveniles exposed to lingering oil. Fish are particularly sensitive to 3- and 4-ring PAH compounds that are relatively abundant in oil. Exposure of fish embryos to PAHs can have population-level consequences through direct mortality and effects on growth, deformities, reproduction, and behavior with long-term consequences on subsequent marine survival (Almeda et al. 2013a). Even low levels of petroleum components (e.g., PAHs) from chronic pollution may accumulate in fish tissues and cause acute and chronic effects, particularly during embryonic development (Carls et al. 1999, Heintz et al. 1999, Heintz et al. 2000). For example, even low doses of PAHs (1 ppt) can have sublethal effects on embryonic heart development which can cause permanent secondary changes in the heart shape and cardiac output in individuals in a population (Peterson et al. 2003). Moreover, studies on the *Deepwater Horizon* oil spill reinforced these finding, specifically that PAHs found in crude oil have deleterious impacts on fish hearts, resulting in acute mortality in individuals and reduced fitness for some pelagic fish populations (Brette et al. 2014, Incardona et al. 2014).

- Nearshore

Accidents and spills occurring during the transport and transfer of oil from ships or pipelines to refineries are the greatest potential threats to EFH because the spilled oil is likely to affect shallow nearshore areas or sensitive habitats, such tidal flats, kelp beds, estuaries, river mouths, and streams (PFMC and NMFS 2014). Oil spills may cover and degrade coastal habitats and associated benthic communities or may produce a slick on the surface waters which disrupts the pelagic community. A major oil spill can produce a surface slick covering several hundred km^2 and oil hundreds of miles of shoreline. The impacts to EFH would depend on a variety of factors including, but not limited to, the type of oil, the life stage affected, species distribution and abundance, habitat dependence (e.g., ocean water column, sea surface, benthos), life history (e.g., anadromous, migratory), the extent and location of spawning areas, species exposure and sensitivity to oil and gas (e.g., toxicology), impacts to prey species, and the location and timing of the spill (NOAA 2011).

If the oil spill moves toward land, habitats and species could be affected by oil reaching the nearshore environment. Immediately after a large spill, hydrocarbons could be acutely toxic to some organisms including fishes. The oil would contaminate waters beneath and surrounding the surface slick. Physical and biological forces act to reduce oil concentrations with depth and distance (NMFS 2005a); generally, the lighter-fraction hydrocarbons evaporate rapidly, particularly during high winds and wave activity. Heavier oil fractions may settle through the water column. Suspended sediment and marine snow can adsorb and carry oil to the seabed. Moreover, hydrocarbons may be physically dispersed as small droplets into the water column by wave action, which may enhance adsorption to nearshore sediments.

Oil reaching nearshore areas may affect productive nursery grounds or areas containing high densities of fish eggs and larvae. Spilled oil concentrated along the coastline and at the mouths of streams or rivers may disrupt migratory patterns for some species, such as eulachon or salmon, if fish avoid the contaminated areas. In some cases, toxic fractions (e.g., PAHs) of spilled oil could also reach freshwater areas where salmon eggs are deposited in stream bottoms (BOEM 2012). Carls et al. (2003) demonstrated that tides and the resultant hydraulic gradients move groundwater containing soluble and slightly soluble contaminants, such as oil, from beaches surrounding streams into the hyporheic zone where pink salmon eggs incubate.

An oil spill near an especially important habitat (e.g., a gyre where fish or invertebrate larvae are concentrated) could cause a disproportionately high loss of a population of marine organisms. In addition to eggs and larvae, planktonic organisms in the upper seawater column would be at risk. Eggs, larvae, and planktonic organisms are small, absorb contaminants quickly, and cannot actively avoid exposure. In addition, some organisms (e.g., zooplankton) do not have efficient metabolic mechanisms for detoxifying oil chemicals. Their proximity to the surface may make them vulnerable to photo-enhanced toxicity effects, which can multiply the toxicity of hydrocarbons (Barron et al. 2003).

