

State of Science on Net-Pen Aquaculture in Puget Sound, Washington

**Jennica L. Hawkins¹, Gretchen E. Bath, Ph.D.¹, Walton W. Dickhoff, Ph.D.¹, and
James A. Morris, Jr., Ph.D.²**

¹CSS, Inc. under contract to the National Oceanic and Atmospheric Administration, National Ocean Service,
National Centers for Coastal Ocean Science, 101 Pivers Island Road, Beaufort, North Carolina

²National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean
Science, 101 Pivers Island Road, Beaufort, North Carolina

Foreword from Washington State Agencies

The *State of Science on Net-Pen Aquaculture in Puget Sound, Washington* was produced by the National Centers for Coastal Ocean Science (NCCOS), part of NOAA, to help provide information to the state of Washington about the safe and effective management of commercial marine net-pen finfish aquaculture. The project began in 2016 led by the Washington Department of Ecology to identify the environmental risks and potential impacts associated with finfish aquaculture. As part of the process, NCCOS agreed to provide a technical report that compiled the latest science associated with the industry.

This compilation process was underway when a commercial net pen off Cypress Island in Puget Sound suffered catastrophic failure on August 19, 2017, in which approximately 240,000 non-native Atlantic salmon escaped to state marine waters. The incident attracted significant public attention and concern about the industry and potential risks that operations raising non-native salmon might pose to native fish populations. As a result, the Washington Legislature passed a new law that effectively terminates non-native finfish aquaculture when current state aquatic lands leases expire in 2022.

The measure also directed the Washington departments of Agriculture, Ecology, Fish and Wildlife, and Natural Resources to continue their effort to update guidance and informational resources for planning and permitting commercial marine finfish net-pen aquaculture in state waters.

To fulfill this mandate, the state and NCCOS continued to develop this report, which was intended to include new guidance and management recommendations. However, for a variety of reasons, the task to develop a document that captured the latest science and management recommendations proved challenging and time-consuming. As a result, the state and NCCOS agreed to complete a state of the science report, with the understanding the state would develop a separate guidance and management recommendations document for future marine net-pen aquaculture activities.

This report provides a significant collection of scientific studies that have analyzed the environmental impacts of fin-fish aquaculture. It should be noted, however, that the document:

- Was not formally peer reviewed, although experts in marine aquaculture contributed to its development.
- Contains portions which may be inconsistent with the state's understanding of the biological, physical, and cultural environment in Washington State.
- Is but one source of information that state agencies are using to inform their recommendations.
- Does not necessarily represent the management or policy views of the state.

Review

While much of the information contained in this report was derived from the peer review literature, this report in its entirety was not subjected to formal or informal peer review. Reviews of some sections were obtained from staff of the Washington Departments of Ecology, Natural Resources, and Fish and Wildlife and were incorporated when possible.

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Margaret Dutch
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Laurie Nieworthy
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Washington Department of Fish and Wildlife

Kelly Britt
Tish L. Conway-Cranos
Meghan Finley
Jennifer R Griffiths
Scott Pearson
Tracey Peterson
Jeb Varney
Ken Warheit

Washington Department of Natural Resources

Cyrilla Cook
Cinde Donoghue
Maria Hunter

Washington Department of Agriculture

Brian Joseph

NOAA

Sally Brick, Northwest Section NOAA Office of General Counsel
Laura Hoberecht, NOAA NMFS
Caitlin Imaki, Northwest Section NOAA Office of General Counsel
Linda Rhodes, NOAA NPFSC
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List of Acronyms

AADAP – Aquatic Animal Drug Approval Partnership

ADD – Acoustic Deterrent Device

AHD – Acoustic Harassment Device

AIS – Automated Identification System

ALL – Aquatic Land Lease

APHIS – Animal and Plant Health Inspection Service

APPL - Assumed Pathogen Prevalence Level

ARNI - Aquatic Resources of National Importance

BIA – Biologically Important Area

BMP – Best Management Practices

CAAP – Concentrated Aquatic Animal Production

CITES – Convention on International Trade in Endangered Species of Wild Fauna and Flora

CFR – Code of Federal Regulations

CUP – Conditional Use Permit

CVM – Center for Veterinary Medicine

CWA – Clean Water Act

CZM – Coastal Zone Management

CZMA – Coastal Zone Management Act

DEM – Digital Elevation Model

DFO – Department of Fisheries and Oceans, Canada

DIN – Dissolved Inorganic Nitrogen

DIP – Dissolved Inorganic Phosphorus

DO – Dissolved Oxygen

DOD – U.S. Department of Defense

DPS – Distinct Population Segment

EDNA – environmental designation for noise abatement

EEZ – U.S. Exclusive Economic Zone

eFCR – Total amount of feed delivered in system
EFH – Essential Fish Habitat
EIS – Environmental Impact Statement
EPA – U.S. Environmental Protection Agency
ESA – Endangered Species Act
ESU – Evolutionarily Significant Units
FAD – Fish Aggregating Device
FAO – Food and Agriculture Organization of the United Nations
FCR – Food Conversion Ratio
FDA – U.S. Food and Drug Administration
FFDCA – Federal Food, Drug and Cosmetic Act
FMP – Fishery Management Plan
GIS – Geographic Information System
HAB – Harmful Algal Bloom
HACCP – Hazard Analysis and Critical Control Points
HAPC – Habitat Areas of Particular Concern
HPA – Hydraulic Project Approval
HU – Hydrologic Units
INAD – Investigational New Animal Drug
ISAV – Infectious Salmon Anemia Virus
IUCN – International Union for Conservation of Nature
JARPA – Joint Aquatic Resource Permit Application
MMPA – Marine Mammal Protection Act
MSP – Marine Spatial Plan
MT – Metric Tons
NEPA – National Environmental Policy Act
NMFS – National Marine Fisheries Service
NMSA – National Marine Sanctuaries Act

NOAA – National Oceanic and Atmospheric Administration
NPDES – National Pollutant Discharge Elimination System
NTU – Nephelometric Turbidity Unit
ORMA – Ocean Resource Management Act
PFMC – Pacific Fishery Management Council
PAR – Photosynthetically Active Radiation
PCE – Primary Constituent Element
PPT – Parts per Thousand
PSU – Practical Salinity Unit
RCW – Revised Code of Washington
SDP – Substantial Development Permit
SEPA – State Environmental Policy Act
SMA – Shoreline Management Act
TMDL – Total Maximum Daily Load
U&A – Usual and Accustomed
USACE – U.S. Army Corps of Engineers
USC – United States Code
USCG – U.S. Coast Guard
USEPA – U.S. Environmental Protection Agency
USFWS – U.S. Fish and Wildlife Service
USGS – U.S. Geological Survey
WAC – Washington Administrative Code
WDFW – Washington Department of Fish and Wildlife
WDNR – Washington Department of Natural Resources
WSDA – Washington Department of Agriculture
WWTP – Waste Water Treatment Plant

Chapter 1: Introduction

The 2018 Washington legislature passed, and Governor Inslee signed, EHB 2957 into law, prohibiting the use of non-native finfish for marine net-pen aquaculture. Additionally, the law requires phasing out Atlantic salmon (*Salmo salar*) facilities on state owned aquatic lands over the next four to seven years. In the law, Governor Inslee directed the Washington State Departments of Agriculture, Ecology, Fish and Wildlife, and Natural Resources to work together to update the state guidance and informational resources for planning and permitting commercial marine net-pen aquaculture. The law requires state agencies to collaborate with the NOAA Ocean Service, National Centers for Coastal Ocean Science (NCCOS), and engage tribal and academic partners. The agencies must report their findings to the Washington legislature by November 1, 2019.

Building on an effort by state agencies in 2016 to improve Atlantic salmon net pen management, the state agencies and NCCOS produced this report. It provides background information and a state of the science. It also discusses the importance of siting for new facilities and improving operations at existing facilities. This report includes information relevant to Atlantic salmon and the native species likely to be farmed in commercial net pens. Atlantic salmon are addressed to ensure the existing facilities are operated as safely as possible until they are phased out in 2022.

Governor Inslee and the four state agency partners are working to ensure commercial marine finfish net-pen aquaculture does not put Pacific salmon recovery at risk. Acknowledging that virtually all human uses have the potential to impact to native salmon recovery, this guidance was drafted consistent with EHB 2957.SL, to mitigate negative impacts to water quality, native fish, shellfish, and wildlife.

Freshwater aquaculture, fisheries enhancement pens, and baitfish rearing pens are not addressed in this document. The science and guidance provided is not intended for designing, siting, or operating non-commercial net pens.

1.1 Project Impetus

Several documents were published in the 1980's and 1990's that informed state oversight of the growing Atlantic salmon net-pen industry (Ecology 1986a, 1986b, 1988, Weston 1986, WDFW 1990, WDNR 1999). Content in this document replaces outdated guidelines and updates the environmental background developed by the state agencies (Ecology 1986b, WDFW 1990). Many aspects of net-pen facilities, including daily operations and our understanding of environmental interactions, have changed substantially in the last 30 years. This guidance is needed at this time for the following reasons.

Legislative direction

Governor Inslee signed EHB 2957 into law during the 2018 legislative session requiring state agencies to develop a guidance document for commercial marine net-pen aquaculture and to provide recommendations to the legislature by November 1, 2019.

Fish health and stock management

There are concerns about interactions between commercially farmed fish and Pacific salmon. Disease transfer and loss of genetic robustness are risks associated with finfish culture. Although the risk may be low at well-managed facilities, the Department of Fish and Wildlife (WDFW) has authority to regulate the species used in aquaculture as well as the importation and transfer of live fish, fertilized eggs, and gametes. WDFW also monitors fish health to ensure native fish are protected. This document will inform WDFW's management actions.

Effects on native fauna and ecosystems

Pacific salmon, orcas, and other native fauna that depend on healthy marine ecosystems are struggling under numerous habitat threats. The state, residents, tribal governments, and public and private partners have made significant investments in protecting these species and recovering Puget Sound, yet significant threats persist. Even though net-pen aquaculture is only one of many marine uses, the state is concerned about any potential risk to our native fauna and ecosystems. This document summarizes the current science to help the state better understand and manage risks to Washington's valuable marine resources.

Water quality permits

To protect state waters, the Department of Ecology (Ecology) issues and manages water quality permits for commercial marine finfish net pens. This document will inform future permits and renewals and make the permitting process more transparent.

Shoreline use planning

As coastal cities and counties implement local land use policies and regulations designed to manage shoreline uses, they contend with the issue of use conflicts and marine protection. Ecology and local governments have a mutual interest in updated planning tools based on current science and operations. Ecology and local governments will benefit from the guidance in this document when updating local shoreline programs and administering shoreline permits.

State-owned aquatic lands

All existing commercial marine net pens are located on state-owned aquatic lands. Any future commercial pens will likely be sited on state-owned aquatic lands in locations that minimize impacts to water quality, benthic habitats, and fish. The Department of Natural Resources (WDNR) is the public steward of these lands and must follow management guidelines that

balance public benefits including “fostering water-dependent uses” and “ensuring environmental protection.”¹ This document provides updated information useful for maximizing public benefits and simultaneously protecting valuable public resources.

Market demand

The aquaculture industry is interested in expanding operations in Washington to meet the growing local and global market demands. The state prohibition on commercial non-native finfish pens makes native finfish aquaculture more commercially attractive. Developing this guidance and the spatial screening tool have helped prepare Washington coastal managers for expansion and ensure state and local responses are based on current knowledge and practices.

1.2 Project Background

Project team

The contents of this report represent significant contributions of time and expertise by members of the project team, and state agency consensus. The project team consisted of Washington Departments of Agriculture, Ecology, Fish and Wildlife, and Natural Resources. Project coordination was provided by Ecology’s Shorelands and Environmental Assistance Program and WDFW’s Fish Health Unit. The project team’s role was to advise the project coordinators on the scope, process, timeline, and specific outcomes, and ensure the contents aligned with state oversight responsibilities. Dr. James Morris and his team at NCCOS provided essential planning and technical services at the invitation and direction of the state. In 2016, letters of support written by the Governor’s Policy Office, Washington State Association of Counties, Northwest Straits Commission, Icicle Seafoods Inc., American Gold Seafood, and the Washington Fish Growers Association resulted in Dr. Morris and his team receiving federal funding to research and write this report, develop the spatial screening tool, and assist with outreach and technical review. NCCOS performed a consultant’s role, with their assistance being directed primarily by the project coordinators. This project would not have been possible without this important federal partner and their national and international expertise in sustainable aquaculture, fisheries, and marine spatial planning.

Engagement of local, federal, and tribal governments

The state’s oversight of commercial marine net-pen aquaculture does not exist in a vacuum. Completing the guidance required a high level of coordination and consultation among the state agencies and other coastal managers. Local governments and the public were engaged in the earlier stages of developing this document to ensure that their concerns would be heard and addressed. NOAA Fisheries, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and

¹ Chapter 79.105 RCW: Aquatic Lands. See RCW 79.105.030 for management guidelines. Also see Leasing and Land Transactions: <http://www.dnr.wa.gov/programs-and-services/aquatics/leasing-and-land-transactions>

other federal agencies all have a role in managing commercial net pens and marine resources. Federal agencies were key partners in developing sections of the document and providing technical review. NOAA's Northwest Fisheries Science Center was especially helpful in providing Washington-specific information. Representatives of the Port Gamble S'Klallam Tribe and the Northwest Indian Fisheries Commission (NWIFC) directly advised the project team on the scope and content of this guidance and relayed information to other tribal governments.

Subject matter experts

NCCOS and the rest of the project team consulted national and international scientific and industry experts as they wrote the guidance document and developed the spatial screening tool. Subject matter experts provided objective input and included those with experience and knowledge in Pacific Northwest ecosystems and Pacific salmon.

Temporal scale

The guidance is based on the most recent science and information relevant to Washington's unique environment and regulatory framework. Aquaculture science and marine ecology are rapidly evolving; therefore, it is recommended the guidance be updated as new information emerges. If new science or better management approaches develop, requirements and operations modifications should be updated.

Spatial scale

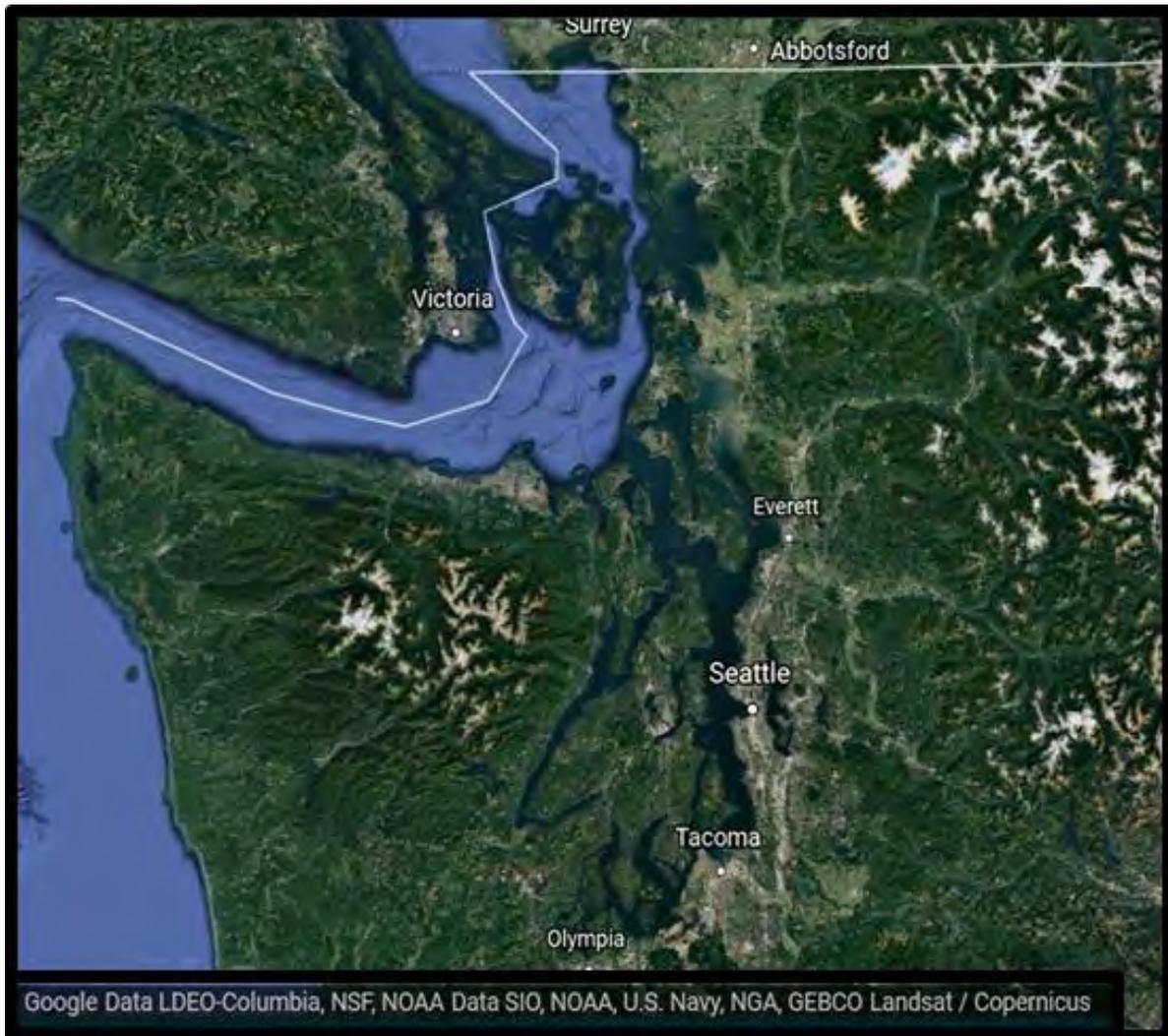
This guidance is broad enough to be applicable to all of Washington's major straits and estuaries. However, the most likely location for commercial marine net-pens is the greater Puget Sound and its complex system of waterways. Outer coastal estuaries open to the Pacific Ocean (e.g. Willapa Bay and Grays Harbor) are generally too shallow and/or have significant use conflicts such as navigation and shellfish production which makes them unsuitable for commercial net-pen aquaculture.²

Scientists and managers define the boundaries of Puget Sound in a variety of ways. In this report, the definition of Puget Sound is derived from the Washington State legislature's expansive definition.³ It includes all salt waters of the state of Washington inside the international boundary line between Washington and British Columbia, and lying east of the junction of the Pacific Ocean and the Strait of Juan de Fuca (Figure 1.2).

² Ecology and NCCOS conducted a preliminary suitability screening of Willapa Bay and Grays Harbor in 2016. The project team determined it was unlikely that commercial pens could operate successfully in these estuaries.

³ RCW 90.71.010 (11). This Puget Sound description is a modification of a state definition of the Puget Sound Basin, leaving out the upland areas and freshwater rivers and streams. See Puget Sound Encyclopedia webpage: <https://www.eopugetsound.org/articles/geographic-boundaries-puget-sound-and-salish-sea>. Accessed 30 November 2018.

Figure 1.2 Map of the study area



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Chapter 2: Aquaculture Industry Overview and Regulation

2.1 The Role of Commercial Aquaculture

Aquaculture is, for some, a controversial industry because of its potential negative impacts on the environment; however, for others it is a clear means to sustainably produce high quality protein for domestic food consumption. Growing seafood in net pens in Washington State and the United States can ensure secure seafood production. Aquaculture creates jobs, reduces our reliance on imports, increases our domestic food security, and improves our blue economy. Responsible aquaculture is increasingly recognized as one of the most environmentally sustainable ways to produce food and protein.

Like agriculture, aquaculture supports jobs in rural areas as well as jobs throughout the supply chain. Marine aquaculture jobs tend to be year-round, living wage jobs, centered in coastal communities. Marine aquaculture operations support working waterfronts and the same infrastructure as capture fisheries, such as docks, boat yards, and processing plants.

However, wherever it is practiced, open net-pen aquaculture is controversial, and critics raise serious environmental concerns. Net-pen aquaculture can negatively affect the surrounding environment. Negative impacts may include altered seafloor communities immediately below and adjacent to the site; bioamplification of parasites and disease organisms that may infect native populations; release of chemicals and antibiotics into the ecosystem; and escapes of farmed fish and associated ecosystem effects. Fish farms need proper engineering, siting, management, maintenance, and regulation in order to reduce and or control these potential negative impacts.

2.2 Overview of Native Species Net-pen Aquaculture

Introduction and brief history

The history of growing salmon in net pens in Puget Sound can be traced back to 1969. NOAA National Marine Fisheries Service (NMFS) was the first to grow Pacific salmon in net pens at their marine research station near Manchester, Washington (near Port Orchard, Kitsap County). The initial objective of the research was to study survival of juvenile stage salmon (smolt stage), the life stage in which the fish are ready to enter seawater. NOAA discovered that, given the correct smolt size and timing of seawater exposure, salmon would survive and continue to grow in seawater pens. Although the initial applied goal of the research was to release the fish from the net pens into the wild, in efforts to enhance local salmon fisheries, NOAA found that coho salmon (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*) could continue to grow in net pens, reaching a marketable size. This discovery led to the development of the first commercial salmon farm in North America, Pacific Ocean Farms.

Pacific Ocean Farms established itself with the financial backing of Union Carbide in 1970, and started building a large floating net pen system, deployed in Rich Passage, near Manchester. Pacific Ocean Farms grew coho salmon, which they harvested as a pan-sized product, equaling a 12-inch, three-quarter pound fish. Within a few years, the commercial farm was producing sixty-five tons of product for test markets. In 1979, Pacific Ocean Farms sold the operation to Campbell Soup Company, which changed the name of the farm to Domsea and continued coho salmon production for many years.

The initial success of Pacific Ocean Farms led to the expansion of commercial Pacific salmon production in other parts of Puget Sound and San Juan Islands, as well as in British Columbia. However, since the 1990s industry has seen two major trends: 1) consolidation of the number of farms, and 2) transition from rearing Pacific salmon to rearing Atlantic salmon (*Salmo salar*). During the last decade in Puget Sound, there were only four major salmon farming sites, all owned by the same company.

Species of current interest: steelhead, coho salmon, Chinook salmon, and black cod⁴

Steelhead (*Oncorhynchus mykiss*), rainbow trout found in seawater, are cultured in marine net pens in several countries and are the second largest salmonid produced by volume after Atlantic salmon. World production of rainbow trout in 2016 was 814,091 metric tons; however, only approximately 200,000 metric tons of annual production occurs in marine net pens. Chile produced 84,000 metric tons of steelhead in 2016. Norway produces about 50 - 60,000 metric tons per year. In the Pacific Northwest, commercial steelhead aquaculture in Canada is less than 1,000 tons annually.⁵ There is no current commercial seawater net-pen steelhead culture in the U.S.

Coho salmon production occurs mostly in Chile, which produced 110,980 metric tons in 2016. Chile's coho salmon production accounts for approximately 80% of global production, with the remaining contributed from Japan and a few other countries.⁶ Coho salmon were purposely released in Chile prior to the development of the net-pen aquaculture industry.

Chinook salmon farming is on a relatively small scale globally, with most of the production by New Zealand (approximately 10,000 metric tons in 2014) and Canada.⁷ Chinook salmon were first introduced to New Zealand in the late 1800's as a sport fish and had established self-sustaining populations, prior to the development of the net-pen aquaculture industry. There is no commercial marine net-pen production of Chinook salmon in the U.S.

⁴ These are the four species that are most likely to be grown commercially in Washington based on research and production that is being undertaken at the time of writing. It is not meant to exclude other native species that may be of interest.

⁵ <http://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm> Accessed 30 November 2018

⁶ Production: <http://www.salmonchile.cl/en/produccion.php>. Accessed 30 November 2018

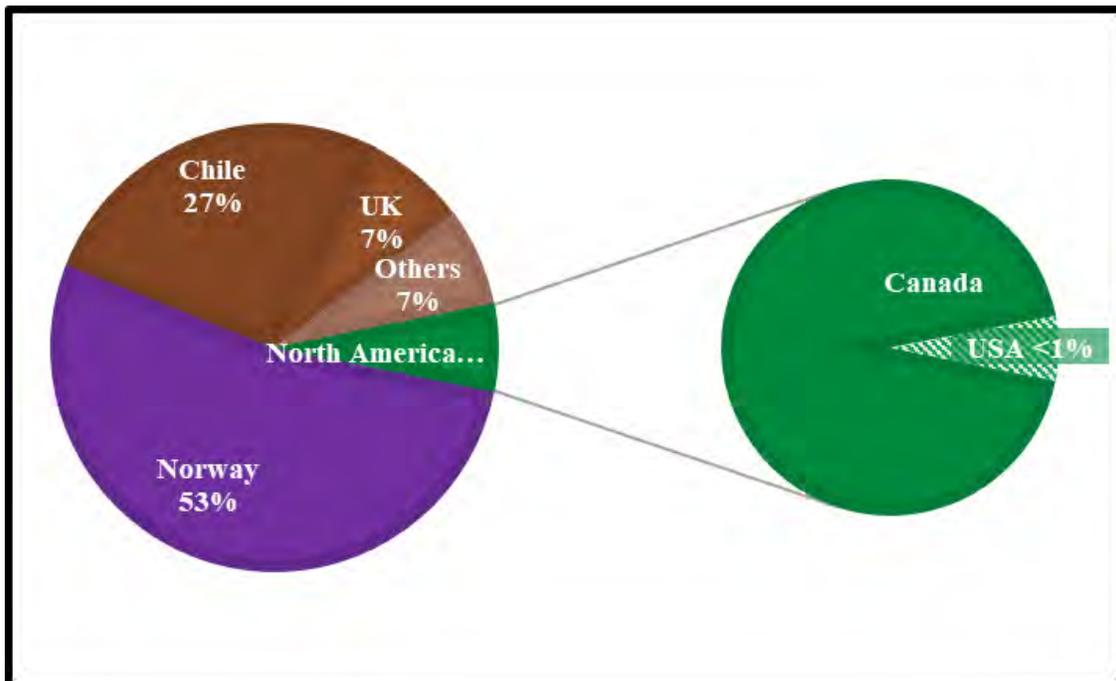
⁷ Department of Fisheries and Oceans, Canada, Aquaculture Production Quantities and Values: <http://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm>. Accessed 30 November 2018

Black cod (*Anoplopoma fimbria*), also known as sablefish or butterfish, is a fatty, cold water fish harvested from Mexico to Alaska. Black cod is an attractive candidate for aquaculture due to its high market price and rapid growth. Although it is a relatively small fishery in terms of landed weight, the black cod fishery ranks third in economic value behind walleye Pollock (*Gadus chalcogrammus*), and Pacific cod (*Gadus macrocephalus*). The culture of black cod began experimentally in the 1990's. Since then British Columbia, Canada has cultured them commercially since 2003. Presently only one company, Golden Eagle Sable Fish of Canada, is culturing sablefish commercially. In Puget Sound, NMFS and the Jamestown S'Klallam Tribe are testing pilot-scale commercial rearing of black cod at the NMFS Manchester Research Station.

2.3 Overview of Net-pen Culture of Atlantic Salmon

Atlantic salmon is the dominant species cultured in marine net pens. In 2016, worldwide harvest of farmed Atlantic salmon reached 2,247,000 metric tons with a value of over \$14 billion U.S. dollars (FAO 2016). Norway is the top producer, followed by Chile, the United Kingdom, and Canada (Figure 2.3). Production of Atlantic salmon takes place on a smaller scale in the United States, Australia, New Zealand, and Ireland (Marine Harvest 2016). Global production of farmed Atlantic salmon is now more than twice the wild capture of all other salmonid species combined, which totaled 937,470 metric tons in 2016 (value: \$3.7 billion U.S. dollars). For the last decade, farmed Atlantic salmon production grew over 7% per year, whereas the wild capture rate of all salmonids has remained fixed.

Figure 2.3 Contributions to global Atlantic salmon production in 2016 by nation or region



Norway

Net pen culture of Atlantic salmon originated in Norway during the 1960s when entrepreneurs succeeded with small pilot efforts to first rear rainbow trout in coastal ponds and embayments. By the early 1970s, the Norwegians had developed techniques to raise Atlantic salmon from egg to adult. Initially, farming expanded with an ad hoc approach to licensing and regulation that embraced a clear objective to ensure the development of rural economies (Phyne 2010, Sønvisen 2003). The first permanent aquaculture act was implemented in 1981 with the aim of locking in economic resilience in rural communities (Sønvisen 2003). Growth of the net pen culture industry came with production challenges (diseases), negative impacts to the environment particularly to wild Atlantic salmon population because of interactions with escaped farmed fish (Liu et al. 2010). Recognizing the need to protect the environment while still fostering industry growth the Norwegian Ministry of Fisheries and Coastal Affairs published Strategy for a competitive Norwegian aquaculture industry (2007), followed by Strategy for an environmentally sustainable Norwegian aquaculture industry (2009). The later document begins to outline what has become the Norwegian Standard for escape prevention through detailed construction and engineering requirements as well as the recognition of important wild salmon waters where aquaculture farms are held to higher environmental standards. Strong government support, ideal culture conditions, and technological innovation have made Norway the global leader in Atlantic salmon aquaculture.

British Columbia

In the early 1970's, Canada Department of Fisheries and Oceans (DFO) started its contemporary aquaculture program, and private salmon farming companies began to form concurrently. Business depended on surplus eggs from federal hatcheries with Chinook becoming the most popular species. Maintaining fish health was the greatest challenge because of diseases, such as vibriosis, and harmful algal blooms. Because of the difficulty in raising a fish to adult size, fish were harvested at portion size (approximately 300 grams) similar to freshwater trout.

An economic development officer from the Sunshine Coast brought salmon farming technology from Norway to British Columbia (B.C.) in the mid-1980s. A Canadian delegation toured the industry in Norway and were impressed by the industry and the markets for Atlantic salmon that it had created. Initially there was intense opposition to the farming of exotic Atlantic salmon in B.C. because of concerns that escapes could potentially colonize and compete with Pacific salmon. However, the fact that Atlantic salmon escapees from Washington net pens were routinely observed in B.C. waters confused the debate: barring Atlantic salmon in B.C. net pens was argued to handicap to B.C farmers without stopping the threat of Atlantic salmon colonization. Ultimately, Atlantic salmon imports were approved. The first batch of Atlantic salmon eggs came from a hatchery in Scotland in 1985. There was an immediate boom from ten sites in 1984 to 113 sites in 1987.

Technology and research continued to advance: vaccines were developed, larger and stronger net pens were designed, nutrition was improved, and Atlantic salmon supplanted Pacific salmon as

the primary product. The industry began to consolidate into a smaller number of larger companies, a process that continued to today's small number of large corporations. Public perception was, and continues to be, one of the industry's greatest challenges. Nearby property owners on the Sunshine Coast object to the encroachment of salmon farms on their views. Fishermen oppose what they consider a threat to their livelihood. Escapes or large mortality events raise concerns that aquaculture could endanger native salmon.

The federal and B.C. provincial governments set up the Salmon Aquaculture Forum in 2003 (Fraser and Beeson 2003). One of the recommendations in the forum's final report was to adopt an ecosystem-based approach to managing salmon farms in the Broughton Archipelago (B.C. Pacific Salmon Forum 2009). In 2008, the Canadian government provided \$70 million for a five-year Sustainable Aquaculture Program to enhance the sustainable development of Canada's aquaculture industry. In 2009, Canada established the Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen Commission). The Commission's final report did not find any single cause for the decline, but made 75 recommendations. Thirteen of the recommendations relate to mitigation of risks related to salmon aquaculture operations on the health of wild Pacific salmon.

DFO has recently provided new siting guidelines to minimize environmental impacts and conducts primary research on farmed salmon. The DFO has the lead role in monitoring environmental interactions and disease occurrence, but monitoring is performed side-by-side with industry increasing transparency. Today in B.C. net-pen aquaculture is producing an average of 122,300 metric tons of salmon (Atlantic and Pacific species) annually.

United States

State and federal programs first began raising Atlantic salmon juveniles for release to supplement declining wild stocks in the Northeast. Success at raising fish to fingerling stage for restocking and the new Atlantic salmon aquaculture industry in Norway prompted the opening of net-pen farms in Maine. In a captive brood stock breeding program initiated by the U.S. Fish and Wildlife Service (USFWS), eggs from endangered Atlantic salmon stocks on the east coast were shipped to the NMFS Manchester Research Station. The program was designed as a genetic back up for the endangered Atlantic salmon that were simultaneously being raised in Maine hatcheries. Biosecurity concerns between the west and east coast resulted in cancelling the transfer of over one million of these captive brood stock eggs. Washington's commercial salmon farmers were allowed to purchase the surplus eggs and began rearing Atlantic salmon in their pens and initiating the commercial net-pen culture of Atlantic salmon in the state (Nash 2011). See Net-pen culture in Washington (pg. 12) for more details.

Maine⁸

Sportfish stock enhancement programs in Maine successfully raised salmon in the early 1970's. The Maine legislature created the Finfish Aquaculture Monitoring Program in 1991 in order to provide uniform and consistent environmental monitoring of finfish operations. Production of Atlantic salmon reached over 12,000 metric tons by 1996. In 1998, non-governmental groups sued the salmon farming industry and regulators for operating without discharge permits under the Clean Water Act. The listing of Maine populations of wild Atlantic salmon as an endangered species in 2000 added additional complexity to the permitting issue. Seeing the need for collaboration, the Maine Aquaculture Association and environmental non-profit organizations developed a memorandum of understanding for developing solutions for industry and the environment. Finally, NPDES permits were issued to Maine farmers under the Endangered Species Act and Clean Water Act in 2003.

Pathogens have been challenging in Maine, as they are elsewhere. The presence of bacterial diseases initiated vaccine development in the late 1980's. The presence of sea lice was confirmed in the mid 1990's and has been an intermittent problem for the Maine net-pen industry since then. ISAV was first identified at some of the Maine net-pen sites in 2000, several years after ISAV was first confirmed in Norway.⁹ The complete depopulation of farmed salmon in Cobscook Bay was ordered by U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) in 2002 to prevent further spread of the virus and thus strict quarantine measures were adopted. Realizing the need for a coordinated approach, Maine fish farmers signed a cooperative bay management agreement that same year to collectively manage local ecosystem impacts and minimize disease risks. Growers voluntarily implemented a 3-year production and fallow cycle in Cobscook Bay beginning in 2005. This is now enforced through Maine's Department of Marine Resources stocking permits. Cooke Aquaculture began purchasing the salmon farms in Maine in 2004 and became the sole owner of all Maine commercial salmon farms by 2006.

Washington

The rapid expansion of net-pen aquaculture of Atlantic salmon in the 1970's and 80's raised concerns about potential harm to the marine environment and conflicts with existing uses. To address these concerns, Washington Department of Fisheries (WDF, now WDFW) with funding from Department of Ecology (Ecology), contracted Dr. Donald P. Weston of the University of Washington's School of Oceanography to review culture around the world and assess environmental impacts. Weston subsequently coordinated with state agencies and science experts to develop the *Recommended Interim Guidelines for the Management of Salmon Net-pen Culture in Puget Sound* (SAIC 1986) to provide a coordinated agency approach to net-pen management

⁸ A detailed timeline of Maine's aquaculture history. Available at: <http://www.maineaquaculture.org/files/2015/03/ARI-Timeline-1lrxai4.pdf>. Accessed 29 November 2018

⁹ An extensive screening for ISAV was conducted by state, federal, and tribal fisheries managers in the Pacific Northwest, which lasted over three years and sampled 4,962 salmonids. ISAV has never been identified in either wild Pacific salmonids or farmed Atlantic salmon in the north Pacific (Alaska to Oregon).

in Puget Sound. The guidelines include a combination of recommendations for siting, operations and annual monitoring. They were intended to assist state and local decision makers in siting pens to avoid significant impacts. The interim guidelines were not intended to replace existing regulations or local shoreline programs and ordinances.

To provide further guidance, the legislature, at the request of the net-pen industry, directed WDF to conduct an environmental assessment of commercial marine net pens in Western Washington marine waters. The environmental assessment was prepared in consultation with Washington Department of Ecology (Ecology), Washington Department of Natural Resources (WDNR), and Washington State Department of Agriculture (WSDA), and was intended to assist state and local decision makers in evaluating proposed net pens. The resulting programmatic *Final Environmental Impact Statement (FEIS): Fish Culture in Floating Net Pens* (Parametrix 1990) provided topical analysis and evaluation of expanded regulations, and recommended changes to agency rules and guidelines. The document includes a discussion on cumulative impacts. Overall, cumulative impacts were not found to be significant if locations of nearby farms were taken into consideration and if siting would occur in areas not known to be nutrient sensitive. It was concluded that additional farms could be sited without significant impacts to Puget Sound if these and other considerations were implemented.

The interim guidelines were not revisited once the FEIS was completed in 1991; however, Ecology did incorporate findings into the 1994 *Shoreline Master Programs Handbook* for local governments and many local governments adopted findings into their local shoreline program standards. The handbook has been updated several times and currently does not include the 30-year-old information.¹⁰ Beginning in 1993, Ecology convened the Net Pen Advisory Workgroup (NPAW) with public participation to determine performance standards for net pens under the guidance of Ecology's Sediment Management Unit. A technical report by Striplin Environmental Associates (1996) reviewed nine years of net-pen benthic sampling data and the ambient environmental conditions in Puget Sound and provided guidance for the workgroup. Ecology's Sediment Management Unit and supervisors decided upon appropriate benthic performance standards at that point, as reviewed by Nash (2001), and those standards were later included in the first National Pollution Discharge Elimination System (NPDES) permits issued in September 1996.

All of the active marine net pens in Washington came under a single company's ownership in 1999. Since that time there have been changes in company structure, ownership and management strategies, farm configuration and operation. Periodically, the net-pen sites have been reconfigured, shifted, reoriented, or moved to comply with regulations or improve operations. In March of 2016, Icicle Seafoods, Inc. applied for permits to relocate the Port Angeles farm to a new location three miles east, necessitated by the installation of a new U.S. Navy pier. This was the first new site application in 20 years. In May 2016, Cooke Aquaculture Pacific purchased

¹⁰ The 1994 handbook is obsolete and no longer available online. Paper copies are available at the Ecology library. The current handbook was published August 2009 and has since been revised. Available at: <https://fortress.wa.gov/ecy/publications/SummaryPages/1106010.html> Accessed 30 November 2018

Icicle Seafoods, Inc. including all of the net pens in Puget Sound and the two inland hatcheries, and assumed responsibility for the new proposed project and permit applications.

In April 2017, Cooke Aquaculture Pacific applied for eight NPDES permits for facilities near Cypress Island, Port Angeles, La Conner, and Bainbridge Island. These facilities were operating under NPDES permits issued in 2007 that were administratively extended in 2012. The applications were for the reissuance of NPDES permits for coverage for five years. The Department of Ecology was initiating the reissuance process when the Cypress Island Site 2 net pen array collapsed on August 19, 2017.

Ecology, WDFW, and WDNR commenced an official investigation of the collapse. The reissuance of the eight NPDES permits were placed on hold. During the fall of 2017, WDNR revoked the aquatic land leases at the Port Angeles and Cypress Island sites that affected four net pen facilities. Some of the reasons for revocation included violation of lease boundaries, unauthorized “improvements” and inadequate maintenance (DNR 2018).¹¹ In January 2018, the report’s findings were published (Clark et al. 2017). The failure of the commercial Atlantic salmon net-pen array at Cypress Island Site 2 caused approximately 250,000 Atlantic salmon to escape into Puget Sound. The collapse was determined to be caused primarily by the drag created on the nets due to excessive biofouling. In addition, structural corrosion and poorly engineered short-term solutions helped set into motion a series of events that led to total structural failure and fish escape on August 19, 2017.

This was one of several Atlantic salmon escape events that have occurred since commercial production of this fish began in Washington thirty years ago. However, the total collapse of a net pen array was unique and enhanced public concern around Atlantic salmon net pen aquaculture. The 2018 Washington State Legislature passed and Governor Inslee signed EHB 2957 into law. The law prohibits the use of non-native finfish for commercial marine net-pen aquaculture, and requires the phase out of Atlantic salmon facilities on state aquatic lands. The WDNR is prohibited from leasing to non-native finfish net pen operations once leases expire and Ecology cannot issue NPDES permits to net pen facilities without a valid WDNR lease.

2.4 Legal Authorities and Requirements

Commercial marine net-pen aquaculture facilities in Washington are regulated by local, state, and federal permits and licenses. An explanation of the legal authorities and most commonly required authorizations for marine net pens of Atlantic salmon are included here. This section is not exhaustive. Additional authorizations may be necessary to site, build, or operate a particular facility.

This section does not provide details on the authorities and requirements related to on-shore activities related to net pens, such as hatcheries or food processing, which are outside the scope of this project. Washington Department of Health, Washington Department of Transportation,

¹¹ Letter to Cooke Aquaculture Pacific. February 2, 2018.
https://www.dnr.wa.gov/sites/default/files/publications/em_atlantic_salmon_cypress_termination.pdf?i8eayb

the U.S. Food and Drug Administration, local governments, and many other entities have roles to play overseeing hatcheries and processing facilities, ensuring worker and food safety, licensing boat operations, and other ancillary activities.

In Washington applicants proposing construction, substantial re-construction/replacement, and removal of net-pen facilities can file the Joint Aquatic Resource Permit Application (JARPA)¹² and submit the same application to multiple agencies (applicable city or county, Ecology, WDFW, WDNR, U.S. Army Corps of Engineers (USACE), and U.S. Coast Guard (USCG)). Each agency may ask for additional information to assist in conducting a thorough and appropriate review of the construction proposed work.

2.4.1 Local authorities and requirements

Cities and counties have a role in authorizing commercial net-pen facilities within their jurisdiction. They review project proposals for compliance with land use regulations codified in their Comprehensive Land Use Plan, Shoreline Master Program, environmental regulations, zoning, and other codes. They typically conduct their proposal review prior to state and federal agencies, and conduct the State Environmental Policy Act (SEPA) review. City and counties have a particular role in considering if the proposed use and its impacts, such as visual or noise impacts, are compatible with existing uses. Some local jurisdictions require a visual impacts assessment as part of the application process.

Shoreline Master Program

Washington's coastal cities and counties are required to have Shoreline Master Programs by the Shoreline Management Act (SMA) of 1971 (Chapter 90.58 RCW). The SMA directs local governments and Ecology to plan for and foster all reasonable and appropriate uses in a manner that enhances the public interest, protects against adverse environmental impacts, and preserves the natural character of shorelines. The SMA was established as a cooperative management program between local governments and Ecology. Within the bounds of Ecology's administrative codes¹³, each local jurisdiction is responsible for developing and administering its own Shoreline Master Program with goals, policies, and regulations adjusted to fit local conditions. Shoreline programs must contain permitting standards consistent with Ecology's permit rule.¹⁴

¹² State of Washington, Governor's Office for Regulatory Innovation and Assistance. ePermitting – home of the JARPA. Available at: http://www.epermitting.wa.gov/site/alias__resourcecenter/9978/default.aspx Accessed 30 November 2018

¹³ Ecology. Chapters 173-18, 20, 22, 26 and 27 WAC: Shoreline Management Act (SMA) Rules. <http://apps.leg.wa.gov/WAC/default.aspx?cite=173>

¹⁴ Chapter 173-27 WAC: Shoreline management permit and enforcement procedures. <http://apps.leg.wa.gov/WAC/default.aspx?cite=173-27>

Substantial Development Permit (SDP)

SDPs are required for substantial shoreline development. Substantial development is any shoreline development where the total cost or fair market value exceeds \$7047, or any development which materially interferes with the normal public use of the water or shorelines of the state.¹⁵ All proposals for new commercial net pens would require a locally-issued SDP because of this cost threshold. Local governments may approve SDPs that are consistent with the SMA and applicable SMP provisions. Local governments may attach project-specific conditions to SDPs. Ecology does not have authority to approve or condition SDPs.

Conditional Use Permit (CUP)

Depending on the standards in each jurisdiction's shoreline program, commercial net-pen facilities may also require a CUP. Local governments may approve CUPs where applicants demonstrate consistency with review criteria found in Ecology rules. The CUP review criteria include, among other things, a demonstration that the project's use of the site and the design will be compatible with other authorized uses in the area, and the proposed use will not cause significant adverse effects to the environment. In granting permits, consideration must also be given to cumulative impacts of additional requests for like actions in the area.¹⁶ CUPs are issued by local governments (approved or denied), then sent to Ecology for further review and approval or disapproval. In authorizing a conditional use, local governments or Ecology may attach special conditions to the permit to prevent undesirable effects of the project.

Applicable state laws and administrative codes

Chapter 90.58 RCW: The Shoreline Management Act of 1971

Chapter 173-27 WAC: Shoreline Management Permit and Enforcement Procedures

2.4.2 State authorities and requirements

Washington Department of Agriculture (WSDA)

WSDA is responsible for fostering the state's aquaculture industry and providing market assistance.¹⁷ WSDA also has a supporting role in the monitoring and control of aquaculture

¹⁵ RCW 90.58.030(3) (e): Definitions and concepts. <http://apps.leg.wa.gov/RCW/default.aspx?cite=90.58.030>. The cost threshold for substantial development permits is adjusted by Washington Office of Financial Management every five years based on inflation. The most recent adjustment was July 1, 2017 and took effect one month after OFM posted it. The next adjustment will occur July 1, 2022.

¹⁶ WAC 173-27-160: Review criteria for conditional use permits. <http://apps.leg.wa.gov/wac/default.aspx?cite=173-27-160>

¹⁷ RCW 15.85.030: Department principle agency for aquaculture marketing support. <http://app.leg.wa.gov/RCW/default.aspx?cite=15.85&full=true#15.85.030>

diseases. The State veterinarian leads WSDA's Animal Health program, which supports WDFW in the monitoring and control of aquaculture diseases. The veterinarian must be notified by WDFW if there is a diagnosis of any regulated finfish pathogens.¹⁸

Applicable state laws and administrative codes

Chapter 69.07 RCW: Washington Food Processing Act

Chapter 15.85 RCW: Aquaculture Marketing

WAC 16-603-010: Aquaculture identification requirements

WAC 220-370-050: Definitions – Aquaculture disease control

Washington Department of Ecology (Ecology)

National Pollutant Discharge Elimination System (NPDES) Permit

EPA authorizes Ecology's Water Quality Program to administer NPDES permits in Washington State on non-Indian lands. EPA permits aquaculture facilities on tribal land. The Water Quality Program mission is to protect and restore Washington's waters to sustain healthy watersheds and communities. Our work ensures that state waters support beneficial uses including recreational and business activities, supplies for clean drinking water, and the protection of fish, shellfish, wildlife, and public health.

An NPDES permit translates the general requirements of the Clean Water Act into specific provisions tailored to each operation discharging pollutants. The permit is a revocable license that allows the permittee to discharge to waters of the state under those provision or conditions. The permit is valid for five years after issuance and must be applied for every cycle.

A net pen facility must adhere to specific operating requirements and best management practices to reduce, eliminate, or prevent water quality impacts. The escapement of Atlantic salmon is considered a pollutant discharge that is to be prevented through conditions laid out in the permit. Feces, food, and disease control chemicals are all considered potential pollutants produced by a net pen facility.

NPDES permits are required for any net-pen operation that qualifies as a Concentrated Aquatic Animal Production (CAAP) facility. CAAP facilities are defined as those facilities that either harvest more than 20,000 lbs. of fish per year or feed more than 5,000 lbs. of fish food during any calendar month.¹⁹

Ecology has updated four Atlantic salmon net pen NPDES permits during the spring of 2019. Updates include the lessons learned from the August 2017 net pen collapse to be more protective

¹⁸ WAC 220-370-050: Definitions – Aquaculture disease control.
<http://app.leg.wa.gov/WAC/default.aspx?cite=220-370-050>

¹⁹ USEPA. NPDES Aquaculture Permitting. <https://www.epa.gov/npdes/npdes-aquaculture-permitting>. Also see 40 CFR Part 122: <https://www.gpo.gov/fdsys/search/searchresults.action?st=40+CFR+122>. Accessed 30 November 2018

of water quality. Permits now require permittees to perform more monitoring and reporting, enhanced emergency response planning and training, more pollution prevention and required maintenance, and structural assessments by licensed professional engineers.

The NPDES permits for commercial net pens of Atlantic salmon in Washington require several plans and reports, and monitoring prescribed in detail within each facility permit. Plans submitted to WDFW that comply with chapter 220-370 WAC²⁰ may meet the NPDES permit requirements if the plan includes conditions addressed in the Pollution Prevention Plan, Fish Escape Prevention Plan, and Fish Escape Reporting and Response Plan sections of the permit.

The NPDES permits for the existing commercial net pens of Atlantic salmon in Washington require:

- Pollution Prevention Plan
- Operations and Maintenance manual
- Net Pen Structural Integrity Assessment Report
- Operational log
- Fish escapement reporting within 24 hours and follow-up response report
- Annual Fish Escape Report
- Sea lice monitoring and reporting of irregularities
- Fish mortality monitoring and reporting of irregularities
- Monthly disease control chemical use report
- Monthly fish biomass and feed report
- Underwater videography and photographic survey
- Annual summary report of disease control chemical use, monthly biomass and feed fed, fish escapement, and noncompliance notifications.
- Once yearly water column dissolved oxygen profile and daily monitoring during critical period (August 15 through September 30)
- Sediment sampling and analysis

If the results of sediment quality monitoring exceed the limits listed in the *Sediment Management Standards*,²¹ an enhanced sediment quality monitoring plan is implemented. Ecology also requires closure monitoring to evaluate benthic recovery if pens are moved or removed.²²

²⁰ Chapter 220-370 WAC Aquaculture. <https://app.leg.wa.gov/WAC/default.aspx?cite=220-370>. Accessed 3 June 2019

²¹ Chapter 173-204 WAC: Sediment Management Standards. <http://apps.leg.wa.gov/WAC/default.aspx?cite=173-204>

²² WAC 173-204-412(3)(e): Marine finfish rearing facilities. <http://app.leg.wa.gov/WAC/default.aspx?cite=173-204-412>

Section 401 Water Quality Certification²³

An installation may require a Section 401 certification. Issuance of a certification means that Ecology has reasonable assurance that the applicant's project will comply with state water quality standards and other aquatic resources protection requirements under Ecology's authority. The certification can cover both the construction and operation of a proposed farm. Conditions of the certification become conditions of the NPDES permit.

Coastal Zone Management (CZM) Consistency Determination²⁴

Activities and development located within Washington's coastal counties that involve federal activities, federal licenses or permits, such as an USACE Section 10 permit, require a written Consistency Determination by the state's CZM Program, which is currently managed by Ecology's Shorelands and Environmental Assistance Program (SEA).

Applicable state laws and administrative codes

Chapter 90.48 RCW: Water Pollution Control

Chapter 173-201A WAC: Water Quality Standards for Surface Waters of the State of Washington

Chapter 173-204 WAC: Sediment Management Standards

Chapter 173-220 WAC: National Pollutant Discharge Elimination System Permit Program

Washington Department of Fish and Wildlife (WDFW)

WDFW's primary responsibility is to preserve, protect, perpetuate, and manage the fish and wildlife species of the state.²⁵ They have a primary role in regulating finfish aquaculture through licensing, permits, and fish health inspection programs.

²³ Ecology. Federal Permits Home. <https://ecology.wa.gov/Regulations-Permits/Permits-certifications/401-Water-quality-certification>

²⁴ Ecology. Coastal Zone Management (CZM), Federal Consistency. <https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Coastal-zone-management/Programs-policies/Federal-consistency>

²⁵ RCW 77.04.012: Mandate of department and commission.
<http://app.leg.wa.gov/RCW/default.aspx?cite=77.04.012>

Aquatic farm registration²⁶

State code requires an aquatic farm²⁷ be registered with WDFW in order to produce private sector cultured aquatic products.²⁸ It also states that registrations must be renewed annually and reporting of aquaculture activities during the previous year constitutes renewal for the following year. Registered aquatic farms are also required to report quarterly on the species cultured, quantity harvested for sale, and unit value.²⁹

Marine finfish aquaculture permit³⁰

In order to raise any species of marine finfish in net pens within Washington's marine waters, aquatic farmers must possess a permit from the WDFW director for rearing or holding a species, stock or race of marine finfish, defined as finfish being raised in marine waters, in net pens, cages, or other rearing vessels. The application must be accompanied by an operations plan, escape prevention plan, and an escape reporting and recapture plan. The permit may stipulate additional conditions consistent with state law, such as marking of fish and the prohibition on transgenic fish.³¹ The permit is valid for five years.

Live fish transport and importation permits³²

Anyone wishing to transport fish into or through Washington must obtain a Fish Transport Permit. The purpose of the Fish Transport Permit is to protect native fish species and ensure that: 1) live fish being brought into Washington are free from reportable fish pathogens; 2) undesirable fish species, if introduced into state waters, cannot cause harm to native species; and 3) Aquatic invasive species do not get shipped with the desired fish species.

Applicable state laws and administrative codes

Chapter 77.115 RCW: Aquaculture Disease Control

Chapter 15.85 RCW: Aquaculture Marketing

Chapter 220-660 WAC: Hydraulic Code Rules

Chapter 220-370 WAC: Aquaculture

²⁶ WAC 220-370-060: Aquatic farm registration required. <http://app.leg.wa.gov/WAC/default.aspx?cite=220-370-060>. See also Governor's Office of Regulatory Innovation and Assistance, Aquatic Farm Registration. <http://apps.oria.wa.gov/permithandbook/permitdetail/26> Accessed 1 August 2017

²⁷ WAC 220-370-040: Aquatic farm – Definition. <http://app.leg.wa.gov/WAC/default.aspx?cite=220-370-040>

²⁸ RCW 15.85.020: Aquaculture Marketing, Definitions. <http://app.leg.wa.gov/RCW/default.aspx?cite=15.85.020>

²⁹ WAC 220-370-160: Duties of Aquatic Farmers. <http://apps.leg.wa.gov/WAC/default.aspx?cite=220-370-160>; WAC 220-370-170: Description of aquatic farm production report. <http://apps.leg.wa.gov/WAC/default.aspx?cite=220-370-170>

³⁰ WAC 220-370-100: Marine finfish aquaculture—Approval permit for marine finfish aquaculture. <http://apps.leg.wa.gov/wac/default.aspx?cite=220-370-100>

³¹ WAC 220-76-100: Marine finfish aquaculture – Approval permit for marine finfish aquaculture. <http://apps.leg.wa.gov/WAC/default.aspx?cite=220-370-100>

³² WDFW. Fish Transport Permits. http://wdfw.wa.gov/licensing/fish_transport/transport_app.html Accessed 30 November 2018

Washington Department of Natural Resources (WDNR)

Aquatic Use Authorization (Aquatic Lands Lease)

WDNR manages state-owned aquatic lands. WDNR manages these lands for a balance of public benefits for all citizens, including encouraging direct public use and access, fostering water-dependent uses, ensuring environmental protection, and using renewable resources. Generating revenue in a manner consistent with these four goals is a public benefit. WDNR must charge rent for the private use of public land.

Aquatic uses proposed on state-owned aquatic lands, such as commercial net pens, require use authorizations (leases) from WDNR. These leases specify location, structural development, operational practices, lease terms, environmental monitoring, rent, and other requirements. The Department may not allow nonnative marine finfish aquaculture as an authorized use of any lease.³³ Leases for net-pen uses are typically for 12 years. WDNR leases require insurance and financial security (e.g., bonds).³⁴ DNR leases also include provisions intended to ensure environmental protection and that the lessee maintains the net-pens in good order and repair.

Lessees must obtain all other local, state, and federal permits before WDNR will grant the lease. WDNR reviews the proposal for consistency with state laws and rules and potential environmental impacts to aquatic lands and the natural resources associated with these lands, and risks to public health and safety. WDNR may develop lease conditions for construction and operations to minimize impacts. WDNR coordinates with other agencies during the application review process.

Applicable state laws and administrative codes

Chapter 79.105 RCW: Aquatic Lands – General Aquatic Use Permit Application and Aquatic Lands Lease

Chapter 79.135 RCW: Aquatic Lands – Oysters, Geoducks, Shellfish, Other Aquaculture Uses, and Marine Aquatic Plants

Chapter 332-30 WAC: Aquatic Land Management

Additional state authorities – Ocean Resource Management Act (ORMA)³⁵

The goal of the ORMA is to establish policies and guidelines for management of Washington's coastal waters, seabed, and shorelines along coastal counties and includes Grays Harbor and Willapa Bay. It gives priority to activities that will not adversely impact renewable resources,

³³ HB 2957 - Reducing escape of nonnative finfish from marine finfish aquaculture facilities. <http://lawfilesexternal.wa.gov/biennium/2017-18/Pdf/Bills/Session%20Laws/House/2957.sl.pdf>. Accessed 7 June 2019

³⁴ WAC 332-30-122(5): Insurance bonds, and other security. <http://apps.leg.wa.gov/WAC/default.aspx?cite=332-30-122>

³⁵ Chapter 43.143 RCW: Ocean Resources Management Act. <http://apps.leg.wa.gov/RCW/default.aspx?cite=43.143&full=true>

and prohibits leasing of Washington’s coast for oil or gas exploration, development, or production. Washington participates in federal ocean policies and marine resource decisions to the fullest extent possible to ensure consistency with the state’s policy (Ecology 2011).

Applicable state laws and administrative codes

RCW 43.143: Ocean Resources Management Act

WAC 173-26-360: Ocean management

Additional state authorities – State Environmental Policy Act (SEPA)³⁶

SEPA requires an analysis of environmental impacts and identification of mitigation options prior to local and state approval of a proposed farm. An environmental impact statement may be required if there are probable significant environmental impacts.³⁷ Cities and counties where a net-pen facility is proposed typically lead the SEPA process on behalf of all agencies with jurisdiction over the proposal.

Applicable state laws and administrative codes

Chapter 43.21C RCW: State Environmental Policy

Chapter 197-11WAC: SEPA Rules

2.4.3 Federal authorities and requirements

National Oceanic and Atmospheric Administration (NOAA)

National Marine Fisheries Service (NMFS)

NMFS does not directly administer permits for aquaculture installations in Washington waters. However, pursuant to the Endangered Species Act (ESA), the Marine Mammal Protection Act and the Magnuson-Stevens Fishery Conservation Act, NMFS provides consultation to federal agencies on any federal action (such as USACE or EPA permit issuance). The consultations may result in recommendations to avoid, minimize, or mitigate for adverse impacts to ESA-listed species, critical habitat, and/or essential fish habitat. There may be situations or activities that require special permits from NMFS such as Incidental Harassment Authorizations or Letters of Authorization for aquaculture activities that interact with marine mammals.³⁸

³⁶ Ecology. State Environmental Policy Act (SEPA). <https://ecology.wa.gov/regulations-permits/SEPA-environmental-review> Accessed 29 November 2018

³⁷ Ecology. SEPA Online Handbook. <https://ecology.wa.gov/Regulations-Permits/SEPA/Environmental-review/SEPA-guidance> Accessed 29 November 2018

³⁸ NOAA. Federal Aquaculture Regulatory Fact Sheet Series. Accessed 30 November 2018
http://www.nmfs.noaa.gov/aquaculture/docs/policy/agency_fact_sheets/noaa_aq_regulatory_fact_sheet_updated.pdf
Accessed 30 November 2018

Office for Coastal Management (OCM)

The Coastal Zone Management Act (CZMA) is administered by NOAA's Office for Coastal Management and implemented through state coastal zone management programs. In Washington, the program is managed by Ecology's Shorelands and Environmental Assistance Program (SEA). The Act requires an applicant for a federal license or permit for an activity affecting the coastal zone to provide a certification that the proposed activity complies with the enforceable policies of approved state coastal zone management programs.

Office of National Marine Sanctuaries (ONMS)³⁹

The National Marine Sanctuaries Act (NMSA) authorizes NOAA's Office of National Marine Sanctuaries (ONMS) to identify, designate, and manage ocean and Great Lake areas of special national significance as National Marine Sanctuaries. Aquaculture may or may not be allowed, with a permit, in a National Marine Sanctuary.

U.S. Army Corps of Engineers (USACE)

The USACE's Regulatory Program involves the regulating of discharges of dredged or fill material into waters of the United States, and structures or work in navigable waters of the United States, under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899. A proposed project's impacts to these areas will determine what permit type is required.⁴⁰ The USACE is required to consult with other federal agencies prior to issuing a permit. The agencies must review the project and, if needed, recommend mitigation measures to protect the environment or wildlife.

Tribal governments also have the opportunity to comment on federal permits. Tribes may comment on proposals regarding habitat and treaty-reserved Usual and Accustomed (U&A) areas and provide information on potential affects to historic properties. The USACE must address comments prior to issuing a permit (Ecology 2015). Absent tribal consent, the USACE is not authorized to permit a project that would qualify or limit the tribes' ability to access one of their usual and accustomed fishing sites or grounds for a purpose other than conservation of salmon.⁴¹ This applies to commercial marine salmon net pens.⁴²

³⁹ NOAA. Olympic Coast National Marine Sanctuary, Management 101.

<http://olympiccoast.noaa.gov/management/management101.html#permits> Accessed 30 November 2018

⁴⁰ USACE. Obtain a Permit. <http://www.usace.army.mil/Missions/Civil-Works/Regulatory-Program-and-Permits/Obtain-a-Permit/> Accessed 30 November 2018

⁴¹ See e.g., *Muckleshoot v. Hall*, 698 F. Supp. 1508, 1514 (W.D. Wash. 1988).

⁴² See *Northwest Sea Farms v. Corps of Engineers*, 931 F. Supp. 1515 (W.D. Wash. 1996).

Section 10 Permit

Section 10 of the Rivers and Harbors Appropriation Act of 1899 requires a permit from the USACE for work taking place in navigable waters of the United States.⁴³ Installation of farm infrastructure (anchors, buoys, and pens) would require a Section 10 permit or Letter of Permission. Issuance of a Section 10 permit also includes consideration of impacts to treaty-reserved rights.⁴⁴

Letters of permission may be used where, in the opinion of the district engineer, the proposed work would be minor, would not have significant individual or cumulative impacts on environmental values, and should encounter no appreciable opposition. In such situations, the proposal is coordinated with federal and state resource agencies, and in most cases, adjacent property owners who might be affected by the proposal. However, the public at large is not notified. The public interest review process is central to the decision-making process for letters of permission.⁴⁵

Section 404 Permit⁴⁶

If activities in waters of the United States result in the discharge of dredge or fill, a Section 404 permit is required.

U.S. Coast Guard (USCG)

The USCG administers the Private Aids to Navigation (PATON) permit for marking a structure/object/hazard and ensuring the safety of the boating public. Permission to install Private aids to Navigation can be obtained by submitting an application. The USACE, WDNR, and local jurisdictions are involved with PATON permit issuance.⁴⁷

U.S. Environmental Protection Agency (EPA)

Section 402 of the Clean Water Act addresses water pollution by regulating point sources that discharge pollutants to waters of the United States through the National Pollutant Discharge

⁴³ U.S. Government Printing Office. 33 U.S.C. 403. Section 10 of the Rivers and Harbors Appropriation Act of 1899. <https://www.gpo.gov/fdsys/pkg/CFR-2011-title33-vol3/pdf/CFR-2011-title33-vol3-part322.pdf> November 30, 2018 See e.g., *Northwest Sea Farms v. Corps of Engineers*, 931 F. Supp. 1515 (W.D. Wash. 1996).

⁴⁴ See e.g., *Northwest Sea Farms v. Corps of Engineers*, 931 F. Supp. 1515 (W.D. Wash. 1996).

⁴⁵ USACE. U.S. Army Corps of Engineers Permitting Process Information. <http://www.lrl.usace.army.mil/Portals/64/docs/regulatory/Permitting/PermittingProcessInformation.pdf> Accessed 30 November 2018

⁴⁶ USACE. Section 404 of the Clean Water Act. <https://www.epa.gov/cwa-404/clean-water-act-section-404> Accessed 30 November 2018

⁴⁷ USCG. PATON (Private Aids to Navigation). https://www.pacificarea.uscg.mil/Portals/8/District_13/dpw/docs/patonguide.pdf?ver=2018-10-15-154537-490 Accessed 30 November 2018

Elimination System (NPDES). NPDES permits are required for discharges associated with Concentrated Aquatic Animal Production (CAAP) facilities.⁴⁸ As discussed in “National Pollutant Discharge Elimination System” on p. 17, Ecology is authorized by EPA to administer the NPDES program for Washington. EPA is the Section 402 permit authority in Indian Country and in Washington, and retains Section 402 permit authority for federal facilities.

U.S. Fish and Wildlife Service (USFWS)

USFWS does not directly administer permits for net pens. However, pursuant to the Endangered Species Act, Migratory Bird Treaty Act, and the Fish and Wildlife Coordination Act, USFWS reviews federal permit applications (such as Section 10). The reviews may lead to recommendations for mitigation measures. The WDFW Live Fish Transport Permit is an extension of the USFWS Injurious Wildlife program.⁴⁹

Aquatic Animal Drug Approval Partnership (AADAP)

The USFWS National INAD Program is administered by AADAP (Bozeman, MT). This program provides the means through which federal, state, tribal, and private agencies or organizations are allowed to use certain critical drugs necessary to maintain the health and fitness of aquatic species under Investigational New Animal Drug (INAD) exemptions. The FDA grants the INAD exemptions.⁵⁰ NPDES permits in Washington do allow for the use of INAD’s under certain circumstances with veterinary oversight. A farm can only obtain the drug once it has registered with AADAP which requires definitive disease diagnosis and detailed reporting of drug use and results.

U.S. Food and Drug Administration (FDA)

Center for Veterinary Medicine (CVM)

The FDA’s Center for Veterinary Medicine approves drugs for use in aquaculture and may allow exemptions for Investigational New Animal Drugs (INAD). INAD exemption is required if a

⁴⁸ USEPA. NPDES Aquaculture Permitting. <https://www.epa.gov/npdes/npdes-aquaculture-permitting> Accessed 30 November 2018

⁴⁹ USFWS. Fisheries and Aquatic Resource Conservation. 2018. <https://www.fws.gov/injuriouswildlife/> Also see

⁵⁰ CFR §16.13: Importation of Live or Dead Fish, Mollusks, and Crustaceans, or Their Eggs.

<https://www.gpo.gov/fdsys/granule/CFR-2001-title50-vol1/CFR-2001-title50-vol1-sec16-13> Accessed 30 November 2018.

⁵⁰ USFWS. Aquatic Animal Drug Approval Partnership. Standards for the U.S. Fish and Wildlife Service’s National INAD Program. <https://www.fws.gov/fisheries/aadap/PDF/NIP-Standards-April-2011.pdf> Accessed 30 November 2018

drug is going to be used on a fish species or pathogen that is not already on the drug label. CVM also regulates animal feed ingredients and feed production.⁵¹

Center for Food Safety and Applied Nutrition⁵²

The FDA operates a mandatory safety program for all domestic and imported fish and fishery products under the provisions of the Federal Food, Drug, and Cosmetic Act (FFDCA), and pertinent regulations. A Hazard Analysis and Critical Control Points (HACCP) program addresses food safety through the analysis of hazards that may arise during the course of a product's production, handling, processing, distribution, and consumption.⁵³ An aquaculture operation may not require a formal HACCP plan if no processing takes place. However, a processor will require information from the grower to include in the processor's HACCP plan. Growers should be familiar with HACCP and the information pertaining to aquaculture drugs, environmental chemical contaminants, and pesticides, which the processor will be required to evaluate as a Critical Control Point in his HACCP plan (Miget 2004).

2.4.4 Regulatory and legislative authorities

Washington State

Washington Shoreline Management Act [WA Ecology]

The Shoreline Management Act of 1971 (Chapter 90.58 RCW) requires all counties and most towns and cities with shorelines to develop and implement Shoreline Master Programs to plan for and foster all reasonable and appropriate uses in a manner that enhances the public interest, protects against adverse environmental impacts, and preserves the natural character of shorelines. Master programs must establish a comprehensive program of use regulations for shorelines and incorporate provisions for specific uses to assure consistency with the policy of the Act and where relevant within the jurisdiction (Shoreline Uses WAC 173-26-241(3)(b)).

Washington State Environmental Policy Act [WDFW]

The State Environmental Policy Act (SEPA) enacted in 1971 requires all state and local governments within the state to use a systematic, interdisciplinary approach through the integration of natural and social sciences and environmental design in planning and decision making on environmental impacts. It was written to ensure environmental amenities and values will be given appropriate attention in decision making along with economic and technical considerations. The policies and goals in SEPA supplement those in existing authorizations of all

⁵¹ FDA. About the Center for Veterinary Medicine (CVM).

<https://www.fda.gov/AboutFDA/CentersOffices/OfficeofFoods/CVM/default.htm> Accessed 30 November 2018.

⁵² FDA. <https://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/default.htm> Accessed 30 November 2018

⁵³ 21 CFR §123.6: Fish and Fishery Products. https://www.ecfr.gov/cgi-bin/text-idx?SID=5e3850f07d9667e3518c8b7f0c1d1793&mc=true&tpl=/ecfrbrowse/Title21/21cfr123_main_02.tpl Accessed 30 November 2018

branches of government of the state of Washington, including state agencies, counties, cities, districts, and public corporations. Any governmental action may be conditioned or denied pursuant to SEPA. SEPA gives agencies tools to consider and mitigate environmental impacts of proposals. Provisions are also included to involve the public, tribal governments, and interested agencies in most review processes prior to a final decision. WDFW determines if a proposed net-pen farm is near habitat of special significance and if necessary, recommend measures to ensure no significant impact would occur to marine mammals or birds.

Federal regulations

National Environmental Policy Act [EPA, NOAA NMFS, USACE]

The National Environmental Policy Act of 1970 (42 U.S.C. § 4321 et seq.) “encourages productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.”

Under NEPA, all federal agencies shall -- (A) use a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making which may have an impact on the environment; (B) identify and develop methods and procedures, in consultation with the Council on Environmental Quality established by title II of the Act, which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision-making along with economic and technical considerations; (C) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on

- a) the environmental impact of the proposed action,
- b) any adverse environmental effects which cannot be avoided should the proposal be implemented,
- c) alternatives to the proposed action,
- d) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
- e) irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Clean Water Act [EPA]

The Federal Water Pollution Control Act of 1948 was the first major U.S. law to address water pollution. The law was amended in 1972 and became commonly known as the Clean Water Act (CWA) (33 U.S.C. § 1251 et seq.). The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, EPA has implemented pollution control programs including setting wastewater standards for industry. EPA has also developed national water

quality criteria recommendations for pollutants in surface waters. The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges (Section 402, 33 U.S.C. § 1342). Washington Department of Ecology has delegated authority to review and issue NPDES permits. Section 404 of the CWA (33 U.S.C. § 1344) establishes a program to regulate the discharge of dredged and fill material into waters of the United States, including wetlands. Under Section 404, 404(q) creates a dispute resolution process if the EPA (or USFWS or NMFS by the Fish and Wildlife Coordination Act) determines that issuing a permit will result in unacceptable adverse effects to Aquatic Resources of National Importance (ARNI). Factors used in identifying ARNI are the economic importance of the aquatic resource, rarity or uniqueness, or the importance of the aquatic resource to the protection, maintenance, or enhancement quality of the Nation's waters. Section 10 of the CWA, the Rivers and Harbors Act of 1899 (RHA) (33 U.S.C. §§ 401 et seq.), is the initial authority for the U.S. Army Corps of Engineers (USACE) regulatory permit program to protect navigable waters in the development of harbors and other construction and excavation.

Endangered Species Act [USFWS, NOAA NMFS]

Section 7 of the Endangered Species Act (ESA) (19 U.S.C. § 1536(c)), requires federal agencies ensure actions authorized, funded, or carried out by the agency do not jeopardize the continued existence of a federally-listed endangered or threatened species, or result in the destruction or adverse modification of the designated critical habitat of a federally-listed species. The action agency is required to consult with the US Fish and Wildlife Service (USFWS) and/or the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS) to determine whether federally-listed threatened or endangered species or critical habitats are found in the area of the proposed project and whether or not the proposed activities will (adversely) impact those species or habitats. The listing of a species as endangered under the ESA makes it illegal to take that species, and similar prohibitions usually extend to threatened species, unless exempted under ESA Section 7(a)(2) or 7(d) or Section 10. Under the ESA, take means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in such conduct.

Critical habitat is defined in section 3 of the ESA (16 U.S.C. § 1532(3)) as: (1) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the ESA, in which are found those physical or biological features (a) essential to the conservation of the species and (b) which may require management considerations or protection; and (2) specific areas outside the geographical area occupied by the species at the time it is listed upon a determination that such areas are essential for the conservation of the species. The ESA defines "conservation" as the use of all methods and procedures needed to bring the species to the point at which listing under the ESA is no longer necessary. Section 4(a)(3)(a) of the ESA (16 U.S.C. § 1533(a)(3)(A)) requires that, to the maximum extent prudent and determinable, critical habitat be designated concurrently with the listing of a species. Designations of critical habitat must be based on the best scientific data available and the agency must consider the economic, national security, and other relevant impacts of specifying any particular area as critical habitat. Once

critical habitat is designated, Section 7 of the ESA requires federal agencies to ensure they do not fund, authorize or carry out any actions likely to destroy or adversely modify that habitat. This requirement is in addition to the Section 7 requirement that federal agencies ensure their actions do not jeopardize the continued existence of listed species.

Joint NMFS/USFWS regulations for listing endangered and threatened species and designating Critical Habitat at Section 50 CFR 424.12(b) state the agencies “shall consider those physical and biological features essential to the conservation of a given species and may require special management considerations or protection (hereafter also referred to as ‘Essential Features’ or ‘Primary Constituent Elements/PCEs’).” Pursuant to the regulations, such requirements include, but are not limited to, the following: (1) space for individual and population growth, and for normal behavior; (2) food, water, air, light, minerals, or other nutritional or physiological requirements; (3) cover or shelter; (4) sites for breeding, reproduction, rearing of offspring, germination, or seed dispersal; and generally; (5) habitats that are protected from disturbance or are representative of the historic geographical and ecological distributions of a species. These regulations go on to emphasize that the agency shall focus on essential features within the specific areas considered for designation. These features “may include, but are not limited to, the following: spawning sites, feeding sites, seasonal wetland or dryland, water quality or quantity, geological formation, vegetation type, tide, and specific soil types.”

Under ESA Section 7, a federal agency undertaking an action (action agency) must determine if the action may affect ESA-listed species and/or critical habitat in the action area. If the action agency determines the action may affect these species or critical habitat, the agency must consult under the ESA with NMFS or USFWS on the action. A federal agency must “insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of [critical] habitat (16 U.S.C. §§ 1536(a)(2)).” For actions that may affect, but are not likely to adversely affect ESA-listed species or critical habitat, an informal consultation is completed, and a letter of concurrence is issued. For actions that may affect and are likely to adversely affect listed species or critical habitat, a formal consultation is undertaken to assess the potential impacts of the action to protected species including ESA-listed marine mammals, sea turtles, fish, and other endangered or threatened marine life. A formal consultation results in a Biological Opinion. When a proposed activity is likely to adversely affect, but not jeopardize, a listed species or not likely to result in the destruction or adverse modification of critical habitat, the Biological Opinion includes nondiscretionary Reasonable and Prudent Measures and Terms and Conditions to minimize the impacts to listed species. These are mandatory actions that must be undertaken by the action agency for any anticipated incidental take to be exempt from the take prohibitions. For aquaculture projects, the federal action is generally the issuance of a permit from the USACE, which is the action agency.

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act of 1934 (16 U.S.C. §§ 661-666c) requires that federal agencies consult with the U.S. Fish and Wildlife Service (USFWS), the National Marine

Fisheries Service (NMFS) and State wildlife agencies for activities that affect, control or modify waters of any stream or bodies of water, in order to minimize the adverse impacts of such actions on fish and wildlife resources and habitat. This consultation is generally incorporated into the process of complying with Section 404 of the Clean Water Act (CWA), National Environmental Protection Act (NEPA) or other federal permit, license, or review requirements.

Marine Mammal Protection Act [NOAA NMFS]

All marine mammal species found in U.S. waters are protected under the Marine Mammal Protection Act of 1972 (MMPA) (16 U.S.C. § 1361), as well as marine mammals listed as endangered or threatened under the ESA. The MMPA prohibits, with certain exceptions, the "take" of marine mammals in U.S. waters and by U.S. citizens on the high seas, and the importation of marine mammals and marine mammal products into the United States. The Act defines "take" as the act of hunting, killing, capture, and harassment of any marine mammal or the attempt as such. Harassment is defined as any act of pursuit, torment, or annoyance with has the potential to injure or disturb a marine mammal in the wild by causing a disruption of behavioral patterns including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering. Enforcement of these prohibitions and issuance of regulations to implement the legislative goals are provided in the MMPA. NMFS has jurisdiction over marine mammal protection with support from Washington Department of Fish and Wildlife (WDFW).

Magnuson-Stevens Fishery Conservation and Management Act [NOAA/NMFS]

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) (16 U.S.C. § 1801 et seq.) was established in 1976 to promote the conservation of marine fishery resources within the US Exclusive Economic Zone (EEZ). Eight regional Fishery Management Councils were established to develop Fishery Management Plans for resources in their jurisdictional waters. Amendments to the Act in 1986, 1996 added protection for Essential Fish Habitat (EFH), recognizing many fisheries depended on estuarine or near shore habitats for part of their life histories. EFH is defined in the Act as "those waters (e.g. aquatic areas and their associated physical, chemical, and biological properties used by fish) and substrates (e.g. sediment, hard bottom, underlying structures, and associated biological communities) necessary for spawning, breeding, feeding, or growth to maturity". The Act mandates NMFS coordinate with other Federal agencies to avoid, minimize, or offset adverse impacts to fish stocks and EFH that would result from the proposed activities within the EEZ.

Coastal Zone Management Act [NOAA NOS]

The Coastal Zone Management Act (CZMA) of 1972 (16 U.S.C. §§ 1451–1464, Chapter 33), administered by NOAA, provides for the management of the nation's coastal resources, including the Great Lakes. The goal is to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone." The CZMA outlines three national programs: the National Coastal Zone Management Program, the National Estuarine Research Reserve System, and the Coastal and Estuarine Land Conservation Program (CELCP). The National Coastal Zone Management Program aims to balance competing land and water issues

through state and territorial coastal management programs, the reserves serve as field laboratories that provide a greater understanding of estuaries and how humans impact them, and CELCP provides matching funds to state and local governments to purchase threatened coastal and estuarine lands or obtain conservation easements.

National Marine Sanctuaries Act [NOAA NOS]

The National Marine Sanctuaries Act (NMSA) of 1972 (16 U.S.C. §§ 1431-1445) authorizes the Secretary of Commerce to designate and protect areas of the marine environment with special national significance due to their conservation, recreational, ecological, historical, scientific, cultural, archeological, educational or esthetic qualities as National Marine Sanctuaries. The primary objective of the NMSA is to protect marine resources, such as coral reefs, sunken historical vessels or unique habitats. NOAA's Office of National Marine Sanctuaries has delegated authority to manage National Marine Sanctuaries.

Migratory Bird Treaty Act [USFWS]

The Migratory Bird Treaty Act of 1918 (16 U.S.C. §§ 703–712) makes it illegal for anyone to take, possess, import, export, transport, sell, purchase, barter, or offer for sale, purchase, or barter, any migratory bird, or the parts, nests, or eggs of such a bird except under the terms of a valid permit issued pursuant to federal regulations. The USFWS administers a permit system to allow selected killing and trapping of nuisance birds to protect aquaculture facilities.

The Bald and Golden Eagle Protection Act [USFWS]

The Bald and Golden Eagle Protection Act (16 U.S.C. §§ 668-668c) enacted in 1940 prohibits anyone, without a permit issued by the Secretary of the Interior, from taking bald eagles, including their parts, nests, or eggs. The Act provides criminal penalties for persons who take, possess, sell, purchase, barter, offer to sell, purchase or barter, transport, export or import, at any time or any manner, any bald eagle ... [or any golden eagle], alive or dead, or any part, nest, or egg thereof. The Act defines take as pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest, or disturb.

International treaties

Convention on International Trade in Endangered Species of Wild Fauna and Flora

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is a voluntary international agreement between international governments. The aim is to ensure international trade of wild animals and plants does not threaten their survival. CITES was drafted as a result of a resolution adopted in 1963 at a meeting of members of IUCN (The World Conservation Union). Although CITES is legally binding on the members it does not take the place of national laws. It provides a framework for which each nation has to adopt its own domestic legislation to ensure that CITES is implemented at the national level. CITES Appendix I includes species threatened with extinction. Trade in specimens of these species is permitted only in exceptional circumstances. CITES Appendix II includes species not necessarily

threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival.

Member of the World Organization for Animal Health (OIE)

The OIE is the intergovernmental organization responsible for improving animal health worldwide. The OIE's primary missions are to ensure transparency about animal diseases, disseminate information, encourage solidarity between nations in combating animal diseases, safeguard world trade by publishing health and trade standards for animals or animal products, improve veterinary resources and to better guarantee the safety of food products that come from animal sources.

2.4.5 Tribal authorities and requirements

Tribal governments of Western Washington are sovereign nations recognized by the United States. They have authority to ensure cultural and natural resources are protected and that treaty rights are upheld. Each tribal reservation constitutes a neighboring jurisdiction to Washington, subject to tribal and federal laws including, in many cases, USEPA approved Clean Water Act water quality standards.

The Treaty Tribes of Western Washington possess treaty-reserved rights to take fish and shellfish at all their usual and accustomed places for commercial, ceremonial, and subsistence purposes. These tribes are co-managers of fisheries resources, including salmon, groundfish, and shellfish.⁵⁴ This authority is exercised during the state and federal permitting process in a variety of ways, including consultations. One such example is the stipulation in the NPDES permit that reporting of fish escapement must include local tribes and the maintenance of current tribal contacts and resources to assist with capture of escaped fish. For further information see the following examples of legal decisions:

United States v. Winans, 198 U.S. 371 (1905)

Case law, U.S. Supreme Court decision establishing treaty interpretation principles and the right of access guaranteed under the treaties negotiated by Territorial Governor Stevens on behalf of the United States. From a case originating on the Columbia River with the Yakama Nation, as party to one of the Stevens Treaties, the Court determined that the Tribe's treaty rights are not subordinate to the state and upheld the Tribe's right of access to private property under the Steven's Treaty.

⁵⁴ Northwest Indian Fisheries Commission, Fisheries Management. <http://nwifc.org/about-us/fisheries-management/> Accessed 30 November 2018

United States v. Washington, 384 F. Supp. 312 (W.D. Wash. 1974)

Case law, the federal district court decision, also known as the Boldt Decision, interpreting tribes' right to harvest share fish "in common with the citizens of the Territory" under the Stevens' Treaties of western Washington.

Washington v. Washington State Commercial Passenger Fishing Vessel Association, 443 U.S. 658 (1979)

Case law, U.S. Supreme Court decision upholding the Boldt Decision and establishing that the Stevens Treaties reserved the tribes' "right of taking fish at all usual and accustomed grounds and stations" and entitle tribes to "take a fair share of the available fish."

United States v. Washington, 759 F.2d 1353, 1358–60 (9th Cir. 1985) (en banc)

Case law, Ninth Circuit Court of Appeals en banc decision upholding the tribes' claim that hatchery fish are fish subject to treaty allocation regardless of whether they originate from state, Indian, or federal hatcheries or from cooperative ventures.

Northwest Sea Farms v. Corps of Engineers, 931 F. Supp. 1515 (W.D. Wash. 1996)

Case law, federal district court decision upholding U.S. Army Corps of Engineers denial of a Section 10 permit for proposed salmon fish farm net pens on the basis of Corps' determination that the project would interfere with the right of Lummi Nation fishers to access one of their usual and accustomed fishing areas.

2.5 The Permitting Process

Project applicants in Washington State have the option to submit the same application to several regulatory authorities (city or county, Ecology, WDFW, WDNR, USACE, USCG, and EPA) at once using the JARPA (Joint Aquatic Resource Permit Application).⁵⁵ However, completing a JARPA is a starting point. It is recommended that project applicants consult individually with each regulating and licensing authority noted above to understand how to apply for all the necessary permits and licenses. The JARPA does not include applying for all the permits or licenses that will be necessary to construct and operate a new net pen aquaculture facility. For instance, the JARPA does not include applying for an NPDES permit to Ecology nor does it include the application for a WDFW Aquatic Farm Registration or Marine Finfish Aquaculture permit.

⁵⁵ State of Washington, Governor's Office for Regulatory Innovation and Assistance. ePermitting – home of the JARPA. http://www.epermitting.wa.gov/site/alias__resourcecenter/9978/default.aspx Accessed 30 November 2018

The applicant then works with the individual agencies to provide additional information as needed and reach agreement on requirements. Typically, the city or county where the proposed project is located completes their review first with the USACE's review overlapping in time. By law, WDNR cannot issue a lease for state-owned aquatic lands until all other authorizations have been acquired by the applicant.⁵⁶

The state and local agencies are also required to conduct an environmental review under the State Environmental Policy Act (SEPA) to supplement their permitting and licensing of net pens. If a city or county has a permit for a proposed facility, then that agency is considered the "lead agency" and is responsible for conducting the process and documenting that review in the appropriate SEPA documents (DNS, DS/EIS, adoption, addendum). Often the SEPA review starts when the applicant completes and submits an Environmental Checklist with the required permit application. Figure 2.5a, Commercial Net Pen Permitting Flowchart, illustrates the most common steps of the authorization process in Washington. Figure 2.5b, NPDES Permitting Flowchart, illustrates the most common steps of the NPDES permit process in Washington. These flowcharts are not exhaustive and other authorizations may be required before siting commercial net pen operations.