Nearshore habitats that are susceptible to damage from oil spills include not only the low-energy coastal bays and estuaries where oil may accumulate but also the high-energy cobble environments where wave action drives oil into the sediments. Many of the beaches in Prince William Sound with the highest persistence of oil following the *Exxon Valdez* oil spill were high-energy environments containing large cobbles overlain with boulders. These beaches were pounded by storm waves that drove the oil into and well below the surface (Michel and Hayes 1999). Oil that mixes into bottom sediments may persist for years. Subsurface oil was still detected in beach sediments of Prince William Sound 12 years after the *Exxon Valdez* oil spill;

much of the oil was unweathered and more prevalent in the lower intertidal biotic zone than at higher tidal elevations (Short et al. 2002, Short et al. 2004). Population reductions due to delayed effects of PAHs in tidal sediments postponed recovery among some species for more than a decade following the *Exxon Valdez* oil spill (Peterson et al. 2003).

The unknown impacts of an oil-related event near and within ice are an added concern. Should oil become trapped in ice, it could affect habitats for months or years after the initial event. Cold climates are likely to affect the impacts and natural dissipation of oil products. For example, an oil spill in the Arctic during the winter months will alter the rate of oil weathering and the ability to respond because of the low temperatures, presence of ice, and length of darkness. Spilled oil could also be transported with the ice floes to a different region (NMFS 2005a). Spills occurring under ice could result in the long-term degradation of EFH because of the cleanup difficulties (BOEM 2012). Onshore and offshore habitat loss due to oiling can result in displacement and stress in the fish and other organisms that depend on these habitats. Displacement may result in blocked or impeded access to spawning, rearing, feeding, and migratory habitats important for survival (NOAA 2011) . It is important to note that even if climate change removes sea surface ice, to allow for additional drilling and shipping opportunities, the Arctic Ocean will still be completely dark for three to four months of the year.

- Benthos

Spilled oil may affect the benthos (Reddy et al. 2012, Almeda et al. 2013b, Valentine et al. 2014). These impacts may eventually lead to the disruption of community organization and the trophic dynamics of the affected regions. The effects of large, catastrophic spills on coastal environments (e.g., *Exxon Valdez* 1989) have been documented; however, the *Deepwater Horizon* oil spill (i.e., Macondo 252 well blowout in 2010) is a reminder that large releases can also occur from drilling operations in the deep sea far from land where the response strategies and subsequent transport and fate of the crude oil differed significantly (Peterson et al. 2012). The *Deepwater Horizon* spill resulted in the release of 5 million barrels of petroleum at a depth of 1,500 m (~5,000 ft) over the course of 87 days. Although some of this oil reached the surface and weathered similarly to vessel accidents, approximately 2 million barrels of liquid and all of the natural gases remained in an intrusion layer between 1,000 and 1,300 m (3,280 and 4,265 ft) that persisted for at least six months. A portion of the sub-sea plume was degraded during its residence time in the water column; however, a significant portion settled at the benthos through physical and biological processes. In addition, at least some of the oil that reached the surface was transported to the benthos (Reddy et al. 2012). These dual modes of deposition resulted in a “bathtub ring;” formed from an oil-rich layer of water literally impinging upon the continental slope at a depth of 900 to 1,300 m (2,953 to 4,265 ft), and a higher-flux “fallout plume” where suspended oil particles sank to the underlying sediment at a depth of 1,300 to 1,700 m (4,265 to 5,577 ft). The sedimentation of oil and contaminants resulted from the initial buoyant rise of hydrocarbons, incorporation into the pelagic biota, biodegradation, and interventions at the well head (e.g., dispersant use). Overall, the fallout plume of hydrocarbons from the Macondo Well contaminated 3,200 km^2 (790,737 ac) of ocean floor (Valentine et al. 2014). It is important to note that some fraction of the crude oil released during a deep discharge will be entrapped in layers above the release depth, resulting in similar hydrocarbon rich layers even in relatively shallow blowouts (48 m [157 ft]) (e.g., Ixtoc blowout) (Boehm and Fiest 1982, Joye et al. 2011).

The adverse impacts of subsurface releases differ significantly from surface spills. During surface spills, like the *Exxon Valdez*, highly water soluble components quickly volatize and are readily lost to the atmosphere, thereby limiting the extent of dissolution into the water column. Subsurface releases have different impacts on EFH because the volatile components are retained in the water column for extended periods of time (Reddy et al. 2012). A significant part of the oil released into the marine environment from surface release or subsurface spill (e.g., well blowout, shipwreck) is retained in the water column with some portion of that oil reaching the benthos. The relative amount of oil which resides in the water column is a function of a number of factors including the chemical and physical nature of the oil, dispersant use, the point of release, the sea surface turbulence, marine snow, and other hydrographic conditions. During a subsurface spill, very favorable conditions exist for retention and transport of particulate and dissolved oil in the water column. For example, the turbulent subsurface release of the oil can enhance the formation of small droplets of oil. These droplets can be retained in the water column for a period of time during which ocean currents can carry them away from the oil spill. The formation of droplets from wave action (e.g., surface spill) or subsurface turbulence (e.g., well blowout) increases the surface area of the oil, thereby increasing the rates of physical, chemical, and biological processes such as microbial action.