⁵⁶ WDNR. Leasing and Land Transactions. <http://www.dnr.wa.gov/programs-and-services/aquatics/leasing-and-land-transactions> Accessed 30 November 2018

Figure 2.5a Finfish net pen permitting flowchart (1 of 2 pages)

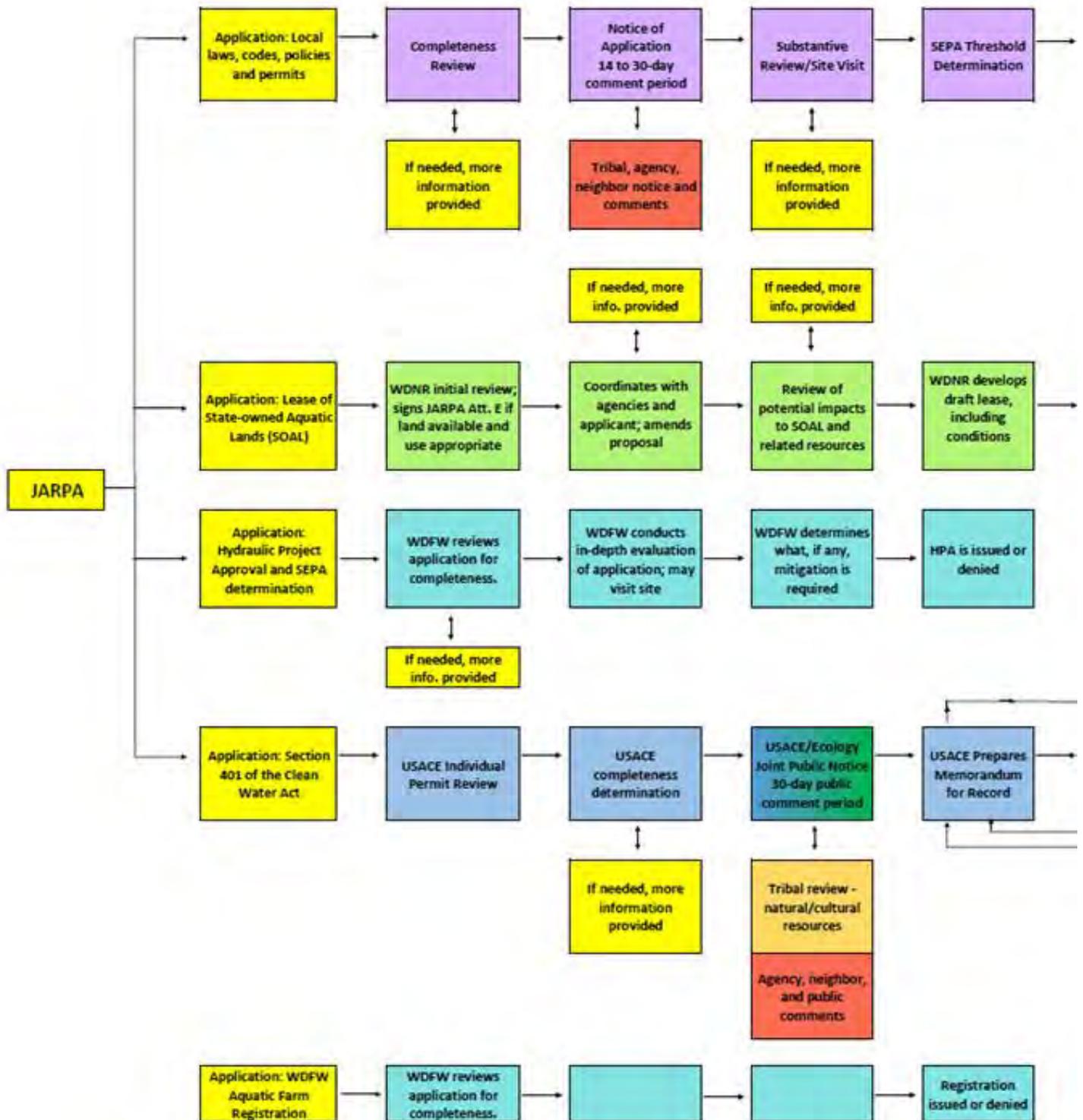


Figure 2.5a Finfish net pen permitting flowchart (2 of 2 pages)

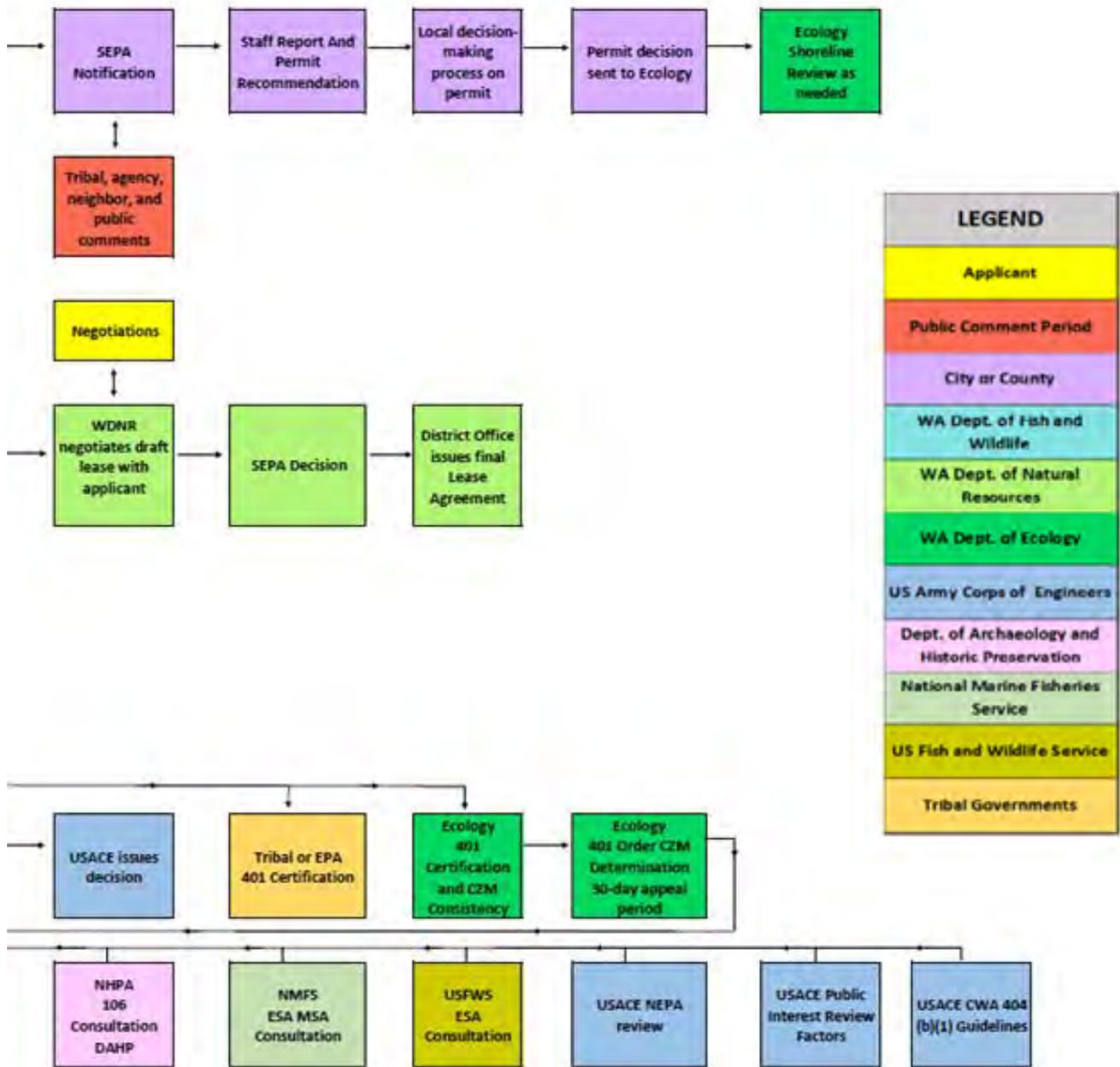


Figure 2.5b NPDES permitting flowchart (1 of 2 pages)

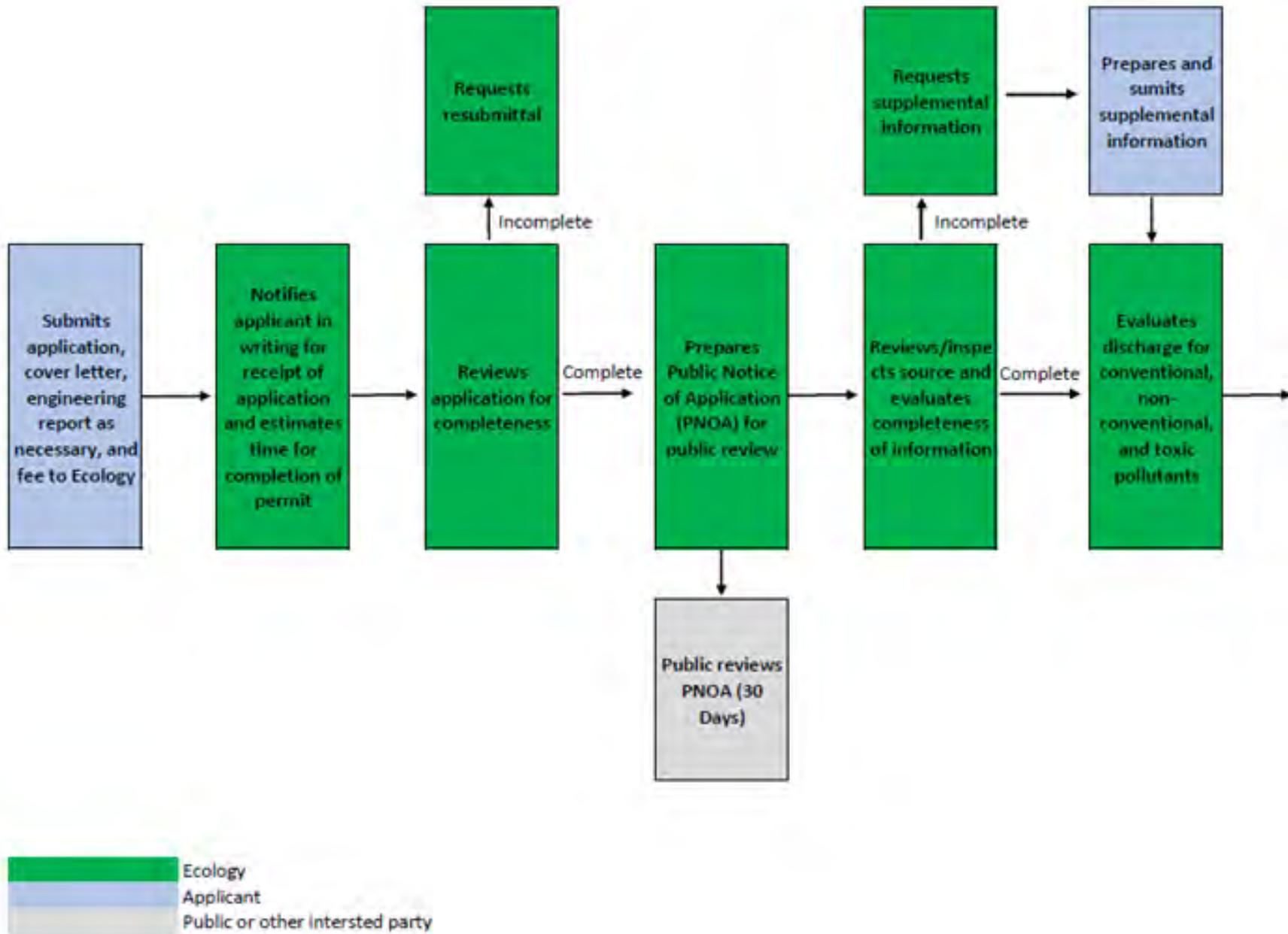
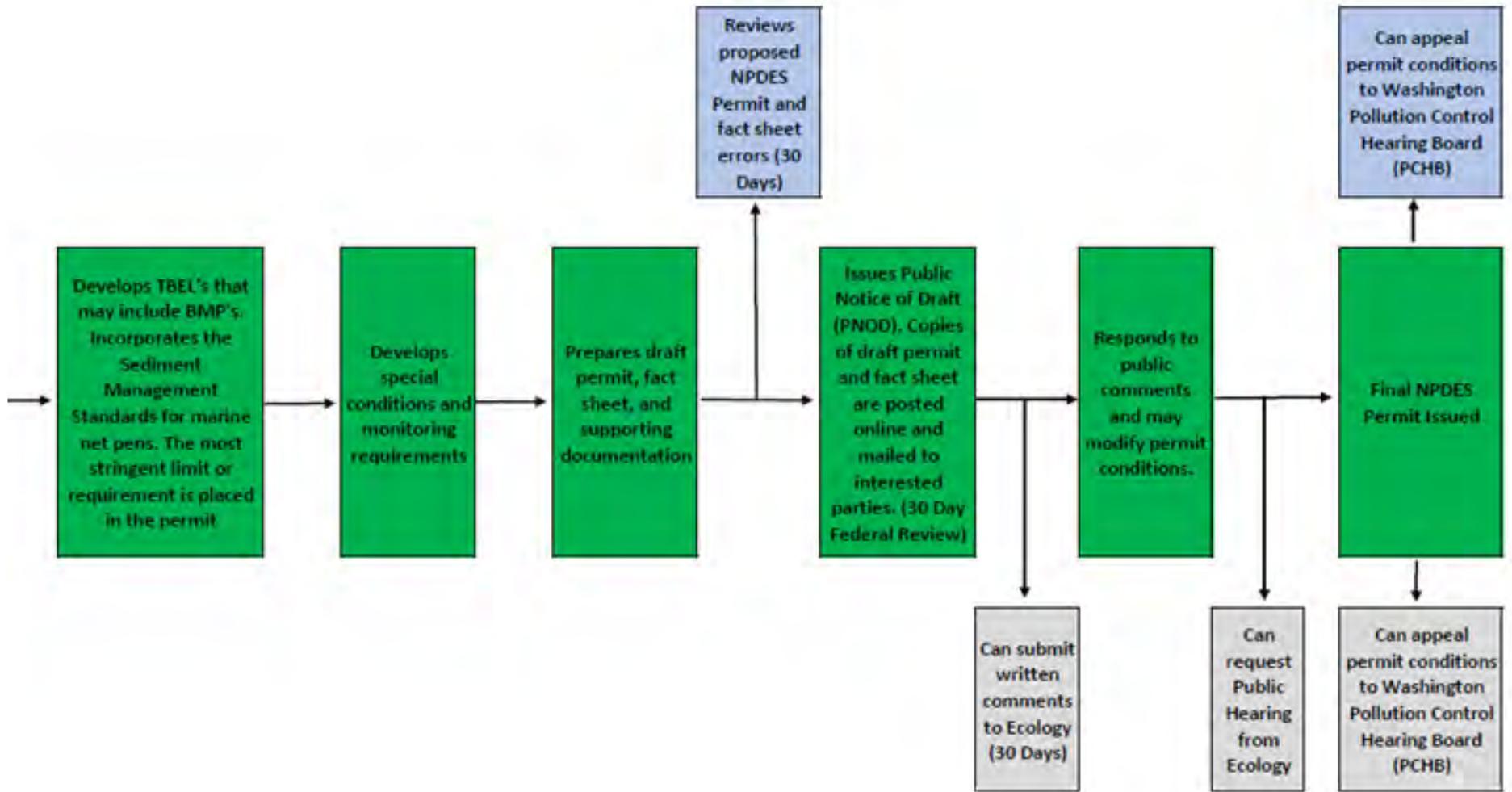


Figure 2.5b NPDES permitting flowchart (2 of 2 pages)



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Chapter 3: Net-pen Aquaculture in the Environment

3.1 Methodology

Over the last few decades, many reports, peer-reviewed journal articles, books, and papers have been written about the environmental effects of marine finfish aquaculture. This document was created using reports and papers, mostly from peer-reviewed professional journals. Several key reports generated by government agencies, academic or research institutions, and private organizations are also cited. Government reports from the U.S. and abroad were accessed through the agency websites or by conducting internet searches using Google or other search engines. Unpublished data from operational commercial farms were obtained through direct personal communication using professional networks. Only reports with scientific citations and published in English were included. Excluded from our review were opinion pieces, magazine articles, reports without scientific references, and papers for which only the abstracts, and not the full manuscripts, were translated into English.

Initial searches of electronic databases included broad keyword combinations which were then narrowed down by carefully reviewing each abstract and full text for direct relevance. We prioritized net-pen aquaculture of salmonids in temperate waters and then narrowed our scope to Atlantic salmon farms as well as farming native finfish species in the Pacific Northwest for the Washington specificity reviews. While not an exhaustive compilation, this effort does provide a comprehensive look at the state of knowledge in the marine finfish aquaculture industry with regard to the environmental effects of cage culture. The collected literature originates from research conducted in countries around the world, covers a range of cultured fish species, includes many new and practical farm management approaches, and addresses ecological processes at many scales.

This chapter has eleven additional sections that present the state of the science for each topic and provide specific information related to Washington State net-pen aquaculture. The topics have been broken down into benthic impacts, water quality, fish health and disease management, feeds, fouling prevention, sensitive habitats, escapes, marine life and protected species interactions, transfer and importation, marine debris, and aesthetics. Net-pen aquaculture site selection was not included as a separate subject here; rather, it is referenced throughout the document as it relates to other sections.

3.2 Benthic Effects

Deposition of organic matter leading to sediment degradation is a well-documented risk associated with net-pen aquaculture (Nash 2003). The physical attributes of the farm site (water depth and currents) and minimizing feed loss and release of biofouling can minimize the potential for negative impacts to surrounding sediment. Regular monitoring of the surrounding sea floor will demonstrate whether siting and operations are adequate. State sediment management standards (Chapter 173-204 WAC) dictate what level of impact or variation from baseline conditions is tolerated. Pens sited on state-owned aquatic lands, may have additional

stewardship measures required as part of their use authorizations to maintain long-term sustainable use of the site.

3.2.1 State of the science

Deposition of nitrogen, phosphorus, and carbon to the benthos

Most marine benthic sediment processes are driven by the decomposition of organic matter and are mediated by a variety of bacteria. Organic enrichment causes changes in sediment chemistry, benthic physical properties, and the benthic community. The sources of enrichment from net-pen aquaculture include uneaten food, fecal pellets, and biofouling drop off. How and where particulate organic matter accumulates is affected by farm size, depth, topography, and current pattern.

The succession of benthic macrofauna was described by Pearson and Rosenberg (1978), (see also Rosenberg 2001) who noted the source of organics does not matter, the biogeochemical alteration tends to be the same. The sediment grain size, water temperature, near-bottom currents, and the benthic faunal community dictate how well oxygenated the upper layers of the sediment are in their natural state. In un-impacted sediments with overlying water currents, the aerobic layer may penetrate several centimeters. Hypoxic (low oxygen levels) or anoxic (extreme hypoxia) conditions form in surface sediments when the amount of organic deposition exceeds the assimilative capacity of the benthic community, negatively affecting megafauna that require oxygen for respiration. Consequently, only species tolerant of suboxic conditions survive, resulting in significant changes in community structure and species composition (Rosenberg 2001, Forrest et al. 2007, Hargrave 2010, Keeley 2013).

Species that are indicative of such conditions vary by location. For example, in urban embayments and terminal inlets in Puget Sound (southern Salish Sea) cirratulid polychaetes of the genus *Aphelochaeta* may dominate⁵⁷, whereas Capitellid polychaetes have been noted as dominating the stressed, benthic infauna communities in other temperate locations (Price and Morris 2013). Findlay and Watling (1997) developed a model to synthesize how sediment oxygen delivery and consumption both play a role in determining benthic community structure. If these two parameters are measured and compared, the level of influence can be predicted.

Through microbial decomposition, nitrogen and phosphorous deposited as particulate matter are reduced to their inorganic form and can be utilized by organisms within the sediment, increasing sediment total organic carbon (TOC). They can also be released back into the water column contributing to eutrophication. Eutrophication occurs when a body of water becomes overly enriched with nutrients that induce excessive growth of plants and algae. In marine systems such as the Puget Sound, nitrogen is the limiting nutrient. This process may result in oxygen depletion of the water body.

⁵⁷ Valerie Partridge (Ecology, Marine Sediment Unit-PSEMP), personal communication April 2, 2019.

Benthic macrofauna feed on particulate matter that descends from the surface. When organic sedimentation begins to increase, there may be an increase in species number and diversity due to an increase in food availability. The movement of fauna through sediment grains may also help oxygenate sediments through the process of bioturbation (Brooks 2003).

Microbial respiration during decomposition of organic material uses oxygen in the sediment in a series of oxidation-reduction (redox) reactions. This will deplete most of the available oxygen when excessive organic enrichment occurs, leading to hypoxic (dissolved oxygen levels less than 2mg/L) conditions. As enrichment increases, the organism diversity decreases and the number of nutrient tolerant organisms such as the polychaete *Capitella capitata* will increase. Without available oxygen, sulfate reduction reactions take place. Redox potential and sulfide concentrations are good indicators of the sediment enrichment stage. Sulfate reduction may account for all the carbon oxidation in organically enriched sediments, resulting in sulfide compounds toxic to benthic organisms. At this stage not even the nutrient tolerant fauna can survive and the area will be void of any macrofauna. However, the conditions become ideal for the overgrowth of *Beggiatoa*, a mat-forming, filamentous bacteria that requires oxygen and hydrogen sulfide for metabolism. It responds negatively to high levels of both oxygen and sulfur. Consequently, its presence indicates the interface between oxic and anoxic conditions, making it a useful indicator for excessive benthic organic enrichment near net pens (Hargrave et al. 2008).

Complex particulate deposition modelling, sediment trap deployment and monitoring, and simple mass balance equations have been used to estimate the amount of carbon, nitrogen, and phosphorus expected to enter the environment from net-pen farms. Varying outcomes have been observed around the world depending on the site specific assimilative capacity of the surrounding environment. The following summaries specific case studies provides insight into general depositional trends.

Significant phosphorus and nitrogen accumulation levels were found in sediment around 29 Atlantic salmon farms in Chile. Phosphorus levels were nearly six times higher at farms than at control sites: 114.8mmol per square kilometer compared to 20.7mmol per square kilometer. Average nitrogen levels in farm sediments were about four times higher than at control sites: 124.1mmol per square kilometer compared to 31.9mmol per square kilometer. The authors noted that high variability among farm sites suggested other geographical sources of nitrogen might also have been a factor (Soto and Norambuena 2004). The authors concluded that phosphorus content in sediments was a promising variable to indicate organic matter deposition resulting from salmon farming.

A fish growth model and mass balance calculations were used to estimate the nitrogen flux from salmon farms in New Brunswick at the level of individual farms and at larger scales including multiple farms (Strain and Hargrave 2005). The authors estimated that for every metric ton of fish produced, 9kg of nitrogen and 2.3kg of phosphorus, accumulated in the sediment over a three-year grow-out cycle. These values are believed to be widely applicable to salmon farms in other parts of Canada and are in close agreement with similar estimates from a comparable study in Scotland (Strain and Hargrave 2005). Olsen et al. (2008) estimated 18.4 percent of carbon, 17

percent of nitrogen, and 42.5 percent of phosphorous in feed is converted to particulate organic waste that can end up on the seafloor.

Bannister et al. (2014) monitored changes in sediment chemistry at an Atlantic salmon farm in Norway over the course of one production cycle. During the study, a total of 3870 metric tons of feed was delivered, producing 2650 metric tons of Atlantic salmon. Results demonstrated that as feed inputs increased, benthic effects followed. Deposition of carbon and nitrogen increased, as did sediment oxygen consumption and ammonium flux, which are indicators of microbial action. The farm was in relatively deep (180 meters/590 feet) water, and mean and maximum current speeds ranging from 3.3 -5.3 cm/second to 22.2 – 31.4 cm/second. At peak production (June to September 2010), sedimentation rates of particulate organic carbon ranged from 1.4 and 2.0 grams/m²/day at the farming location. Secondary production rates were stimulated and species richness increased, and diversity decreased and composition changed to include more opportunistic nutrient-tolerant species such as *Capitella capitata* (Bannister et al. 2014). This site had been in operation for ten years, and given a six month fallow period before restocking.

Research conducted by Srithongouthai and Tada (2017) investigated the effects of enrichment on sediment chemistry at a yellowtail (*Seriola quinqueradiata*) farm in Shido Bay, Japan⁵⁸. The farm consisted of thirty pens, each 1100 cubic meters, located in relatively shallow water (approximately 10 meters deep). The current velocity at the farm site was not given, but velocity in the bay ranges from 15-20cm/s at the mouth of the bay to < 10 cm/s inshore. The bay is described as having tidal fluctuations of two meters so significant flushing is expected to occur with the tides. Seasonal differences in feed rates based on water temperature affected rates of deposition. During high feeding times, the mean deposition rate of nitrogen and carbon under the pens were 2.28g N/m²/day and 11.7g C/m²/day, respectively. Nitrogen flux increased as did levels of ammonia, nitrite + nitrate, and phosphate in the bottom water (Srithongouthai and Tada 2017). The effects were detected beyond ten meters outside the net-pen array. The authors indicated the sediment was becoming anoxic, and this has the potential for negative effects in this particular bay which has a large number of fish and seaweed aquaculture installations.

Changes in biogeochemistry with enrichment

Sediment characteristics help determine sensitivity to enrichment. For example, depositional sites are at greater risk of becoming enriched compared with areas subject to erosion. Depositional sites are generally characterized by higher silt/clay and overall organic content, compared to sand-dominated areas with frequent erosion. Sediments with a higher iron content may have fewer toxic effects on benthic fauna, because iron will bind to sulfides reducing their bioavailability to benthic organisms (Holmer et al. 2005). In a laboratory study, sandy sediments accumulated less organic matter and had lower sulfide and ammonium levels than muddy sediment when exposed to equal amounts of fish fecal pellets (Martinez-Garcia et al. 2015). This study also demonstrated that bioturbation by the polychaete *Hedise diversicolor* decreased the organic matter in heavily impacted sediments. Displacement of benthic fauna exacerbates

⁵⁸ Although this report describes fish species and environments that are not found in Washington, the authors wished to include it, because it is a recent example of what type of changes may be induced if a farm is poorly sited.

hypoxic conditions, due to loss of benthic faunal movements mixing the sediment and facilitating oxygenation (Sanz-Lazaro and Marin 2008).

Chemicals

Antibiotics, antifoulants, and heavy metals can accumulate in sediment in proximity to net-pen facilities (Nash 2003). These chemicals are introduced either as medication for the farmed fish, as a result of antifoulants used on net pen materials (copper) or through the feed (zinc). Further discussion about the uses of antifoulants can be found in Section 3.6 Biofouling prevention and management, and antibiotics in Section 3.4 Fish health and disease management. Price and Morris (2013) report the use of antifoulants, chemicals, and antibiotics in Puget Sound aquaculture has decreased by over 95% in the last 20 years. In addition, all of the commercial net pens have reduced or eliminated the use of antifoulants in favor of net removal which means nets are transported and cleaned at an uplands facility preventing the biofoulants from entering the water and accumulating beneath and adjacent to the net pens. Washington National Pollution Discharge Elimination System (NPDES) permits can require antibiotic resistance testing, if their use warrants investigation.

Heavy metals in sediment associated with net pens

Heavy metals accumulation in sediments impacts benthic communities below net pens. Several metals are essential for biological processes but become toxic above a threshold value, causing changes in community structure as less tolerant species are excluded. There is also the potential for the transfer of some metals through the food chain since benthic invertebrates are a food source for many organisms (Dean et al. 2007).

Ionic forms of copper, from marine anti-fouling compounds used on net pens, and zinc, from fish feeds, can be toxic to marine organisms. Levels of copper are elevated around some net-pen farms which use government-approved anti-fouling paints on structures or treat their nets with approved commercial compounds containing copper (see Section 3.6 Biofouling prevention and management). The chemical forms of copper in aquatic environments are maintained in a dynamic state of equilibrium dependent upon salinity, temperature, pH, alkalinity, dissolved oxygen, sediment physicochemical characteristics, and the presence of other inorganic and organic molecules (Brooks and Mahnken 2003). The detected additions of copper in the water following the installation of newly-treated nets are biologically insignificant, except to organisms which settle on the nets (Nash 2001). The potential rate of copper accumulation in sediments can be significantly reduced by washing the nets at upland facilities and properly disposing of the waste in an approved landfill (Nash 2001).

Zinc is an essential element used in salmon aquaculture as a feed supplement. Zinc has been measured in sediments near salmon aquaculture sites at concentrations that exceed sediment quality guidelines in Canada. The feed formulation is related to elevated zinc concentrations in sediments. The majority of feed manufacturers now use reduced amounts of a more bioavailable form of zinc, or a methionine analog, which overall has led to reducing the amount of zinc added to the sediments (Nash 2001).

Given the nature of sediments under some salmon cages (smaller grain size with higher TOC levels), zinc and copper are generally considered to be unavailable to most aquatic organisms. In sediments near salmon farms where sulfate reduction is the dominant metabolic pathway, metals can be bound as insoluble sulfides, reducing the bioavailability of zinc and copper (Nash 2001, Brooks and Mahnken 2003). Long-term studies have demonstrated that zinc and copper concentrations return to background levels during fallowing, likely because they are released through re-oxidation of sediments and mineralization of organic matter, after the period of chemical remediation and there is no evidence of a long-term buildup under salmon farms (Brooks and Mahnken 2003, Sutherland et al. 2007). Washington NPDES permits require sediment monitoring for zinc and copper.

Siting considerations: physical characteristics and faunal community

The deposition and accumulation of nitrogen and phosphorus in benthic sediments below marine net pens is widely studied and highly variable. Siting of farms in deep areas with sufficient flushing and consideration of the cumulative effects of multiple farms are among the best tools for minimizing long-term harmful impacts. Another important component is siting net pens over erosional substrates, which helps prevent the bioaccumulation of organic compounds (Price and Morris 2013). The relationship between farm size, water depth, and current velocity is complex and must be examined on a case-by-case basis.

At most modern farm facilities, nitrogen and phosphorus enrichment in benthic sediments is minimal and restricted to the areas beneath and within 500 meters (Price and Morris 2013). Studies and data reviewed by Nash (2001, 2003) indicated that, generally, carbon was elevated in sediments around Pacific Northwest salmon farms to about 30 meters beyond the pens, although effects could extend to over 200 meters depending upon the degree of flushing. Recent work in the Mediterranean has found increased levels of carbon, nitrogen, and phosphorous in proximity to net pens, but these levels were indistinguishable 100 meters away (Farmaki et al. 2014).

The 2005 benthic monitoring data collected by the Scottish Environmental Protection Agency (Scottish EPA) were analyzed to determine what factors (biomass, current speed, depth, and distance from pens) had the greatest effect on benthic impact indices such as sediment total organic carbon (TOC), benthic macrofauna, and sediment nitrogen concentration. Many relationships were examined. Notably, current speed did not contribute as a factor in any of their models. This led to the conclusion that with larger farms (>1000 metric tons of production) current speed alone cannot predict benthic impact. The farms studied had been sited prior to the use of a siting model (DEPOMOD), and the authors suggest earlier modelling may have only been correctly predictive of farms producing less than 800 metric tons. A holistic approach to modeling farm impacts was suggested by Mayor et al. (2010). This opinion was shared by authors of another study comparing benthic recovery at two salmon net-pen sites during a three month fallowing period in Tasmania (Macleod et al. 2007). The benthic community at the sheltered, deep water (40 meters) site was more impacted prior to fallowing, but the community recovered faster than at the more exposed, shallow (20 meters) site. The results of this study indicate community structures will recover at different rates. In the Tasmanian situation three

months was an adequate time for the benthic community to recover to pre-stocking levels. The two sites had similar stocking densities and feed rates, but differed by exposure and depth.

The impact to the benthic community can be mediated by bioturbation from wild fish and benthic invertebrates. The use of enclosed fish to reduce benthic effects was assessed in Israel by Katz et al. (2002) who reported that after 70 days of allowing gray mullet in small bottom pens to feed on waste below sea bream pens, several indicators of enrichment showed these detritivores had a positive impact. Sediment sulfide levels and sediment oxygen demand decreased by 85 percent and 31 percent. The enriched sediment layer was dramatically reduced by 5cm within the enclosures due to ingestion and resuspension by the mullet. These results have promising implications for both remediation of enriched sediments and development of commercially viable integrated multi-trophic aquaculture practices (Katz et al. 2002).

Investigation into the effects wild fish have on waste consumption in Western Australia found significantly greater accumulation of nutrients and fine sediments under the pens that excluded wild fish. The accumulation of nutrients was correlated to distinct changes in macrofaunal community composition, with a sharp increase in overall macrofaunal abundance and a growing dominance of capitellid polychaetes. Based on a comparison between sedimentation rates within and outside excluded areas, the proportions of the total deposited nutrients consumed by wild fish were calculated to be 40 to 60 percent (Felsing et al. 2005).

Wildish et al. (2001) found significant reductions in species abundance, diversity, and evenness indices at Atlantic salmon farmed sites as compared to control sites in the Bay of Fundy. Brooks et al. (2003) found the effects to be greatest within 30 meters of the cages, but were measureable 105-185 meters downstream in British Columbia. To reduce the effect on benthic environments, fallowing period is a management measure used in aquaculture where the production is stopped for a few months to allow benthic environments to recover (Zhulay et al. 2015). Following harvest, sediment chemical levels began to return to the unaffected state. Biological remediation, defined as a return to macrofaunal diversity comparable to reference conditions (Brooks et al. 2003) was completed within 6 months of fallowing. Brooks et al. (2003) demonstrated rapid recolonization of annelids, crustaceans, and mollusks in a balanced community in six months. Fallowing periods need to align with relevant biological processes including benthic species recruitment seasonality and the resilience of the local benthic system (Zhulay et al. 2015). Thus, a fallowing period starting before or early in the reproductive period may be more effective than one that starts in summer. If biological recovery is a concern, site rotation where the farm is left to fallow for at least one year is more prudent than a period of a few months (Zhulay et al. 2015).

3.2.2 Washington specificity

Benthic profiles for Puget Sound

The physical and chemical characteristics of sediment vary considerably throughout Puget Sound. Natural variation in sediment characteristics further leads to variable benthic communities. Weakland et al. (2018) reported that benthic community structure throughout most of the region was related to the water depth and sediment grain size. There are areas of Puget

Sound where conditions are naturally less favorable for a diverse benthic community (such as areas of depositional sediment having hypoxic conditions). In several areas of Puget Sound anthropogenic forces have negatively affected the benthic assemblage, particularly in terminal inlets and bays throughout Puget Sound.

San Juan Islands (Northern Puget Sound)

The inter-island channels and straits in northern Puget Sound are current-swept, resulting in low amounts of soft sediment. The sediments are mostly (70-80%) silt-clay, though contained a sizable gravel fraction (up to 30% by weight) the first few years sampled. TOC content is generally just under 1.5% (Partridge et al. 2013).

Central Puget Sound

Central Puget Sound consists of urban and rural embayments, industrial harbors, and deep basins and passages from 3 to 252 meters deep. Sediments in passages have been found to be predominantly sandy and sediments in other locations have been found to be largely finer-grained (greater than 80 percent silt-clay). TOC content in Central Sound has been found to range from 0.06 percent to 3.98 percent, averaging 1.28 percent across samples (Partridge et al. 2013). Both organic matter and chemical contaminants tend to adhere to fine sediments, primarily clay and silt. Therefore, bioavailability of pollutants is partly related to total organic carbon (TOC) and grain size.

Standards, required monitoring, and reporting for net-pen facilities

For existing facilities, various parameters are required to be monitored for regulatory purposes in the sediment and waters below and immediately surrounding a net pen facility. The parameters grain size (percent silt-clay), TOC and benthic infaunal abundance are stipulated in WAC 173-204-412 for routine, exceedance, enhanced, and closure monitoring. A Sample and Analysis Plans or SAPs for each type of monitoring must be submitted to, and approved by, Ecology in the timeframe laid out in the permit.

Location and frequency for TOC, benthic infaunal abundance, and other parameters are determined by Ecology and identified in the NPDES permit. The locations of sediment and water sampling is related to the sediment impact zone (SIZ), which is defined by rule in WAC 173-204-412 as 100 feet in every direction from the perimeter of the facility.

New facilities will be required to perform a baseline sediment quality study that includes benthic infaunal abundance, TOC, and grain size in the location proposed and in areas downcurrent likely to be affected by the discharge.

Ecology's NPDES regulatory standards for net pens include TOC and benthic abundance to determine the impact from the facility's discharge. However, to best characterize the benthic habitat and community, other biogeochemical factors such as sulfides concentration and levels of oxygen in the sediment are important to consider. Additionally, infaunal abundance examined alone can be a misleading indicator for community structure (M. Dutch personal

communication). Ecology’s Ecological Assessment Program looks at a suite of benthic community indicators that includes abundance, species richness, evenness, dominance, and the presence or absence of disturbance sensitive and tolerant species to determine whether the benthos population is considered healthy or impacted.

Standards for TOC

Total organic carbon (TOC) content in Puget Sound sediments ranged from <0.1% to 7.2%, with a mean of 1.5%. Higher TOC content tended to be found within bays and inlets throughout the region. Harbors had the highest TOC concentrations (Wekaland et al. 2019). Washington State regulates the net pen discharge based on TOC content of sediment. Routine monitoring results of TOC are either compared to a baseline site value or an index value (WAC 173-204-412). An index value based on sediment grain size for each sample is possible because silt and clay content of marine sediments are positively correlated with TOC content (Table 3.2a). If TOC levels exceed either thresholds, exceedance monitoring is triggered, which is to include benthic infaunal abundance. If exceedance monitoring fails, enhanced monitoring is triggered and that includes consultation with Ecology to implement changes to get the SIZ back into compliance.

Table 3.2a. TOC Values for exceedance monitoring

| Silt-Clay Particles (Percent Dry Weight) | Total Organic Carbon (Percent Dry Weight) |
|---|--|
| 0-20 | 0.5 |
| 20-50 | 1.7 |
| 50-80 | 3.2 |
| 80-100 | 2.6 |

Standards for Copper and Zinc

There is a potential for zinc and copper to be discharged in a net pen operation. Both of the metal standards “correspond to a sediment quality that will result in no adverse effects, including no acute or chronic adverse effects on biological resources and no significant health risk to humans” (Chapter 173-204 WAC). If either metal levels are above the cleanup screening levels (CSLs) stated in WAC 173-204-520, additional step-wise monitoring (i.e., exceedance and then enhanced) is enacted until documentation of site recovery is reported. Table 3.2b describes the monitoring for routine, exceedance, enhanced, and closure purposes. Copper CSL: 390 mg/kg dry weight (required if copper-based antifoulants are used on the facility or nets). Zinc CSL: 410 mg/kg dry weight.

Table 3.2b NPDES required monitoring for net-pen aquaculture facilities in Washington State

| 1. Routine Monitoring | | | | |
|---|--|--|--|---|
| Parameters | Frequency/ Timing | Sample | Sample Location | Report |
| Sediment silt-clay particles, TOC, copper (if anti-foulants are used), zinc | Annually between Aug. 15 and Sept. 30 and estimated peak biomass | Grab | Specified in facility NPDES permit | Annual |
| DO (surface, half the depth of the net pen, and within one meter of the bottom) | Annually, between Aug. 15 and Sept. 30 | Grab | Co-located with sediment monitoring stations | Annual compare to reference site |
| DO at edge of pen (surface, mid-net pen depth and <1 meter above bottom) | Daily between Aug. 15 and Sept. 30 | Grab | Edges of pen | Weekly and Monthly (high, low, average) |
| Underwater video and photographic survey. <i>Beggiatoa</i> spp. presence and quantity | Annually between Aug. 15 and Sept. 30 and estimated peak biomass | Video and Photo | Locations described in facility NPDES permit | Annual |
| 2. Exceedance Monitoring | | | | |
| Parameters | Frequency/ Timing | Sample | Sample Location | Report |
| Sediment silt-clay particles, TOC, benthic infaunal abundance, copper, zinc | If required, as per the approved SAP | Field replicate grabs per PSEP protocols | Outside Sediment Impact Zone (SIZ) | Results and statistical comparisons for all samples and reference locations |

| 3. Enhanced Monitoring | | | | |
|---|--|--|------------------------|---|
| Parameters | Frequency/ Timing | Sample | Sample Location | Report |
| Sediment silt-clay particles, TOC, benthic infaunal abundance, copper, zinc | If required as per the approved SAP | Field replicate grabs per PSEP protocols | As per approved SAP | Results and statistical comparisons for all samples and reference locations |
| 4. Closure Monitoring | | | | |
| Parameters | Frequency/Timing | Sample | Sample Location | Report |
| Sediment silt-clay particles, TOC, benthic infaunal abundance, copper, zinc | Six months and one year after site closure | Field replicate grabs per PSEP protocols | As per approved SAP | Results and statistical comparisons for all samples |

Underwater video and photographic surveys

Permittees are required to conduct an underwater video and photographic survey of the seafloor between August 15 and September 30 sediment sampling stations described in the NPDES permit for the facility, typically four locations on edge of the SIZ.

The sediment surface at each station shall be documented using an underwater camera or video camera, from a distance of three to seven feet. Use artificial light (50 watt or greater) at all times to take four to five color photographs or 15-30 seconds of motion photography. The permittee shall provide reference information on linear dimensions, time, date, station location, and net pen facility with each picture or section of film footage.

- Photographs and videos shall clearly portray the appearance of the seafloor at each station.
- Report any *Beggiatoa spp.* presence and estimate percent of coverage.
- The survey results shall be submitted with the data reports as required in permit.

Antibiotic resistance

The NPDES permit may require monitoring of resistance to antibiotics of the bacteria that live in the benthos by either an administrative order or permit modification if Ecology determines the

permitted discharge poses a threat to human health or the environment. The basis for requiring monitoring for benthic bacterial antibiotic resistance may be, but is not limited to, the following:

- New information on the environmental impacts of antibiotics, or abnormally high usage levels of antibiotics by the permittee.
- Any permit modification or administrative order requiring the permittee to monitor benthic bacterial antibiotic resistance is subject to the administrative procedures under Chapter 43.21C RCW.

Results of benthic monitoring at Washington net pens

Prior to the net-pen collapse at Cypress Island (Deepwater Bay) in 2017, two of the eight operating sites in Puget Sound had exceeded TOC trigger levels for enhanced monitoring. All eight have met state water quality standards. The two farms that did have exceedances of TOC in the sediment followed the NPDES permit steps to measure the expanse of the sediment enrichment and took steps to move farms into deeper waters more favorable to dispersion and assimilation of the farm wastes.

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3.3 Water quality

3.3.1 State of the science

Marine finfish net pens are open systems. Seawater, controlled by tides and currents flows freely through the pens. As seawater enters it provides oxygen to the fish, and particulate and dissolved wastes are removed from the system as the water flows out. Feed needs to be provided to the majority of commercially cultured species. The feed used in salmonid aquaculture is a compounded diet manufactured into a dry pellet. Consequently, finfish aquaculture is considered a nutrient additive process because the feed and associated metabolic waste add nutrients (nitrogen and phosphorous) and organic matter to the surrounding environment. Dislodged fouling organisms can also concentrate nutrients in the area of the pens. Drugs and antifoulants might be released into the water column if they are used at the farm site. In Washington, the Department of Ecology regulates discharge into the water column through NPDES permits. Water quality standards and additional narrative criteria are in place to ensure minimal or no impact to water quality. Water quality impacts must be minimized or prevented for the surrounding beneficial uses stated in WAC 173-201A-210 (1-4).

The contribution of additional nutrients from farms could affect primary production or phytoplankton community structure, but the likelihood of that will depend on the scale of finfish net pens, other anthropogenic inputs and flushing characteristics of the receiving waters (Mente et al. 2006 and Morata et al. 2015). An increase in algal biomass can result in greater turbidity and lower DO concentrations in the water column from algal decomposition. Fish absorb dissolved oxygen in the water column and are adversely affected if levels are too low. The DO can decrease either because of their own oxygen consumption (respiration), natural and enhanced biological processes (i.e. photosynthesis and decomposition), and local stratification and upwelling events.

In order to illustrate the current global understanding of net-pen aquaculture's effects on water quality this section includes information from several countries where the species of fish cultured differ from those in Washington. The authors feel these were appropriate to include, because they are recent, clear examples of how net pens can impact (or not impact) nearby water quality. Washington specific information is provided in Section 3.3.2.

Nitrogen

Nitrogen is released from finfish net pens in several forms: dissolved organic nitrogen (DON) made up of urea, dissolved inorganic nitrogen (DIN) consisting of ammonia, nitrite and nitrate, and particulate organic nitrogen (PON) bound in uneaten food and feces. The amount of nitrogen released is directly related to farm biomass, the nitrogen content of fish feed, the fish's food conversion ratio (FCR), and the fish's nitrogen assimilation efficiency. A 2005 review of nitrogen budgets in aquaculture reported that up to 80 percent of the nitrogen in feed goes back to the environment (Islam 2005). However, these results were highly variable and dependent on feed type, feed conversion ratio, and fish species. Importantly, the operations that had high FCRs included unprocessed fish in the diet. Those operations with lower FCR's used a compound

pelleted feed, which is they type of feed provided to fish in Washington. Further, the use of fish or fish parts to feed fish in net pens is specifically prohibited in Washington.

When modelling nutrient output from Norwegian Atlantic Salmon farms, Wang et al. (2012) estimated that 62 percent of in-feed nitrogen was released into the environment, and that 50 kilograms of nitrogen are released per ton of fish produced (wet weight). These numbers are in accordance with Olsen et al. (2008) who estimated that 44 kilograms of nitrogen are released per ton of Atlantic salmon produced in Norway. The rate of release changed seasonally, based on water temperature. Feed use and nutrient release increased from April to August as water temperature rose, then decreased when waters began to cool in September. During this one-year study, 62 percent of the feed used on the farms was delivered between April and August.

A measurable effect on the nitrogen levels in the water column near net-pen facilities may or may not be evident. A 2013 synthesis of global aquaculture literature by Price and Morris reported ranges of no impact (no difference from background) to significant impact (significant increase above background concentrations) on nitrogen levels in the waters around net-pen facilities. The authors further explained that a measurable difference in nitrogen levels was rarely seen beyond one hundred meters from the net pens. The ability for a farm's effluent to alter the levels of nitrogen in the water column in a detectable way depends on hydrodynamics, farm size, trophic status of the ecosystem, and feed formulations. Significantly, higher levels of nitrogen appear when farms are sited in areas of lesser water exchange. A year-long monitoring project in Loch Fyne, Scotland, which has a 10-day turnover time (turnover is defined as a 60 percent exchange of the original water mass), noted significantly higher ammonia levels at a salmon net-pen farm when compared to a reference station 480 meters away (Navarro et al. 2008).

Phosphorus

In many freshwater systems and in some marine systems (select areas of the Mediterranean Sea) phosphorous has been found to be the nutrient whose levels limit primary production (Krom et al. 1991, Lazzari et al. 2016). Further, alterations in stoichiometric ratios of nutrients in the water column can lead to alterations in phytoplankton community structure. Therefore, the amount of phosphorous that is released, or would be released, from finfish farms should be considered when evaluating potential environmental impacts. The amount of phosphorus in finfish aquaculture effluent has decreased over time as nutritionists have gained a better understanding of fish physiological requirements and decreased levels of phosphorus in diets (Gaitlin and Hardy 2002). Phosphorous waste is excreted primarily via feces, with a lesser percentage released as dissolved inorganic phosphorous (DIP) in urine (Olsen et al. 2008). Whether or not the phosphorous released from a fish farm negatively impacts the surrounding waters is dependent upon biological characteristics of the fish as well as the hydrodynamics of the farm site (Morata et al. 2015).

Islam (2005) reviewed phosphorus budgets of marine fish farms and reported an average of 71.4 percent of the phosphorus in feed was released into the environment, with the amount varying with the species cultured, the type of feed used, the feed conversion ratio, and feeding efficiency. Similar results were reported by Wang et al. (2012) who estimated that 70 percent of in-feed

phosphorous would eventually be excreted back into the environment. Meaning for every ton of salmon produced, 9.3 kilograms of phosphorous was released. They further specified 18 percent of in-feed phosphorous would be excreted as dissolved inorganic phosphorous (DIP), making it immediately available for uptake by primary producers.

Soto and Norambuena (2004) evaluated 43 Atlantic salmon farming sites (of which 29 were in operation) grouped into nine locations in Chile order to assess aquaculture induced changes to nutrient levels in water chemistry and benthic sediment chemistry. The study found no distinct effect on orthophosphate in the water column attributable to the farms. They did note that phosphorous levels in the sediment near farms were elevated (see Section 3.2 Benthic effects).

Dissolved oxygen

Sufficient levels of dissolved oxygen (DO) in the water column are essential to aquaculture and have been extensively studied and monitored in all types of culture operations. A meta-analysis of 30 peer-reviewed articles conducted by Sarà (2007) found aquaculture operations generally do not affect dissolved oxygen. Price and Morris (2013) indicated that seasonal, tidal, and diurnal fluxes often cause more changes in dissolved oxygen than fish farms.

A reduction in dissolved oxygen has been attributed to net-pen facilities located in shallow depths and in slack water, which emphasizes the importance of proper siting. Burt et al. (2012) described multiple hypoxic events (defined as DO below 6 mg/L for Atlantic salmon) occurring within the periphery of moderately-stocked salmon net pens (10 kilograms per cubic meter) in Newfoundland. Importantly, the water at this site was described as stratified, with surface temperatures 5°C higher in the first six meters, and a current profiler indicated little to no water movement below a depth of four to five meters (Burt et al. 2012).

Importantly, if dissolved oxygen levels decrease in pens, operators will amend practices to lessen hypoxic stress to the fish. As noted in Burt (2012) any feeding will stop. In Washington, if oxygen levels decrease supplemental aeration is provided to the fish (Kevin Bright, personal communication May 16, 2017).