The vertical transport of marine oil snow (flocculation, sedimentation, accumulation) of surface spills and well head spills can significantly affect EFH through the contamination of benthic habitats. The interaction of petroleum compounds with high concentrations of marine snow and suspended particulate matter in the water column can result in rapid sedimentation from the surface to the seabed. This process is possibly intensified by the use of chemical dispersants (Kinner et al. 2014). As the hydrocarbons enter the marine environment, oil rich particles accumulate on the seafloor with consequences for benthic food webs and fauna (Montagna et al. 2013). The protracted exposure of eggs, embryos, and larvae to, and metabolism of, toxic petroleum hydrocarbons can adversely affect ecologically and economically important benthic fishes. Once in the benthos, petroleum toxins will reside for extended period of time due to cold temperatures, the lack of photochemical alteration, and the low oxygen content if buried.

Zooplankton play a large, relevant role in the distribution of petroleum in the sea (Graham et al. 2010). Zooplankton ingest hydrocarbons and passively adhere droplets of oil on their bodies, resulting in bioaccumulation of pollutants. PAHs are considered bioaccumulative because they are lipophilic and can accumulate in organisms, particularly invertebrates. PAHs can be bioaccumulated and potentially transferred up the food web and contaminate apex predators (Almeda et al. 2013b). Moreover, zooplankton are able to excrete high concentrations of toxins like whole oil droplets and PAHs in fecal pellets, speeding the decent of contaminants to benthos. A deeper understanding of the chronic, delayed, and indirect long-term risk and impacts of PAH contamination of the deep sea bed is needed to predict impacts to EFH should a large spill or chronic small spills contaminate the benthos in Alaska.

In summary, large oil spills and chronic small oil spills can adversely affect EFH because residual oil can build up in sediments and impact living marine resources. Oil can persist in coastal and oceanic sediments for years after the initial contamination (NAS 2003), interfering with the physiological and metabolic processes of federally managed demersal fishes

(Vandermeulen and Mossman 1996, Incardona et al. 2014). Thus, the chronic toxic effects to benthic habitat are a real concern, especially for EFH.

- Response

Lethal and sublethal impacts can also result from oil spill response methods including chemical dispersants, burning, and skimming (BOEM 2012). Despite the toxic effects, best practices have shown it is better to capture, burn, or disperse oil at sea before it can reach the shore (Alaska Federal/State Preparedness Plan for Response to Oil & Hazardous Substance Discharges/Releases) (EPA et al. 2010, USCG 2014). These response activities may be more hazardous to plants and animals than the oil itself and may also adversely affect fish habitat (PFMC and NMFS 2014). To predict acute and long-term impacts to EFH, it is crucial to understand the fate of pelagic crude oil not captured by skimming or lost to controlled burns in the marine environment. While dispersants are likely to be deployed by planes and vessels in rougher seas, skimming and burning can be effective if equipment is close at hand and calm weather prevails. Large catastrophic spills in remote areas (e.g., Chukchi Sea) can spread before gear can be deployed to such an extent that skimming (or burning) becomes much more complicated (Prince 2015). Moreover, a lack of daylight would further hinder response efforts. For example, large-scale skimming during the *Deepwater Horizon* spill resulted in only 3 percent of the spilled crude oil being recovered and only 5 percent being burned (Lubchenco et al. 2012). Thus, it is far more likely that an offshore spill in Alaska would be addressed with chemical dispersants.

Chemical oil dispersants are applied to spills to enhance the rate of oil degradation by physical, chemical, and biological processes in order to minimize the impacts to nearshore and coastal areas and surface inhabitants (e.g., birds, marine mammals) (Couillard et al. 2005). Chemical dispersants are introduced to surface slicks by spraying via an airplane or ship. Then, wave action and turbulence mixes and breaks up free oil products into small oil droplets that disperse into the top several meters of the water column. Similarly, dispersants can be used in the subsea in an uncontrolled well release.

Dispersant toxicity varies by species and dispersant type. Newer dispersant formulations (e.g., COREXIT® 9500) appear to be significantly less toxic to fish than oil alone. However, few species have been tested. Regardless of the type of chemical dispersant deployed, the added toxicity from oil-dispersant mixtures could be significant for some species (Hemmer et al. 2011). The use of dispersants causes a larger volume of the water column to be impacted by oil chemicals, but it may increase dilution and degradation rates. Chemical dispersants move the impacts associated with spilled oil from the sea surface into the water column, and a portion of that oil eventually accumulates in benthos. Chemical dispersants are typically applied in waters deeper than 10 m (33 ft) to avoid or reduce potential toxicity to nearshore organisms (NOAA 2011); however, the offshore application of chemical dispersants could degrade water quality and impact pelagic organisms.

Dispersants generally increase the total concentrations of petroleum compounds (dissolved and particulate oil) in seawater (Barron et al. 2003). The use of dispersants in an oil spill increases the concentration of less water-soluble hydrocarbons, which can induce enzymatic activity that can metabolize PAHs into toxic forms that cause a variety of detrimental effects (Couillard et al. 2005, Van Scoy et al. 2010). The photic zone (0 to 200 m [0 to 656 ft]) is particularly vulnerable because aromatic hydrocarbons are known to be phototoxic. Sunlight can intensify the toxic effects (2- to a 1,000-fold increase in toxicity) of oil, especially dispersed oil, on transparent life stages of embryonic and larval fish (Barron et al. 2003, Incardona et al. 2012a, Incardona et al. 2012b). One study on the impacts of crude versus dispersed oil on salmon post-smoltification found that dispersant treatment significantly decreased the lethal potency of crude oil to salmon smolts (Lin et al. 2009).

Components of the planktonic biota mitigate many of the adverse effects of spilled oil by absorption, transformation, and excretion. The chemical dispersion of the oil results in increased bioremediation of the oil by microorganisms (Hazen et al. 2010, Prince et al. 2013); however, the addition of dispersants is known to increase the total concentration of PAH components in the surrounding water (Couillard et al. 2005). Chemical dispersants accelerate the vertical transport of oil from the surface through the water column; therefore, there is less opportunity for volatile hydrocarbons (e.g., PAH) to evaporate at the surface (Prince 2015). Similarly, dispersed oil is more likely to be concentrated and transported to the benthos through biological interactions in the food web (Almeda et al. 2013b, North et al. 2015). Consequently, decision makers will need to consider impacts to benthic communities due to both physical and toxicological impacts of the petroleum residue as well as the impacts caused by any invasive response actions (Dollhopf et al. 2014).

- Platform storage and pipeline decommissioning

Oil and gas platforms may consist of a lattice-work of pilings, beams, and pipes that support diverse fish and invertebrate populations and are considered de facto artificial reefs (Love and Westphal 1990, Love et al. 1994, Love et al. 1999, Helvey 2002). Because decommissioning includes plugging and abandoning all wells and removing the platforms and associated structures from the ocean, impacts to EFH are possible during removal. The demolition phase may generate underwater sound pressure waves that impact marine organisms. Removal of these midwater structures may eliminate habitat for invertebrates and fish. In some areas of the U.S., offshore oil and gas platforms are left in place or submerged after decommissioning to provide permanent habitat for some organisms (Hanson et al. 2005).

Depending upon the circumstances, region or marine environment, after an oil and gas platform has outlived its use, it must be decommissioned according to the terms of the Department of the Interior (DOI) lease and terms by which the platform was authorized (Broughton 2012). DOI regulations include a disposal option that, under certain circumstances, allows keeping a biologically valuable structure in the marine environment as an artificial reef through a process called “Rigs-to-Reefs.” Artificial reefs not only can enhance aquatic habitat, but also provide an additional option for conserving, managing, and/or developing fishery resources and can provide recreational opportunities.