Turbidity

Turbidity is an optical property of water where suspended and dissolved materials such as silt, clay, finely divided organic and inorganic matter, chemicals, plankton, and other microscopic organisms cause light scattering. Measurements of turbidity estimate the amount of suspended solids such as sediment within a sample of water and describe the effect of suspended solids blocking the transmission of light (Bash et al. 2001).

High levels of turbidity can negatively affect primary production through blocking light for photosynthesis. Fines (dust) from broken feed pellets and fish waste are two primary sources of turbidity associated with finfish net pens (Pergent et al. 1999). Scraping biofouling may also result in temporary decrease in water clarity (Hargrave 2003). In general, high flushing rates will minimize turbidity. A 2005 study conducted in Maine found that light penetration levels (an indicator of turbidity) at both cage and control sites met water quality targets (Sowles 2005).

However, when flushing rates are low due to tidal or seasonal shifts in water currents (Price and Morris 2013) or due to siting in areas with decreased flow, feed and waste suspended in the water column may increase turbidity. Conversely, Harrison et al. (2005) reported in southwestern New Brunswick, Canada, Secchi depth readings at cage sites were significantly lower than at control sites. Increased turbidity may result in lower light penetration reducing phytoplankton production. Depending on the level and composition of the particulates, increased turbidity may or may not affect fish and wildlife (Bash et al. 2001).

Chemicals

Several types of chemicals are associated with salmon net-pen aquaculture (BurrIDGE et al. 2010):

- Therapeutics used for the treatment of disease, including antibiotics and parasiticides,
- Antifoulants such as biocidal compounds painted on submerged equipment,
- Disinfectants used to clean equipment, and
- Anesthetics used to sedate the fish during handling.

The use of chemicals in net-pen aquaculture and the potential for negative impacts is a global concern. The availability of aquaculture chemicals in the United States is regulated by the U.S. Food and Drug Administration (FDA) (therapeutics, anesthetics, and some disinfectants) and the U.S. Environmental Protection Agency (EPA) (antifoulants and some disinfectants). State and local laws also regulate use of chemicals. For example, a NPDES permit would be required by EPA or a state with delegated NPDES authority before a pesticide to control sea lice could be applied. To minimize effects of these chemicals on water quality, regulatory agencies can dictate protocols to minimize their introduction to the environment. For example, if a disinfectant is used to clean equipment, the farm operator can make sure equipment is dry before going back into the water and that disinfectant waste is properly disposed of at a land-based facility.

Most of the chemicals and their environmental effects will be discussed in detail in Benthic effects (Section 3.2), Fish health and disease management (Section 3.4), and Biofouling prevention and management (Section 3.6).

3.3.2 Washington specificity

General description of the project area waters

The greater Puget Sound is part of the Salish Sea, an estuarine system stretching from southern Puget Sound into British Columbia (B.C.), including the Strait of Georgia. Saltwater enters from the Pacific Ocean through the Strait of Juan de Fuca and mixes with freshwater draining from the surrounding watersheds with the Fraser River being the largest contributor. Water within Puget Sound and the Straits exhibits a wide range of salinities and temperatures dependent upon depth, season, weather conditions, and proximity to river mouths. The combined effects of tidal exchanges, estuarine circulation, and the presence of sills, results in complex circulation patterns (Roberts et al. 2014). The greater Puget Sound is composed of several sub-basins that differ in

water quality and circulation characteristics. Some are well-mixed while others are fjord-like with longer water residence times and greater stratification (Sutherland et al. 2011). The Fraser River in B.C. is the source of two-thirds of the freshwater entering the Salish Sea. Its influence is enough to affect waters within Puget Sound south of Admiralty Inlet (PSEMP 2016). The other third of the freshwater comes from watersheds emptying into the sound. Salinity fluctuates significantly with proximity to river mouths but ranges from 29 to 33psu (practical salinity units) where rivers are not a major influence.

Nitrogen

The Pacific Ocean is the dominant source of both water and nitrogen into Puget Sound and the Straits. Other primary sources of nitrogen in the area are rivers and streams bringing natural and anthropogenic nitrogen, wastewater, and industrial discharges (municipal wastewater treatment plants and industrial facilities), and re-mineralization of sediment nitrogen and atmospheric deposition (Ahmed et al. 2019). In 2014, rivers and point sources (waste water treatment plants) brought approximately 69,000 kg/day of DIN into Puget Sound, with roughly 32,000 kg/day coming from wastewater treatment plants (Ahmed et al. 2019). Actual levels of DIN or its specific components in the water column will vary based on proximity to sources, circulation, and uptake by primary producers. The average level of ammonium across Ecology's monitoring stations can range from less than 0.5 to over 2 micromoles per liter (Krembs 2016).

Evaluations for siting net-pen aquaculture farms in Puget Sound proper and Strait of Juan de Fuca were published in 2007 (Rensel et al. 2007). The study indicated that nitrogen released from a properly sited salmon net-pen facility is unlikely to have an adverse impact on the water quality or cause algae blooms (Rensel et al. 2007). The amount of nitrogen already in the system, coupled with a well-mixed water column, allows nutrients released from pens to assimilate into the environment immediately. Net-pen facilities in Puget Sound have been monitored for 30 years as a requirement for their operating permits and as the subject of scientific study, however nitrogen in any form is not a required parameter for monitoring. Multiple studies of the Puget Sound salmon farms have noted slightly increased nitrogen levels in the center of net pens, but no measurable difference 30 meters away (Brooks et al. 2003). Rensel (1989) studied dissolved nitrogen production at two poorly flushed farms in Washington. Reference (up-current) concentrations of 0.0003 mg/L were increased to 0.0023mg/L in the center of the net-pen complex, but they decreased to background concentrations at downstream stations. Rensel (1989) also observed maximum un-ionized ammonia levels equivalent to six percent of the EPA criteria in the center of the net-pen complexes during slack tide. These case studies indicate the concentration of dissolved inorganic nitrogen added to marine water at salmon farms is low along the net pen perimeter and essentially undetectable at 30 meters down current (Brooks et al. 2003).

Phosphorus

Phosphate concentrations in Puget Sound increase with depth and vary seasonally. Water quality monitoring stations throughout greater Puget Sound show an average range of phosphate is 0.02-0.08 mg/L (Khangaonkar et al. 2012). Evidence suggests nitrogen is the limiting nutrient in the

greater Puget Sound, which is typical for marine systems. Nash (2001) did not identify dissolved phosphorus from salmon farms in the Pacific Northwest as a concern. Rensel et al. (2007) predicted no adverse effects to water quality due to offshore fish farming in the Strait of Juan de Fuca. They further postulated that the influx and vertical mixing of nutrient-rich deep seawater (entering from the Pacific Ocean) was why no nutrient effects were seen in the area near the fish farm.

Dissolved oxygen

Dissolved oxygen in greater Puget Sound is quite variable spatially and temporally and can quickly shift in response to wind, weather patterns, and upwelling (PSEMP 2016). Most of the Straits, Puget Sound main basin, and Hood Canal are designated as extraordinary water quality, indicating the target level of dissolved oxygen is maintained at 7 mg/L or greater (Table 3.3a).

Dissolved oxygen tends to be higher in surface layers where atmospheric exchange and photosynthesis (during the day) add oxygen to the water. During warmer months, the photosynthetic action of phytoplankton blooms in Puget Sound can raise localized daytime dissolved oxygen to above ten milligrams per liter. Oxygen levels decrease as depth increases because of the influx of deep water from the Pacific, which is naturally low in dissolved oxygen, bacterial decomposition of particles as they sink through the water column, and because of the biological oxygen demand of benthic organisms. Circulation as well as respiration by phytoplankton and other organisms also affect dissolved oxygen levels. Organic matter decomposition can decrease oxygen levels, typically near the bottom layers of Puget Sound (Khangaonkar et al. 2012).

Low dissolved oxygen occurs naturally in some parts of Puget Sound. Human activities contribute nutrient pollution, which is contributing to low dissolved oxygen in some areas of Puget Sound, predominantly poorly-flushed inlets (Ahmed et al. 2019). Many areas of Puget Sound do not meet the state DO standards. The Clean Water Act 303(d) listings document the DO limitations, which can be found at Assessment-of-WAstate-waters-303d.⁵⁹ Different areas within Puget Sound will have different characteristics that should be carefully considered when evaluating project siting or operations (Albertson et al. 2002). Using the 303(d) list and the information gathered by the Nutrient Forum conducted by Ecology (Reducing Puget Sound Nutrients) is the best and most current information to assess sites.

Fish are highly sensitive to low levels of dissolved oxygen, with 6 mg/L being the recommended minimum concentration for feeding, which allows salmon to remain healthy and grow (Burt et al. 2012). In 1990, as part of a Programmatic EIS, the potential effects of net pens on dissolved oxygen levels in Puget Sound were evaluated and it was determined that fish farms would rarely affect dissolved oxygen, and if they did, it would be when temperatures were highest and in areas with lower background dissolved oxygen levels. Water quality monitoring of existing net pens in Washington have showed that a dissolved oxygen depression downstream of the cages is

⁵⁹ See WAC 173-201A-610 and 612, 173-201A-210, 240, and 260 for designated uses for marine waterbodies marine criteria.

minimal in distance, usually no more than 0.1 to 0.2 mg/L just five meters downstream and virtually never more than thirty meters downstream (Nash 2001). This is in accordance with findings expressed in reviews conducted by Brooks and Mahnken (2003) and Price and Morris (2013).

Table 3.3a Dissolved oxygen threshold for water quality designation

| Category | Lowest 1-day minimum Dissolved Oxygen (mg/L) |
|-----------------------|--|
| Extraordinary Quality | 7.0 |
| Excellent Quality | 6.0 |
| Good Quality | 5.0 |

Turbidity

Increased levels of turbidity have the potential to affect primary production, and can adversely affect fish and other wildlife dependent upon the level and characteristics of the suspended material. Washington’s water quality criteria protect the environment by limiting a facility’s allowable effects on turbidity. This includes requirements to maintain stock nets with minimal biofouling and to remove nets to uplands facility for cleaning. See below in Section 3.3.3 regarding NPDES requirements to minimize and prevent turbidity.

Chemicals

As part of net-pen facility NPDES permit conditions in Washington, the use of any chemical must be reported. See below in Section 3.3.3 regarding NPDES requirements to minimize and prevent chemical discharges to waters of the state. Details about these various compounds, their legal use, and environmental interactions are discussed in Fish health and disease management (Section 3.4) and Biofouling prevention and management (Section 3.6).⁶⁰

Algal blooms

Blooms of marine algae are included in this section because of the close association between phytoplankton and DO levels and nutrients in the water column. This subsection describes how net-pen effluent, dissolved oxygen, and phytoplankton may affect each other. More specific information on Harmful algal blooms (HABs), those that pose a risk to human or animal health through the production of toxicants or physical damage, is discussed in Fish health and disease management (Section 3.4).

Periodic blooms of microalgae throughout the spring, summer, and fall, which may or may not be harmful, characterize Washington’s coastal waters. As phytoplankton biomass increases,

⁶⁰ There is no specific reporting requirement associated with disinfectants or cleaning agents in Washington because there is no permitted discharge of these chemicals. Any such discharge would be a violation of RCW 90.48.080.

photosynthesis increases the concentration of dissolved oxygen in the water column. Likewise, levels of inorganic nitrogen and phosphorous will decrease as these nutrients are used by the phytoplankton for growth. For example, the 2015 Puget Sound Marine Waters report described seasonal decreases in nitrate and nitrite levels consistent with phytoplankton uptake in surface waters (from 0-2 meters) (PSEMP 2016). Presumably then, increasing the levels of inorganic nutrients would allow more phytoplankton to grow.

However, because of the size of greater Puget Sound size, complexity and numerous sources of nutrients, it would be difficult to name a single source of nutrients, as the cause of an algal bloom (PSEMP 2016). There is broad agreement that shallow bays with significant freshwater input and minimal flushing are considered poor sites for net-pen facilities because water column stratification coupled with the farm's nutrient inputs could favor algal growth within that water body.

3.3.3 Standards, required monitoring, and reporting for net-pen facilities

Washington NPDES permits require net pen facilities to monitor DO levels in the water column at the edges of the net pen facility from August 15 through September 30 daily when farms are likely to have an adverse effect. An annual survey must be conducted to monitor the dissolved oxygen profile of the water column at designated sampling stations surrounding the facility and a separate reference station during the same period of time. The facility is required to compare the results from the reference site with results from the annual sampling stations. Daily monitoring is reported weekly and monthly and any exceedances and may be addressed by requesting aeration. In both cases, DO is analyzed at three vertical locations within the water column (within one meter of the water surface, at about half the depth of the pen, and within one meter of the bottom). Monitoring of DO provides information about nutrient discharge effects immediately adjacent to the facility and around the sediment impact zone.

Net-Pen Facility Operations and Maintenance

The NPDES permit requires a net pen facility to properly operate and maintain the facility to meet the requirements of WAC 173-221A-110. The permittee must submit an Operations and Maintenance (O & M) Manual for Ecology's approval. The Permittee must:

- a) Update the O&M Manual such that it meets the requirements of 173-221A-110 WAC and submit it to Ecology for approval.
- b) Review the O&M Manual at least annually and confirm this review by letter to Ecology each year.
- c) Submit to Ecology for review and approval changes or updates to the O&M Manual whenever it incorporates them into the manual.
- d) Keep the approved O&M Manual at the permitted facility.
- e) Follow the instructions and procedures of this manual.

The O&M Manual must include procedures to address the following:

1. The Permittee must take immediate action to correct any noncompliance with the water quality or sediment management standards. Corrective actions may include reduction in feeding rate, removal of fish from net pens, or other remedies.
2. Emergency procedures for spills, fish escapes, and structural failures.
3. A review of components, which, if they failed, could cause the discharge of pollutants to surface waters, including the release of fish.
4. Any directions to staff when performing maintenance, cleaning, or other tasks that are necessary to ensure the proper operation of the facility.
5. Minimum staffing adequate to operate and maintain the facility and carry out compliance monitoring required by the permit.
6. The Permittee must feed fish in a manner that minimizes the amount of uneaten fish food, and maximizes ingestion by reared fish.
7. The Permittee must utilize properly sized feed for the size of fish in each individual net pen.
8. The Permittee must utilize feed that is free of excessive fines and high in digestibility.
9. The Permittee must routinely collect environmental data and accurate data on fish numbers in the pens, size, growth, and food conversion rates necessary to determine and update optimal feeding rates.
10. The Permittee must remove fish carcasses from the net pens on a frequent basis.
11. The Permittee must collect and store fish carcasses in leak proof containers, and disposed of in approved land-based disposal facilities. Carcasses shall not be disposed of in surface waters.
12. The Permittee must store and dispose of fish mortalities, harvest blood, and leachate from these materials in a manner which prevents such materials from entering waters of the state.
13. The Permittee must maintain all structural and mechanical systems associated with the net pens, including but not limited to floats, walkways, mooring points, and all components of the anchoring systems in good working order. Maintenance and repairs to the structural or anchoring systems shall be documented and records maintained on site and available to Ecology upon request, as well as reported to Ecology.
14. The Permittee must prevent the excessive accumulation of marine growth on the stock nets. The Permittee shall maintain documentation of net cleaning activities and effectiveness of net washing shall provide verification of the efficacy of in situ net cleaning to Ecology upon request.
15. The Permittee must minimize the storage quantities of all necessary chemicals, petroleum products, and potentially toxic substances essential to the day-to-day operation at the facility. These products must be kept in leak proof storage areas that provide secondary containment.

16. The Permittee must not discharge sanitary waste, floating solids, visible foam other than in trace amounts, or oily wastes that produce sheen on the surface of the receiving water.
17. The Permittee must not discharge toxic chemicals in toxic amounts to the receiving water.
18. The Permittee must not discharge soaps, detergents, or disinfectants to the receiving water.
19. The Permittee may not pressure wash any portion of the net pen structure or any equipment, docks, barges, or other apparatus associated with the operation of the facility, if the water from pressure washing could enter waters of the state. In situ washing of the stock nets and predator exclusion nets is the only permitted use of pressure washing.
20. The Permittee must keep items associated with the operation of the net pens secured on the net pen structures and associated service areas, such as docks and barges, in order to prevent debris from entering the water.
21. The Permittee must recover floating debris that enters the receiving water as soon as it is safe to do so.
22. The use of tributyl tin (TBT) compounds is prohibited.
23. When in use, predator nets shall be maintained above the sea floor at all times. Nets may not impede the current flow or tidal exchange so as to contribute to the deposition of solids that would impair water quality or sediment standards. The storage of predator control nets on the sea floor is prohibited. Any net accidentally dropped or lost during a storm event that is not recovered immediately shall be tagged with a float, positioned using differential GPS, and reported to Ecology within 24 hours. The net shall be recovered within 30 days from the date lost, unless Ecology allows a longer time in an individual case. Ecology shall be notified on the date the net is recovered.

Disease Control Chemical Use Requirements

The following requirements only apply to those drugs and chemicals included in feed, administered by a bath, dip treatment that results, or may result in those materials being discharged to waters of the state. These requirements do not apply to drugs and chemicals administered by injections or by dip treatments that result in no discharge to waters of the state.

- Only disease control chemicals and drugs approved for use by the United States Food and Drug Administration (FDA) or the United States Environmental Protection Agency (EPA) may be used.
- FDA-approved Investigational New Animal Drugs (INADs) may also be used at a facility, provided the conditions detailed in a facility's INAD permit application are met.
- All disease control drug and chemical use must be done in conformance with product label instructions, approved INAD protocols, or be administered by, or under the supervision of, a licensed veterinarian.

- Disease control drug and chemicals that are not used in accordance with product label instructions, or under FDA-approved INAD protocols, must be administered by, or under the supervision of, a licensed veterinarian, and be approved in advance by Ecology.

Pollution Prevention Plan

The pollution prevention plan must specify operating conditions that do not violate other conditions of this permit. This plan must address operations, spill prevention, spill response, solid waste, and stormwater discharge practices that will prevent or minimize the release of pollutants from the facility to the waters of the state.

1. The Permittee must operate the facility in accordance with this plan along with any subsequent amendments or revisions. The pollution prevention plan must include procedures to prevent or respond to spills and discharges of oil and hazardous materials. These procedures must address the following:
 2. A list of all oil and petroleum products and other materials used and/or stored on-site, which when spilled, or otherwise released into the environment, designate as Dangerous Waste (DW) or Extremely Hazardous Waste (EHW) by the procedures set forth in WAC 173-303-070. Include other materials used and/or stored on-site that may become pollutants or cause pollution upon reaching state's waters.
 3. A description of preventive measures and equipment that prevent, contain, or treat spills of these materials.
 4. The reporting system the Permittee will use to alert responsible managers and legal authorities in the event of a spill.
 5. A description of the spill response procedures and equipment that will be used.
 6. A description of staff training to implement the spill plan.
 7. The pollution prevention plan must also include the following:
 - a. A description of how fish feeding will be conducted to minimize the discharge of unconsumed food.
 - b. An explanation of how disease control chemicals are used within the facility to ensure that the amounts and frequency of application are the minimum necessary for effective disease treatment and control. The concentration of disease control chemicals in the facility's discharge must be minimized.
 - c. Practices for the storage and, if necessary, disposal of disease control chemicals.
8. How solid and biological wastes are collected, stored, and ultimately disposed of at an upland facility. Among the solid wastes of concern are:
 - a. Any fish mortalities under normal operations.
 - b. Fish mortalities due to a fish kill involving more than five percent of the fish.
 - c. Blood and waste from harvesting operations.
9. Schedule of inspections of exposed surface lines, shackles, and mooring points, as well as inspections of components and anchoring system below the water line. Detailed inspection and maintenance protocols required in the fish escape prevention, response,

and reporting plans can be referenced to meet the requirements of the pollution prevention plan.

10. Procedures to identify and prevent existing and potential sources of stormwater pollution.
11. Procedures for conducting routine maintenance of the facility and supporting structures (including barges and docks) and equipment in such a way as to prevent pollutants from entering state waters in violation of RCW 90.48, including but not limited to cleaning structures and equipment, maintenance of generators, compressors, boats, or other vehicles, and welding procedures.

Operational Log

The Permittee must keep records on all disease control chemicals used at the facility. All variances from the disease control chemical use procedures contained in the facility Pollution Prevention Plan must be documented. These records must include:

- Person responsible for the administration of the disease control chemical if different from the individual identified in the facility Pollution Prevention Plan.
- The date of application of the disease control chemical used. For disease control chemicals that are used routinely, the frequency of application may be recorded in place of each individual application date.
- The trade name of the disease control chemical used.
- The treatment concentration of the active ingredient, duration of treatment, and amount of the chemical used.
- The reason for use and method of application.

The permittee must keep records of the average and maximum amount of fish on hand in pounds and the total amount of food fed in pounds for each calendar month at the facility. The information contained in the operational log must be used to complete the disease control chemical use reporting requirements.

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3.4 Fish health and disease management

Optimizing fish health while balancing environmental and economic pressures is the crux of farm management strategies. A variety of stressors can negatively impact fish leading to a state of disease. Successful fish health management begins with disease prevention. A prevention-based approach to pathogen management is considered a priority for conservation (Samsing et al. 2017) as well as for the economic success of fish farms. In this document the term disease is broadly defined as any condition that impairs normal body functions. Not all diseases cause mortality. Sublethal effects of disease may include decreased growth, susceptibility to infection, and degradation in fish condition that negatively impacts the cost of production or marketability of the final product (Borno and Linaker 2014). Further, the presence of a pathogen does not necessarily mean the fish or population is diseased, nor does the absence of pathogens mean a fish is at an optimum state of health.

Diseases can be broken down into two categories:

Non-communicable (non-infectious) disease: caused by factors other than a pathogen, such as water quality or nutrition, which cannot be transmitted among individual fish

Examples: hypoxia, microalgae toxicity, green-liver syndrome (Tagaki 2005, DFO 2017, DFO 2018).

Communicable (infectious) disease: those caused by a pathogen that can be transmitted among individuals

Example: Sea lice or Viral Hemorrhagic Septicemia (Kent et al. 1998).

A holistic approach is required to prevent and manage diseases in net-pen aquaculture. On-farm husbandry, sanitation, nutrition, and animal welfare practices should be optimized and fish stress minimized. Both acute and chronic stressors can induce immunosuppression, further, non-infectious diseases may be sources of stress allowing for the onset of infectious diseases or exacerbating their effects. Hence, this section reviews disease prevention strategies before discussing infectious agents specifically.

3.4.1 State of the science

Maintaining fish health and preventing disease

Operations and husbandry

There are a variety of stock management strategies and husbandry measures that are employed to optimize fish health and decrease the opportunity for pathogen infection. Regional level planning, site selection, vaccination, biosecurity, and employee diligence will all help to minimize the onset and spread of infectious diseases.

Biosecurity

Biosecurity describes infrastructure and husbandry practices employed to protect farms from disease. Here the aim is to reduce the opportunity for diseases to enter the farm and reduce

impacts and spread of disease when it occurs. Biosecurity is also practiced on regional, state, and national levels. The global nature of the seafood industry (the import and export of cultured or wild caught fish and the transfer of gametes, eggs, and fish across state or international boundaries) makes biosecurity of the utmost importance. Washington has detailed screening and stock movement regulations in place to protect wild fish stocks. At the farm level, biosecurity procedures include methods for obtaining healthy stock, the movement of personnel and materials, and harvesting practices as well as activities necessary during a disease event response. If multiple farm sites are in a region, operators should address biosecurity collaboratively by taking into account water movement and vessel traffic. Disease management and treatment options are limited when outbreaks occur. Therefore, prevention remains the best line of approach for aquaculture.

Siting

The location of a net pen is fundamental to fish health. Water quality, proximity to wild fish habitat, and proximity to other marine industries can all factor in preventing the onset and transmission of disease, both among farm sites and between farmed and wild fish (Zweig et al. 1999). Important considerations for water quality include salinity, temperature range, dissolved oxygen, current velocity and direction, and phytoplankton density. Proximity to runoff containing land-based pollutants should also be considered due to the potential for chronic or acute toxicity to farmed fish. Low dissolved oxygen, dramatic fluctuations in salinity or temperature can weaken the fish's immune system increasing susceptibility to infection (Kent 1992, Noga 2010). Changes in salinity and temperature can have positive or negative impacts on growth performance and immune function (Kim et al. 2017). For example, lower salinity of the Puget Sound compared to the Broughton Archipelago is likely why sea lice have not been as problematic in Washington as they are in British Columbia (B.C.) (Bricknell et al. 2006).

Wild fish are the source of many pathogens that affect net-pen farms (Marty 2010, Johansen 2011). Avoiding locations known to be reservoirs of a pathogen in wild conspecifics (Hammell et al. 2009) may decrease opportunity of exposure to pathogens. In an investigation of the 2002-2003 IHNV epidemic in B.C., Saksida (2006) correlated wild fish spawning migration to outbreaks of the virus. The first Atlantic salmon that contracted the virus had been in seawater for more than one year and were greater than three kilograms, which suggests initial exposure to the IHNV virus likely occurred in seawater. The onset of this disease and a previous epidemic coincides with wild Pacific salmon returns (July and August), and participants noted wild fish had been seen at the farm sites prior to the outbreak. Further, the fifth and final farm zone impacted was on the west coast of Vancouver Island, and although the timing did not correlate to salmon migrations, the farm was in close proximity to a herring test fishery. Proximity of farms to processing plants coupled with the use of well boats for fish transport were then implicated in the spread of the virus.

Including epidemiological principles and risks in the planning stages of a farm business and reevaluating these steps on a regular basis is important for recognizing and mitigating risk. In Norway, zoning and the spatial rearrangement of marine production sites have helped to minimize the horizontal spread of infections (Midtlyng et al. 2011). Future industry could benefit

from research predicting how climate change might impact water chemistry and temperature in Washington. Additionally, amending the models developed in Canada and Europe that estimate the dispersion of viral particles (Salama 2013, Foreman et al. 2015) could help inform future farm site location decisions.

Source of stock

Sourcing specific pathogen-free stock (either fertilized eggs or fish) from specialized production facilities is a regular practice for some aquatic species, such as Atlantic salmon, rainbow trout, and other sport or baitfish. The brood fish and/or the stock must be certified pathogen free before they can be shipped across state or national borders. Depending on the origin of the fish eggs, aquaculture businesses may need to adhere to pathogen screening and certification regulations by state, federal, and international agencies. For newly domesticated species, there may not be a commercially available source of stock, so interested producers must begin their own breeding programs by collecting healthy, wild brood fish and screen them for pathogens of concern. For example, WDFW requires wild sablefish to be quarantined and screened for pathogens before they can enter the general population in aquaculture holding systems. To further reduce risk, Washington requires fish be screened before stocking in net pens, even if brood fish are found to be pathogen free.

Vaccination

Vaccinating fish is a means to prevent or mitigate the severity of bacterial or viral infection. Norwegian's production of farmed salmonids has more than doubled between 2003 and 2014, and the use of antibiotics in aquaculture has decreased by half over the same time period (Miranda et al. 2018, Norwegian Veterinary Institute 2016). This decrease is a direct result of highly effective vaccines against furunculosis and vibriosis, and rapid implementation of sanitary measures as well as significant improvement in biosecurity policies (Midtlyng et al. 2011). Importantly, while bacterial infections and antibiotic use has decreased in Norway, the industry still contends with viral infections.

Vaccines are delivered prior to stocking fish stocking in net pens and are delivered either by injection, in a bath, or in feed. Long et al. (2017) reported that an IHNV vaccine offered Atlantic salmon significant protection from IHNV infection. Further, they did not transmit the infection to naïve⁶¹ sockeye salmon. Vaccine availability is not always assured, particularly for new species being cultured. Unfortunately, some infections need to occur before a vaccine can be developed.

There are several commercially available vaccines in the United States, but they are only available for commonly cultured fish species (e.g. catfish and salmonids). An additional option for vaccination is the autogenous vaccine (a vaccine made from a particular pathogen isolated from diseased fish at a specific facility). Importantly, this can only be produced and used under the direction of a licensed veterinarian within the context of a veterinarian-client-patient

⁶¹ In this context, the word “naïve” describes an organism that has not been exposed to a particular pathogen or antigen. Consequently, the organism has had no opportunity to develop an immune response.

relationship for specific purposes provided (Yanong 2017). The USDA is the agency charged with regulating vaccines for aquaculture.

Stocking strategies

There are environmental and economic factors to consider when designing or evaluating a fish farm stocking and production plan (availability of fingerlings and smolts, animal health, seasonal differences in water temperature, etc.). Separation of year classes is a well-documented means of disease prevention in net-pen farms (Alvial et al. 2014). Generally the longer fish have been in a net pen, the higher the chance that they are carrying a pathogen from the environment. Therefore, stocking only one year class per site reduces pathogen transmission and effects. In addition, fallowing sites for several weeks or months breaks the cycle of disease because there are no fish to act as a reservoir for pathogens. Fallowing is required in many salmon farming locations. Importantly, for operators to practice this basic principle, they must be allowed to obtain multiple site locations (Hammell et al. 2009). Further, transfer of fish between net-pen sites is discouraged in case a subclinical infection is present (Werkman et al. 2011).

Feeds

Optimum nutrition promotes fish growth, reduces stress, and prevents the onset of disease (Cho 2002, Pohlenz and Gaitlin 2014). Beyond providing the minimum energy requirements for fish to grow, recent research in the field of nutrient and nutraceutical immunoprophylaxis and immunostimulation has indicated fish immune systems may be enhanced through the inclusion of various nutrients in the diet during times of stress or infection (Pohlenz and Gaitlin 2014). Functional feeds are diets that contain ingredients that enhance fish immune systems, growth, or other performance measure. Many of the ingredients in these diets have shown potential to help offset the impacts of disease (probiotics, beta-glucans, Vitamin C.). The U.S. Food and Drug Administration (FDA) regulates what ingredients are allowed to be used in aquaculture feeds, but does not validate the health claims made by manufacturers. Using these emerging modalities to combat disease is desirable; however, other tools are still required by the aquaculture industry to treat fish if diseases occur.

Pathogens

Pathogenic organisms are a normal occurrence in the marine environment and are present in all species of fish cultured in net pens, as well as their wild counterparts. Pathogen proliferation poses risks to farmed and wild stocks, and pathogen exchange can happen in both directions. If used excessively, some of the drugs used to treat diseases in farmed fish can persist in the environment at concentrations high enough to harm non-target organisms. Further, pathogens can evolve resistance to drugs if they are exposed regularly.

Pathogen introduction

Pathogens are introduced to net-pen populations through several vectors such as: the use of wild-sourced larvae, juveniles, or broodstock; a water supply holding infected fish; siting pens close to pathogen reservoirs; use of unpasteurized products in feed; immunosuppressive conditions; high density culture with continuous inputs of naïve animals; culture of fish populations naïve to the

endemic pathogens or the introduction of exotic pathogens into naïve populations; and culture of multiple species in close proximity (Kurath and Winton 2011). As the industry has matured in recognizing these vectors, husbandry practices have been designed to prevent them. Examples include the use of compound feeds made with pasteurized ingredients, domesticated, pathogen-free brood stock; low stocking density in pens, and fallowing a site after harvest. Several pathogens have been spread internationally by salmonid aquaculture. Viral Hemorrhagic Septicemia Virus (VHSV) and Infectious Salmon Anemia Virus (ISAV) are well studied pathogens that have been spread through the international transport of salmonids⁶² (Kurath and Winton 2013, Alvial 2014). Studies of VHSV showed multiple routes of introduction to regions of Europe during the mid-twentieth century. Multiple strains have been found on the U.S. East Coast and Great Lakes. VHSV was found to switch host species and be transmitted from wild fish to farmed fish, and later back to other wild fish. Notably, the use of unpasteurized wild fish as a feed source was determined to be the vector in several instances (Kurath and Winton 2013).

The ISAV epidemic in Chile was caused by a strain of the virus imported from Europe, likely with Atlantic salmon eggs (Kibenge et al. 2009). Inadequate import regulations, explosive industry growth and overcrowding, lack of coordination and communication between companies, and poor husbandry practices are among the factors that facilitated the virus to spread, eventually leading to a 33% decrease in Chile Atlantic salmon production from 2008-2010. As a result, Chile adopted stricter regulations for farm siting, area management, and importation (Figure 3.4a) (Alvial et al. 2014).

⁶² VHS is endemic to Washington. ISAV has never been confirmed in Washington or British Columbia.

Figure 3.4a Biosecurity requirements in Chile resulting from the ISAV epidemic

- Testing of fish for pathogens within 15 days of any fish movement
- A ban on movement of smolts from potentially infected zones to zones thought to be free of infection (all diseases)
- Requirement that a designated fish health professional be appointed for each company
- All-in all-out stocking, and stocking a site to be completed within a 3-month period
- Mandatory fallowing between year classes
- Designation of neighborhood zones, with coordinated fallowing within zones
- Minimum distances between salmonid farms and between farms and processing plants
- No sharing of day-to-day equipment between saltwater farms; mandatory disinfection of larger equipment that is shared among farms
- Regulation of net cleaning operations
- No movement of fish after stocking for grow-out
- Daily removal and proper disposal of dead fish
- Regulation of fish density in cages
- Containment of liquid waste during harvest and treatment before disposal
- Treatment of effluent water during transport for fish known to be infected with ISAV
- Reinforcement and control of all eggs' disinfection
- No importation of eggs from countries with ISAV or pancreas disease
- Mandatory disinfection of all processing plant effluents receiving fish from a quarantine area (since 2009)

Pathogen transmission, mutation, and amplification

Farmed fish generally are not subject to processes in free-ranging populations that naturally separate healthy and diseased fish (e.g., migration, predation, competition) (Groner et al. 2016). Diseases affecting fish in net pens often originate from the surrounding environment (VHSV in Europe (Johansen et al. 2011) and sea lice in British Columbia (Marty 2010), though a clear relationship between pathogen populations in farmed fish and nearby wild populations is not always evident (Mladineo et al. 2009). Parasites and bacteria that are present in wild fish without inducing disease can lead to disease in an aquaculture setting. Clinical disease occurs when the number of pathogens is high enough to overwhelm the fish's immune system. As a result of confinement pathogens amplify and can be easily transmitted among live fish and from dead to live fish within net pens (Kurath and Winton 2011). Hence, it is important to remove dead or moribund fish as often as possible, ideally daily. Net pens are in a fixed location, so fish cannot swim away from unfavorable environmental conditions. Lillehaug et al. (2003) noted distinct seasonality to several bacterial disease infections occurring in farm-raised fish in Norway. If there are clear patterns to disease onset, then this information can also be used for farm management purposes.

Pathogen transmission between farm sites is complex. Examination of an IHNV dispersion model indicated importance of UV radiation in the prevalence of IHNV in British Columbia; higher UV irradiance led to fewer active viral particles in July compared to that in April (Foreman et al. 2015). Processing facilities and well boats used for fish transfer have been identified in the spread of IHNV in BC (Saksida 2006) and ISAV in the United Kingdom (Murray 2002). In an analysis of the dynamics of virus transfer between farmed and wild fish, Kurath and Winton (2011) observed the transfer of viral pathogens from wild to domestic hosts appears to be the more frequent disease route than the reciprocal traffic from domestic to wild hosts. Further, the wild to domestic transfer was deemed to be of greater significance in terms of disease impact. They suggest conditions in aquaculture provide greater transmission potential in cultured compared to free-ranging populations, leading to increased opportunities for viral amplification and transmission, and for viral mutations, potentially leading to greater viral pathogenicity. Complexities of pathogen exchange vary by the pathogen and the environment. Johansen et al. (2011) reported various instances of pathogen exchange in a review of European disease research. A study by Wallace et al. (2008) explained therein, found significantly higher prevalence of IPNV in wild fish (0.58%) caught within 5 kilometers of IPNV-positive fish farms (Scotland) compared with the prevalence of IPNV elsewhere in the marine environment (0.15%).

Host immunity (innate or acquired), pathogens, and environmental conditions all influence whether or not transmission will occur, and if there is an onset of clinical disease in either the host or wild population. Minimum infective dose differs between species and life stage, and the longevity of the pathogen in the marine environment differs depending on the pathogen and the environmental conditions acting upon it. The complex nature of aquatic epidemiology indicates it is risky to make general assumptions about pathogen transmission and the development of disease without regard to specific hosts, pathogens, or environment.

Drugs for disease treatment in the United States

The Federal Food, Drug, and Cosmetic Act (FFDCA) defines the term drug broadly to include articles intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease (Bowker and Trushenski 2016). In aquaculture, this includes antibiotics and anti-parasitic compounds, fish sedatives and anesthetics, gender manipulators, and spawning aids. In net-pen aquaculture, drug use is generally limited to treating parasite infections (anti-parasitic) or bacterial infections (antibiotics). Anti-parasitic compounds can be administered in feeds or as a bath, whereas antibiotics are mostly delivered in feeds (Other routes are possible, but they are not used in net pens due to cost and logistics.). Another class of compounds referred to as biologics, includes a range of products of biologic origin used in the diagnosis, prevention, and treatment of diseases. Vaccines are the most commonly used biologics in aquaculture, however commercially available vaccines are produced for a limited number of diseases and fish species (vaccines will be discussed in greater detail below).

Regulatory oversight

All drugs available for use in domestic net-pen aquaculture require oversight by one or more of the following entities: a veterinarian, the USFWS Aquatic Animal Drug Approval Partnership

(AADAP INAD) program, the FDA, the Department of Homeland Security (DHS), the National Pollution Discharge Elimination System (NPDES) permitting authority, or a combination thereof (Bowker and Trushenski 2016, USFWS 2018). Furthermore, specific states and other jurisdictions may have additional regulatory requirements. The extent of oversight varies with how the drug is applied and what condition it is used to treat. This oversight is intended to ensure proper dosage, treatment, and record-keeping, making it less likely that excessive use and resulting environmental harm will occur. It is a violation to use federally-regulated aquaculture products in a manner other than that specified on the product label unless either the drugs are being used with an Investigational New Animal Drug (INAD) exemption or as an extra-label prescription issued by a licensed veterinarian (Bowker and Trushenski 2016).

The antibiotics issues

The use of antibiotics is often listed as a negative aspect to finfish aquaculture. This section describes the negative effects to the environment that could occur when antibiotics are used at net-pen farms. To minimize the potential for these concerns to be realized a description of the regulations in the United States and good management practices are included.

The evolution of antibiotic-resistant bacteria is a global human and animal health concern.⁶³ Antibiotic use in net-pen aquaculture could lead to resistance making fish pathogens harder to treat. Further, resistance genes in fish pathogens could transfer to human pathogens. An increase in the presence of antibiotic-resistant genes in sediment near fish farms and in the fish themselves increases any time antibiotics are used, but the occurrence of these genes decreases with time if use stops (Capone et al. 1996, Herwig et al. 1997, Miranda 2018). Importantly, the extent of antibiotic detection and the occurrence of resistance correlates with the amount used and the frequency of use (ibid). Part of the drug approval process in the United States includes FDA microbiologists' considering the drug's ability to cause bacteria to become resistant and the impact of that resistance on public health.⁶⁴ An antibiotic will not be labelled for use in aquaculture if the risk to human health is too great.

Antibiotics are delivered to fish in net pens via the feed. If medicated feed is wasted, then wild fish or other organisms nearby could consume it, or it will settle nearby accumulating in sediment. Some of the medication could pass through the fish without being metabolized and thus introduce it to the surroundings. A 1996 study by Capone et al. found that red rock crab (*Cancer productus*) collected under cages at a Washington fish farm (described as a heavy user of antibiotics) contained oxytetracycline in meat during and 12 days after treatment. They further noted oysters and Dungeness crabs collected at the farm did not contain more than trace amounts. The state of Maine requires signage be posted on net pens during the course of antibiotic treatments to warn fishers that animals in the nearby area might contain antibiotics.

⁶³ FAO Antimicrobial resistance. <http://www.fao.org/antimicrobial-resistance/background/what-is-it/en>

⁶⁴ U.S. Food and Drug Administration. Animal & Veterinary. From an Idea to the Marketplace: The Journey of an Animal Drug through the Approval Process. Available at: <https://www.fda.gov/AnimalVeterinary/ResourcesforYou/AnimalHealthLiteracy/ucm219207.htm#misconceptions> Accessed 4 February 2019

Using the minimum amount of antibiotics required for an effective treatment and minimizing feed wastage will prevent other animals from consuming the medication. All medicated feeds need to be prescribed by a veterinarian, putting responsibility for antibiotic application and judicious use on veterinarians as well the producers.

Antibiotics in the sediment can alter the naturally occurring bacterial community, leading to a potential harmful change in benthic ecology. This change can be prevented by minimizing the amount of antibiotics used in the environment and by keeping the environment under and around the farm as healthy and diverse as possible. If sediment is already heavily impacted by farm (or other) operations, then the additional stress of antibiotics is more likely to have a negative impact than it would on sediment that has a healthy community of flora and fauna.

Impacts to non-target organisms

Under the National Environmental Policy Act (NEPA), the FDA must consider how a correctly applied drug might affect the environment. Physical, chemical, and biological factors in the environment dictate how long drugs persist and whether they might be consumed or absorbed by non-target organisms. Therefore, if a drug is available for use to aquaculture (either approved or via an INAD exclusion) an Environmental Assessment (EA) or Environmental Impact Statement (EIS) will have been completed (FDA 2018). These studies give reasonable assurance that when used in accordance with their labelled instructions, drugs will have little to no toxic effects to non-target organisms in the immediate area of the farm site. Further, if aspects of the studies indicate potential toxicity, the FDA suggests conditions that operators or regulatory bodies can follow to ensure that the potential toxicity is not realized (Schmidt et al. 2007, FDA 2007) and that there should be little harm to the surrounding environment. There is evidence some chemicals used in aquaculture can persist in the sediment and induce localized antibiotic resistance or be taken up into the tissue of nearby organisms. Similarly, after use has stopped, the incidence of antibiotic resistance genes also decreases (Capone et al. 1996, SEPA 2018). Hence, some states include conditions in NPDES permits that require sediment testing if regulators believe there is cause for concern.

3.4.2 Washington specificity

Native species considerations

Currently in Washington, commercial aquaculture of Pacific salmonids is limited to freshwater environments, either land-based or within freshwater net pens. Disease management here is regulated through Washington Administrative Code (WAC) 220-370.

There is an extensive network of state, tribal, and federal Pacific salmonid hatcheries in Washington for the purpose of producing fish for harvest, enhancement, or recovery. Many of these facilities culture anadromous salmonids where individuals are spawned and reared in freshwater hatcheries, but eventually fish are released and sea-ranched into marine waters. Disease management within these facilities is dictated through the co-managers disease policy and through the WDFW Fish Health Unit and the Northwest Indian Fish Commission Fish

Health Unit. Further, the WDFW Fish Health Unit manages private aquaculture through regular inspections, transfer permits and provisions. These fish health units are responsible for regular health exams, and treatments. The co-managers disease policy is about moving fish around the state to prevent disease movement not proper diagnosis and treatment management. Fish Health Units provide training in animal husbandry and stress management to prevent disease, reducing antibiotic use. USFWS also participates as a formal cooperater. Additionally, the Pacific Northwest Fish Health Protection Committee (PNFHPC) provides fish health technical and policy support in Alaska, British Columbia, Montana, Idaho, Washington, Oregon, and California. This organization is composed of federal, state, and tribal agency representatives and commercial fish producers. It was formed to discuss and resolve fish health issues, to disseminate research findings and educational material, and to communicate openly on all matters as they relate to production of healthy fish in the cultured and natural environments.⁶⁵

Sablefish are being raised commercially in British Columbia⁶⁶, and in Washington, a private entity (collaborating with NOAA's Northwest Fisheries Science Center) has a pilot-scale sablefish net-pen facility (J. Parsons, personal communication February 21, 2018). As of this writing, no novel diseases have been seen in sablefish. They are, however, susceptible to some of the diseases that have also been seen in salmonid net pens (Bell et al. 1990, Arkoosh and Dietrich 2015). The development of vaccines for sablefish is one area of active research toward making the species commercially viable for aquaculture.

Atlantic salmon considerations

Atlantic salmon have been cultured in net pens within the Puget Sound for almost 40 years. Over this course of time, government policies and the industry practices have evolved in an effort to maximize farmed fish health and minimize impacts to the surrounding environment and particularly Washington native fish species. Prompted by the failure of a commercial net-pen system in August 2017, Washington rules toward Atlantic salmon aquaculture have changed. Leases for aquatic lands will no longer be granted for non-native species culture, and all of the operating Atlantic salmon farms will be phased out over the next several years, as current leases expire. This section describes Washington policies surrounding Atlantic salmon health and some of the methods used by the commercial producer in Washington to prevent or manage diseases. Further information about some pathogens of concern is presented in Table 3.4a.

⁶⁵ The Pacific Northwest Fish Health Protection Committee (PNFHPC). <https://pnfhpc.wordpress.com/about/> Accessed 14 January 2019

⁶⁶ Department of Fisheries and Oceans Canada. Search Aquaculture Farmed Species. <http://www.dfo-mpo.gc.ca/aquaculture/farmed-elevage/listing-eng.htm> Accessed 14 February 2019

Table 3.4a Pathogens of concern for net-pen aquaculture in the Puget Sound

| Pathogen | Present in Puget Sound | Additional information |
|--|-------------------------------|---|
| Pathogens regulated by State or Federal Law, or International Agreement | | |
| Infectious hematopoietic necrosis virus ^{1,2} | Y | Severity of the associated disease is influenced by location, virus type fish species and life stage |
| Infectious pancreatic necrosis virus ¹ | Y | There is an active surveillance effort by WDFW |
| Infectious salmon anemia virus ^{1,2} | N | This presence of this virus has never been confirmed in Washington or British Columbia. There is an active surveillance effort by federal, state, and provincial governments in PNW |
| <i>Oncorhynchus masou</i> virus ¹ | N | There is an active surveillance effort by WDFW |
| Viral hemorrhagic septicemia virus ^{1,2} | Y | There is an active surveillance effort by WDFW |
| <i>Gyrodactylus salaris</i> ² | N | The presence of this parasite has never been confirmed in the Pacific Northwest |
| Pathogens encountered in Puget Sound or under surveillance | | |
| Piscine reovirus (PRV) | Y | Several “genogroups” of PRV exist. PRV has been found in farmed and wild salmonids in the Salish Sea, but is not clearly associated with HSMI. |
| <i>Tenacibaculum maritimum</i> | Y | “Yellowmouth” |
| <i>Flavobacterium psychrophilum</i> | Y | Cold Water Disease |
| <i>Piscirickettsia salmonis</i> | Y | Salmonid Rickettsial Syndrome |
| <i>Vibrio anguillarum</i> and <i>V. ordalli</i> | Y | Vibriosis |
| <i>Aeromonas salmonicida</i> | Y | Furunculosis |
| <i>Renibacterium salmoninarum</i> | Y | Bacterial Kidney Disease |
| <i>Caligus elongates</i> and <i>Lepeophtheirus salmonicida</i> | Y | “Sea lice”. The salinity of many areas in Puget Sound is below optimum for sea lice, so they are rarely problematic. However, fish in pens are actively screened for them. |
| <i>Neoparamoeba</i> spp. | Y | Amoebic Gill Disease. <i>S. salar</i> tend to be more susceptible |
| <i>Nucleospora salmonis</i> | Y | |
| ¹ Pathogens regulated by WAC 220-370-050 or listed by the Fisheries Co-Managers of Washington State (FCWS 2006) | | |
| ² Notifiable pathogens listed by the World Organization for Animal Health (OIE 2018) | | |

In May 2018 WDFW released a draft document: *Surveillance and Monitoring Program for Commercial Atlantic salmon Marine Net Pens*, which outlines a program to provide consistency in guidance and requirements for commercial as well as other state, federal, and tribal agencies rearing fish in Washington. Additionally, it is consistent with USDA Animal and Plant Health Inspection Service (APHIS) Commercial Aquaculture Health Program Standards (CAHPS) and the National Aquatic Animal Health Plan of the U.S. It describes a monthly and annual surveillance program, and it suggests threshold morbidity and mortality rates to initiate investigation by a fish health specialist.

The plan was designed in part to assist Atlantic salmon farmers develop management plans, some of which are conditional requirements in farm operating permits. Management plans required by WA State agencies for permitting Atlantic salmon net pens include:

- Monthly monitoring plan
- Annual surveillance plans
- Biosecurity plan
- Disease containment plan
- Escape prevention plan
- Escape reporting and recapture plan
- Employee training

Though this list was created specifically for Atlantic salmon, the adherence to national standards indicates the contents could likely be applied to any other species cultured in marine net pens.

Currently, the company operating Atlantic salmon net pen sites in Washington does not use local brood stock; rather, eggs are sourced from a breeder in Iceland. There are state and federal regulations designed to protect native wildlife from foreign pathogens. In Washington, these regulations are enforced by WDFW through the Fish Transfer and Import permit requirement. These permits are only granted after eggs are thoroughly screened and the brood stock are confirmed to be free of pathogens.

The Atlantic salmon brood fish used to supply eggs to the commercial producer in Washington are raised entirely in captivity. Each year class population is subsampled at least annually during the four year rearing process and screened for viral pathogens.⁶⁷ At spawning, all (100%) of brood fish (males and females) contributing to the egg sale are screened for the same viral pathogens.⁶⁸ WDFW also requires:

- 1) Eggs are iodine disinfected prior to entering the hatchery building,
- 2) Eggs are kept in a quarantine building during incubation through start feeding,

⁶⁷ OMV, VHS, IHN, IPN and other pathogens that are not listed in the Title 50 requirements such as ISA, SAV/PD

⁶⁸ This is above what the requirements are to meet Title 50 Certification and is an additional requirement by Washington Dept. of Fish and Wildlife for the approval to import eggs.

- 3) The effluent water used on the eggs and fish is sterilized before discharge, and
- 4) At approximately 30 days post hatch (swim-up fry), 150 fish from the population are collected at the facility by an American Fisheries Society (AFS) certified fish health specialist, USDA accredited aquatic animal health inspector, or AFS certified fish pathologist and sent to a laboratory to be screened for regulated viral pathogens on cell culture lines as well as PRV and ISAV.

The viral screening results must be negative for the fry to be moved out of the quarantine building. When fish reach smolt size, another viral assay occurs on the smolt population. Negative results are necessary for the approval of the WDFW Transport permit from the hatchery to the seawater site.

Experience reveals Atlantic salmon in net pens are susceptible to the same parasites as native fish species (Figure 3.4b). To help protect Atlantic salmon from contracting a disease once in the net pen, juvenile Atlantic salmon are vaccinated against bacterial and viral diseases which have historically been problematic in Puget Sound net pens (vibriosis, furunculosis, and IHNV) (K. Bright personal communication October 12, 2017).

Figure 3.4b Infectious hematopoietic necrosis virus

Infectious hematopoietic necrosis is a serious disease of salmonids in captive and wild populations (Traxler et al. 1993). IHNV is naturally occurring in most Pacific watersheds from Alaska to California that contain salmonids. There are three major subgroups of IHNV, designated U, M, and L because they occur in the upper, middle, and lower parts of the IHNV geographic range². Each genogroup can infect multiple fish, though they show some host specificity.

The virus is transmitted from parent to offspring (vertical) or through waterborne exposure (horizontal). IHNV particles can be introduced to new locations by water currents or by sharing farm equipment between sites without disinfection. The latter can be controlled with biosecurity measures, which are currently implemented at salmon production sites in Washington. It is also feasible to develop risk assessments for waterborne transmission between farm sites (Foreman et al. 2015).

In 2012, an outbreak of IHNV occurred at an Atlantic salmon farm in Puget Sound (Rich Passage). The public was concerned Atlantic salmon would amplify, make more virulent, and shed virus particles putting native salmon at risk if they swam past net pens. During the course of the outbreak, WDFW ordered the fish from the affected facility be removed from the water. In this case, it is highly likely IHNV was transmitted from free-ranging sockeye to Atlantic salmon. The clade of IHNV that caused the disease is highly virulent in sockeye (UP clade). This strain of the virus is endemic to Puget Sound and has low virulence in Chinook, steelhead, and chum. Later evaluation by WDFW indicated there is low risk for Chinook, steelhead, or chum populations to be negatively affected by the occurrence of IHNV in Atlantic salmon net pens (Warheit 2017).

IHNV is a regulated pathogen, and Atlantic salmon are tested for it prior to transportation into or within the state (ibid). It is highly unlikely Atlantic salmon will introduce an exotic strain of IHNV because there are multiple instances of screening for pathogens before the fish can be transferred to net pens, including testing 100% of the brood fish that contributed eggs. Current industry vaccinates Atlantic salmon for IHNV before transfer to net pens.

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3.5 Feeds

Finfish aquaculture economic, environmental, and societal sustainability are linked to the dependence on feed. How feed ingredients are produced along with operational practices influence the extent and severity of aquaculture interactions with local and global ecosystems. The production and manufacture of feed and feed ingredients can have economic impacts at the regional or national level. Feed ingredients and feeding practices play significant roles in product marketability and business profits. Interactions with the water column (Section 3.3), the benthos (Section 3.2), and other marine organisms associated with feed (Section 3.9) are discussed elsewhere in this document. Here we discuss ingredient sustainability, new (alternative) ingredients and trends, impacts to other users, and feeding practices. Finally, we include information specific to the marine net-pen industry in Washington State.

3.5.1 Ecological Sustainability

Concern has been raised about the ecological sustainability of using aquaculture feeds that contain fishmeal and fish oil (Naylor and Burke 2005). The main sources of fishmeal and fish oil are wild forage fish, including anchovies, herring, and menhaden, among other species. It was anticipated as the aquaculture industry grew, the demand for fishmeal and fish oil would result in increased harvest of forage fish to unsustainable levels (Naylor et al. 2009). Forage fish are an important lower trophic part of the marine food chain and sustain large predatory fish, marine mammals, and birds. Thus, the concern is forage fish overharvest for aquaculture feed production may have far-reaching detrimental effects on the ecosystem. Since 2016 the commercial harvest of forage fish on the west coast of the U.S. has been regulated to reduce impacts on higher trophic levels in the ecosystem.⁶⁹

Another concern about sustainability of fish feeds containing large amounts of fishmeal and fish oil is the overall efficiency of feeding wild fish to farmed fish. The primary concern is if culturing carnivorous marine finfish could lead to a net decrease in marine fish available for human consumption. In the early days, culture of carnivorous fish was a net fish consumer and not a net fish producer. Aquafeeds for salmon, for example, often contained 35-40% fishmeal and 25% fish oil. Currently, because of improved knowledge of nutrient requirements and advanced feed processing equipment, most salmon diets contain approximately 15% fishmeal and 8% fish oil (Seafish 2016). This reduction in fish-based feeds leads to a net increase in fish production.

An additional argument raised against wild-sourced ingredients is that forage fish should be used for direct human consumption, rather than being reduced to fishmeal and fish oil. Thus, the overall socioeconomic concern is that aquaculture consumes more fish than it produces, and thus, is not providing a net benefit to human nutrition on a global scale.

⁶⁹

https://www.westcoast.fisheries.noaa.gov/newsroom/2016/01_noaa_proactively_protects_commercial_fishing_on_several_species_of_forage_fish.html

3.5.2 State of the Science

Opportunities for alternative ingredients

The aquaculture industry has used more efficient diets and reduced their dependence on fishmeal and fish oil by using alternative ingredients. Global aquaculture has expanded at approximately 8% per year for the last 30 years whereas fishmeal and fish oil production has not changed and forage fish harvest has remained relatively stable (Froehlich et al. 2018b). Aquaculture still uses approximately 70% of the global production of fishmeal, but future expansion of the industry is not dependent on greater harvest of forage fish (Froehlich et al. 2018b).

The fish in fish out ratio (FIFO) is a way to explain how wild fish use in aquaculture feeds relates to harvested biomass (Tacon and Metian 2008). If the FIFO ratio is above 1:1 then the operation is a net user of fish. In some aquaculture operations, the ratio of wild fish in to farmed fish could range from two to three or more wild fish in to farmed fish out (Tacon 1997). For the salmon aquaculture industry the proportion of marine ingredients in salmon feed has gone from 90% in the 1990s to 30% in 2013 (Ytrestoyl et al. 2015), and the proportion of marine ingredients continues to decline. The FIFO ratio for Norwegian salmon farming has dropped significantly from 4.4:1 in 1990 to 0.7:1 in 2013 (Ytrestoyl et al. 2015). Thus, salmon aquaculture is now a net fish producer (Ytrestoyl et al. 2015).

Fishmeal and fish oil are not nutritionally required for farmed fish to grow. Fishmeal and fish oil were preferred ingredients in fish feeds because they contain nutrients in perfect balance, are easily digested, result in good growth and health, and provide human health benefits. Scientific, technical, and management advances in the last several decades have significantly improved efficiency of aquafeeds and reduced the reliance on fishmeal and fish oil by providing alternative ingredients that are both cost effective and maintain nutritional value of farmed fish (Rust et al. 2011). Alternatives for fishmeal as a protein source and fish oil as a fat source in feeds include soybean, rapeseed oil, oil seed meals, nut meal, leaf meal, rice and wheat protein, microalgae, seaweed, insects, animal processing wastes, animal processing by-products, and fish wastes, among others (Teves and Ragaza 2016). Formulated feeds with no fishmeal or fish oil have been shown to support good performance and growth of a number of culture species (Rust et al. 2014). Non-salmonid marine species being produced at relatively small scales in the U.S., as well as species under investigation for commercialization, will often demonstrate FIFO ratios above 1:1 (Rust et al. 2014). In such instances diets may contain higher fishmeal and fish oil percentages than what is found in salmonid diets, or the growth rates have not been optimized requiring higher amounts of feed used during production.

Feed ingredients impact the marketability of the final product. For example, certain markets will not accept fish that have trace amounts of land animal byproducts in their feed. FIFO ratio is an important factor in an operation obtaining a sustainable seafood certification label. The FIFO value might vary depending on the type of fish being cultured (show examples of what is required for salmon versus something else). The use of genetically modified crops in fish feed can also dictate whether or not buyers will purchase the fish.

A balance between feed price and feed quality is an important consideration for the aquaculture business. Fish feeds usually account for approximately 50% of the commercial salmon farm operational budget, so a small change in fish feed usage or price can have a great impact on profitability. Feed manufacturers look for least-cost formulations based on available ingredients, and must balance feed quality and price with fluctuating availability of commodities. As alternative sources of aquaculture feeds expand, selective breeding programs for cultured species that would better tolerate plant-based meals and oils may be developed. There is evidence that some strains of trout show better growth performance than others consuming alternative feeds (Abernathy et al. 2017).

Feeding management

In the early days of commercial salmon farming, staff hand broadcast feed on the surface of the net pens until surface fish feeding activity was visibly reduced. The observed surface feeding behavior was not a reliable indicator of how fish were feeding deeper in the pen or how much uneaten food was passing through the net. This sometimes leads to significant feed loss (up to 20% (Braaten et al. 1983)) leading to negative environmental effects and reduced profits. Currently fish farms use cameras submerged in the pens to monitor feeding activity (Nagarajan 2017). Divers will also observe feedings where conditions allow. In larger salmon farming operations, operators monitor cameras and control feed rate with handheld electronic tablets with wireless connection to a computer-regulated feed dispenser. Feed wastes are nearly eliminated because feed delivery is curtailed before uneaten feed can pass through the net. Additional environmental monitors of temperature, current, and oxygen can be used to regulate feeding rate, reduce feed wastage, and improve feed conversion.

Ecological impacts of demand for fish feed ingredients

There is little evidence human consumption will transition to forage fish presently used in feeds (Freon et al. 2014, Hannesson 2015). Culture, dietary preferences, and market forces affect seafood preferences. Except for herring, it is doubtful that sizeable markets for direct human consumption versus fishmeal production can develop for anchovy and menhaden, among other forage fish species (Freon et al. 2014, Hannesson 2015). Furthermore, even if all forage fish production (20-30 million metric tons annually) was channeled to direct human consumption, it would not be sufficient to meet a projected seafood demand of 200 million metric tons by 2050 (Froelich et al. 2018b).

Trends in usage and production

Fishmeal and fish oil are global commodities (Freon et al. 2014, Froehlich et al. 2018b). Production of fishmeal and fish oil is mainly from Peru, Chile, Scandinavia, the United States, and Japan. China is largest importer of fishmeal. Salmonid aquaculture in Europe and Chile, is the largest user of fish oil (Cao et al. 2015, Chatvijitkul et al. 2017). Fishmeal and fish oil prices have increased dramatically since the 2000's (Tacon and Metian 2015), and the high price is a primary motivation for incorporation of alternative ingredients in fish feeds. Salmon feed consists of protein, fat, carbohydrates, pigments, and micronutrients. Feed manufacturers rely on

least-cost formulations based on available ingredients. As prices for fishmeal and fish oil increase, alternative ingredients are used to match the requirements for percentages of crude protein, fat, fiber, ash, and moisture for a particular species.

The use of fish oil as a nutritional supplement for direct human consumption has contributed to the price increase (Misund et al. 2017). Consequently, fish oil inclusion in salmonid feeds has gone from 25% of the diet to 12% from 2000 to 2014. In the Norwegian salmon aquaculture industry, rapeseed oil has replaced fish oil so total fish oil consumption has remained at 2,000 metric tons, despite a doubling in salmon production. However, the decline in fish oil use in aquaculture results in lower levels of healthy omega-3 fats in salmon. Future increases in farmed salmon may drive down omega-3 content unless fish oil prices decline or economically feasible substitutes with high omega-3 fats (algae, yeast, bacteria, among others) are found, which seems promising (Bairagi et al. 2017, Shepherd et al. 2017).

Although there are many alternative ingredients for aquaculture feeds, they differ in suitability, nutritional profile, scalability of production and price, and environmental impacts (Pelletier et al. 2018). Furthermore, some of these feed ingredient attributes are dynamic in terms of price and availability, which is a challenge for industry, planners, and policy makers.

The role of feed in fish health

Nutritional deficiencies may compromise fish growth, immune function, and resistance to disease (Pelletier et al. 2018). Some alternative feed ingredients may contain antinutritional factors⁷⁰ that need to be removed when those meals are used to substitute for fishmeal (Rust et al. 2011). For example, at higher rates of inclusion (35% - 40%) soybean meal can negatively affect rainbow trout and Atlantic salmon because lectins and trypsin inhibitors are present (Hart et al. 2008). Viable alternative ingredients must have a suitable amino acid profile, required fats, high digestibility, and acceptable palatability.

Using functional feeds/medicated feeds

Beyond providing the minimum energy requirements for fish to grow, recent research in the field of immune-nutrition has indicated the fish's immune system may be enhanced during times of stress or infection through the inclusion of various nutrients in their diets (Pohlenz and Gaitlin 2014). Such diets are termed functional feeds, and may include compounds such as probiotics, beta glucans, or vitamin C. Several commercial aquaculture feed manufacturers produce these diets for a variety of fish species and life stages.^{71,72,73} Importantly, although the U.S. Food and Drug Administration (FDA) regulates animal feed ingredients, it does not validate any of the

⁷⁰ Substances that when present in animal feed or water reduce the availability of one or more nutrients.

⁷¹ <https://www.skretting.com/en-CA/research--innovation/#>

⁷² <https://www.cargill.com/animal-nutrition/species/feed-additives>

⁷³ <http://www.zeiglerfeed.com/Literature/FinFish%20Vpak.pdf>

health claims made about additives. Medicated feeds (discussed in more detail in Fish health and disease management (Section 3.4) are used sparingly and usually as a last resort in attempts to reduce mortality due to bacterial epizootics. Vaccinations for specific diseases are preferred as preventative measures. The use of antibiotics in feeds has declined substantially in Atlantic salmon culture in Norway and Canada.⁷⁴

Atlantic salmon considerations

Atlantic and Pacific salmon have basically the same nutritional requirements, although minor modifications in diet formulations are often made. Atlantic and Pacific salmon have been grown successfully on diets containing no fishmeal and minimal amount of fish oil, with acceptable growth and performance (Rust et al. 2014, Davidson et al. 2016). One goal of commercial salmon production is to use fish oil for finishing diets to take advantage of the high capacity of salmonids to retain healthy omega-3 fatty acids that provide human health benefits. Alternative sources of healthy omega-3 fatty acids are being explored.

Native species considerations

Commercial sablefish culture currently uses diets comparable to salmonids (W. Fargrieve, personal communication, January 29, 2019). Sablefish nutrition is still the subject of research, and optimal diets containing a range of alternative ingredients need to be determined. Similar to salmonids, sablefish have a high capacity for retention of heart-healthy omega-3 fatty acids.

3.5.3 Washington specificity

Specific details related to how feed can affect water quality or benthic sediment can be found in Section 3.2 Benthic effects and Section 3.3 Water quality.

⁷⁴ <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/therapeut/index-eng.html#antibacterials>

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3.6 Biofouling prevention and management

Any industry operating in the marine environment contends with biofouling⁷⁵: the colonization of in-water nets, line, floats, and other infrastructure with marine organisms (e.g. mussels, anemones, kelp). This section is an overview of the effect of biofouling on net-pen facilities, an introduction to materials and techniques for biofouling management in aquaculture, and recommendations for effective biofouling management. This information is not exhaustive as new materials and equipment are being developed constantly for use across the maritime industries.

The environmental impact potential as well as the recommendations are general and provide guidance to evaluate site-specific scenarios. How a facility manages fouling is dictated by several factors including:

- Local regulations pertaining to chemical use and in situ cleaning
- Farm site characteristics such as depth and current
- Labor costs
- Product marketability – retailers and certification bodies have specific requirements regarding antifoulant coatings. Some buyers may not purchase fish that have been grown in net pens with copper coatings.
- The makeup of the fouling community and the colonization rate and seasonality

3.6.1 State of the Science

Effects of fouling

Fouling of infrastructure is a concern for any industry working in the marine environment, and net-pen aquaculture is no exception. Fish health, infrastructure integrity, and environmental impacts are directly influenced by biofouling growth. Net pen cleaning must occur frequently and regularly as biofouling grows constantly. Once certain organisms such as mussels become established they are very difficult to remove (Clark et al. 2017).

Fouling growth on the nets is of particular concern because it impedes water flow through the pens. This process is commonly referred to as “occlusion,” and diminishes water quality within the pens, with the greatest impact on dissolved oxygen availability. Without sufficient dissolved oxygen, the health and growth rates of the cultivated fish are negatively impacted. Additionally, fouling is strongly correlated with the drag on net pens due to tidal currents. The increased drag can, at minimum, deform cages (Lader et al. 2008) and stress infrastructure, or worse, cause failure of the net pens or other components. Highly deformed nets can increase structural stresses on areas of the pens that are not designed to withstand such forces. In 2017, one of the

⁷⁵ Inorganic fouling (such as corrosion) will not be discussed. The terms biofouling and fouling are used interchangeably here.

commercial Atlantic salmon net-pen systems in Puget Sound collapsed. The collapse led to the release of over 250,000 fish, prompting state agencies to launch an investigation into the cause. Failure by the operator to adequately control biofouling was determined to be the primary cause for the failure (Clark et al. 2017). A study in the northeastern U.S. found the drag on fouled nets can be three times greater than that on clean nets (Swift et al. 2006). Reports of fouling biomass range from 7g/m² on nets with antifoulant coating to 4.9kg/m² on untreated nets.

Adverse impacts to benthic sediments due to organic enrichment or accumulation of anti-fouling compounds is a concern (Burrige et al. 2010). In situ net pen cleaning in poorly flushed sites results in the accumulation of dislodged fouling organisms on the benthos. The abrasive nature of in situ cleaning techniques can also cause antifoulant coatings to slough off and accumulate in the sediment (Nash 2003).

Certain organisms that make up the biofouling community may be pests or vectors for pathogens. The structure and increased surface created by fouling growth can become habitat for certain parasites (Fitridge et al. 2012). The risk posed by these scenarios depends on the species of cultured fish and the presence of pathogens in the area. Capsalid monogeneans (ectoparasitic marine flatworms) are known to infect many warm water marine species that are grown in net pens. Tendrils on the eggs of these external parasites get caught in biofouling. When the eggs hatch, the larval pathogens infect the fish. Some sessile cnidarians (hydroids) can colonize net pens and sting fish or farm workers (Baxter et al. 2012).

Net-pen facilities have been implicated in the spread of invasive species. Invasive species can use aquaculture structures as stepping stones, enabling invasive organisms to spread further and faster than if no structure existed. If an invasive species is part of the fouling community, it can proliferate on the available structure, then be dispersed by cleaning activities (James and Shears 2016, Belle and Nash 2008). However, this is not unique to aquaculture; marinas, navigation aids, boats, and fishing gear also provide structure for or act as a pathway to invasive species spread (NOAA Marine Debris 2017).

Fouling is not entirely negative. Net-pen facilities also can be colonized by rare or desirable native organisms. For example, commercially desirable seaweed species have been documented on Puget Sound net pens in Washington. Nutrients released from the farmed fish may be integrated into the tissue of some fouling organisms, indicating nutrients may be sequestered within the vicinity of the farm (Rensel and Forster 2007). This can mitigate the potential for nutrient enrichment elsewhere, particularly if the fouled nets are removed and cleaned at an upland facility.

Control methods

Biofouling control focuses on nets, both stock nets and predator exclusion nets, rather than on floats or lines. This is because the relative area is far greater and because it is biofouling on nets that can adversely affect fish health.

Biocide based coatings

Historically, the aquaculture industry has borrowed anti-fouling technologies from other marine industries that use chemical compounds. Paints impregnated with biocidal compounds are the most common. These paints leach biocidal compounds such as heavy metals and organic biocides onto the surface, producing a thin, toxic layer, which prevents the onset of biofouling. However, many of the chemicals and heavy metals used are recognized as harmful to marine ecosystems (Fitridge et al. 2012).

Copper-based coatings are the most commonly used antifoulant in aquaculture because copper is effective in preventing or delaying the colonization of algae, molluscs, and crustaceans (Burridge et al. 2010). For example, after eight months of immersion at a British Columbia salmon farm, the biomass on nets treated with a copper-based antifoulant coating was 7 g/m². The biomass on untreated control nets was 604 g/m². Similarly, after 10 months immersion on a Scottish salmon farm, the biomass of fouling on untreated netting was 4.9 kg/m², compared to 1.6 kg/m² on treated nets (Braithwaite et al. 2007, Edwards et al. 2015).

Other pesticides such as Diuron, Irgarol 1051, and isothiazolinones are used as antifoulant coatings in other marine industries and preliminary research into their efficacy in aquaculture has been undertaken (Svane 2006, Bazes et al. 2006, Guardiola et al. 2012, Kaonga et al. 2015). These products have been successful in decreasing the amount of fouling when compared to untreated control netting, though are not as effective as copper-based treatments. Regardless, these are toxicant-based compounds and ultimately their use has potential to negatively impact the surrounding environment. Any antifoulant product that contains a pesticide would need to be approved for use by the EPA as well as other regulatory authorities (see Section 2.4 Legal authorities and legislation).

Non-biocide based coatings

Hodson et al. (2000) found treating nylon net with a silicon-based coating significantly reduced the weight of fouling organisms present after a 140-day immersion at a Tasmanian salmon farm. Organisms that grew on the silicon coating were easily removed by spraying water on the nets at a low pressure (Hodson et al. 2000). One of the disadvantages of silicon-based coatings is its lack of abrasion resistance. Two wax-based coatings were compared in a study by Edwards et al. (2015) and were found to be ineffective at preventing fouling.

Net materials

Nets make up most of the surface area (about 90%) available for colonization by fouling organisms at a net-pen facility (Rensel and Forster 2007); therefore, the type of net material is integral to fouling management. There is a wide variety of net material available for use. Traditionally, nets in salmon farming were either steel or nylon, but adaptations from other industries have led to new material choices that aid in fouling management either through their structure or chemical composition.

In recent years, copper alloy mesh (CAM) nets have been installed at commercial and research facilities in several countries to test the efficacy and the impact of copper levels to the surrounding environment (Chambers et al. 2012). The proposed advantage of CAM nets was that they resist corrosion, ripping, and degradation; deter fouling; and require less cleaning and diver maintenance (Ayer et al. 2016). The material prevents or slows the growth of fouling organisms, resists tearing by storms or predators, and decreases labor costs (Chambers et al. 2012, Ayer et al. 2016).

Chambers et al. (2012) and Kalantzi et al. (2016) demonstrated that CAM nets do not cause increased levels of copper in the tissue of the fish inside the pens. A life cycle analysis published in 2016 by Ayers et al. stated the use of CAM could result in a more cyclical and sustainable use of copper in the aquaculture industry relative to the one-time use and permanent loss of copper used in anti-fouling paints for nylon nets. Although it appears efficacious in preventing fouling, the cost of CAM, the cost of the additional infrastructure necessitated because of its weight, and the negative perception of copper as a toxicant are cited as negative aspects of CAM (Fitridge et al. 2012).

Polyethylene terephthalate (PET) monofilament is a rigid smooth monofilament used in fish cage construction. One brand has been approved for use in aquaculture according to Norwegian Standard 9415 - NS9415, to stay in the water for up to 14 years. The smooth surface of the monofilament, compared to a woven fiber provides less surface area for organisms to settle. Those that do settle appear to be easier to remove.⁷⁶ One manufacturer claims that the strength of the material makes it resistant to damage from cleaning (compared to nylon net)⁷⁷.

High-performance polyethylene fiber (HPPE) is a fiber that looks similar to nylon, but it differs because of its exceptional strength, and has been gaining popularity as a material for net pens (Cardia and Lovatelli 2015). An HPPE net was found to have significantly less fouling growth than an untreated control in a study by Edwards et al. (2011) in British Columbia.

Cleaning nets in situ

If permitted, in situ cleaning can cause a temporary increase in turbidity and potentially impact the benthos at shallower sites but not cause measurable impacts at deeper sites with high current. Cleaning is accomplished by abrasion or a high pressure water stream to remove the fouling. Either of these can be done manually by divers or with mechanized cleaning systems specifically designed for use on net pens. These systems range in size from being small enough to be operated by one person, to large enough that a boom crane is required.⁷⁸

The effectiveness of various cleaning techniques and machines vary. In Washington, current industry practice is to use several types of machines and larger, more automated machines. Cleaning effectiveness also appears to vary depending on mesh size, with some machines being

⁷⁶ KikkoNet Fish cages. Available at: http://kikkonet.com/net_pens.php Accessed 17 January 2019

⁷⁷ Final Environmental Assessment for the Expansion of Blue Ocean Mariculture, Unualoha Point. 2015

⁷⁸ AKVA Group, Net Cleaning Systems. Available at: <http://www.akvagroup.com/products/cage-farming-aquaculture/net-cleaning-systems> Accessed 22 July 2017

more effective on larger mesh nets than others. As discussed above, cleaning effectiveness varies depending on the species mix, with some fauna such as older mussels being particularly challenging to remove from smaller mesh sized nets.

For a detailed examination of the different types of cleaning machines and the challenges of keeping them operating, please see the chapter on biofouling in the *2017 Cypress Island Atlantic Salmon Net Pen Failure: An Investigation and Review* (Clark et al. 2017).

Some net pen designs allow operators to lift portions of nets out of the water to dry (shortening the nets). As the fouling organisms dry some fall off of the net. This technique is most effective when performed regularly. The heavier the fouling, the longer it takes the net to dry. Because the entire net pen can't be cleaned this way, drying is often integrated into a fouling management plan along with other techniques or materials.

Changing nets

In Washington, the current NPDES permits require that after harvest, nets be cleaned at an upland facility where fouling waste and water is collected. This method virtually removes impact to the surrounding environment associated with cleaning (sedimentation, noise). Also important, removing the nets breaks pathogen cycles and effectively fallows the farm. Given the growth rates of biofouling organisms, changing nets is not a viable management tool by itself as it would necessitate net swaps as frequently as monthly during summer months. Net swaps, however, are a cost-effective remedy in the case of heavy biofouling or biofouling of a size or type that cannot be cleaned in situ. Some cages are designed specifically for nets to be changed while fish are inside. A clean net is installed then the fouled net is removed. When done properly net changing minimizes the amount of fouling and chemicals potentially released into the environment.

Another way in which changing nets during grow out can help manage biofouling is to change nets once or more to increase mesh size as fish size increases. For example, in the recent past, the Washington state net pen industry has used smaller mesh size when the fish are smaller and swapped the initial grow out net for a final grow out net with larger mesh size once the fish reached a given size. This has two benefits: 1) it “re-sets” the level of biofouling to zero as a clean net is put in the water and 2) nets with larger mesh are generally easier to clean and create less drag when biofouled.

Risk of bioaccumulation and indirect effects of biocidal antifoulants

Any biocidal antifouling should be used with caution, as the nature of their efficacy means that they have the potential to harm organisms nearby. Persistence of antifouling compounds in the sediment near finfish net pens is well documented. Guardiola et al. (2012) provided a review of the environmental effects of many anti-fouling compounds used in fish farming that includes their use, mode of action, and effect on aquatic organisms. Many of these compounds induced embryo toxicity to teleosts and echinoderms, while others were immunosuppressive or teratogenic to exposed organisms.

An overview of sediment monitoring near Canadian and Scottish net-pen facilities reported the presence of salmon farms correlated with increased copper in the sediment (Burridge et al. 2010). Copper in sediment surrounding a Scottish farm was elevated from background levels ~300m in the direction of the prevailing current (Dean et al. 2007). The rate of copper released from antifoulant paints is affected by water temperature, current speed, speciation, and frequency of net scrubbing (Guardiola et al. 2012). The chemical form of copper in the environment and consequently its toxicity is dependent on pH, salinity, alkalinity, and presence of organics in the sediment (Brooks and Mahnken 2003).

Kalantzi et al. (2016) examined the environmental effects of a CAM fish cage and a conventionally treated (coated with copper-based antifoulant) net cage for one year at a commercial SeaBream farm in Greece. During the first six months of cage deployment the CAM net seemed to release more copper to the surrounding environment and affect the biota more (elevated copper concentrations in muscle tissue and fish tissue) than the conventional net. However, at the end of the experimental period, equilibrium was reached in the copper alloy net cage with similar values of dissolved copper and copper in organisms as the conventional net cage. The author noted that at no time did copper levels in the environment or in the edible animal tissue reach the levels deemed unsafe by the European Union. No effect from copper on the sediment was detected.

Copper persistence in the sediment under net-pen sites can negatively impact benthic organisms (Burridge et al. 2010). The presence of copper in sediments changed the burrowing behavior of clams (Burridge et al. 2010). Nikolaou et al. (2014) found higher levels of copper in sediment near fish farms in the Mediterranean, though the levels in fish muscle tissue were within safe limits. The chemical forms of copper in aquatic environments are maintained in a dynamic state of equilibrium influenced by salinity, temperature, pH, alkalinity, dissolved oxygen, sediment physicochemical characteristics, and the presence of other inorganic and organic molecules (Brooks and Mahnken, 2003). Larval fish may be directly impacted by levels of copper in the water column, but this does not always hold true for adult fish (Solomon 2009). The bioavailability of copper depends on speciation and is a function of fish size and metabolism. Bioaccumulation of copper in fish tissue is regulated physiologically and is species specific (Guardiola et al. 2012).

In an effort to minimize net-pen aquaculture environmental impact, many facilities are changing the way antifoulant coatings are used, if they are being used at all. Sustainable seafood certification bodies such as the Global Aquaculture Alliance (Best Aquaculture Practices) and the Aquaculture Stewardship Council have specific language dictating how nets treated with a toxicant (copper or other) based antifoulant be maintained to prevent the coating from being leached into the environment.

3.6.2 Washington Specificity

An extensive evaluation of the fouling community at a Puget Sound net-pen facility in 2004 and 2005 described the variety of organisms present and estimated the total mass (Rensel and Forster 2007). Over 100 species of organisms including macroalgae, invertebrates, and fish had

colonized the farm infrastructure. The maximum biomass in the summer of 2005 was estimated to be 55.6 metric tons. The authors described that the net pens created a floating reef with high biological diversity. Stable isotope analysis of nitrogen and carbon in fouling organisms at the fish farm and at a reference area indicated fouling biota provided some degree of nutrient trapping of waste carbon and nitrogen, and were part of the local food web. Colonization rates were seasonally dependent: fastest in spring and slowest in winter. The species assemblage differed among structures (nets, floats, anchor lines). Other factors influencing the distribution of organisms around the farm were exposure to sunlight and presence or absence of antifoulant coatings (Rensel and Forster 2007).

Management of biofouling on the nets, referred to typically as “net hygiene,” consists of two types of cleaning:

- Cleaning of nets between 18-month grow out cycles. During the eight-week following period between crops, both the predator exclusion net (which consists of panels sewn together) and the individual stock containment nets are removed from the net pen array. The nets are sent to a company in British Columbia where they are washed in machines, strength-tested, repaired as needed, and disinfected. Typically, stock nets are used for three grow out cycles before being replaced.
- In-situ cleaning during the grow-out cycle. In-water cleaning of nets occurs on a regular, on-going basis year round.

Biofouling and in situ cleaning is seasonally driven. Growth rates of flora are directly correlated with sunlight availability and water temperature and are highest from late spring to early fall. Net cleaning is continuous during this time, with equipment allocated amongst farms such that it is always being used; once all the stock nets in a farm (which consists of multiple arrays except at Hope Island) have been cleaned, workers return to begin the process all over. This process results in stock net walls being cleaned once every three weeks during the peak biofouling growth period from May to September. The stock net floor panels are to be cleaned every five weeks or sooner depending on observations by staff. Growth of fauna varies somewhat by geography, with mussels common at the Cypress Island, Hope Island, and Rich Passage farms but less common at Port Angeles.

Net hygiene was a significant aspect of net pen operations at Cooke net pens prior to the August 2017 Cypress Island failure and became even more important thereafter. Beginning in late 2017, Cooke tested and committed to use of more capable net cleaning machines. In cooperation with DNR staff, in 2018, Cooke undertook improved record keeping of net hygiene activities and began assigning numerical scores to track the degree of biofouling. These scores were verified by DNR staff using randomly assigned video verification surveys. By the end of 2018, DNR staff concluded the monitoring and verification effort was working as intended to confirm the nets were being maintained in good order and repair, as required under the terms of the DNR leases.

Washington NPDES permit conditions require sediment testing if copper coatings are used on net pens. Copper levels in sediment must be lower than 390 mg/kg (WAC 173-204). Currently,

none of the existing fish farms in Washington use antifoulant coating on their net pens.⁷⁹ This was a management decision, not because regulation prohibits its use. The nets are removed from the water and cleaned at an upland facility. Routine monitoring conducted at all farm sites in Puget Sound during 2015 indicated the levels of copper in sediments near farm sites were below the regulatory threshold. Washington is requiring that recreational boats no longer use copper-based antifouling agents in paints (RCW 70.300.020).

⁷⁹ Personal communication, K. Bright Cooke Aquaculture Pacific. April 19, 2017.

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3.7 Sensitive habitats

3.7.1 State of the science

Estuaries

Estuaries are highly valuable ecosystems that support commercial and recreationally important fisheries, conserve wildlife, and protect endangered and threatened species. Estuaries are semi-enclosed, brackish bodies of water where rivers meet the ocean and include bays, sounds, inlets, river mouths, deltas, and lagoons. They are exceptionally productive, nutrient rich ecosystems that support a wide range of species at different life history stages and provide numerous ecosystem services (Nixon 1988, Costanza et al. 1995, Beck et al. 2001, Agardy et al. 2005). Processes affecting ecosystem structure and function include tidal mixing, sediment dynamics, river plumes, larger-scale climate patterns, and weather (Andrews et al. 2015). Ocean upwelling and downwelling significantly influence larger estuarine bodies along the coast. These systems are composed of various sediment types (e.g., gravel, sand, mud, or silt) which are affected by wave exposure, with sand flats replacing mud in areas with more wave energy. Freshwater inputs are highest in the winter and lowest in the summer.

Estuaries provide important habitat for marine and terrestrial species. Phytoplankton, benthic diatoms, benthic microalgae, macroalgae, eelgrass, kelp, salt marsh plants and terrestrial plants are the primary producers in these ecosystems, their distribution and abundance influenced by tidal elevation and salinity. Invertebrates include insect larvae, amphipods, polychaetes, burrowing shrimp, brittle stars, sea stars, sea urchins, and others (Skewgar and Pearson 2011). Fish and shellfish are abundant in estuaries and many commercially important species use them as nursery habitats for their larval and juvenile stages (Beck et al. 2001). Eelgrass beds and oyster reefs are important biogenic habitats within estuaries that provide ecosystem services to these species by creating three-dimensional structure, slowing water currents, dampening waves, and trapping sediments (Skewgar and Pearson 2011). Additionally, eelgrass beds locally ameliorate ocean acidification and influence dissolved oxygen levels (Groner et al. 2018). Oyster reefs circulate and clarify water, reduce hypoxia, and filter nutrients.

Potential impact of net-pen aquaculture

Estuaries can be impacted by anthropogenic activities including fishing, boating, dredging, stormwater runoff, coastal development, shoreline armoring, commercial shipping, and aquaculture. Pollution from nutrient loading, sedimentation, and chemical contamination impacts estuaries and compromises their ecosystem functions (Cloern et al. 2016). The magnitude and extent of net-pen aquaculture effects on estuaries depends on interrelated farm and physical environmental attributes (Stenton-Dozey 2013). The design, management, and husbandry practices of a farm determine the amount of dissolved nutrients and solid waste entering the water column. The number of farms in an area, number of fish per net pen, the feed conversion ratio, and the net pen design and orientation are the key farm attributes. These farm factors interconnected with water temperature, water depth, water residence time, and current speed,

affect the overall impact of the net-pen farm on the estuary. Water quality and trophic-level effects are multifaceted and can be mitigated or impactful depending on farm and physical environmental factors (Rust et al. 2014).

Dissolved inorganic nutrients are released into the water column directly as fish waste, or indirectly from remineralized particulate organic waste (Navarro et al. 2008). Nutrient enrichment from nitrogen and phosphorus can impact phytoplankton, microalgal and macroalgal production, as well as enhance the rate of bacterial heterotrophic activity which could reduce oxygen levels in the water column (Forrest et al. 2007). Phytoplankton species composition can change with altered nutrient ratios and harmful algal blooms can also grow and benefit from added nutrients. Excess organic waste can increase turbidity and reduce light penetration to photosynthetic species. The spatial extent and intensity of enrichment is site specific and net pens in deeper water with high flow rates will produce a more diffuse footprint (Forrest et al. 2007, Stenton-Dozey 2013).

Seagrasses

Seagrasses are vascular flowering plants that grow in submerged marine environments and form beds of leafy shoots in soft sediments of the intertidal and subtidal zone year round. They grow in calm bays and harbors as well as open coast regions. These plants fertilize and set seeds underwater and also spread through vegetative growth by rhizomes. These seagrass beds provide a range of ecological services, namely serving as an important marine habitat, nursery, feeding grounds, and shelter to fish and shellfish at different life stages (Phillips 1984). They perform a primary production role in the nearshore food webs, serve as an important food source for migrating birds, and provide habitat for epiphytes, microalgae, macroalgae, and invertebrates that attach to the leaves and are consumed by fish and sea birds. Seagrasses play an important role in reducing coastal erosion by trapping sediment, stabilizing the substrate, and reducing the force of wave energy (NOAA West Coast Fisheries, 2014). Seagrass beds are ranked among the most productive and valuable habitats in the biosphere (Costanza et al. 1997), are an important carbon sink on a global scale (Fourqurean et al. 2012), and have the ability to mitigate ocean acidification effects (Unsworth et al. 2012, Manzello et al. 2012, Hendricks 2014). Seagrass beds are able to reduce the relative abundance of pathogenic bacteria in the water column (Lamb et al. 2017) and algaecidal bacteria associated with seagrass leaves may impact the abundance of harmful algae in nearshore environments (Inaba et al. 2017, Christiaen et al. 2017).

Given their presence throughout inshore areas, seagrasses are susceptible to several anthropogenic stressors including physical disturbance, sedimentation, invasive species, reductions in water quality and photosynthetically active light, and nutrient and organic matter loading (Thom et al. 2011). Because of their vulnerability, seagrasses are effective indicators of ecosystem condition (Kenworthy et al. 2006, Orth et al. 2006). Global declines in seagrass beds have brought political and ecological attention to protecting these ecosystems (Duarte 2002, Orth et al. 2006).

Seagrass beds are usually found in clear water with high rates of advective exchange, areas which are also good for farming fish (Price and Morris 2013). When poorly sited, fish farms can

have negative impacts on seagrasses from sedimentation, nutrient loading, and therefore reduced water clarity (Cancemi et al. 2003, Dolenc et al. 2006). Organic loading can result in anaerobic sediment conditions and the accumulation of sulfides in root zones, both of which may be toxic to seagrass (Holmer et al. 2003, 2005). Increased primary production in seagrasses may occur at low levels of nutrient input, but a possible secondary increase in herbivore pressure may lead to an overall decrease in seagrass biomass (Price and Morris 2013). Net pen structures could also reduce the amount of photosynthetically active radiation (PAR) reaching the seabed and thereby reduce seagrass production (Keeley 2013).

Terlizzi et al. (2010) documented changes in macrofaunal assemblages in seagrass meadows due to fish farm effluent. Meadows heavily impacted by farm effluent showed a shift toward mollusk, gastropod, and polychaete species associated with muddy and organic rich sediment and stressed habitats. In a review by Pergent-Martini et al. (2006), the authors found fish farms contributed to a decrease in seagrass meadow surface area and cover, shoot density and size, leaf and rhizome growth and photosynthetic capacity, as well as increases in epiphyte biomass and leaf size. They recommended siting farms at least 200 meters away from seagrass beds in well-flushed, deep waters and include monitoring for early response. This recommendation corresponds to the effective area of impact on the benthos (Doglioli et al. 2004). The siting distance should be increased near the meadow's lower limit (more sensitive to turbidity than shallow water meadows) and varied depending on currents and the fish farm size.

Seagrass growth is greatly dependent on the availability of light and consequently the majority are found in subtidal habitats and shallow intertidal habitats down to a depth of 10 meters or less; although, some species can grow at 50-60 meters. The effect of net-pen structures on light availability is more likely to occur in temperate waters than tropical waters because they already have higher light extinction coefficients and shallower euphotic zones; however, the risk is presumed to be minimal (Nash et al. 2005).