6.4.5.2 Recommended Conservation Measures

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of oil and gas exploration and development to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Conduct preconstruction biological surveys in consultation with resource agencies to determine the extent and composition of biological populations or habitat in the proposed impact area. Construction should be sited to minimize impacts to fishery resources.
- During seismic surveys, utilize ramp-up procedures to allow fish to move away from the source before exposure to detrimental sound levels occur (NOAA 2011). Use marine vibroseis instead of airguns when possible. Use the least powerful airguns that will meet the needs of the survey. Survey the smallest area possible to meet the needs of the survey. When salmon are migrating through the area, provide sufficient breaks in the survey to allow transit through the area.
- Schedule exploration and development activities when the fewest species and least vulnerable life stages are present. Appropriate work windows can be established based on the multiple season biological sampling. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Avoid the discharge of produced waters into marine waters and estuaries. Reinject produced waters into the oil formation whenever possible.
- Avoid discharge of muds and cuttings into the marine and estuarine environment. Use methods to grind and reinject such wastes down an approved injection well or use onshore disposal wherever possible. When this is not possible, provide for a monitoring plan to ensure that the discharge meets EPA effluent limitations and related requirements.
- To the extent practicable, avoid the placement of fill to support construction of causeways or structures in the nearshore marine environment.
- As required by federal and state regulatory agencies, encourage the use of Geographic Response Strategies (GRSs) that identify EFH and environmentally sensitive areas. Identify appropriate cleanup methods and response equipment.
- Evaluate the potential impacts to EFH that may result from decommissioning activities. Minimize such impacts to the extent practicable.
- Vessel operations and shipping activities should be familiar with Alaska GRSs which detail environmentally sensitive areas of Alaska’s coastline. Currently, GRSs exist for the many different regions and areas including southeast Alaska, southcentral Alaska, Kodiak Island, Prince William Sound, Cook Inlet, Bristol Bay, Northwest Arctic, North Slope, and the Aleutian Islands (see http://www.dec.state.ak.us/spar/perp/grs/home.htm).
- Avoid using dispersants in areas that could adversely impact EFH or HAPC.
- Consider the potential impacts to EFH as part of oil spill response planning.
- Include an analysis of impacts to EFH as part of any damage assessment analysis.

- Conduct preconstruction water quality sampling specific for PAHs as a tool to determine or accurately compare PAHs during pre and post events.

6.4.6 Habitat Restoration and Enhancement

Habitat loss and degradation are major, long-term threats to the sustainability of fishery resources (NMFS 2002). Viable coastal and estuarine habitats are important to maintaining healthy fish stocks. Good water quality and quantity, appropriate substrate, ample food sources, and adequate shelter from predators are needed to sustain fisheries. Restoration and/or enhancement of coastal and riverine habitat that supports managed fisheries and their prey will assist in sustaining and rebuilding fish stocks by increasing or improving ecological structure and functions. Habitat restoration and enhancement may include, but are not limited to, the improvement of coastal wetland tidal exchange or reestablishment of natural hydrology; dam or berm removal; fish passage barrier removal or modification; road-related sediment source reduction; natural or artificial reef, substrate, or habitat creation; the establishment or repair of riparian buffer zones; the improvement of freshwater habitats that support anadromous fishes; the planting of native coastal wetland and SAV; and improvements to feeding, shade or refuge, spawning, and rearing areas that are essential to fisheries (PFMC and NMFS 2014). Restoration efforts should consider a watershed or basin approach. Efforts undertaken without an understanding of hydrogeological and ecological conditions in the watershed may be unsuccessful. Additionally, habitat restoration activities based solely on an individual species without consideration of the immediate ecosystem may not restore habitat function (PFMC and NMFS 2014).

6.4.6.1 *Potential Adverse Impacts*

The implementation of restoration and enhancement activities may have localized and temporary adverse impacts on EFH. Possible impacts may include: (1) localized nonpoint source pollution, such as influx of sediment or nutrients; (2) interference with spawning and migration periods; (3) temporary removal of feeding opportunities; (4) indirect effects from the construction phase of the activity; (5) direct disturbance or removal of native species; and (6) temporary or permanent habitat disturbance.

Habitat restoration activities that include the removal of invasive species may cause disturbances of native species. For example, the netting and trapping of invasive fish species may result in unwanted bycatch of native fish and other aquatic species.

The temporary or permanent habitat disturbance associated with restoration or enhancement activities can cause adverse impacts. Fish passage restoration and other hydrologic restoration activities, such as the removal of culverts or other in-stream structures, installation of fishways, or other in-water activities will require temporary rerouting of flows around the project area. (Thorne et al. 2006)This could temporarily disturb onsite or adjacent habitats by altering hydrologic conditions and flows during project implementation.