Kelp beds and rocky reef habitats

Kelp are brown macroalgae that attach to rocky substrates and either float and form canopies or are submerged. Canopy-forming kelps in the Pacific Northwest are dominated by giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*) in the outer Strait of Juan de Fuca and coast, and bull kelp (*Nereocystis luetkeana*) in Puget Sound. There are 22 species of submerged kelp including *Laminaria spp.* and *Pteryogophora californica*. Worldwide, kelp provide an enormous amount of primary production in nearshore waters (Duggins et al. 1989, Mumford 2007). Because kelp is photosynthetic and unable to root in soft substrate, it requires high ambient light, hard substrate, minimum sediment, low marine water temperatures (<15°C), and moderate to high salinities (>25psu) (Druehl 1981). Kelp are confined to nearshore habitats and require moderate to high water velocities (Mumford 2007). The distribution of substrate material is influenced by nearshore processes involving sediment movement. Rocky reefs are included in the kelp forest habitat category because animals that inhabit kelp forests also inhabit shallow rock reefs without canopy-forming kelps. Rocky reefs form high profile rock outcrops colonized by organisms such as hydroids, macroalgae, abalone, sea urchins, sea anemones, sea stars, and other attached organisms.

The complex structure of kelp forests provides a nursery habitat, refuge, and forage area for a variety of fish, especially rockfish, sculpins, greenling, lingcod, perch, juvenile salmon, herring, and pinto abalone. Floating kelp provide surface habitat that dampens waves and provides foraging habitat for seals, sea otters, and sea birds (WA MSP 2018). The total extent of kelp surface canopy, area, and density affects the species assemblages found in this habitat. Kelp forests supply particulate organic matter and dissolved organic matter to the food chain. Decomposing kelp supports bacterial communities that fuel phytoplankton and benthic filter feeders in the near shore environments. Kelp breaks apart and sinks to the benthos and washes ashore, providing food for scavengers including crustaceans (Mumford 2007).

Kelp populations fluctuate seasonally depending on herbivore pressure, oceanographic conditions, and reproductive cycles. Changes in food webs negatively impact kelp if they result in increased grazing pressure (Vergés et al., 2016). A wide spread kelp deforestation quantified in the northern hemisphere was caused by sea urchin grazing (Steneck et al. 2002). Kelp production is impacted by both direct and indirect effects of high or low nutrient levels. Nutrient poor water associated with El Niño and nutrient rich waters associated with La Niña cycles control the growth cycles of kelp and therefore the amount of coverage in ocean waters (Tegner and Dayton 1991). Excess nutrients, primarily nitrogen, may cause eutrophication and hypoxia in estuarine systems and thus reduce kelp productivity. Light penetration is an important physical factor controlling kelp production. Light levels are often decreased by turbidity caused by eutrophication and suspended organics or by overwater structures such as piers, docks, moored boats, and net-pen aquaculture structures. In addition to compromised water quality, light reduction from net-pen structures could also impact natural kelp beds.

Shellfish beds

Shellfish beds formed by clams and oysters create three-dimensional biogenic habitats in lower intertidal and subtidal zones and provide shelter to fish and invertebrates, clarify water, filter nutrients, and reduce hypoxia. When shellfish feed, they filter phytoplankton, resulting in improved water clarity and quality. Clear water allows sunlight to reach the seafloor, promoting the growth of healthy seagrass habitats. They serve as predictable sources of food for carnivores in nearshore habitats and predators that are part of the ecological balance of nearshore ecosystems. Most have larvae or juveniles that spend time in the water column, where they provide food for a variety of valued fishes (Dethier 2006).

Threats to shellfish beds come from a variety of sources in addition to commercial and recreational overharvesting. The trend toward aquaculture reduces the pressure on native populations; however, most cultured species are non-native. Shellfish have distinct types of sediment in which they recruit and grow the best; thus, any process that alters sediment amount, grain sizes, organic content, etc., may negatively impact local shellfish populations. Land-based runoff, sediment loads carried by rivers and streams, and altered sediment supply from bluffs that have been hardened can effect shellfish production. Key water quality parameters include temperature and salinity, turbidity, oxygen, and pollutants. All these parameters can be affected by land use, shoreline modifications, stormwater and sewage discharge, industrial discharge, aquaculture, and other human activities. Additional changes to habitat characteristics such as the

abundance of eelgrass and the type and abundance of predators, competitors, and parasites (e.g., aiding the establishment of invasive species) can have an impact on shellfish populations (Dethier 2006).

Net-pen aquaculture could affect the water quality if sited near shellfish beds without enough depth and current velocity to dilute nitrogen and carbon inputs from the fish and feed. Biodeposition and resulting turbidity and reduced dissolved oxygen levels in the water cause stress on aquatic species. In addition to low levels of oxygen, excess nutrients can cause acidification, which compromises or inhibits shell formation by shellfish. Food web dynamics change as a result of the number and types of benthic organisms. Increases in nuisance macroalgae can impair shellfish bed productivity by smothering them and limiting bivalve access to flowing oxygen and nutrient rich water.⁸⁰ (For more details on benthic impacts see Section 3.2 and water quality see Section 3.3)

3.7.2 Washington specificity

Endangered Species Act Critical Habitat

Critical habitat as defined within Section 7 of the Endangered Species Act (ESA) is the specific areas within the geographic area, occupied by the species at the time it was listed that contain the physical or biological features essential to the conservation of endangered and threatened species and may need special management or protection. (See Chapter 2 for more information.) Critical habitat may also include areas that were not occupied by the species at the time of listing but are essential to its conservation. An area may be excluded from critical habitat designation based on economic impact, the impact on national security, or any other relevant impact, if it is determined that the benefits of excluding it outweigh the benefits of including it, unless failure to designate the area as critical habitat may lead to extinction of the species. The ESA requires the designation of critical habitat for listed species when prudent and determinable. In consultation the NMFS evaluates the status of ESA Critical Habitat to be affected by the proposed action by examining the condition of the primary constituent elements (PCEs) throughout the designated areas. See Figure 3.7f for a summary of risks to critical habitat and mitigation strategies.

Salmon Critical Habitat

Pacific Salmon listed under the ESA include Puget Sound Chinook, Hood Canal Summer Chum, and Coastal Puget Sound Bull Trout (1999); and Puget Sound Steelhead (2007). In addition, several Columbia River species have been designated. Pacific salmon have both designated Critical Habitat (Table 3.7a) and Essential Fish Habitat (EFH) as defined under the Magnuson-Stevens Fisheries Conservation and Management Act. Critical Habitat was designated for Pacific salmon starting in 1991; while EFH was identified and described in 1998 and extends from the U.S. Exclusive Economic Zone (EEZ) into freshwater systems to include both marine and freshwater portions of their lives (see EFH detailed in section below).

⁸⁰ <https://ecology.wa.gov/Water-Shorelines/Puget-Sound/Helping-Puget-Sound/Reducing-Puget-Sound-nutrients>

Many salmonid species inhabit Puget Sound and are listed as threatened or endangered, or are recognized as a priority species for conservation and management by Washington Department of Fish and Wildlife (WDFW). These species include coho salmon, Chinook salmon, chum salmon, pink salmon, steelhead trout, bull trout, Dolly Varden, and cutthroat (Morandi et al. 2016). Most salmon juveniles migrate out of Puget Sound to forage in the open ocean, although some Chinook and coho salmon remain in the sound year round (Parametrix 1990). Several salmon species in Puget Sound are managed and listed as evolutionarily significant units (ESUs) or distinct population segments (DPSs) and are federally listed as threatened, endangered, or a species of concern (NOAA 2016). WDFW has designated critical habitats for many of these DPSs including the waters and substrates in the Strait of Georgia, Puget Sound, Hood Canal, and the Strait of Juan de Fuca, as well as in many of the creeks flowing into these water bodies (Morandi et al. 2016). Major tributary river basins in the Puget Sound basin include the Nooksack, Samish, Skagit, Sauk, Stillaguamish, Snohomish, Lake Washington, Cedar River, Sammamish River, Green River, Duwamish River, Soos Creek, Puyallup River, White River, Carbon River, Nisqually River, Deschutes, Skokomish, Duckabush, Dosewallips, Big Quilcene, Elwha, and Dungeness Rivers.

Table 3.7a Salmon Critical Habitat designation Primary Constituent Elements (PCE) by site type

| Site Type | Site Attribute | Species Life History Event |
|----------------------|--|---|
| Estuarine Areas | Food resources Migratory corridor Natural cover Salinity Water quality Water quantity | Adult sexual maturation Adult reverse smoltification Adult upstream migration, holding Fry/parr seaward migration Fry/par smoltification Smolt growth and development Smolt seaward migration |
| Coastal Marine Areas | Food resources Migratory corridor Natural cover Water quantity Water quality | Adult sexual maturation Smolt/adult transition |

Because salmon are dependent on inland, estuarine, and coastal marine ecosystems throughout their life histories, they are vulnerable to stock decline from anthropogenic alterations in each of these habitats. The location and operations of net pen aquaculture farms can affect salmon critical habitat and essential fish habitat in Puget Sound. Clean water, prey availability, and unobstructed migratory pathways are considered necessary for their survival.

Green Sturgeon Critical Habitat

Green Sturgeon are long lived anadromous species that range from the Bering Sea, Alaska, to Ensenada, Mexico. Based on genetic analyses and spawning site fidelity (Adams et al. 2002, Israel et al. 2004), the NMFS determined green sturgeon are comprised of two DPSs: a northern

DPS consisting of populations originating from coastal watersheds northward of and including the Eel River and a southern DPS consisting of populations originating from coastal watersheds south of the Eel River. The only known spawning population for the Southern DPS is in the Sacramento River. Northern and Southern DPS sturgeon occupy coastal waters from southern California to Alaska and are known to aggregate in the Columbia River estuary, Washington estuaries, and Oregon estuaries in the spring to late summer months (Israel et al. 2004, Moser and Lindley 2007, Lindley et al. 2008). Green sturgeon observed in coastal bays, estuaries, and coastal marine waters outside natal rivers may belong to either DPS. The green sturgeon Southern DPS is listed as threatened under the ESA but the Northern DPS is not. In Washington, Willapa Bay and Grays Harbor are listed as critical habitat for the Southern DPS (Table 3.7b). Willapa Bay is recognized as an important over-summering habitat for green sturgeon. Willapa Bay is a very productive estuary with abundant food resources (e.g., burrowing shrimp, other benthic invertebrates) to support feeding by adult and subadult green sturgeon (Moser and Lindley 2007, Dumbauld et al. 2008). Like the lower Columbia River estuary and Willapa Bay, Grays Harbor provides important over-summering habitat for both adult and subadult Northern DPS and Southern DPS green sturgeon.

Willapa Bay and Grays Harbor are impacted by land use practices such as forestry, riparian habitat destruction, dams and water diversion, agriculture, dredging, and urban development. Commercial shipping and pollution from point and non-point sources (e.g., agriculture, pulp mill runoff) may also reduce water quality with the discharge of contaminants into the water. These practices compromise the water quality and directly impact green sturgeon critical habitats. Sturgeon are adapted to feed in silty substrates at low light levels. Their marine food preference consists of small fishes and benthic invertebrates typical of sandy/silty substrates of the continental shelf, and benthic fauna of shallow coastal bays with mud/silt substrates. Based on tagging studies subadults and adults require a minimum of 6.54 mg O₂/L dissolved oxygen levels (Moser and Lindley 2007).

Subadult and adult green sturgeon require unimpeded passage within coastal marine waters to access over-summering habitats within coastal bays and estuaries and over-wintering habitats within coastal waters between Vancouver Island, BC and southeast Alaska. Movement within these areas is important for green sturgeon to forage for prey and make lengthy migrations to reach additional foraging areas. Uninterrupted passage to the Sacramento River is critical for spawning adults.

Table 3.7b Green Sturgeon Critical Habitat designation Primary Constituent Elements (PCE) by site type

| Site Type | Site Attribute | Species Life Stage |
|----------------------|--|----------------------|
| Estuarine Areas | Food resources Water flow Water quality Migratory corridor Water depth Sediment quality | Migration Feeding |
| Coastal Marine Areas | Migratory corridor Water quality Food resources | Migration Feeding |

Rockfish Critical Habitat

Under the ESA, critical habitat is designated for the threatened DPSs of yelloweye rockfish (*Sebastes ruberrimus*), the threatened DPS of canary rockfish (*Sebastes pinniger*), and the endangered DPS of bocaccio (*Sebastes paucispinus*). The geographical area occupied by each DPS includes the Puget Sound/Georgia Basin. Within the U.S. portion of the geographical area, five specific areas are identified based on the distribution of each species, geographic conditions, and habitat features. These five interconnected basins are: (1) The San Juan/Strait of Juan de Fuca Basin, (2) Main Basin, (3) Whidbey Basin, (4) South Puget Sound, and (5) Hood Canal (Tonnes et al. 2016). These specific areas have received critical designation because they contain the essential habitat features, which may require special management considerations.

Much of the life history of these three species is similar. The life histories of listed rockfish include pelagic larval and juvenile stages, followed by a juvenile stage in shallower waters, and a sub-adult/adult stage. Rockfish are long-lived, iteroparous species (i.e., have multiple reproductive cycles during their lifetime), with internal egg fertilization, and give birth to live larvae. Their diets are diverse and include many species of marine invertebrates and fish. Successful reproduction occurs only sporadically and may be associated with broad-scale environmental conditions (NMFS 2014).

Adult canary rockfish and bocaccio, and adult and juvenile yelloweye rockfish inhabit benthic habitats deeper than 30m (98ft) of complex rocky bathymetry. These habitats are essential to conservation because these features support growth, survival, reproduction, and feeding opportunities by providing the structure for rockfish to avoid predation, seek food, and persist for decades (Table 3.7c). The attributes important for designated critical habitat include: 1) quantity, quality, and availability of prey species to support individual growth, survival, reproduction, and feeding opportunities, 2) water quality and sufficient levels of dissolved oxygen to support growth, survival, reproduction, and feeding opportunities, and 3) the type and amount of structure and rugosity that supports feeding opportunities and predator avoidance.

Juvenile canary rockfish and bocaccio settle in nearshore habitats with sand, rock, and/or cobble substrate compositions that also support kelp. These habitats are essential for conservation and recovery of rockfish because these features support forage opportunities and refuge from predators, and enable behavioral and physiological changes needed for juveniles to occupy deeper adult habitats. The attributes important for designating critical habitat include: 1) quantity, quality, and availability of prey species to support individual growth, survival, reproduction, and feeding opportunities, and 2) water quality and sufficient levels of dissolved oxygen to support growth, survival, reproduction, and feeding opportunities.

The primary habitat feature that may be affected by aquaculture net pens is the benthic environment near marine finfish rearing facilities. Fish net-pen operations have the potential to release toxic contaminants from the use of therapeutics, anesthetics, antifoulants, and disinfectants, and also release excess nutrients; thus altering local habitat characteristics. A study of three salmon net-pen operations in British Columbia, Canada found that quillback rockfish (*Sebastes maliger*) and copper rockfish (*S. caurinus*), down-current of the net pens, had elevated levels of mercury relative to fish from reference sites (deBruyn et al. 2006). Elevated mercury levels were attributed to food given to farmed fish that had settled to the seafloor (and released in feces), in addition to the mobilization of naturally occurring mercury in sediment under and near the net pens because of farm-induced anoxia. Mercury was then incorporated through the localized food web because nearshore sub-tidal and intertidal epibenthic invertebrates are important prey for juvenile rockfish and the prey of rockfish such as herring and sand lance. Rockfish with elevated levels of mercury may have reduced growth rates and reproductive impairment (Drake et al. 2010).

Table 3.7c Rockfish Critical Habitat designation Primary Constituent Elements (PCE) by site type

| Site Type | Site Attribute | Species Life Stage |
|----------------------|--|---|
| Estuarine Areas | Food resources Water quality Dissolved Oxygen Refuge from predators | Growth Survival Reproduction Feeding |
| Coastal Marine Areas | Food resources Water quality Dissolved Oxygen | Growth Survival Reproduction Feeding |

The location of aquaculture facilities may impact rockfish and their habitat. Net-pen facilities alter habitat characteristics from open-water pelagic environments to habitats that more closely resemble nearshore habitat. Kelp growing on nets, floats, and anchor lines may attract juvenile rockfish (Rensel and Forster 2007). Proposed fish net-pen structures should be located to reduce impacts from nutrient loading or potential toxic contaminants from the use of therapeutics, anesthetics, antifoulants, and disinfectants. Shellfish aquaculture facilities should be located

away from native aquatic vegetation such as kelp or eelgrass and operated in a way to reduce sediment-disturbing activities.

Killer Whale Critical Habitat

The Southern Resident killer whale Distinct Population Segment was listed as endangered under the ESA in 2005 and the final rule to designate critical habitat for Southern Residents was effective December 29, 2006 (71 FR 69054). In the listing, the NMFS identified three main threats to their survival: 1) scarcity of prey, 2) high levels of contaminants from pollution, and 3) disturbance from vessels and sound. In 2018, the Southern Resident Orca Task Force reiterated these threats and in addition acknowledged climate change and ocean acidification as overarching threats that will exacerbate the current stresses on the population. The primary concerns are these threats will manifest throughout the food web as warmer stream and ocean temperatures, lower summer stream flows, heavier winter rainstorms, and sea-level rise impact salmon, forage fish, and the entire ecosystem upon which orcas rely (Southern Resident Orca Task Force 2018).

Southern Resident Killer Whales rely on echolocation to forage for prey, and thus may be particularly sensitive to the introduction of noise to the environment. Southern Resident killer whales spend a significant portion of the year in the inland waterways of the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound, particularly during the spring, summer, and fall. Southern Residents occur in coastal waters off Washington, Oregon, and Vancouver Island and are known to travel as far south as central California and as far north as the Queen Charlotte Islands, British Columbia.

There are three distinct forms of killer whales in the northeastern Pacific Ocean, termed as residents, transients, and offshores. These forms display significant genetic differences due to a lack of interbreeding even though there is considerable overlap in their ranges (Stevens et al. 1989, Hoelzel and Dover 1991, Hoelzel et al. 1998, Barrett-Lennard 2000, Barrett-Lennard and Ellis 2001, Krahn et al. 2004). In addition to genetic differences, there are important differences in ecology, behavior, morphology, and acoustics (Baird 2000, Ford et al. 2000). The Southern Resident DPS consists of three pods, identified as J, K, and L pods, that reside for part of the year in the inland waterways of Washington State and British Columbia (Strait of Georgia, Strait of Juan de Fuca, and Puget Sound), during the late spring, summer, and fall (Ford et al. 2000, Krahn et al. 2002). Pods visit coastal sites off Washington and Vancouver Island (Ford et al. 2000), but travel as far south as central California and as far north as the Queen Charlotte Islands. Offshore movements and distribution are largely unknown for the Southern Resident DPS (NMFS 2006).

Killer whales are highly mobile, can cover large distances, and range over a variety of habitats, including inland waters and open ocean coastal areas and do not appear to be constrained by water depth, temperature, or salinity (Baird 2000). Southern Resident killer whales require open waterways that are free from obstruction to move between important habitat areas, find prey, and fulfill other life history requirements. Individual knowledge of productive feeding areas and

other special habitats is probably an important determinant in the selection of locations visited and is likely a learned tradition passed from one generation to the next (Ford et al. 1998).

The Southern Residents spend large amounts of time in core inland marine waters coinciding with congregations of migratory salmon returning from the Pacific Ocean to spawn in U.S. and Canadian Rivers.

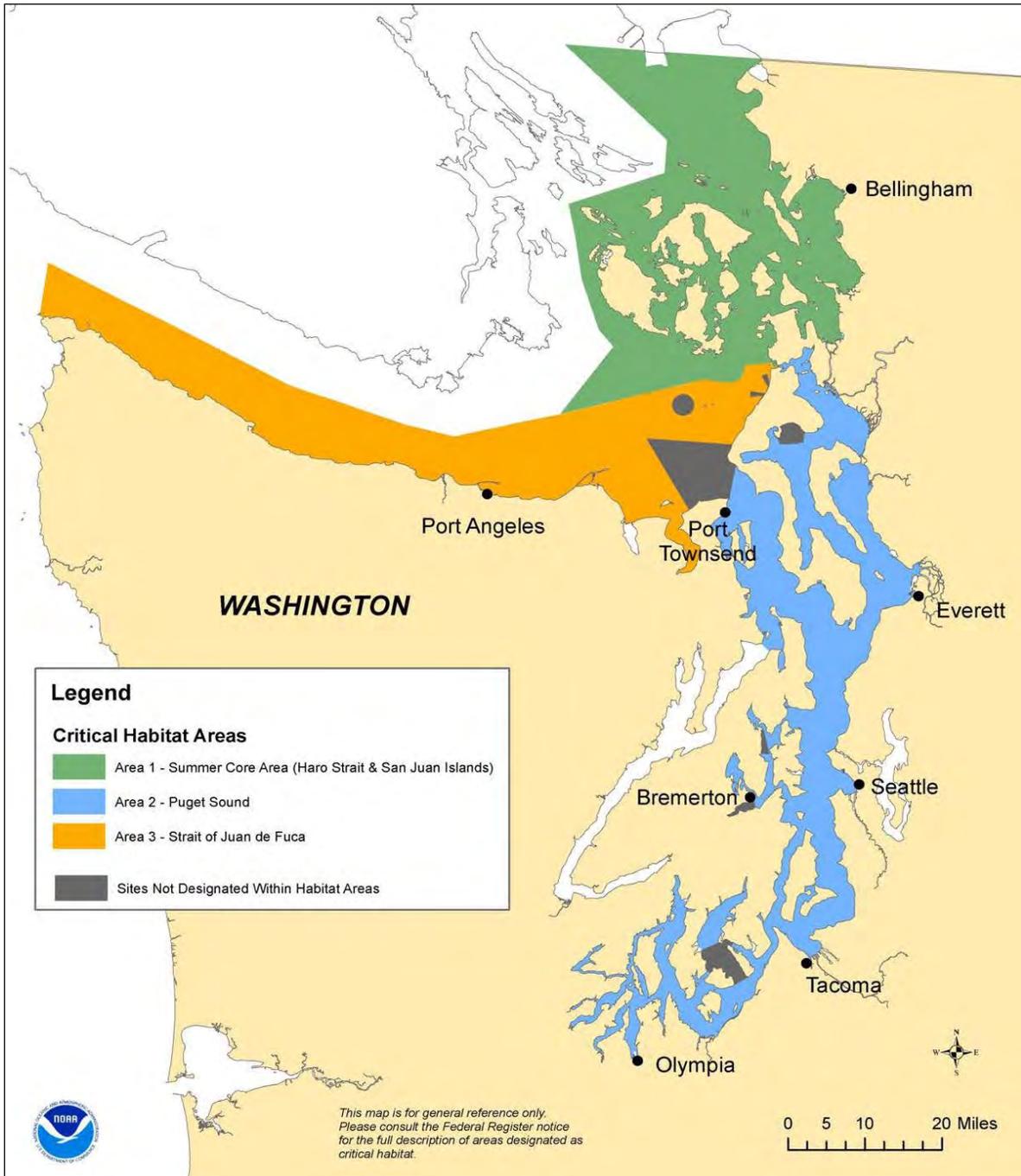
Area 1. Core Summer Area - Bordered to the North and West by the US/Canadian border, Area 1 includes the waters surrounding the San Juan Islands, the 26 U.S. portion of the Southern Strait of Georgia, and areas directly offshore of Skagit and Whatcom counties (Figure 3.7a). Area 1 is important for all J, K, and L pods. Southern Resident killer whales have been sighted in Area 1 during every month of the year, but sightings are more consistent and concentrated in the summer months, June through August (Figure 3.7a). Occurrence in Area 1 coincides with concentrations of salmon: Area 1 is considered a primary feeding area for Southern Residents. Runs of salmon passing through Area 1 include Chinook, chum, coho, pink, and sockeye salmon, which have all been identified as prey for Southern Residents (Ford et al 1998, Ford and Ellis 2005). The Strait of Juan de Fuca, Haro, and Georgia Straits are relatively narrow channels and concentrate salmon returning from the Pacific Ocean to spawn in U.S. and Canadian rivers. In particular, Area 1 lies near the mouth of the Fraser River, which has the largest salmon runs in the Georgia Basin/Puget Sound region (Northcote and Atagi 1997).

Area 2. Puget Sound - south from Deception Pass Bridge, entrance to Admiralty Inlet, Hood Canal Bridge. Southern Resident killer whales have been seen in parts of Area 2 in all seasons. The presence of Southern Residents in Area 2 is intermittent, with the smallest number of sightings in May-July. There are different sighting patterns in Area 2 for the three pods (Figure 3.7a).

Area 3. Strait of Juan de Fuca – Deception Pass Bridge, San Juan, and Skagit County lines to the northeast, entrance to Admiralty Inlet to the southeast, U.S. Canadian Border to the north, Bonilla Point/Tatoosh line to the West. All pods regularly use the Strait of Juan de Fuca to transit from Areas 1 and 2 to outside waters in the Pacific Ocean. Area 3 is predominantly a passage used to access oceanic waters, including Swiftsure and La Perouse Banks, off Tofino, British Columbia, and Westport, as well as other areas with unknown usage, such as the coast of northern California (Figure 3.7a).

The topographic and oceanographic features in these core areas include channels and shorelines used to assist with foraging. Prey availability changes seasonally, and may be a limiting factor when Southern Residents are outside of the core summer areas. Sufficient prey abundance is necessary to support growth to reach sexual maturity and reproduction, including lactation and successful calf rearing.

**Figure 3.7a Designated Critical Habitat for Southern Resident Killer Whales: November 2006
NOAA Fisheries Northwest Region**



The PCEs for critical habitat designation are: (1) Water quality to support growth and development; (2) Prey species of sufficient quantity, quality, and availability to support individual growth, reproduction and development, as well as overall population growth; and (3) Passage conditions to allow for migration, resting, and foraging (Table 3.7d).

Table 3.7d Southern Resident Killer Whale Critical Habitat designation Primary Constituent Elements (PCE) by site type

| Site Type | Site Attribute | Species Life Stage |
|----------------------|---|--|
| Estuarine Areas | Water quality Food resources Passage conditions | Growth Survival Reproduction Feeding Migration Rest |
| Coastal Marine Areas | N/A | |

Net-pen aquaculture in Puget Sound can affect water quality, prey availability, and migratory pathways throughout the critical habitat areas for the Southern Resident killer whales. Killer whales are particularly vulnerable to increased vessel traffic and forage less when vessels are present (Lusseau et al. 2009). Additional vessel traffic to tend to the net pens may exacerbate the impact.

Magnuson-Stevens Fisheries Conservation and Management Act Essential Fish Habitat

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) (16 U.S.C. § 1801 et seq.) was established in 1976 to promote the conservation of marine fishery resources within the U.S. Exclusive Economic Zone (EEZ). Eight regional Fishery Management Councils were established to develop Fishery Management Plans (FMPs) for resources in their jurisdictional waters. Amendments to the Act in 1986, 1996 added protection for Essential Fish Habitat, recognizing many fisheries depended on estuarine or nearshore habitats for part of their life histories. EFH is defined in the Act as “those waters (e.g. aquatic areas and their associated physical, chemical, and biological properties used by fish) and substrates (e.g. sediment, hard bottom, underlying structures, and associated biological communities) necessary to fish for spawning, breeding, feeding, or growth to maturity”. Under Section 305(b)(4), the Act mandates the NMFS coordinate with other federal agencies to avoid, minimize, or offset adverse impacts to fish stocks and EFH that would result from the proposed activities. The NMFS must provide the consulting Federal agency with EFH conservation recommendations for any action that would adversely affect EFH. Within 30 days of receiving these recommendations, the consulting action agencies must provide a detailed response in writing to the NMFS that includes measures proposed to avoid, minimize, or offset the impact of proposed activities on EFH.

MSA EFH Habitat Areas of Particular Concern (HAPC)

HAPCs in the state of Washington are estuaries, canopy kelp, seagrass, rocky reefs, and "areas of interest" which include a variety of submarine features, such as banks, seamounts, and canyons, along with Washington State waters. HAPCs are described in the regulations as subsets of EFH that are “rare, particularly susceptible to human-induced degradation, especially ecologically

important, or located in an environmentally stressed area” (50 CFR 600.815). The implementing regulations for the EFH provisions of the MSA (50 CFR 600) recommend the FMPs include specific types or areas of habitat within EFH as HAPCs based on one or more of the following considerations: (1) the importance of the ecological function provided by the habitat; (2) the extent to which the habitat is sensitive to human-induced environmental degradation; (3) whether, and to what extent, development activities are, or will be, stressing the habitat type; and (4) the rarity of the habitat type. The intended goal of identifying such habitats as HAPCs is to provide additional focus for conservation efforts, although it does not require any additional regulatory activity during the EFH consultation process. Designated HAPC are not afforded any additional regulatory protection under MSA; however, HAPCs are considered high priority areas for conservation, management, or research and thus federal projects with potential adverse impacts to HAPC are more carefully scrutinized during the consultation process. Although these habitats are particularly important for healthy fish populations, other EFH areas that provide suitable habitat functions are also necessary to support and maintain sustainable fisheries and a healthy ecosystem.

The MSA EFH mandate applies to all federally managed fish species under Fishery Management Plans (FMPs). For the Pacific west coast there are three FMPs covering Pacific salmon species, groundfish, and coastal pelagics. Impacts on EFH from the proposed action must be considered for any species managed under the FMPs.

Pacific Salmon – Chinook, coho, and pink salmon

EFH for Pacific salmon includes the waters and substrate necessary to support salmon production for long term sustainable fisheries and healthy ecosystems. Thus EFH includes all streams, lakes, ponds, wetlands, and all viable water bodies that have historically and currently support salmon life history stages in Washington, Oregon, California, and Idaho. Salmon EFH in estuarine and marine waters extends from the nearshore and tidal submerged environments within state waters out to the U.S. Exclusive Economic Zone (EEZ; 200 miles). The five HAPCs for Pacific Coast salmon are complex channels and floodplain habitats, thermal refugia, spawning habitats, estuaries, and marine and estuarine submerged aquatic vegetation (Stadler et al. 2011, PAFMC and NMFS 2014).

Pacific salmon distribution can only be identified generally throughout the EEZ, because distribution is extensive, varies seasonally and inter-annually, and has not been extensively sampled in many ocean areas. In estuaries and freshwater, delimiting habitat to that which is essential is difficult, because of the diversity of habitats used by Pacific salmon coupled with (1) natural variability in habitat quality and use; (2) the current low abundance of Pacific salmon; (3) the lack of data on specific stream-by-stream historical distribution; and (4) the fact that salmon migrate through the entire continuum of habitats (PAFMC and NMFS 2014).

EFH is designated at a watershed level of the U.S. Geological Survey (USGS) 4th field hydrologic units (HUs). Such an approach is appropriate, because it (1) recognizes the species’ use of diverse habitats and underscores the need to account for all of the habitat types supporting the species’ freshwater and estuarine life stages, from small headwater streams to migration

corridors and estuarine rearing areas; (2) considers the variability of freshwater habitat as affected by environmental conditions (droughts, floods, etc.) that make precise mapping difficult; and (3) reinforces important linkages between aquatic and adjacent upslope areas. Habitat available to salmon changes frequently in response to floods, landslides, woody debris inputs, sediment delivery, and other natural events.

Groundfish

EFH for groundfish is defined as the aquatic habitat necessary to allow groundfish production to support long term sustainable fisheries and healthy ecosystems. The descriptions of EFH for 83 species of groundfish and their life histories result in over 400 EFH classifications. The groundfish EFH in total include all waters from the mean higher high water line and the upriver extent of saltwater intrusion in river mouths along the coast of Washington, Oregon, and California seaward to the U.S. EEZ. (USACE and NMFS NWR 2009)

The overall extent of groundfish EFH for all groundfish species is identified as all waters and substrate within the following areas:

- Depths less than or equal to 3,500 meters (1,914 fathoms) to mean higher high water level (MHHW) or the upriver extent of saltwater intrusion, defined as upstream and landward to where ocean-derived salts measure less than 0.5ppt during the period of average annual low flow
- Seamounts in depths greater than 3,500 meters as mapped in the EFH assessment GIS
- Areas designated as HAPCs not already identified by the above criteria

The EFH identification is based on the maximum known depth because uncertainty still exists about the relative value of different habitats to individual groundfish species/life stages, and thus the actual extent of groundfish EFH. Ideally, EFH would be defined by delineating habitat in terms of its contribution to spawning, breeding, feeding, growth to maturity, and production; however, comprehensive data on these functions are not available. Because of these data limitations, a model was developed to predict an overall measure of the suitability of habitat in particular locations for as many groundfish species as possible. This model uses available information on the distribution and habitat-related species density. The model characterizes habitat in terms of three variables: depth, latitude, and substrate (both physical and biogenic substrate, where possible). For the purposes of the model, these three characteristics provide a reasonable representation of the essential features of habitat that influence the occurrence of fish. The EFH assessment model provides spatially explicit estimates of HAPCs for 160 groundfish species/life stage combinations, including the adults of all groundfish species. Both areas and habitat types are identified as HAPCs for groundfish and include estuaries, canopy kelp, seagrass, rocky reefs, other areas of interest including seamounts and canyons, and oil platforms (PAFMC 2005).

Coastal Pelagic Species

The Coastal Pelagic Fishery Management Plan describes the habitat requirements of five pelagic species: northern anchovy, Pacific sardine, Pacific (chub) mackerel, jack mackerel, and market squid, grouped because of their similar life histories. The east-west boundary of EFH for this species complex includes all estuarine and marine waters from the shoreline to the U.S. EEZ and above the thermocline where sea surface temperatures range between 10-26°C off Washington, Oregon, and California. The southern boundary extends to the Mexico/U.S. maritime boundary and the northern boundary is defined as the 10°C isotherm, which varies seasonally and annually.

Habitat classifications for Puget Sound - Habitats of Special Significance

Critical saltwater habitats (WAC 173-26-221(2)(c)(iii)(A))

Critical saltwater habitats include all kelp beds, eelgrass beds, spawning and holding areas for forage fish, such as herring, smelt and sand lance; subsistence, commercial and recreational shellfish beds; mudflats, intertidal flats with vascular plants, and areas with which priority species have a primary association. Critical saltwater habitats require a higher level of protection due to the important ecological functions they provide. Ecological functions of marine shorelands can affect the viability of critical saltwater habitats. Therefore, effective protection and restoration of critical saltwater habitats should integrate management of shorelands as well as submerged areas.

Estuaries

Puget Sound is a large salt water estuary composed of many smaller estuarine components. In these estuaries, denser saltwater sinks deeper and moves toward the land with tides, while freshwater moves seaward as a surface layer. Shallow sills (submerged ridges that separate basins of water) in Puget Sound's sea floor disrupt tidal movements and promote mixing water layers. Exchange of water between estuarine Puget Sound and saline Pacific Ocean primarily occurs through the Strait of Juan de Fuca, northwest of Puget Sound. Limited exchange occurs through a more obstructed pathway along the eastern side of Vancouver Island, through the Georgia and Johnstone Straits north of Puget Sound. Puget Sound has significant variability with respect to water quality parameters across different parts of the water body. Additionally, water quality is influenced by natural variability, and discerning natural changes from anthropogenic changes is an ongoing challenge. (USACE 2016)

Washington's largest coastal estuaries are critical habitats for a variety of marine and terrestrial organisms. Fish and shellfish are abundant in the estuaries of Puget Sound. Shellfish species include the Olympia oyster (*Ostrea lurida*), Geoduck clams (*Panopea generosa*), non-native Pacific oyster (*Crassostrea gigas*), non-native Manila clam (*Venerupis philippinarum*), and Dungeness crab (*Metacarcinus magister*). Several commercially important fish species spend at least part of their life cycle in the estuary including six species of salmon, rockfish, herring, three-spined stickleback, sturgeon, eulachon, spiny dogfish, sevengill sharks and more. (See Section 3.10 for more information on specific fish species.) Estuaries are important foraging

habitat for migratory sea birds, marine mammals, sharks, and terrestrial animals like deer and elk. Harbor seals and sea lions haul out on rocks, reef, beaches, and docks and feed on invertebrates and fish in estuarine waters of Puget Sound. The State of Washington identifies Grays Harbor and Willapa Bay as Ecologically Important Areas.

Seagrasses

Along the West Coast, the Pacific Fishery Management Council identified seagrasses as Habitat Areas of Particular Concern (HAPCs). These plants support a diversity of life and can form extensive beds in shallow, protected, estuarine, or other nearshore environments. Two common seagrasses that occur in the Washington coastal area are eelgrass (*Zostera marina*) and surfgrass (genus *Phyllospadix*), with eelgrass being the most prevalent and occurring in Washington, Oregon, and California (Mumford 2007).

In Puget Sound eelgrass grows in depths as shallow as 1 m below the low tide line (MLLW) to greater than 10 m. Much of the eelgrass in Puget Sound is subtidal; half the sites sampled for the WA State Department of Natural Resources monitoring program have eelgrass extending to depths greater than 3 m below the low tide line (maximum depth of eelgrass in Puget Sound). (Christaen et al. 2017). Padilla Bay tidal flats contain approximately 15% of all seagrass growing in Puget Sound, About half of all seagrass in Puget Sound grow in narrow fringing beds along steeper shorelines which serve as corridors for migrating salmon and other wildlife (Christaen et al. 2017).

Substantiated by 18 years of monitoring (2000-2017), WA DNR estimates there are approximately 23,000 hectares of eelgrass in Greater Puget Sound. The total amount of eelgrass has remained relatively stable in Puget Sound since the monitoring program inception in 2000, although current conditions have not yet met the Puget Sound Partnership's target for a 20% increase in eelgrass area by 2020 (sound-wide eelgrass area) (Christaen et al. 2017).

Kelp Beds

There are 23 species of kelp in Puget Sound and the majority are either low growing or prostrate and do not form canopies (Mumford 2007). These types are found in the nearshore shallow waters where they have access to light as compared to the floating kelp beds that are limited by the availability of suitable substrate. Kelp require moderate to high water movement and energy levels. Kelp are held to the bottom by holdfasts, which unlike typical plant roots, do not penetrate the substrate or carry nutrients to the plant. Because they lack a root system, kelps require stable substrate for attachment such as bedrock, boulders, cobbles, boat bottoms, pilings, docks, or ropes. The primary canopy-forming kelp are bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis integrifolia*). In the Northeast Pacific most kelp species require a combination of fairly high salinity (>25psu) and fairly low temperatures (<15°C) (Druehl 1981). Canopy kelp in Puget Sound is vulnerable to light availability, changes in substrate, nutrient levels, herbivory, hypoxia, pollution, and direct interaction or damage from boats or oyster harvest.

In many areas of Puget Sound kelp remain at historic levels, although some eastern populations in proximity to greater human populations are the exception to this pattern (Pfister et al. 2017). In central and south Puget Sound, bull kelp distribution has decreased over the last 100 years (Mumford 2007, Van Wagenen 2015). Anthropogenic impacts to kelp forests include reduced light and buried hard substrate from sedimentation and poor water quality from pollutants and excess nutrient inputs (Andrews et al. 2015, WA Ecology et al. 2018). Pollution from sewage, inorganic fertilizers, pesticides, and industrial waste carried from freshwater runoff can impair kelp reproduction and growth. Excessive sedimentation from watershed development activities may smother younger kelp and rocky substrate.⁸¹

In Washington three species of urchins graze on kelp: red (*Mesocentrotus franciscanus*), purple (*Strongylocentrotus purpuratus*), and green (*S. droebachiensis*). Sea urchin abundance is controlled by sea otter, sea star, crab, and human predation. The sea urchin, sea otter, kelp trophic interaction has been well documented in the Pacific Ocean (Andrews et al. 2013). The reintroduction and range extension of sea otters in Washington State has led to decreases in sea urchin abundance and some localized increases in kelp densities, (Kvitek et al. 1998, Laidre and Jameson 2006, WA Ecology et al. 2018).

Bull kelp can occur on all submerged structures of net pen operations in Puget Sound and is most abundant along the shallow ends of anchor lines (Rensel and Forester 2007). Kelp that has settled on anthropogenic structures likely has a different ecological function than kelp growing on a benthic substrate. The surface layer provides vertical habitat stratification and stability and enhances phytoplankton productivity throughout the growing season of late winter through early fall (Rensel and Forester 2007).

Rocky Reefs

Rocky reefs are high profile rock outcrops that afford protection for juvenile and smaller fishes and are colonized by organisms including hydroids, macroalgae, abalone, sea urchins, sea anemones, starfish, and other attached organisms. These rocky intertidal reefs are an interface between land and sea, spanning from shore out to deeper water. Most rocky reef habitats are beneficial as they provide a physical structure and support diverse, highly productive ecosystems rich in corals, invertebrates, algae, shellfish, and finfish. These structures are vulnerable to bottom trawl fishing gear as well as human disturbance given their proximity to shore and therefore accessibility. Additionally, rising ocean temperatures and ocean acidification will impede many colonial invertebrates, including corals, from secreting their skeletons and subsequently reduce the biodiversity and productivity of rocky reefs.

Shellfish beds

Native shellfish in Puget Sound are diverse, both in terms of species and in the ways that they use nearshore ecosystems. In Puget Sound, all major shellfish species use nearshore ecosystems for part or all of their life histories. Clams and oysters are an important part of the Puget Sound

⁸¹ https://www.westcoast.fisheries.noaa.gov/habitat/fish_habitat/kelp_forest_habitat_types.html

ecosystem, regional economy, and have cultural significance for Native American tribes. These native and non-native species are associated with the intertidal and subtidal zones; crabs and oysters dwell on the substrate surface while the clams bury themselves at various shallow depths. The substrate preferences range from mud and sand to gravel and rocks (Dethier 2006). All prefer sediment mixed with gravel or cobble. Washington State is the lead producer of shellfish farming in the United States. Washington shellfish farming represents 12% of the total employment for U.S. aquaculture, and generated over \$185 million in state income in 2015 (FAO 2016).

Geoduck clams (*Panopea generosa*) are the largest of the bivalve species in Puget Sound, especially abundant in the south sound, ranging from the lowest intertidal elevations to depths of 110 meters but most abundant at 9-18 meters (Goodwin and Pease 1989). These large clams can reach over 80 years old. Geoduck populations with densities exceeding 0.4 animals/m² are used by the state to identify major geoduck beds by Washington State. Washington State and Puget Sound Treaty Tribes co-manage a sustainable wild stock geoduck fishery in the state. The state and Tribes each have a right to 50 percent of the sustainable, allowable geoduck catch. Geoduck auctions for the harvest of wild stock generate nearly \$22 million of revenue each year. This revenue is used, in part, to fund restoration of aquatic habitats and public access improvements throughout the state. Geoduck aquaculture (cultivation of farmed stock) is increasing along beaches and embayments of south Puget Sound and Hood Canal, as demand for overseas export increases.

Hardshell clams, including littleneck (*Mercenaria mercenaria*), butter (*Saxidomus giganteus*), and horse (*Tresus capax* and *T. nuttallii*) clams, are abundant throughout Puget Sound, primarily in the intertidal and shallow subtidal zones. All prefer sediment mixed with gravel or cobble, and their populations are sometimes enhanced by adding gravel to sandy or muddy beaches. Hardshell clam populations with densities exceeding 1.2 kg/m² is the density required for hardshell clam harvest by Washington State.

Native Olympia oysters (*Ostrea lurida*) grow best in shallow subtidal mixed sand-mud habitats but prefer to settle as larvae onto pieces of harder substrate such as shells or pebbles. Populations of native oysters have virtually disappeared due to overharvesting and pollution, but there are increasing efforts to reestablish them. Willapa Bay historically supported large populations of the Olympia oyster in the low intertidal and shallow subtidal zones but may have been uncommon in Grays Harbor (Baker 1995, Cook et al. 2000). The severe depletion of the Olympia oyster in the early 1900's was a result of overharvest and habitat loss (reviewed in Zu Ermgassen et al. 2013). The ability of this species to recover has been hindered by the removal of shell accumulations as larval habitat and the expansion of eelgrass beds. Recent aquaculture is focused on non-native Pacific oysters.

The Pacific oyster (*Crassostrea gigas*) introduced from Japan, is artificially propagated throughout Puget Sound. Pacific oysters could not sustain themselves as a population without aquaculture efforts as they require higher temperature for reproduction; however, they occasionally reproduce successfully in the wild. There are self-sustaining populations of Pacific oysters in Hood Canal.

Washington Marine Spatial Planning

Washington State law requires the Marine Spatial Plan to identify environmentally sensitive and unique resources that warrant protective measures (RCW 43.372.040(6)(c)). Therefore, the plan is designating Important, Sensitive, and Unique Areas (ISUs) in state waters that have high conservation value, high historic value, or key infrastructure. The ISUs include standards to maintain the high values of these areas and to protect the ISUs from adverse effects of offshore development, while allowing existing compatible uses such as fishing.

ISUs are specific areas in state waters that meet one or more of the following criteria:

1. Areas that are environmentally sensitive, or contain unique or sensitive species or biological communities that must be conserved and warrant protective measures (RCW43.372.040(6)(c))
2. Areas with known sensitivity and where the best available science indicates the potential for offshore development to cause irreparable harm to the habitats, species, or cultural resources
3. Areas with features that have limited, fixed, and known occurrence
4. Areas with inherent risk or infrastructure incompatibilities (e.g. buoys or cables)

Ecological ISUs:

1. Biogenic habitats: aquatic vegetation, corals, and sponges
2. Rocky reefs
3. Seabird colonies: islands and rocks used for foraging and nesting by seabirds
4. Pinniped haul-outs
5. Forage fish spawning areas: intertidal areas used for spawning by herring, smelt or other forage fish

Aquatic non-native species

Table 3.7e provides a list of non-native species that pose potential risks to Puget Sound ecosystems. Some species may use net-pen structures to colonize and propagate.

Table 3.7e Aquatic Non-native Species Identified as Risks to Puget Sound Ecosystems

| | |
|--------------------|---|
| Diatomaceous algae | Pseudo-nitzschia australis |
| Macroalgae | Dead man's fingers (Codium fragile tomentosoides) |
| Macroalgae | Japanese weed (Sargassum muticum) |
| Macroalgae | Lomentaria (Lomentaria hakodatensis) |
| Macroalgae | Tocoroten red algae (<i>Gelidium vagum</i>) |
| Vascular plant | Common cordgrass (<i>Spartina anglica</i>) |

| | |
|----------------|---|
| Vascular plant | Saltmeadow cordgrass (<i>Spartina patens</i>) |
| Vascular plant | Smooth cordgrass (<i>Spartina alterniflora</i>) |
| Vascular plant | Japanese eelgrass (<i>Zostera japonica</i>) |
| Tunicate | <i>Styela clava</i> |
| Tunicate | <i>Didemnum vexillum</i> |
| Tunicate | <i>Ciona savignyi</i> |
| Crustacean | European green crab (<i>Carcinus maenas</i>) |
| Crustacean | Chinese mitten crabs (<i>Eriocheir sinensis</i>)* |
| Mollusc | Asian marine clam (<i>Corbula amurensis</i>)* |

*Although populations of these invasive species are not observed to be established in Puget Sound, they pose a threat to sensitive habitats as their ranges expand (<https://invasivespecies.wa.gov/index.shtml>)

Table 3.7f Summary of risks to critical habitat and mitigation strategies

| Site attributes for critical habitat | How net-pens could affect critical habitat | Practices to minimize the potential for effect⁸² |
|---|--|---|
| Food resources | <p>Net pens often act as a fish-aggregating device (FAD), which may alter the amount of prey in an area, or change their distribution (Fernandez-Jover, et al. 2008, Dempster et al. 2009).</p> <p>The particulate organic waste released from net pens can increase or decrease the diversity and abundance of benthic fauna (Price and Morris 2013, Keeley et al 2014). This might change the availability of food resources in the immediate area of the net pens.</p> <p>If fish escape from pens, some individuals may consume wild food resources.</p> <p>If fish escape from net pens they could become prey for protected species.</p> | <p>Monitor farmed fish during feeding so excess feed is not released into the environment. Uneaten feed is an attractant for some wild fish.</p> <p>Keep infrastructure clean of excessive biofouling growth, and in-situ cleaning should be done when conditions minimize build-up of organics (see Section 3.7 Fouling Prevention).</p> <p>Locate net-pen farms in areas where currents will disperse solid waste to prevent sedimentation.</p> <p>Farms are required to have detailed escape prevention; reporting and recapture programs (see Section 3.8 Escapes).</p> |
| Migratory corridor | <p>The physical location of the farm within marine mammal migration routes could present a navigation obstacle.</p> | <p>Site pens in open water where their presence will not impede animals passing through an area.</p> |
| Natural cover | <p>Net pens could cause shading and therefore reduce light available for plant growth.</p> <p>Increased nutrients or particulate matter from net pens could damage habitat forming organisms (Hall-Spencer et al. 2006, Doleneć et al. 2006).</p> | <p>Site net-pens away from critical habitat and consider local currents to ensure waste would not be carried to habitat.</p> |
| Salinity | <p>NA</p> | |
| Water quality | <p>Net-pen operations could release nutrients, drugs or antifouling compounds that will diminish water quality (Brooks & Mahnken 2002, Sará 2007, Farmaki et al. 2014).</p> | <p>Manage farm within the assimilative capacity of the site, so nutrients do not become concentrated in an area.</p> <p>Only use drugs approved for use by the FDA, under the direction of a veterinarian.</p> |

⁸² The state and federal permitting process includes regulatory agency consultation for protected species interactions, and requires monitoring currents at farm sites (see Chapter 2), should ensure that most of these issues do not occur.

| | | |
|------------------------------|--|---|
| | | Adhere to the management and monitoring requirements in farm NPDES permits. |
| Water quantity | Net pens will act as a semi-permeable obstruction and alter the way the water flows around them. This could alter the natural water flow dynamics in the immediate area of the cages, which in turn will change the rate of sedimentation or erosion (Gansel et al. 2008, Poizot et al. 2016). | Site farms in areas where the pens' effect on water flow will not impact the surroundings. Keep pens clean of bio-fouling to reduce drag. Use netting with as large an aperture as possible (without risking fish escapes). |
| Sediment quality | Particulate organic matter from net-pens will lead to sediment conditions that are unfavorable for benthic fauna (Sar 2007, Price and Morris 2013). | Adhere to the management and monitoring requirements in farm NPDES permits. Site farms where current conditions are dispersive. |
| Dissolved oxygen | Fish in pens will consume dissolved oxygen (DO). | Low DO will harm the fish in the pens. Farms in WA have the ability to aerate water in the pens if DO decreases. ⁸³ |
| Refuge from predators | Net-pens could alter the way wild prey and predator species are dispersed in an area. Predators may learn to target prey that is near fish pens (Barret et al. 2018) | Pens can be sited so they do not impact natural structures. Pens may act as additional structure and refuge from predators. |
| Passage conditions | Farm effluent or on-farm activities could disturb animals as they migrate through an area. Loose lines and nets are an entanglement risk Some animals may be attracted to farm sites (Clement 2013). | Follow permit requirements for maintaining environmental quality. Site farms in areas of open water where animals can avoid the pens. Work with regulatory authorities to develop farm specific protected species management plans. |

⁸³ K. Bright, Cooke Aquaculture Pacific, personal communication May 16, 2017

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3.8 Environmental risks of escaped fish

3.8.1 State of the science

Background

The potential exists for fish to escape from aquaculture net pens because marine cage culture often occurs in dynamic and unpredictable environments. Unfortunately this potential has been realized in most places where fish are cultured in net pens. The effects of escapes may be immediate, long-term, or virtually non-existent and will vary based on the number of fish escaped, fish size, fish condition, escape frequency and timing, species, geography, and the abundance and health of native fish populations, among a host of other factors. This section provides an evaluation of the types of interactions that can occur between escaped Atlantic salmon (*Salmo salar*), Pacific salmon (*Oncorhynchus* spp.), sablefish (*Anoplopoma fimbria*), and native conspecifics or predatory marine wildlife in Washington's coastal waters. To provide this science assessment, we researched peer-reviewed literature, industry reports, direct communication with domestic and international salmon producers, communication with regulatory agencies in Washington and British Columbia, and publicly available information provided by the Washington Department of Fish and Wildlife, the Washington Department of Ecology, and Department of Fisheries and Oceans Canada.

General considerations of risks

The contents herein will not discuss the risks specific to Atlantic salmon being farmed in their native range, such as decreasing genetic fitness of wild salmon due to cross-breeding with domestic stock, because there are no wild conspecifics in Washington. It will also not detail the potential for hybridization between Pacific and Atlantic salmon because research has shown it is unlikely to occur (Nash 2001).

Fish may escape from net pens in large numbers during singular events like total net-pen system failure, caused by extreme weather or current conditions. Additionally and more typically, fish escape in smaller numbers through damaged nets or during harvest and may go unnoticed if nets are not regularly inspected (this type of escape is termed leakage). Regardless of the circumstances causing escapes the risks are generally the same. The major concern of escapes is potential impacts on the abundance, health, and fitness of wild fish, particularly conspecifics. The risks of most concern, among others, are 1) potential interbreeding of domesticated cultured fish with wild conspecifics and resulting loss of fitness, 2) direct competition for food and space, and 3) transmission of disease.

Dispersion patterns of escapees

The specific risks pose by escaped cultured fish depends on where they disperse in the environment. Fish dispersion depends on multiple factors including fish age, season, and reproductive condition. Migration of salmonids is highly complex and variable (Cooke et al. 2011), as is the case for most migratory fish species (Binder et al. 2011). In general, results from

scientific studies as well as experiences with documented escapes of cultured salmonids from marine net pens suggest escaped fish disperse quickly and/or remain near the net pens, may migrate considerable distances, or may seek nearby rivers, especially if they are reproductively maturing. The seasonal timing of escapes may be one factor contributing to the lack of a clear pattern for dispersion. If fish escape during their normal ocean migration season, they may disperse quickly to the open ocean. In contrast, if they escape before or after the normal out-migration period, then their dispersion may be more local. For example, in a program to create resident salmon in Puget Sound, hatchery reared Pacific salmon have been held in freshwater longer than their normal release times or put into seawater net pens at their normal seawater entry time but not released from the net pens until several months of seawater rearing. The delayed-release salmon do not migrate to the open ocean but remain in Puget Sound waters to support local recreational fisheries.

Captures of Atlantic salmon escapees in the Pacific indicate they do not appear to follow a clear dispersion pattern after release from net pens, although specific tracking studies have not been conducted for Atlantic salmon in the Pacific. Tagging and tracking studies in Norway and recapture studies in various salmon farming countries suggest most appear to disperse quickly. Tagged Atlantic salmon have been found to swim an average of two, and up to 29 kilometers per day (Solem et al. 2013). Some will travel great distances upon release, but others may remain in proximity to fish farms, and some may swim up rivers (McKinnell et al. 1997, Soto et al. 2001, Thorstad et al. 2008).

Studies from Norway, using domesticated European stock, imply if fish are released at an age and during a season that corresponds with natural life history patterns they may disperse in a manner that mirrors wild behavior. For example, domesticated Atlantic salmon smolts demonstrated strong migratory behavior when they were released from net pens in the spring or early summer (the natural time of migration), but this behavior was significantly less pronounced if released in the fall (Skillbrei 2010, Skillbrei 2013). The results from tracking studies in Europe are not always consistent. A 2010 study by Hansen and Youngson reported seven percent of salmon intentionally released in Norway just prior to sexual maturity (during spring) were recaptured in nearby rivers within four months, indicating they remained near shore and began to migrate up rivers following natural patterns. The same report explained salmon of similar age, released that season from a Scotland location behaved differently. Less than one percent of those fish were recaptured, the few that were recovered were found 400-1600 kilometers away in Norway and Sweden.

While information from European studies should be considered when planning for Atlantic salmon farms in Washington, without controlled release studies it is impossible to predict where escapees in Puget Sound might go and what, if any, migratory cues they might follow. The location, age at escape, and season during which the escape occurred can affect survival, dispersion, and interaction probability with native salmonids. The data from recovery of escaped Atlantic salmon in summer/autumn of 2017 indicated that the escaped fish were captured in large numbers (approximately 57,000 fish caught out of approximately 300,000 escaped fish) within

approximately six weeks after the event. The distribution of recovered fish and the relatively short duration of recaptures suggest that the fish disappeared within a month or so of the event.⁸⁴

3.8.2 Competitive interactions with native salmonids

Predatory interactions

The results of studies conducted in Norway, Chile, Australia, and British Columbia suggest the risk of escaped Atlantic salmon successfully competing for prey with wild salmonids is unlikely. When farmed Atlantic salmon are released some may become adept at catching wild prey but it appears that many will not (Jacobsen and Hansen 2001). Soto et al. (2001) reported stomach content analysis for three salmonid species captured between November 1995 and December 1996 in Southern Chile. These fish were part of the over four million salmon that had escaped from regional net-pen farms between 1994 and 1995. A total of 271 Atlantic salmon were captured, 50% of which were 3+ years old, an age and size typical for successful predation on smaller fish. Stomach content analysis revealed 42.3% had not fed recently. Pellets were the most commonly encountered feed item and small fish were found in approximately 15% of the fish that had eaten. While stomach content analyses have limited utility in assessing long term effects, the information may be useful when examined in the wider context. The same study reported recaptured Atlantic salmon had a reduced growth rate compared to captive Atlantic salmon from the region in the same year class. This is in contrast to the escaped coho salmon (*Oncorhynchus kisutch*) who were found to have equal or greater growth rates than their captive counterparts. Similarly, Abrantes et al. (2011) reported low incidence of feeding in recaptured Atlantic salmon escapees in Tasmania. Stable isotope analysis and fatty acid profiles performed on the escapees indicate the majority of escaped salmon did not feed on native fauna. The escape event of August 2017 from Cooke aquaculture pens indicated that none of the examined fish had food in their stomachs.

The recapture of tagged, intentionally released fish after three years at sea suggests escapees can become successful predators and complete migration in Norway (Skillbrei 2010). Other intentional release studies reveal the season of escape impacts feeding and behavior, in Atlantic salmon's native range. Eighty percent of the smolts released during fall in Norway had empty stomachs after four weeks. After 12 weeks, 80-90% of the recaptured fish had feed pellets in their stomachs, though some fish were found with small shrimp and fish fry. Fatty-acid profiles of tissue from fish recaptured after one year showed they did not switch to wild prey, but continued eating feed pellets (Olsen and Skillbrei 2010). In 1997 McKinnell et al. reported the results of Atlantic salmon stomach content analysis from fish captured in Alaska and British Columbia between 1990 and 1995. Most of the fish analyzed had empty stomachs. The 82 fish found in Alaska had a mean weight of 2.7 kilograms and 13.2% had prey in their stomachs. The same report explained 5.8% of Atlantic salmon captured in British Columbia waters had wild prey in their stomachs (478 fish examined, mean weight 3.2 kilograms). A later study of captured escaped Atlantic salmon in British Columbia examined stomach contents of 775 fish

⁸⁴ https://www.dnr.wa.gov/sites/default/files/publications/aqr_cypress_investigation_report.pdf?vdqi7rk

(Morton and Volpe 2002). Identifiable stomach contents were examined in 30 fish, which was 3.9% of total number of fish examined. Of the 30, 18 fish had consumed pellets, woody debris, or Styrofoam, 13 fish had consumed a finfish species and only one had consumed a salmonid fish.

In a cohabitation study by Volpe et al. (2001a), juvenile steelhead (*Oncorhynchus mykiss*) tended to be the more aggressive species (and more successful feeder) when housed with juvenile Atlantic salmon. The exception to this was when Atlantic salmon were allowed to reside in the system before the steelhead. Longer residency lead to greater feeding success and aggression.

Reproductive interactions

It is unlikely escaped Atlantic salmon will negatively affect the reproductive success of native salmon, although isolated incidents could occur. The probability of a negative encounter is related to the time of year, the location of release, and size and age of escapees. Disruption of courtship, or damage to redds (nests) by Atlantic salmon are the likely means of impact, though the probability of this occurring on a large scale is low and would be situationally dependent. A detailed investigation by Waknitz et al. (2002) describes similar results based on native and Atlantic salmon biology and specific husbandry practices in Washington. Though some of the details explained in that report may have changed since its release (such as industry's source of broodfish⁸⁵), their reasoning is still sound (precocious males are selected against through breeding). As fish migrate up river, space becomes confined, which may lead to aggression. Farmed Atlantic salmon are consistently found to be less aggressive (Scott et al. 2005) and less fit than wild counterparts, but they can be larger which is presumed to be advantageous. In a controlled cohabitation study (*S. salar* and *Oncorhynchus mykiss*), young Atlantic salmon tended to be more aggressive to conspecifics than to other species (Volpe et al. 2001a). Atlantic salmon's lower aggression and fitness leads one to believe it is possible but unlikely escapees would prevent or significantly deter Pacific salmon from completing their migration. Volpe et al. (2001b) found sexually mature Atlantic salmon, sourced from a British Columbia farm were not as aggressive as their wild counterparts, but they did successfully create redds in a controlled stream.

There are no recorded interactions between adult Pacific and Atlantic salmon in Pacific Northwest spawning grounds. However, observations from the Great Lakes could provide clues as to what interactions might occur if Atlantic and Pacific salmon were found together during spawning. Atlantic salmon became extirpated from Lake Ontario, at the end of the nineteenth century. Since then, several species of trout and Pacific salmon have been introduced to the Great Lakes Basin, becoming self-sustaining populations (Fuller et al. 2017a, 2017b). To learn how these populations might affect Atlantic salmon reintroduction efforts, Scott et al. (2005) released adult hatchery-raised Atlantic salmon into Ontario rivers where Pacific salmon had become established. Brown trout (*Salmo trutta*), Chinook (*O. tshawytscha*), and coho salmon (*O. kisutch*) were seen interacting with spawning Atlantic salmon in approximately 25% of the

⁸⁵ The industry in Washington currently sources eggs from a facility in Iceland. K. Bright, Cooke Aquaculture Pacific. Personal communication. April 23, 2017.

observations. The interactions consisted of exotic male salmonids courting female Atlantic salmon, chasing females from redds, guarding nesting females, and chasing other male Atlantic salmon in the vicinity. One cannot presume this is how fish would behave in Pacific spawning rivers, but it is clear the fish would interact and there may be aggression, though as noted above, the Pacific salmon were always the aggressors in the Ontario study.

Prior Atlantic salmon releases

In order to address the possibility that Atlantic salmon might establish sustainable reproducing populations in the west coast of North American, it is important to note many unsuccessful attempts were made to establish spawning populations of Atlantic salmon on the west coast. Millions of Atlantic salmon eggs, fry, fingerling, and smolts have been released into the waters of the Pacific Northwest by state, provincial, and federal governments as well as private industry or individuals. The majority of these were intentional with over eight million salmon deliberately introduced into British Columbia between 1905 and 1935 alone. Early stocking efforts released fish that were predominantly in the advanced fry stage (Ginetz 2002). The Washington State Department of Fisheries also tried unsuccessfully to establish Atlantic salmon in Puget Sound. In more recent decades, hundreds of thousands of Atlantic and Pacific salmon of various sizes have escaped from net pens used by commercial aquaculture industries in British Columbia and Washington (Table 3.8a). Despite these large number of releases, there are no confirmed records of established populations of Atlantic salmon along the Pacific coast of North America. Atlantic salmon have not established self-sustaining populations anywhere outside their home range, despite numerous attempts over the past 100+ years. In addition, there is no documented evidence of natural spawning of Atlantic salmon in waters of the Pacific Northwest. Potential reproduction of Atlantic salmon in one river in British Columbia has been inferred (Volpe et al. 2000), but alternate interpretations such as juvenile migration into the river after escape from a hatchery was not disproved. When considering the historic record and the results of intensive investigations in the United States and Canada, the risk of Atlantic salmon colonizing Washington waters is considered by most to be low (Ginetz 2002, Walknitz et al. 2002).

Table 3.8a Escaped salmon reported in Salish Sea

| Year | WA Atlantic salmon ^a | BC Atlantic salmon ^b | BC Pacific salmon ^b |
|------|---------------------------------|---------------------------------|--------------------------------|
| 1996 | 107,000 | 13,137 | NR |
| 1997 | 368,000 | 7,472 | 38,956 |
| 1998 | 22,639 | 80,975 | 1,900 |
| 1999 | 115,000 | 35,954 | NR |
| 2000 | NR | 31,855 | 36,392 |
| 2001 | NR | 55,167 | NR |

| | | | |
|--------------|-----------------------|---------|---------|
| 2002 | NR | 11,257 | 9,198 |
| 2003 | NR | 30 | 10 |
| 2004 | 24,552 | 43,969 | 16 |
| 2005 | 2,500 | 21 | 43 |
| 2006 | 0 | 17 | 19,068 |
| 2007 | 0 | 19,223 | 23 |
| 2008 | 0 | 111,769 | 57 |
| 2009 | 0 | 48,857 | 23,888 |
| 2010 | 0 | 27,024 | NR |
| 2011 | 0 | 12 | NR |
| 2012 | 0 | 8 | 2,752 |
| 2013 | 0 | NR | 300 |
| 2014 | 0 | 20 | 13,707 |
| 2015 | 0 | 2 | 1 |
| 2016 | 0 | 23 | NR |
| 2017 | ~200,000 ^c | 9 | NR |
| TOTAL | 639,691 | 531,210 | 152,311 |

^a Washington Department of Ecology, Personal communication, September 13, 2017.
^b <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/escapes-evasions/index-eng.html>.
^c Clark et al. 2017.

3.8.3 Interactions with native species

Genetic interactions with native salmonids

Risks of genetic interactions through interbreeding of cultured fish with wild conspecific is well recognized in salmonid populations. The magnitude and type of genetic risk depends on 1) the number of escaped fish relative to the size of the natural population, 2) the difference in genetic makeup between farmed and wild fish, 3) the likelihood of interbreeding, and 4) the reproductive fitness of the escaped fish (Ford 2004, Waples et al. 2012). Domestication of cultured fish would decrease survival and reproductive success in the wild, which would reduce risk to native populations in 1 through 3 above. However, domestication would increase risk to native populations in terms of loss of fitness as a result of interbreeding (item 4 above). Net-pen culture

of Pacific salmon in Washington waters would increase risk to native salmon stocks, in a manner similar to the established risks of rearing non-integrated hatchery salmon for release in watersheds containing natural spawning populations. Ironically, rearing Atlantic salmon poses no risk to native conspecifics since Atlantic salmon are not native to Washington state waters.

Mitigation to reduce risks of rearing Pacific salmon in commercial net pens in the state has relied primarily on the use of reproductively sterile triploid species, for example the rearing of triploid steelhead (*O. mykiss*) in the Columbia River. Sterilization and other management actions that reduce the number of reproductively viable escapes can substantially even if they are not 100% effective. Even 90% sterilization greatly reduces risks (Basket et al. 2013).

Sablefish

Risks of genetic interactions through interbreeding sablefish would be a concern depending on the development of sablefish commercial production. Sablefish are currently cultured in British Columbia, but the number of cultured fish produced is probably small compared to the native population since there is only one company engaged in sablefish culture. The wild population of sablefish ranges from Mexico to the Bering Sea and appears to be one large interbreeding population with no discernable genetic subgroups (Jasonowicz et al. 2014). Sablefish are sustainably managed as separate stocks because of their geographic/geopolitical distribution. The Alaska and West Coast sablefish stock biomass is estimated as greater than 300,000 metric tons. In Washington State sablefish culture is being developed on a small experimental pilot scale. If sablefish aquaculture develops in Washington State risks will need to be assessed more formally.

Disease interactions

The potential for escaped Atlantic or Pacific salmon to cause a disease outbreak in native salmonids appears low given the factors required for the onset of clinical disease, the pathogen transmission processes, and the history of Atlantic salmon in the Pacific Northwest.

The onset of clinical disease and the severity of the disease are dependent on complex interactions between the fish (host), pathogen, and environment. The ability for a pathogen to infect a host depends upon its life history strategy, strain, and concentration in the environment (Hedrick 1998). Some infective microorganisms are highly pathogenic while others are not (Wade 2014). The diseases that have affected Atlantic salmon in Washington are naturally occurring in the environment. Thus far, farmed Atlantic salmon appear to be more susceptible than Pacific salmon to local pathogens when challenged in a laboratory environment (Amos and Thomas 2002, Garver et al. 2016).

It is likely native fish populations have evolved greater innate immunity mechanisms to local pathogens and wild individuals have also acquired specific immunity to bacteria or viruses via environmental exposure (LaPatra 1998, Amos and Thomas 2002). Hatchery raised Atlantic salmon may be more susceptible to pathogens in the Pacific environment because they are immunologically disadvantaged compared to wild Pacific salmon. The strains of Infectious Hematopoietic Necrosis Virus (IHNV) and their differing pathogenicity to each *Oncorhynchus* species and age exemplifies this susceptibility (LaPatra 1998, Garver 2013). IHNV vaccines are

proven to reduce or even prevent the onset of disease and consequently, they prevent pathogen transfer. Vaccination prior to cage grow-out is essential to prevent occurrence of bacterial and viral diseases (Long 2017).

There appears to be considerable differences in pathogenicity of viruses between salmon farming regions, which must be considered when evaluating literature from the Atlantic or Chile and applying it to Washington State (House et al. 1999, Yazawa et al. 2008). For example, the species of reovirus that has been associated with Heart and Skeletal Muscle Inflammation (HSMI) in Norway, also naturally occurs in Pacific salmonids. However, in laboratory studies the strain of HSMI virus that comes from the Pacific does not induce HSMI (Garver et al. 2016). Laboratory studies also indicate susceptibility to Infectious Salmon Anemia Virus (ISAV) differs between *Oncorhynchus spp.* and Atlantic salmon. Atlantic salmon suffered from the disease in this trial, while no ISAV-related mortality occurred in the *Oncorhynchus spp.* (Roland and Winton 2003).

The likelihood of escapes introducing new pathogens is also considered low because of the extensive screening required of broodstock, eggs, and fry before any eggs can be brought into Washington from other states or foreign countries. Current industry practice is to raise salmon in hatcheries for several months prior to stocking them in net pens. During this period fish are tested multiple times for pathogens of concern and hatchery effluent water is disinfected prior to its release. Washington Department of Fish and Wildlife will only allow fish to be stocked into pens if they are free of all the pathogens monitored by the state (K. Bright, personal communication, November 2, 2017). Pathogens previously thought to be exotic, such as Viral Hemorrhagic Septicemia Virus and Piscine Reovirus, have been determined to be of local origin (Amos and Thomas 2002, Garver et al. 2016). Importantly, PRV from the North Atlantic and Eastern Pacific are genetically distinct. WDFW's policy to restrict the introduction of North Atlantic PRV into Eastern Pacific waters.

Escaped salmonids tend to disperse widely, and natural processes such as microbial action and photo-inactivation may degrade viral pathogens once they have been shed from the host (Garver 2013). Therefore, if pathogens are shed by escaped salmonids into the environment, their concentrations become diluted, which decreases potential for other fish to become infected. Under specific circumstances, a pathogen could transfer from an escapee and negatively impact a native fish. Given the number of variables required, the likelihood is low for transfer between escaped and wild individuals and consequently it is low at a population level. Continued diligent monitoring, depopulation of farms when certain diseases are diagnosed, and vaccination are management strategies that minimize risk of diseased farmed fish and protect native species.

Interactions with other marine life

If a facility regularly experiences leakage (the accidental release of a small number of fish during the course of regular operations) predators may alter normal behavior and choose to reside near the farm site in order to consume escapees. Unusual or increased sightings of predators near a farm may indicate the occurrence of escape events that may have otherwise gone unnoticed. The release of Atlantic salmon is now illegal in Washington State, therefore leakage should not be

allowed to occur, giving no incentive for seals or other predators to reside at the facilities. Hansen and Youngson (2010) suggest predation may be a significant factor in escaped fish dispersal, even for large salmon. The aforementioned study reported two intact and dislodged tags were recovered on Scottish beaches, leading to the conclusion intact, dislodged tags signal predation. They speculated more tags were likely distributed on Scottish beaches but they were never recovered because of inaccessibility.

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3.9 Protected species and other marine life interactions

3.9.1 State of the science

Marine mammal interactions

There are two categories of concern regarding the relationship between marine mammals and net-pen aquaculture farms (Parametrix, Inc. 1990, Würsig and Gailey 2002, Clement 2013). The first is farms sited near sensitive habitats including known haulouts, and the impact on the corresponding animal populations. The second is the effect of animal predation on farms and the counteracting anti-predator response measures on animal populations.

Marine mammal encounters have been recorded in all areas where finfish net pens exist (Lopez et al. 2005, Vilata et al. 2009, Northridge et al. 2010, 2013, Piroddi et al. 2011, Clement et al. 2013, Bonizzoni et al. 2014, Price et al. 2016). Predatory marine mammals are attracted to these facilities because fish congregated in pens are a potential source of prey. Which species are observed in proximity to farms and the frequency and nature of the encounters are based on naturally occurring populations in the vicinity and the behavior of these species. Pinnipeds and cetaceans are the groups most commonly associated with direct interactions. Lopez (2012), Clement (2013), and Price et al. (2016) have identified habitat exclusion, entanglement, and behavioral alterations (attraction, avoidance, or food preference) as the primary risks posed to marine mammals by finfish net pen facilities and operations.

Habitat modification, exclusion, or competition for space

The physical location of the farm within marine mammal migration routes, haulouts, or habitats is the main factor that leads to potentially adverse interactions or avoidance issues. Avoidance may be of the farm itself or the broader sound/bay. Farm site selection should consider minimizing spatial overlap with home ranges, critical breeding, foraging habitats, and migration routes. In some cases, net pen structures may not have a major impact as sited currently; however, their cumulative effects may need to be considered in relation to larger scale offshore sites.

The potential for aquaculture excluding marine mammals from critical habitats depends on the size and concentration of farm sites, farm operations, and the behavior of the particular marine mammal species (Kemper and Gibbs 2001, Kemper et al 2003, Watson-Capps and Mann 2005, Heinrich 2006, Clement 2013). Aquaculture structures that occupy a portion of the water column present a navigation obstacle that may deter some species from traversing, although some animals may be attracted to sites. Acoustic Harassment Devices (ADDs or AHDs) are used purposefully to deter seals and sea lions from feeding on the net pen stock, although their effectiveness varies and may displace cetaceans from their habitats or interfere with echolocation (Clement 2013).

Entanglement

Physical interactions between marine mammals and net pens increases the risk of entanglement in structures such as anti-predator nets (Moore and Wieting 1999, Clement 2013, Price et al. 2016, Barrett et al. 2018). Marine mammals can be attracted to the structures that house potential prey or in search of other aggregating fish near the pen sites for shelter or food waste. Dolphins have been documented feeding on wild fish attracted to fish farms off Italy, but did not target caged fish (Lopez et al. 2005). Lopez and Shirai (2007) estimated one bottlenose dolphin entanglement and subsequent mortality per month in fish farms off Italy. In a five year study at sea bass, sea bream, and meagre cages off Italy, Lopez et al. (2012) quantified five dolphins entangled in nets during the study period. Fatal entanglements of dolphins in predator nets have been reported in Australia (Kemper and Gibbs 2001, Kemper et al. 2003), and New Zealand (Clement 2013). Fur seals have also entangled and drown in predator nets in New Zealand (Clement 2013). In Canada one humpback was entangled in net-pen gear in November 2016 and died. According to Price et al. 2016, from 2010 - 2016, 550 marine mammal observations were reported by farm workers at a marine fish farm in the United States. During that time no entanglements, injuries, or mortalities occurred, despite being located less than one mile from a Whale Sanctuary. However, in 2017 a Hawaiian Monk Seal drowned in a partially decommissioned sea cage at that location. Although rare (Würsig and Gailey 2002, Price et al. 2016), fatal entanglements must be avoided at all costs, which means having timely monitoring and rescue protocols in place if such an event occurs.

Methods to minimize entanglement risk⁸⁶ described in Parametrix (1990), Clement (2013), and Price et al. (2016):

- Follow strict guidelines to for loose ropes and nets
- Monitoring and meticulous logging of interactions and presence
- Timely and orderly disposal of non-biological waste
- Reduce feed waste to minimize attraction by other fish or predators.
- Locate far from haul out sites, critical habitats, migration routes, known foraging areas, and breeding colonies
- Use predator avoidance techniques including avoidance nets, rigid nets, electric fences
- Phase out ineffective AHDs and ADDs
- Complete and timely maintenance and record keeping

Underwater noise disturbances

Net-pen operations produce underwater noise (from vessels, feeding systems, net cleaning equipment, etc.) which is a form of habitat alteration and may either deter or attract marine mammals. Underwater noise disturbances may affect marine mammals by altering their

⁸⁶ Many of the recommendations suggested by previous authors are still valid, and for others the action has occurred. For example, ADD's and AHD's have not been used in Washington for many years.

behavior; cause temporary, permanent injury, or death; invoke a stress response, habitat displacement or avoidance, attraction to the noise source; and cause disruption to underwater acoustic cues for navigation, foraging, and communication (Olesiuk et al. 2002, Nowacek et al. 2007, Northridge et al. 2010, 2013, Clement 2013). The level and persistence of underwater noises depends on farm features, operations, habitat characteristics, and compounding factors like the number of pens and proximity to other sound-generating sources. Habitat characteristics including water depth, sediment type, location, and coastline configuration impact noise sources and propagation. Whales may be more sensitive to increased noise production along migration routes in critical habitat (Gard 1974, Bryant et al. 1984, Glockner-Ferrari and Ferrari 1990, Clement 2013), while pinnipeds demonstrate tolerance and do not avoid underwater noises (Richardson 1995). Moreover, curiosity is exhibited in response to underwater noises by dolphins (Cawardine 1995, Dawson et al. 2000, Clement 2013). Although not always effective, the use of ADDs and ADHs to prevent pinniped predation has resulted in killer whale, harbor porpoise, and dolphin displacement from areas with active devices (Olesiuk et al. 2002, Northridge et al. 2010, Clement 2013).

Attraction to artificial lighting

Lighting above and submerged lighting around net pens may attract marine mammals to caged prey or similarly aggregated wild fish, causing trophic level disruptions (Cornelisen and Quarterman 2010, McConnell et al. 2010). The effect is localized but may also attract animals from longer distances, especially at night (Vilata et al. 2010). The combination of noise and lights attracts animals more than light alone. Schooling bait fish are often associated with lit cages and therefore will attract curious foraging predators. To avoid disrupting wild animal behavior around net pens, light may be shielded from all but essential directions. Spot lights above pens may be positioned high above the water to diffuse penetration through the water column (Cornelisen and Quarterman 2010, Cawthron Institute 2012).

Indirect impacts via alterations in trophic pathways

Cumulative effects through food web pathogen and antibiotic transfer can occur in top predators (see Fish health and disease management, Section 3.4).

Depredation mitigation

Aquaculture operations use a suite of methods to reduce marine mammal depredation: harassment, aversive conditioning, exclusion, non-lethal removal, lethal removal, and population control (Moore and Wieting 1999, Würsig and Gailey 2002). Rigid bag nets or curtain nets and double bottom nets provide the most effective protection against seals and sea lions (Güçlüsoy and Savas 2003, Barrett et al. 2018). Exclusion nets must be strong enough to resist chewing or tearing (Price and Morris 2013, Barrett et al. 2018). Lines made of stiff material will also prevent entanglement. Seal bombs and shooting to scare animals away are most effective if used before the animals have acclimated to the net pens and developed a permanent interest in the farm (Rueggeberg and Booth 1989, Parametrix 1990). Underwater acoustics are minimally effective (Rueggeberg and Booth 1989, Parametrix 1990, Würsig and Gailey 2002). Top nets and jump

nets are effective deterrents to river otters and mink as long as there are no gaps or holes for them to crawl or swim through. Electric fences are effective against otters and have been used to prevent pinnipeds from hauling out on farm structures (Rueggeberg and Booth 1989, Rojas and Wasdsworth 2007, Belle and Nash 2008).

Wild fish interactions

Habitat structure and shelter

Fish farms may affect the presence, abundance, diet, and residence times of wild fish attracted to the net pen structures (Carss 1990, Cornelisen 2013, Barrett et al. 2018). Net pens serve as fish aggregating devices (FAD) because they provide structure in open water, introduce feed to the environment, and may use supplemental lighting at night (Freon and Dagorn 2000, Forrest et al. 2007, McConnell et al. 2010, Cornelisen 2013). Net pen operations introduce organic material into the environment via uneaten feed (Forrest et al. 2007, Aas et al. 2011, Dempster et al. 2011, Cornelisen 2013, Barrett et al. 2018); dissolved and particulate nutrients from feces (Holmer 2010, Barrett et al. 2018); ammonia and urea excreted through gills (Randall and Tsui 2002); and organic matter from removal of fouling organisms on net walls (Carl et al. 2011, Uglem et al. 2014). Additionally, biofouling communities on cages provide a food source for wild fish, and their presence may further attract larger predators. (Serra-Llinares et al. 2013, Barrett et al. 2018).

Wild fish aggregations around fish farms exhibit spatial and temporal variability in their composition and structure (Dempster et al. 2002, Dempster 2005, Valle et al. 2007, Bacher et al. 2012). There is a positive correlation between proximity to natural habitat and the diversity of fish species around fish cages (Dempster et al. 2002, Boyra et al. 2004, Barrett et al. 2018), albeit with seasonal and temporal variations (Valle et al. 2007, Fernandez-Jover et al. 2008, Ballester-Molto et al. 2015) depending on temperature ranges (see Boyra et al. 2004). Wild fish assemblages around cage farms may be strongly influenced by depth, coastal geomorphology, and distance to shore (Fernandez-Jover et al. 2008, Ballester-Molto et al. 2015). Dempster et al. (2009) found wild fish assemblages at salmon farms were consistently different than those at natural locations, showing higher abundances in the summer, indicating farms attracted and concentrated wild fish populations. These seasonal aggregations represented a redistribution of wild fish in fjord and coastal waters and a substantial ecosystem-level effect on wild fish as a direct consequence of the aquaculture operations. Although, in general, wild fish assemblages aggregated around farms are strongly dominated by few species, which may reduce biodiversity and the potential positive ecological effect of an artificial habitat (Dempster et al. 2009, Valle et al. 2007, Fernandez-Jover et al. 2008, Bacher et al. 2012).

Dietary shift

Uneaten feed attracts wild fish to net-pens and can become a primary food source if regularly available. (Fernandez-Jover et al. 2007, 2008, 2011, Forrest et al. 2007, Dempster et al. 2009, Cornelisen 2013, Uglem et al. 2014). Dempster et al. (2009) demonstrated wild fish play a significant role in assimilating nutrient wastes. This dietary shift results in an increase in fish

condition and a modification of fatty acid composition in the tissues (Fernandez-Jover et al. 2007, 2011, Dempster et al. 2009, Ramirez et al. 2013). Ingestion of high-energy waste feed may increase the energy stores in wild fish and alter their fecundity. Whether or not this influences offspring viability is unknown (Uglem et al. 2014). The potential exists for wild fish to eat medicated feed that is released from fish pens (Dempster et al. 2009, Barrett et al. 2018). See Sections 3.4 and 3.5 for more information on fish health, disease management, and feeds.

Light

Marine net pen salmon farms in the Pacific Northwest illuminate pens during winter and spring to maintain fish growth rate and delay gonadal maturation. The consequences to wild marine fish distribution and abundance is unknown (McConnell et al. 2010, Cornelisen 2013, Stewart et al. 2013). Light alteration is a potential stressor on the surrounding ecosystems. Fish change their individual and schooling behaviors, spatial distribution, migration, reproduction, and population dynamics in the presence of artificial light (Longcore and Rich 2004, Nightingale et al. 2006). McConnell et al. (2010) suggest lights commonly used in net-pen aquaculture increased the abundance of some wild fish and zooplankton species around pens. Aggregations of fish in and around net pens may result in increased predation of wild fish that enter net pens by farmed fish (McConnell et al. 2010). Inspection of gut contents during routine fish disease examinations would assist in determining if wild fish are consumed by aquaculture fish (Cornelisen 2013).

Altered availability of wild fish to fisheries

How net-pen farms will impact the local availability of wild fish to capture fisheries is unclear, although there is potential for both positive and negative impacts. Aquaculture net pens may serve as ecological traps; ecological traps occur where animals preferentially select a habitat in which they do poorly relative to other available habitats (Robertson and Hutto 2006, Fletcher et al. 2012). Conversely, net pens may serve as protection areas (sources) where harvest is prohibited within a certain radius to conserve wild stocks (Dempster et al. 2011, Özgül and Angel 2013, Barrett et al. 2018). The European and Mediterranean studies referenced above all found a clear cage effect leading to decreasing fish abundance as distance from the farm increased. Net-pen farms could lead to increased fish production locally, but with altered availability to fishermen (Forrest et al. 2007, Cornelisen 2013). The increased concentration of fish makes them more vulnerable to fishing pressure (Forrest et al. 2007, Dempster et al. 2009, Uglem et al. 2014). Catch per unit effort in these locations would remain high and thus potentially mask any population decline. The outcome would be determined by how close the fish are to farm structure, the type of gear used to capture them, and if access to the area of the farm where the fish occur is restricted. It is unclear if aggregating fish around these structures will have long-term population effects (see Dempster et al. 2011); it is clear that localized fish aggregation occurs which could alter commercial and recreational fishermen's fishing behavior (Bohnsack and Sutherland 1985).

Pathogen and parasite transfer

Other potential effects to wild fish populations resulting from the transfer of pathogens and parasites are discussed in Sections 3.4 and 3.8.

Ecological effects

Ecological impacts of salmon net pens on wild fish attracted to the farms may not be solely negative or positive, but rather depend on many factors and thus vary along a continuum. Potential ecological effects would vary among species, sex, seasons, years, ontogenetic stages, locations, and other factors (Cornelisen 2013, Uglem et al. 2014.) Thus, the implications may vary among stakeholder groups.

Benthic invertebrate (megafauna) interactions

Nutrient enrichment and sediment chemistry changes to benthic faunal communities resulting from marine fish farms are well-documented (Pearson and Rosenberg 1978, Wildish et al. 2001, Forrest et al. 2007, Keeley 2013). Details of the changes to sediment biogeochemistry can be found in Section 3.2 Benthic effects.

Net biofouling drop-off and biodeposition leads to aggregations of predators and scavengers such as crab, sea cucumbers, sea stars, and benthic-feeding fish (Keeley 2013). Infaunal composition can be altered and diversity enhanced by fallen shell material and debris providing substrate for sessile organisms. The deposited fouling biomass could exacerbate enrichment effects associated with other processes (Keeley 2013). More detailed information on biofouling effects can be found in Section 3.6 Biofouling prevention and management.

Given the interest in benthic ranching under net pens in British Columbia Van Dam-Bates et al. (2016) studied California sea cucumber (*Parastichopus californicus*) movement in response to enriched aquaculture sites. In laboratory studies, sea cucumbers moved more rapidly and randomly in areas with higher concentrations of total organic matter. This behavior would keep an animal in areas with high total organic matter and attract nearby animals to the same sites, ensuring new resources are encountered and thus potentially altering populations and trophodynamics. Their findings suggest aquaculture tenures may retain a population of cultured individuals as well as attract wild individuals from the surrounding area. Sea cucumbers *Holothuria sanctori*, *H. arguinensis* and other echinoderms like sea stars, have shown similar foraging behavior, moving more rapidly in areas with more food availability (McClintock and Lawrence 1985, Beddingfield and McClintock 1993, Navarro et al. 2013, 2014, van Dam-Bates et al. 2016).

Dietary shift

Net pen aquaculture subsidizes benthic nutrients providing a consistent, nutrient rich food source for mobile benthic invertebrates. White et al. (2017) used fatty acid biomarkers to demonstrate sea urchins (*Echinus acutus*) will consume aquaculture waste under net pens in Norway. Diet experiments showed *E. acutus* had the capacity for dietary sparing and biosynthesis of long-

chain fatty acids and that assimilation of aquaculture waste has been shown to affect fatty acid metabolism; thus concluding *E. acutus* can exploit aquaculture waste as an energy-rich subsidy. Fish farms had positive effect on prawn in the Mediterranean by facilitating their growth (Izquierdo-Gomez et al. 2015). Prawn sampled near fish cages were larger and heavier than those further away, which was consistent with laboratory feeding trials and the availability of fish food near the pens.

Reduced natural light

Photosynthetic active radiation (PAR) could be reduced beneath and adjacent to farm structures, thereby reducing primary productivity of microalgae, macroalgae, and eelgrass (Keeley 2013) which serve as habitat and nutrients for benthic invertebrates. Flora near farms located in typically clear water would be most affected by blocked PAR. Mitigation measures include selecting sites away from habitats that are dependent on photosynthesis to minimize areas shaded, fine scale cage positioning, and modifying feed levels to site physical conditions (Keeley 2013).

Artificial light

Net pen farms in the Pacific Northwest illuminate their pens during winter and spring to extend the photoperiod so fish growth rates are maintained and gonad development is delayed with reduced ability of the fish to recognize day length. Economic yield is thus maximized for the aquaculture operation (Stewart et al. 2013). The addition of artificial light is a potential stressor on the benthic ecosystem because invertebrates including sea cucumbers, sea stars, mollusks, and crustaceans may change their behaviors, spatial distribution, migration, and reproduction in the presence of artificial light (Longcore and Rich 2004, McConnell et al. 2010). McConnell et al. (2010) demonstrated a marginally significant increase in gastropods, bivalves, and calanoid copepods in lit areas compared to control sites but indicated their behavior is most likely affected by both the light and tidal cycle.

Ecological effects

Most of the ecological effects on benthic macrofauna relate to seabed enrichment and elevated rates of biodeposition at farm sites (Keeley 2013). Farm sites should be selected for dispersive properties considering flow, depth, connectivity with larger water bodies and broad-scale positioning to avoid sensitive habitats. Depositional modeling can be used to predict the magnitude and the spatial extent of impact under different feeding methodologies and capacities, so feed management can be matched to the areas physical characteristics. Fine scale positioning of cages can be used to optimize the dispersal of waste and minimize benthic effects. A staged development plan that starts with lower production levels and integrates environmental monitoring during scale-up is another prudent mitigation strategy.