Artificial reefs are sometimes used for habitat enhancement; however, these structures could create a loss of EFH depending on where the reef material is placed and if inappropriate materials are used for construction. Usually, reef materials are set on flat sand bottoms or "biological deserts" which end up burying or smothering bottom-dwelling organisms at the site or even preventing mobile forms (e.g., benthic-oriented fish species) from using the area as habitat. Some materials used as artificial reefs may be inappropriate for the marine environment (e.g., automobile tires or compressed incinerator ash) and can serve as sources of toxic releases or physical damage to existing habitat when breaking free of their anchoring systems (Collins et al. 1994).

6.4.6.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of habitat restoration and enhancement activities to EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- Use BMPs to minimize and avoid potential impacts to EFH during restoration activities. BMPs should include, but are not limited to, the following actions.
  - Use turbidity curtains, hay bales, and erosion mats.
  - Plan staging areas in advance and keep them to a minimum size.
  - Establish buffer areas around sensitive resources.
  - Remove invasive plant and animal species from the project site before starting work. Plant only native plant species. Identify and implement measures to ensure native vegetation or revegetation success.
  - Establish temporary access pathways before restoration activities are implemented to minimize adverse impacts from project implementation.
- Avoid restoration work during critical life stages for fish (e.g., spawning, nursery, and migration). Determine these periods before project implementation to reduce or avoid any potential impacts.
- Provide adequate training and education for volunteers and project contractors to ensure minimal impacts to the restoration site. Train volunteers in the use of low-impact techniques for planting, equipment handling, and any other activities associated with the restoration activity.
- Conduct monitoring before, during, and after project implementation to ensure compliance with project design and restoration criteria.
- To the extent practicable, mitigate any unavoidable damage to EFH within a reasonable time after the impacts occur.
- Remove and, if necessary, restore any temporary access pathways and staging areas used in the restoration effort.
- Determine benthic productivity by sampling before any construction activity in the case of subtidal enhancement (e.g., artificial reefs). Avoid areas of high productivity to the maximum extent possible. Develop a sampling design with input from state and federal resource agencies. Before construction, evaluate of the impact resulting from the change

in habitat (e.g., sand bottom to rocky reef). During post-construction monitoring, examine the effectiveness of the structures for increasing habitat productivity.

6.4.7 Marine Mining

Mining activities, which are described in Sections 3.1.1 and 3.1.2 of the EFH EIS (NMFS 2005a), can lead to the direct loss or degradation of EFH for certain species. Offshore mining, can increase turbidity, re-suspend fines, or directly injure or displace fish. Further impacts to eggs, hatched larvae, and adult fish may occur. Mining large quantities of beach gravel can also impact turbidity and may affect the transport and deposition of sand and gravel along the shore at the mining site and at down-current sites (NMFS 2005a).

Offshore dredging and the discharge of spoils have the potential to affect aquatic resources via habitat alteration, including increased turbidity, entrainment of organisms, exposure to trace metals, noise and disturbances, and fuel spills (MMS 1991). Previous mining operations off Nome resulted in considerable localized substrate alteration. Sediment fines destabilized by mining operations were redistributed by local currents and sea conditions (Jewett 1999). Studies also suggest that recolonization of benthic communities to their original structure may not occur after mining disturbances; instead, a somewhat different assemblage may result. Actual recovery times for a community to stabilize (i.e., recolonization of dredged sites to comparable density, biomass, and number of taxa) are unknown. Studies associated with the Nome Offshore Placer Project showed that even seven years after mining, seafloor habitats and species assemblages had not recovered to pre-disturbance conditions (Gardner and Jewett 1994).

6.4.7.1 *Potential Adverse Impacts*

Impacts of mining on EFH include both physical impacts (e.g., intertidal dredging) and chemical impacts (e.g., additives such as flocculates) (NMFS 2005a). Physical impacts may include the removal of substrates that serve as habitat for fish and invertebrates; habitat creation or conversion in less productive or uninhabitable sites, such as anoxic holes or silt bottom; the burial of productive habitats, such as in nearshore disposal sites (as in beach nourishment); the release of harmful or toxic materials either in association with actual mining or in connection with machinery and materials used for mining; the creation of harmful turbidity levels; and adverse modification of hydrologic conditions so as to cause erosion of desirable habitats. Submarine disposal of mine tailings can also alter the behavior of marine organisms. Submarine mine tailings may not provide suitable habitat for some benthic organisms. In laboratory experiments, benthic dwelling flatfishes (Johnson et al. 1998a) and crabs (Johnson et al. 1998b) strongly avoided mine tailings.

During beach gravel mining, water turbidity increases, and the resuspension of organic materials can affect less mobile organisms (e.g., eggs and recently hatched larvae) in the area. Benthic habitats can be damaged or destroyed by these actions. Changes in bathymetry and bottom type may also alter population and migrations patterns (Hurme and Pullen 1988).

Offshore gold placer mining in the Norton Sound region has occurred for many years. The Western Gold Exploration and Mining Company (WestGold) conducted the largest and most notable project, the Nome Offshore Placer Project, from late 1985 through September 1990. The project mined the seafloor with a 170-m (558-ft) dredge vessel incorporating a bucket ladder system of 134 buckets. Each bucket had a 0.84 m^3 (1.1 yd^3) capacity. The dredge could operate in water depths of up to 45 m (148 ft) and cut to a depth of 3 m (10 ft) below the seafloor. Typically, 7,646 to 15,291 m^3 (10,000 to 20,000 yd^3) of material were processed each day, and mining occurred in water depths of 6 to 18 m (20 to 60 ft).

Studies of the WestGold project note several impacts that offshore placer mining may have on the benthic community: habitat loss, alteration, re-suspension of fine sediments, removal of benthic infauna and epifauna, and injured marine organisms. Dredged areas can still be witnessed and are void of re-colonization – to date. Injured organisms may not reach maturity to reproduce and/or may be subject to increased predation. The long-term result of such disturbances is an overall decrease in benthic species and their habitats.

WestGold's studies documented that deeper waters (deeper than 6 m [20 ft]) support more diverse and abundant species complexes, especially in the cobble habitats. These studies also suggest that significant storm events and longshore currents cause extensive mixing of nearshore sediments and alteration of the seafloor. These natural events occur within nearshore waters less than 7.6 m (25 ft) in depth (Jewett 1999). Ice gouging is also a common occurrence in the region. The seaward edge of the ice typically extends to the 18-m (60-ft) isobath and may be anchored by ice keels in depths from 9 to 18 m (30 to 60 ft) (Jewett 1999).

These studies further conclude that the re-colonization of species after disturbance occurs at a slow rate with a wide range of impacts. Suspended sediments can travel well outside the disturbed area and settle on other undisturbed marine substrates. Sediment was found in red king crab stomachs, but it is not known if this was due to increases in suspended sediment or associated with a food source. Some sediment is probably ingested while feeding on tube worms, starfish, and sea urchins. Fine sediments may inhibit the growth in some species and smother benthic organisms.

Benthic communities do not recover quickly from rapid change, and effects may not be easily measured. NMFS studies related to the effects on benthic substrates and their inhabitants (NMFS 2005a) also found that many seafloor organisms are slow growing and reach their age of maturity (spawning age) later during their life history. Additionally, in Alaskan waters, many species' life history traits are unknown. According to video analysis results, even the smallest of epifauna (sponge, tunicate, or sea pen) will be in association with a larger fish or crab. Direct association is unknown; however, the larger species are often attracted to the structure, possibly for cover or feeding.

6.4.7.2 *Recommended Conservation Measures*

The following recommended conservation measures should be viewed as options to prevent and minimize adverse impacts of marine mining on EFH and to promote the conservation, enhancement, and proper functioning of EFH.

- To the extent practicable, avoid mining in waters containing sensitive marine benthic habitat, including EFH (e.g., spawning, migrating, and feeding sites).
- Minimize the areal extent and depth of extraction to reduce recolonization times.

- Monitor turbidity during operations, and cease operations if turbidity exceeds predetermined threshold levels. Use sediment or turbidity curtains to limit the spread of suspended sediments and minimize the area affected.
- Monitor individual mining operations to avoid and minimize cumulative impacts. For instance, three mining operations in an intertidal area could impact EFH, whereas one may not. The disturbance of previously contaminated mining areas may cause additional loss of EFH.
- Use seasonal restrictions as appropriate to avoid and minimize impacts to EFH during critical life history stages (e.g., migration and spawning) of managed species.
- Deposit tailings within as small an area as possible.

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