Shark interactions

Given large numbers of aggregating fish around farms, top level predators such as sharks have been documented as being attracted to net pens in the Pacific Northwest (Nash et al. 2005),

Puerto Rico (Alston et al. 2005), Hawaii (Papastamatiou et al. 2011), the Bahamas (Benetti et al. 2005), Latin America (Rojas and Wadsworth 2007), New Zealand (Forrest et al. 2007), and Australia (Australian Government 2009, Price and Morris 2013). Some sharks that are attracted to fish farms could pose a threat to divers working on the pens. Further, their bite could damage netting leading to escapes or perhaps their own entanglement. Increased encounters with sharks could occur if the animals are attracted to net pens that share space with recreational or commercial divers (Gaitán-Espitia et al. 2017).

Dietary shift

Some local impacts have been observed and documented that may not scale up to the ecosystem level. Off the coast of Chile where there is intensive salmon aquaculture, Gaitán-Espitia et al. (2017) reported female spiny dogfish *Squalus acanthias* had salmon pellets present in their stomachs. This raises concern about the potential effect of farms on the biology of predators, their trophodynamics, and ecosystem function in the area. Additionally, the use of antibiotics in the feed have the potential to accumulate in the tissues of organisms around the cages and result in side effects including liver damage, toxic effects, bacterial resistance, and immune suppression (Gaitán-Espitia et al. 2017).

Shark diet changes with ontogenetic shifts and variation in length. Smaller immature sharks feed on anchovies, whereas mature females may feed on larger prey items. Structure and composition of benthic faunal communities in the vicinity of net pens (Kutti et al., 2007, Guilpart et al. 2012) and the reduction of crustaceans (Hall-Spencer et al. 2006, Buschmann et al. 2009, Outeiro and Villasante 2013) may force the sharks to alter their diets. If preferred prey items are not available, the sharks may not be selective and pellet ingestion from farms is likely.

Deterring shark predation

Shark predation at net pens is deterred by the use of tear-resistant nets known as shark guards (Price et al. 2013). Shark guards are small rigid mesh nets installed at the bottom of fish cages to prevent sharks from feeding on accumulated dead fish (Jamieson and Olesiuk 2001). Routinely removing dead and sick fish from the cages deters predatory sharks (Price et al. 2013).

Sea bird interactions

Net pen aquaculture may negatively affect sea birds through entanglement and potential drowning, habitat exclusion and displacement from feeding grounds by physical structures, changes to the food web, disturbance of breeding colonies and birds feeding, ingestion of debris and blocked digestive tract, injury or death following collision into structures, and spread of pathogens or pest species (Forrest et al. 2007, Price et al. 2013, Sagar 2013, Surman and Dunlop 2015). Potential beneficial effects from net-pen farms include roost sites closer to foraging areas which would reduce energy expenditure and flying time, and the attraction and aggregation of forage fish around farm structures providing enhanced feeding opportunities (Rueggeberg and Booth 1989, Sagar 2013, Barrett et al. 2018). The increased number of birds around net-pen structures could also add large amounts of nutrients to the surrounding water which may affect growth of fouling organisms on nets (Sagar 2013, Barrett et al. 2018).

Entanglement

Entanglement poses the biggest threat to sea birds (Belle and Nash 2008, Surman and Dunlop 2015). Diving birds become entangled in underwater nets used to contain the fish and drown. Birds can also be entangled in above water predator exclusion nets, resulting in limb injuries and death. Net type plays an important role in entanglement risk and nets with large meshes and small twine are more likely to cause sea bird entanglement (Nemtsov and Olsvig-Whittaker 2003, and Varennes et al. 2013). Net condition and maintenance also play important roles in the number of entanglements and subsequent mortality in exclusion nets (Nemtsov and Olsvig-Whittaker 2003), and thus frequent maintenance, repair, and cleaning should be considered and evaluated prior to installation. Enclosing predator nets at bottom of cages, keeping nets taut, mesh sizes less than 6cm, maintaining nets, repairing holes, and using top nets over cages to exclude birds will help mitigate entanglements (Sagar 2013). Although exclusion nets can be an effective solution, they cannot be used everywhere and thus must be used judiciously (Varennes et al. 2013).

Habitat exclusion

Habitats available for surface feeding birds (gulls, terns, shearwaters) are reduced because of the physical structures of net pens (Forest et al. 2007, Surman and Dunlop 2015). Net pen site selection to minimize or avoid range overlap of critical breeding and feeding habitats is prudent (Bridger and Neal 2004, Borg et al. 2011, Surman and Dunlop 2015).

Change in prey abundance

Small fish are attracted to net pen structures, residual food, and lights (Dempster et al. 2002, 2009, McConnell et al. 2010). These prey fish aggregations attract feeding birds. Additionally, added nutrients in the water column can cause algal blooms and alter the birds' ability to locate prey. Changes to benthic communities induced by fish farms could disrupt feeding preferences of some birds. Practices that minimize residual food as well as siting farms in areas with strong currents to disperse nutrients away from the net pen footprint will reduce the potential for negative interactions fostered by aggregating prey (Sagar 2013, Surman and Dunlop 2015).

Disturbances

Presence of added activity and boat traffic around net pens disrupts sea bird breeding and feeding behavior. (Surman and Dunlop 2015). Net pens should be placed with minimal spatial overlap with species' home ranges, breeding grounds, and foraging habitats (Sagar 2013).

Provision of roosts

Floating structures may provide roosting sites for birds close to their foraging sites and away from terrestrial predators (Forrest et al. 2007, Surman and Dunlop 2015). Ensuring nets are kept taut and using mesh sizes less than 6 cm will help to avoid entanglement (Sagar 2013).

Attraction to light

Flying sea birds are attracted to lights around net pen facilities, similar to oil platforms, fishing boats, and light houses (Cawthorn Institute 2012, Sagar 2013). The type of lighting matters to avoid collisions with net pen structures which could result in injury or death (Surman and Dunlop 2015). Minimizing spatial overlap with species' home ranges, breeding grounds, and foraging habitats and directing light downward can avoid collisions (Sagar 2013).

Ingestion of and entanglement with foreign objects

Ingestion and entanglement of marine debris from associated net pen activities could block the digestive tracts of sea birds and cause death. Continuous monitoring and debris removal will reduce the risk of ingestion or entanglement (Sagar 2013, Surman and Dunlop 2015). A more thorough discussion of marine debris impacts is covered in Section 3.11.

Predation on net fauna

Research from Washington indicated diving birds often feed on the fauna colonizing farm structures. (Nash et al. 2005, Rensel and Forster 2007). Minimizing the growth of biofouling on nets and keeping them taut will reduce the risk of attraction and entanglement.

Farm siting considerations

The location of the farm and the conservation status of birds in the area need to be considered. Siting fish farms away from important sea bird habitats is encouraged or required in many countries to avoid conflicts (Bridger and Neal 2004, Borg et al. 2011, Price et al. 2013, Surman and Dunlop 2015). Locating a farm in close proximity to a breeding colony is likely to have immediate influence on the birds' behavior. If seabird interactions are identified as a concern, detailed monitoring of sea bird presence and activities around net pen structures should be recorded for species-specific management strategies (Sagar 2013). Understanding the intensity, frequency, and timing of sea bird predation, both aerial and diving, at a site is critical to using the best predation prevention method.

3.9.2 Washington specificity

Marine mammal interactions

Marine mammals live along the shoreline and open waters of Puget Sound (Table 3.9a). Four species of marine mammals are of particular concern to salmon net-pen farms: harbor seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and river otters (*Lontra canadensis*). Resident killer whales (*Orcinus orca*) forage throughout Puget Sound, primarily on salmon, rockfish, and cod but have not been implicated in any net pen interactions⁸⁷ (Parametrix 1990). Harbor porpoises (*Phocoena phocoena*) are

⁸⁷ Kevin Bright, Cooke Aquaculture. Personal communication October 12, 2017

abundant in Puget Sound but are not reported to interact with salmon net pens (Evenson et al. 2016).

Table 3.9a Protected and priority marine mammals that may occur within or near Puget Sound

| Marine Mammals | |
|--|--------------------------------|
| Blue Whale* | <i>Balaenoptera musculus</i> |
| Fin Whale* | <i>Balaenoptera physalus</i> |
| Guadalupe Fur Seal* | <i>Arctocephalus townsendi</i> |
| Northern Pacific Right Whale* | <i>Eubalaena japonica</i> |
| Sei Whale* | <i>Balaenoptera borealis</i> |
| Southern Resident Killer Whale* | <i>Orcinus orca</i> |
| Sperm Whale* | <i>Physeter microcephalus</i> |
| Humpback Whale* | <i>Megaptera novaeangliae</i> |
| Dall's Porpoise | <i>Phocoenoides dalli</i> |
| Eastern Pacific DPS Gray Whale | <i>Eschrichtius robustus</i> |
| Pacific Harbor Porpoise | <i>Phocoena phocoena</i> |
| Harbor Seal | <i>Phoca vitulina</i> |
| Northern Elephant Seal | <i>Mirounga angustirostris</i> |
| California Sea Lion | <i>Zalophus californianus</i> |
| Steller Sea Lion | <i>Eumetopias jubatus</i> |
| River Otter | <i>Lontra canadensis</i> |
| Sea Otter | <i>Enhydra lutris</i> |
| * indicates endangered or threatened, see Table 3.9f | |

Harbor Seal, Steller Sea Lion, and California Sea Lion

Both harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*) reside in Washington waters year round, posing the biggest risk for interactions with net-pen farms; harbor seals being the most widely distributed (Parametrix 1990). Harbor seal abundance has increased in the Puget Sound ecosystem over the past three decades while many of their preferred prey species have simultaneously declined (Jeffries et al. 1990, Berejikian et al. 2016). Seals and sea lions rest or haul out along shorelines and floating objects and can do significant damage to nets and floats (Nash et al. 2000). Initial research into how pinnipeds in Washington interact with net pens observed pinnipeds hunting in groups (Tillapaugh et al. 1993). Consequently, the aquaculture industry in Washington employs rigid predator nets that prevent seals or other predators from contacting the fish containment nets.

Primarily male California sea lions (*Zalophus californianus*) reside in Washington waters October through May but do not use haul out sites in Puget Sound (Parametrix 1990). These males are highly aggressive toward people (NOAA 1997, Nash 2000) and have been reported to attack divers (Nash 2000). As animals become less frightened of humans, shooting is not an effective deterrent (Pemberton and Shaughnessy 1993). Harbor seals and sea lions are deterred by bull rails and electric fences on the net pens (Rueggeberg and Booth 1989). Strong predator exclusion nets are necessary to protect farmed salmon from these cunning and aggressive feeders.

River otter and Sea otter

River otters (*Lontra canadensis*) are found throughout Puget Sound and they forage along shore and offshore. River otters are reported to be the primary predators of salmon in net pens (Parametrix 1990) and are also deterred by electric fences. Sea otters (*Enhydra lutris*) are found regularly in the western end of the Strait of Juan de Fuca and are periodic visitors to more inland areas. Sea otters do not pose a problem to net-pen farms because their preferred prey are mollusks.

Gray Whale

The Eastern Pacific DPS (Distinct Population Segment) Gray Whale (*Eschrichtius robustus*) population which is not listed under the Endangered Species Act (ESA) but is protected under the Marine Mammal Protection Act (MMPA) (Calambokidis et al. 2015), migrates through Washington coastal waters between January and summer and is thus vulnerable to interactions with humans and industrial development. General threats to gray whales near shore include vessel collisions, entanglement in fishing gear, and disturbance from noise, ecotourism, and whale-watching (Morandi et al. 2016). Due to their proximity to net pen farms during these migrations, there is the potential for interaction. To date the only report of grey whale entanglement in aquaculture gear is from 2000 in California where marine finfish net pens do not exist although this report was unverified (Price et al. 2016).

Humpback Whale

There is a biologically important area (BIA) off northern Washington for humpback whales (*Megaptera novaeangliae*), which represents a distinct feeding aggregation from those off Oregon and California (Calambokidis et al. 2015). This California/Oregon/Washington stock occurs in Washington waters between July and September. They are listed as endangered under the ESA and the State of Washington and are federally protected under the MMPA. Humpbacks face the same threats as gray whales. There have been no whale entanglements reported in Puget Sound net pens. In British Columbia in November 2016 one humpback drown in net-pen gear because it breached the predator net (Price et al. 2016).

Killer Whale

Killer whales (*Orcinus orca*) are listed as endangered under the ESA and by Washington State Department of Fish and Wildlife and are federally protected under the MMPA. The Southern Resident Killer Whales (SRKW) are listed as a DPS and in spring, summer, and fall, this population inhabits inland waters of Washington State and the transboundary waters between the U.S. and Canada (Morandi et al. 2016). High levels of the toxins dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyl (PCBs), chemical/oil contamination, vessel noise, and whale watching pose significant threats to this distinct population (WDFW 2012c, Morandi et al. 2016). Most importantly, their primary food source chinook salmon is in serious decline. Critical habitat was designated in 2006, encompassing the waters in the Strait of Juan de Fuca and Puget Sound beyond 20ft depth (Morandi et al. 2016). (See Section 3.7 Sensitive habitats for more detailed information.)

The scale and magnitude of net-pen aquaculture impact on marine mammals depends on the species and its population range, particularly if it is endangered, threatened, or a species of concern (MPI 2013). Increased vessel traffic around net pens and the potential for oil spills pose additional risks to transient marine mammals in the vicinity (Morandi et al. 2016). In over 30 years of net-pen farms operating in Puget Sound, American Gold Seafoods did not have any incidents of marine mammal entanglements in predator exclusion nets and reported whales do not appear to be attracted to the structures (Morandi et al. 2016).

Wild fish interactions

Salmonids

Many salmonid species inhabit Puget Sound and are listed as candidate species that will be reviewed for status assignment of threatened or endangered at some point in the future, or recognized as a priority species for conservation and management by Washington Department of Fish and Wildlife. These species include coho salmon, Chinook salmon, chum salmon, pink salmon, steelhead trout, bull trout, Dolly Varden, and cutthroat (Morandi et al. 2016). Most salmon juveniles migrate out of Puget Sound to forage in the open ocean, although some Chinook and coho remain in the sound year round (Parametrix 1990). Several salmon species in Puget Sound are managed and listed as evolutionarily significant units (ESUs) or distinct

population segments (DPSs) and are federally listed as threatened, endangered, or a species of concern (NOAA 2016) (Table 3.9b). Washington Department of Fish and Wildlife has designated critical habitats for many of these DPSs including the waters and substrates in the Strait of Georgia, Puget Sound, Hood Canal, and the Strait of Juan de Fuca, as well as in many of the creeks flowing into these water bodies (Morandi et al. 2016). For more information on sensitive habitats see Section 3.7. Because freshwater systems are essential for salmon life histories, anthropogenic effects on freshwater systems pose the greatest threat in addition to overfishing, predator/prey dynamics in the region, and hatchery practices (NOAA 2016, Morandi et al. 2016). Marine net pen operations will likely have little direct impact on the salmon physical habitat. Additional concerns about net pen effects on wild salmonids are presented in Sections 3.4, 3.7, and 3.8.

Table 3.9b Protected and priority wild fish that may occur within or near Puget Sound

| Wild fish | |
|---|-----------------------------------|
| Bocaccio Puget Sound DPS * | <i>Sebastes paucispinis</i> |
| Yelloweye Rockfish Puget Sound DPS * | <i>Sebastes ruberrimus</i> |
| Columbia River Smelt, Eulachon* | <i>Thaleichthys pacificus</i> |
| North American Green Sturgeon* | <i>Acipenser medirostris</i> |
| Chinook Salmon Puget Sound DPS* | <i>Oncorhynchus tshawytscha</i> |
| Steelhead Trout Puget Sound DPS* | <i>Oncorhynchus mykiss</i> |
| Coho Salmon Puget Sound, Strait of Georgia DPS* | <i>Oncorhynchus kisutch</i> |
| Pacific Cod Salish Sea* | <i>Gadus microcephalus</i> |
| Pacific Hake Georgia Basin DPS* | <i>Merluccius productus</i> |
| Rockfish species | <i>Sebastes spp.</i> |
| Pacific Herring | <i>Clupea pallasii</i> |
| Walleye Pollock | <i>Gadus chalcogrammus</i> |
| Lingcod/Greenling | <i>Ophiodon elongatus</i> |
| Soles and Flounder | <i>various</i> |
| Cabzone | <i>Scorpaenichthys marmoratus</i> |
| Sculpins | <i>Cottoidei</i> |
| Sea Perch | <i>various</i> |
| Bull Trout | <i>Salvelinus confluentus</i> |

| | |
|--|--------------------------|
| Dolly Varden | <i>Salvelinus malma</i> |
| Canary Rockfish Puget Sound, Georgia Basin DPS | <i>Sebastes pinniger</i> |
| * endangered or threatened, see Table 3.9f | |

Rockfish

Many species of rockfish are found in Puget Sound inhabiting rocky areas primarily, but are found near all bottom types and are often attracted to submerged structures like artificial reefs and net pens (Parametrix 1990). Boccacio (*Sebastes paucispinis*), and yelloweye rockfish (*Sebastes ruberrimus*) are two species identified as candidates for listing by WDFW. Boccacio is federally listed as endangered and yelloweye rockfish is listed as threatened. Critical habitat was designated in the Puget Sound and Georgia Basin region for rockfish species DPSs. The most significant threat to rockfish is their low recovery due to slow growth rates and low productivity (Tonnes et al. 2016, Morandi et al. 2016). Anchor lines and nets may beneficially provide additional structure for prey colonization for rockfish species (Morandi et al. 2016).

Eulachon

Eulachon (*Thaleichthys pacificus*), also known as Columbia River smelt, are federally listed as threatened. They live in nearshore waters over the continental shelf and spawn in freshwater rivers. The greatest threat to eulachon is reduced habitat availability, particularly in the Columbia River basin due to dam construction and dredging (Morandi et al. 2016). Water quality around net pens could affect eulachon phytoplankton and zooplankton prey availability.

Green Sturgeon

Green sturgeon (*Acipenser medirostris*) are anadromous and spawn in the Klamath, Rogue, and Sacramento Rivers but live primarily at sea or in estuaries. They are federally listed as threatened under the ESA but do not have a priority status in Washington. They are separated into a northern DPS, and a southern DPS. The threats to sturgeon include dam construction, as obstacles to spawning habitats, poor water quality, historical overfishing, entrainment by water projects, and contaminants in rivers (Morandi et al, 2016). Bycatch and fishing mortality are also impacting green sturgeon populations. Green sturgeon are benthic feeders so the availability of benthic habitat for prey is important. Net pen nutrient loading on the benthos could affect green sturgeon by attracting or deterring prey species depending on management practices at the facility.

Pacific Cod

The Salish Sea Pacific cod (*Gadus microcephalus*) population is found in Puget Sound, the Strait of Juan de Fuca, and the Strait of Georgia. Adults are found in depths of 160-980ft over sand and mixed coarse bottom substrates (Gustafson et al. 2000, Morandi et al. 2016). They are federally listed as a species of concern and state listed as a candidate species due to past

overfishing and genetic data that distinguished a DPS in the Salish Sea, which made that coastal population more vulnerable to bycatch and habitat loss. Because they feed on demersal crustaceans, Pacific cod could be impacted by their prey displacement due to benthic disturbances and enrichment under net pens; however, they could also benefit from aggregations of prey species around well managed farms.

Pacific Hake

Pacific hake (*Merluccius productus*) is state-listed as a candidate species and federally listed as a species of concern. One of the three Pacific hake stocks is the Georgia Basin DPS, which includes the Puget Sound and the Strait of Georgia. The main threats are overfishing, pinniped predation, habitat alteration and loss, and environmental changes (Gustafson et al. 2000). They are also deep water dwelling fish, like Pacific cod and feed on some demersal crustaceans and therefore share the same concern with net pen effects.

Pacific Herring

Pacific herring (*Clupea pallasii*) occur throughout Puget Sound, spawning from late winter through spring in eelgrass beds, mapped by WDFW (Parametrix 1990). They are harvested for both food and bait. Pacific herring are not federally listed but are listed as a candidate species by WDFW. Herring are a coastal schooling species that spawn in shallow areas along shorelines where their eggs are deposited on structures, kelp, and eelgrass beds. Specific threats to herring include the destruction of spawning grounds and feeding and rearing habitats. Their pelagic prey could be affected by water quality and their demersal prey could be displaced by benthic disturbances (Morandi et al. 2016). Net pens may provide additional structure for herring eggs.

Walleye Pollock

Walleye pollock (*Gadus chalcogrammus*) inhabit nearshore areas, large estuaries including Puget Sound, coastal embayments, and open ocean basins (Gustafson et al. 2000). Juveniles are found in a variety of habitats including eelgrass beds and over gravel and cobble. They are not federally listed but are state listed as a candidate species (Morandi et al. 2016). The threats to walleye pollock are similar to Pacific cod and include prey habitat destruction, increase in predator populations, and fishing exploitation. Water quality impacts from net-pen operations could affect walleye pollock prey, but net pens could also serve as prey aggregating structures and be beneficial to walleye pollock.

Benthic invertebrates (megafauna)

Geoduck

Geoducks (*Panopea generosa*) are not a federally or state listed species but support significant commercial and recreational fisheries in the State of Washington (WDFW 2016). They are found in lower intertidal and subtidal depths greater than 110m in soft mud, mud/sand, and sand substrates and are abundant in Puget Sound (Table 3.9c). Changes to the benthos from nutrient loading and potential anoxia pose a potential threat to geoducks in the footprint of net pens

(Morandi et al. 2016); however, the impact would likely only occur directly under the net pen if sited and managed properly.

Dungeness Crab

Dungeness crabs (*Metacarcinus magister*) occur throughout Washington State waters (Table 3.9c), including coastal estuaries and inland marine waters and are commercially harvested (Morandi et al. 2016). They occupy different habitats at each life stage: larvae are planktonic, juveniles are in intertidal mixed sand or gravel with algae and kelp, and adults are found in subtidal areas with sand, mud, and eelgrass beds (Morandi et al. 2016). Dungeness crabs are impacted by loss of habitat availability and compromised condition. Dungeness crabs could be displaced from benthic habitats shadowed by net pens due to biodeposition and nutrient over-enrichment.

Pinto Abalone

Pinto abalone (*Haliotis kamtschatkana*) is identified as a species of concern from Sitka, Alaska to Baja California, Mexico by NOAA Fisheries Service. Pinto abalone are found associated with kelp beds and rocky reef habitat between water depths of 10-60ft in Washington State waters (Table 3.9c) (Morandi et al. 2016). The population decline since the early 1970's is attributable to overharvest, illegal harvest, increased predatory sea otter populations, disease, and kelp habitat loss. Pinto abalone habitat should be considered when siting net pens given their population and conservation status.

Table 3.9c Protected and priority invertebrates that may occur within or near Puget Sound

| Invertebrates | |
|--|-----------------------------------|
| Pinto Abalone* | <i>Haliotis kamtschatkana</i> |
| Sea Cucumbers | <i>Various</i> |
| Red Sea Urchin | <i>Mesocentrotus franciscanus</i> |
| Sea Anemones | <i>Various</i> |
| Sea Stars | <i>Various</i> |
| Geoduck | <i>Panopea generosa</i> |
| Hardshell Clam | <i>Mercenaria mercenaria</i> |
| Dungeness Crab | <i>Metacarcinus magister</i> |
| Pandalid Shrimp | <i>Pandalidae</i> |
| * endangered or threatened, see Table 3.9f | |

Shark interactions

There is little published information about the interactions between sharks and net pens in Washington State. Six species of sharks frequent the waters of Puget Sound (Table 3.9d). Basking sharks (*Cetorhinus maximus*) in the Eastern North Pacific population are federally listed as a species of concern. Historically basking sharks in this region had been targeted for fishmeal and oil as well as eradicated for interactions with salmon fisheries in Canada (NMFS 2010). They are particularly vulnerable to vessel strikes because they feed close to the ocean surface. They are also known to have low reproductive rates and thus a low intrinsic rate of recovery (NMFS 2010). Although no reports of net pen interactions have been recorded, basking sharks are vulnerable to vessel strikes and potential entanglement.

Table 3.9d Protected and priority sharks that may occur within or near Puget Sound

| Sharks | |
|--|---------------------------|
| Basking Shark* | <i>Cetorhinus maximus</i> |
| Spiny Dogfish | <i>Squalus acanthias</i> |
| Sixgill Shark | <i>Hexanchus griseus</i> |
| Salmon Sharks | <i>Lamna ditropis</i> |
| Blue Shark | <i>Prionace glauca</i> |
| * endangered or threatened, see Table 3.9f | |

Sea bird interactions

Both aerial and diving birds inhabit the Puget Sound ecosystem (Table 3.9e). Predation by birds is less of a concern because anti-predator nets are used on net pens, strings placed in parallel over the farm, and the normal level of human activity associated with operation (Parametrix 1990). Some farmers use dogs to chase birds off the net pens (Rueggeberg and Booth 1989). Lethal depredation permits must be obtained from the WDFW as the piscivorous birds in conflict with net pens are protected under the United States Migratory Bird Treaty Act (Belant et al. 2000). Birds can be a problem when the salmon are small. Most diving birds are attracted to the small fish that concentrate around salmon net pens feeding on the excess food. Other species feed on the mussels and other net fouling organisms. In these cases, net pen farms can benefit some bird populations by providing food sources and additional roosting sites (Rueggeberg and Booth 1989, Parametrix 1990).

Table 3.9e Protected and priority birds that may occur within or near Puget Sound

| Birds | |
|--|-----------------------------------|
| Bald Eagle* | <i>Haliaeetus leucocephalus</i> |
| Brown Pelican* | <i>Pelecanus occidentalis</i> |
| Marbled Murrelet* | <i>Brachyramphus marmoratus</i> |
| Common Loon | <i>Gavia immer</i> |
| Brandt’s Cormorant | <i>Phalacrocorax penicillatus</i> |
| Tufted Puffin | <i>Fratercula cirrhata</i> |
| Great Blue Heron | <i>Ardea herodias</i> |
| Belted Kingfisher | <i>Megaceryle alcyon</i> |
| Osprey | <i>Pandion haliaetus</i> |
| Pigeon Guillemots | <i>Cepphus columba</i> |
| Gulls | <i>Laurus spp.</i> |
| Crows | <i>Corvus spp.</i> |
| Grebes | <i>Podicipedidae</i> |
| Diving ducks | <i>Anatidae</i> |
| Dabblers | <i>Anas spp.</i> |
| Alcids | <i>Alcidae</i> |
| Mergansers | <i>Mergus spp.</i> |
| Shorebirds | <i>various</i> |
| * endangered or threatened, see Table 3.9f | |

Bald Eagle

Despite the delisting of bald eagles (*Haliaeetus leucocephalus*) under the ESA in 2007, they remain a species of concern under the protection of the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act (Morandi et al. 2016). In western and northeastern Washington, they nest along shorelines and rivers and are thus affected by development, clear cutting, chemical pollution, loss of prey, and illegal killing (WDFW 2012a, Morandi et al. 2016). In general, the bird exclusion nets are effective at minimizing interactions with the net-pen structures (Morandi et al. 2016).

Brown Pelican

Brown pelicans (*Pelecanus occidentalis*) are state-listed as endangered and federally-listed as a species of concern. They forage in shallow coastal waters in the Strait of Juan de Fuca and Puget Sound from April through November (Morandi et al. 2016). Reduction in prey abundance and timing of prey availability are a concern for these diving birds. Additional threats are habitat loss, nesting and roosting site disturbances, oil spills, harmful algal blooms, and entanglement (Morandi et al. 2016). Net-pen structures could provide roosting sites and a source of aggregated prey. Net entanglement is a concern and could be mitigated by the use of bird exclusion nets.

Common Loon

Common loons (*Gavia immer*) are state listed as a sensitive species, vulnerable or declining and likely to become threatened or endangered throughout their range in Washington without management actions (WDFW 2012b, Morandi et al. 2016). Washington is the only state in which common loons are known to overwinter in both fresh and saltwater (WDFW 2012b). In autumn, most loons move to coastal marine locations where they remain throughout winter. The most significant threats to loons include predation, oil spills, shoreline development, lead poisoning, and drastic changes in reservoir levels (Morandi et al. 2016). Similar to the brown pelican resource needs, net-pen structures could serve as roosting sites and wild fish prey resource and bird exclusion nets would be necessary to avoid entanglement.

Tufted Puffin

Tufted puffins (*Fratercula cirrhata*) in Washington are considered a species of concern by the U.S. Fish and Wildlife Service and were petitioned for listing under the federal Endangered Species Act in 2015 (Hanson and Wiles 2015) although the petition is still under review to date. Tufted puffins had been a candidate for listing since 1998 at the state level (Hanson and Wiles 2015) and finally listed as endangered based on the findings and recommendation of the status report in April 2015. Once abundant in Washington waters, causes for the decline are unknown, but potentially include a number of historical and recent factors such as reduced prey availability, changing oceanic and climatic conditions, entrapment in fishing nets, mortality from oil spills and chemical contaminants, human disturbance of breeding colonies, impacts from introduced species, and increased bald eagle predation (Hanson and Wiles 2015). Given the rate of recent population decreases, widespread colony abandonment, ongoing threats from multiple factors, and the challenging ocean conditions expected for piscivorous seabirds in the years ahead, tufted puffins are likely to continue declining in Washington. Although no interactions with net pens have been documented, puffins could become entangled in nets. Nesting sites should also be considered when siting net pens to avoid major disturbance given their vulnerability status.

Marbled Murrelet

The marbled murrelet (*Brachyramphus marmoratus*) is a seabird in the family Alcidae in nearshore waters of the Pacific Northwest, and nests in adjacent old-forest conifers 80km offshore. They are a conservation concern due to habitat loss and declining numbers and are

listed as threatened under the ESA in the United States in the portion of its range from the Washington-British Columbia border to the southern end of its range in California (USFWS 1997, WDFW 2012d, Raphael et al. 2015). Murrelet numbers have seriously declined in recent decades and continue to decrease in the waters of Washington State (Miller et al. 2012, WDFW 2012d, Raphael et al. 2015). At the scale of individual conservation zones that were sampled in 2016, they continue to find evidence for population declines in Conservation Zone 1 (Puget Sound) (Lynch et al. 2016). Mariculture developments have proliferated throughout nearshore feeding ranges in British Columbia (Rodway et al. 1992) and Washington State. One entanglement was reported at one of 68 British Columbia net-pen farms (Rodway et al. 1992). Potential problems for marbled murrelets because of net-pen farms include displacement from traditional foraging areas, contamination of food supplies by antifoulants and antibiotics, alteration of local food supply from organic wastes, and entanglement in nets.

Aquatic Invasive Species Identified as Risks to Puget Sound Ecosystems

Net-pen structures can harbor invasive species introduced by other mechanisms such as hitching rides on floating marine debris, and in vessel ballast water disposal. The most threatening aquatic invasive animals to Puget Sound habitat and marine life restoration efforts are the following (Ray 2005):

- Asian corbula clam (*Pomatocorbula amurensis*)
- Asian date mussel (*Musculista senhousia*)
- Atlantic oyster drill (*Urosalpinx cinerea*)
- Atlantic salmon (*Salmo salar*)
- Boring sponge (*Cliona thoesina*)
- Copepod sp. (*Pseudodiaptomus inopinus*)
- Eastern mud snail (*Nassarius obsoleta*)
- European green crab (*Carcinus maenas*)
- Japanese false cerith (*Batillaria attramentaria*)
- Japanese oyster drill (*Ceratostoma inornatum*)
- Japanese purple varnish clam (*Nuttalia obscurata*)
- Ribbed mussel (*Geukensia demissa*)

Table 3.9f Protected Species that occur within or near Puget Sound including their federal and state conservation status and the likelihood of occurrence by net pens

| Species | Scientific name | Conservation status | Likelihood of occurrence by net pens | comments |
|------------------------------|--------------------------------|---|--------------------------------------|---|
| Marine Mammals | | | | |
| Blue Whale | <i>Balaenoptera musculus</i> | CITES Appendix II ESA Endangered MMPA Depleted MMPA Protected WA endangered | unlikely | Does not enter the inner marine waters of Washington State |
| Fin Whale | <i>Balaenoptera physalus</i> | CITES Appendix I ESA Endangered MMPA Depleted MMPA Protected WA endangered | unlikely | Present off Washington for most of the year but does not enter inner marine waters of WA |
| Guadalupe Fur Seal | <i>Arctocephalus townsendi</i> | ESA Threatened MMPA Depleted MMPA Protected | unlikely | Typically found further south but increasingly have been observed in OR and WA waters in recent years |
| Humpback whale | <i>Megoptera novaeangliae</i> | CITES Appendix I ESA Endangered MMPA Depleted MMPA Protected WA endangered | likely | 1 take in BC waters in November 2016 |
| Northern Pacific Right Whale | <i>Eubalaena japonica</i> | CITES Appendix I ESA Endangered MMPA Depleted MMPA Protected | unlikely | Does not enter inner marine waters of Washington State |

| | | | | |
|------------------------------------|-------------------------------|---|----------|--|
| | | WA endangered | | |
| Sei Whale | <i>Balaenoptera borealis</i> | CITES Appendix I ESA Endangered MMPA Depleted MMPA Protected WA endangered | unlikely | Occurs in deep waters and rarely off the US west coast. There have been no sightings in inner marine waters 1991-2008. |
| Southern Resident Killer whale | <i>Orcinus orca</i> | CITES Appendix II ESA Endangered MMPA Depleted MMPA Protected WA endangered | likely | Although they are seen around net pens, there is no reported interaction |
| Sperm Whale | <i>Physeter microcephalus</i> | CITES Appendix I ESA Endangered MMPA Depleted MMPA Protected WA endangered | unlikely | Species present in deep water and does not enter inner marine waters of Washington State |
| Wild Fish | | | | |
| Puget Sound DPS Bocaccio | <i>Sebastes paucispinis</i> | ESA endangered WA candidate | likely | Present in Puget Sound |
| Puget Sound DPS Yelloweye Rockfish | <i>Sebastes ruberrimus</i> | ESA threatened WA candidate | likely | Present in Puget Sound |
| Columbia River Smelt, eulachon | <i>Thaleichthys pacificus</i> | ESA threatened WA candidate | likely | Present in Puget Sound |
| North American Green Sturgeon | <i>Acipenser medirostris</i> | CITES Appendix II ESA Threatened | likely | Present in Puget Sound |

| | | | | |
|---|---------------------------------|------------------------------------|--------|------------------------|
| Chinook Salmon Puget Sound | <i>Oncorhynchus tshawytscha</i> | ESA Threatened WA candidate | likely | Present in Puget Sound |
| Steelhead Trout Puget Sound DPS | <i>Oncorhynchus mykiss</i> | ESA Threatened | likely | Present in Puget Sound |
| Coho Salmon: Puget Sound, Strait of Georgia | <i>Oncorhynchus kisutch</i> | Species of concern | likely | Present in Puget Sound |
| Pacific Cod: Salish Sea | <i>Gadus microcephalus</i> | Species of concern WA candidate | likely | Present in Puget Sound |
| Pacific Hake: Georgia Basin DPS | <i>Merluccius productus</i> | Species of concern WA candidate | likely | Present in Puget Sound |
| Sharks | | | | |
| Basking Shark | <i>Cetorhinus maximus</i> | Species of concern | likely | Present in Puget Sound |
| Invertebrates | | | | |
| Pinto Abalone | <i>Haliotis kamtschatkana</i> | Species of concern WA candidate | likely | Present in Puget Sound |
| Birds | | | | |
| Bald Eagle | <i>Haliaeetus leucocephalus</i> | Species of concern | likely | Forages in Puget Sound |
| Brown Pelican | <i>Pelecanus occidentalis</i> | Species of concern | likely | Forages in Puget Sound |
| Marbled Murrelet | <i>Brachyramphus marmoratus</i> | ESA Threatened WA endangered | likely | Forages in Puget Sound |
| Tufted Puffin | <i>Fratercula cirrhata</i> | ESA under review WA Endangered | likely | Forages in Puget Sound |

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3.10 Transfer and importation

3.10.1 State of the science

Transporting live fish and live fish eggs is a common practice in commercial aquaculture (Watson et al. 2010). Some examples of when this occurs are eggs' being imported to a hatchery from a breeder; bringing fish to net pens for grow out; and bringing live fish to a processing plant. How fish are transported depends on fish age and size as well as economic and logistical considerations. Small fish and fish eggs are regularly shipped internationally in boxes that hold the animals in sealed plastic bags containing water and oxygen. Larger fish travel in live hauling trucks between inland locations. Boats equipped with large live wells or water tanks on the deck bring fish to net-pen sites. If done without caution, introduction of foreign fish or pathogens can occur when fish are transported between regions. Additionally, transporting fish can contribute to the spread of epizootic diseases within a region (Murray et al. 2002, Saksida 2006).

Maintaining adequate water quality during shipping can be challenging. The density of fish in containers can quickly lead to a decrease in pH and dissolved oxygen concentration, coupled with an increase in the concentration of ammonia. To mitigate this, supplemental oxygen is provided to fish that are transferred by boat or by truck. To prevent excess ammonia excretion, food is often withheld for 24-48 hours prior to transport (Watson et al. 2010). When transferring fish by boat, it is common practice for operators to circulate seawater through holding tanks. This provides an additional level of assurance for water quality, but it can expose the cultured fish to endemic pathogens. Further, circulating water into a ship and then releasing it elsewhere can disperse pathogens. Studies investigating the 1989 ISAV outbreak in Scotland and the 2002-2003 IHNV outbreak in British Columbia identified transport vessels as one of the causative agents in the spread of both pathogens (Murray 2002, Saksida 2006). These and other investigations into epizootic disease outbreaks have resulted in the development of good practices that can be used to prevent the transmission of pathogens during fish transportation.

3.10.2 Washington specificity

An approved Fish Transport Permit from the Washington Department of Fish and Wildlife (WDFW) is required to transport fish into and through Washington State. The purpose of the Fish Transport Permit is to protect native fish species by ensuring:⁸⁸

- Live finfish being brought into Washington State are free from regulated and reportable fish pathogens;
- If a non-native fish species was introduced to Washington State waters, it would not cause harm to native species; and

⁸⁸ The items in the following list come from “The Fisheries Co-Managers of Washington State’s Salmonid Disease Control Policy” (2006), WDFW’s website <https://wdfw.wa.gov/licenses/fishing/fish-stocking-transport#> and WDFW’s 2018 guidance document, “Commercial Atlantic salmon Marine Net-Pen Surveillance and Monitoring Requirements of Washington State”.

- Shipped fish are not carrying aquatic invasive species.

Preventing introduction or establishment of endemic pathogens to new state watersheds

People wishing to obtain a Fish Transport Permit need to apply for it prior to the intended transfer date. The application must include a fish health examination report and the results of pathogen screening on the population being shipped. All health examinations must be done by a licensed veterinarian or accredited fish health professional, and any testing must be performed at an accredited laboratory. The species of fish being shipped, its life stage, its location of origin, and the source of its holding water are all factors considered when evaluating an application.

Native species considerations

Any species of fish transferred between locations in Washington will be required to have a health screening before transport. Transferring native salmonids between regions or watersheds increases the opportunity for introducing or amplifying endemic pathogens. This risk can be mitigated by following the methods outlined in The Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (2006), which include testing brood stock. There may be specific health screening requirements for brood and hatchery stocks depending on species and water source to be granted a fish transport permit.

Atlantic salmon considerations⁸⁹

Contingent upon fish health, prior to transport, smolts are tested for regulated pathogens at the 2% assumed pathogen prevalence level (APPL)⁹⁰.

1) Inspection, conducted by an agency-approved Certified Fish Health Specialist⁹¹, within eight weeks of the proposed transfer at the Farm Site of origin. Required samples may need to be collected at the 5% or 1% Assumed Pathogen Prevalence Level (APPL), as determined by WDFW.

2) Summary of Reportable Pathogens detected in the Lot proposed for transfer at the Farm Site of origin or detected in other Lots currently reared at the Site.

3) Summary of any Epizootics and Diagnostic cases experienced by the Lot proposed for transfer and other Lots currently reared at the Site.

⁸⁹ The information in this section was adapted from a 2018 WDFW document, “Commercial Atlantic salmon Marine Net-Pen Surveillance and Monitoring Requirements of Washington State”.

⁹⁰ The percentage of a population that is expected to be carrying a detectable level of a specific pathogen

⁹¹ An individual with specialized training in evaluating the health of aquatic animals. This individual must have knowledge of the biology and life history of the animal, husbandry practices, disease identification, sample collection, disease treatments, and the aquatic ecosystems inhabited by both wild and cultured animals. This may include state licensed USDA Category II Accredited veterinarians, American Fisheries Society/Fish Health Section (AFS/FHS) Certified Fish Pathologists and Fish Health Inspectors.

- 4) A fish health monitoring report on the Lot proposed for transfer performed by a Certified Fish Health Specialist no earlier than four weeks prior to proposed transfer. The report should include a description of the health status of the Lot of fish being transferred.
- 5) Risk Assessment Report if a Reportable Pathogen was detected in the Lot proposed for transfer. This Report will include:
 - a) The likelihood that the proposed transfer will result in the introduction and establishment of the Reportable Pathogen to Free-Ranging or commercially-cultured fish in the new location.
 - b) The consequences to commercially-cultured and Free-Ranging fish populations in the new location if the pathogen did become established.
- 6) Fish transfer will not be allowed without approval from the Director or designee and consultation with relevant tribal and federal co-managers if any of the following conditions exist:
 - a) Fish lot tests positive for Regulated or Emerging pathogens while in saltwater.
 - b) Fish lot is experiencing an Epizootic at the time of the proposed transfer.
 - c) Fish are to be moved by relocation or movement of the net-pen structure.
 - d) If any of the required information is not available.
- 7) Fish transfer will not be allowed if the lot tests positive for an exotic pathogen or an exotic pathogen genetic variant.
- 8) Fish transfers will not be allowed unless the fish are being moved into net pens with current and valid leases that are structurally sound, as determined by a third party marine engineering firm.
- 9) No fish will be transferred into a farm site unless the required fallowing period has elapsed.

A fallowing period will be required at each Farm Site between routine harvest and restocking with a new lot of fish. This fallowing period may be shortened or extended by the Department if depopulation was due to an early removal or disease event. The fallowing period does not begin until containment nets are removed and farm and dive equipment have been disinfected. The containment nets must be replaced, or disinfected and repaired, as part of the fallowing process. As part of the transport permit application process, the farm operator will notify WDFW when the containment nets have been removed and farm and dive equipment has been disinfected.

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3.11 Marine debris

3.11.1 State of the science

What is marine debris?

Marine debris is any persistent, manufactured, or processed solid material intentionally or unintentionally discarded or abandoned in the marine and coastal environment (UNEP 2009, 15 CFR 909.1). Marine debris consists of materials made or used by people and deliberately discarded into the ocean, rivers, or on beaches; brought indirectly to the ocean by rivers, sewage, storm water, or winds; or accidentally lost, including fishing gear or cargo lost at sea during inclement weather (UNEP 2009).

Marine debris can injure and kill marine wildlife; degrade ocean habitats; interfere with navigation safety; cause economic loss to shipping, fishing, and coastal communities; and pose a threat to human health (NOAA 2008). The abundance, durability, and persistence of debris in the marine environment affects marine biodiversity (Derraik 2002, Gregory 2009, Gall and Thompson 2015), aesthetics (Smith et al. 1997, Balance et al. 2000, Somerville et al. 2003), global economies (McIlgorm 2011), and ecosystem sustainability (Smith and Edgar 2014). Most marine debris has a slow rate of decomposition, leading to a gradual, but significant accumulation in the coastal and marine environment (UNEP 2009).

Aquaculture as a source of marine debris

Aquaculture gear lost from a facility or not disposed of properly can contribute to marine debris (Cirim et al. 2014). Sometimes it may be difficult to determine the origin of a buoy line or loose rope on a beach as similar materials are used in commercial fishing; however, other litter, such as feed bags and debris on the ocean floor near a net pen, may be more readily traced back to aquaculture activities. While it is established that marine wildlife is impacted by marine debris through entanglement, ingestion, bioaccumulation, and habitat effects (Vegter et al. 2014, NOAA MDP 2015, 2016), the relative contribution of aquaculture gear to marine debris effects is uncertain. Some strategies for reducing marine debris from fishery activities may transfer well to aquaculture activities.

Daily operations

Potential sources of marine debris from net pen aquaculture include feed sacks, rope, nets, buoys, plastics, wood, cardboard, rags, tools, plastic bags, paper waste, oil filters, scrap metal including railings, weights associated with the nets, and general human trash (wrappers, cups, cans etc.). Instilling an environmental ethic and best management practices by farms can reduce the possibility of marine debris being released into the surrounding ecosystems.

Some net pens feature predator exclusion nets along the perimeter of the net pen array and along the sides of walkway surfaces to prevent access by marine mammals (e.g., pinnipeds). These net

features extend from the walkway surface to above chest height. This netting reduces the likelihood that larger objects will be blown or washed off the net pen array.

Another impact associated with daily operations is loss of tools, equipment, and materials as a result of storm-related wind and wave action. In January 2018, net pens in Nova Scotia, Canada, lost a number of plastic pipes associated with the feeding system in a storm.⁹² Either due to sinking to the bottom or being conveyed far from the net pen by wind and currents, it is likely that some of this debris was not recovered.

Decommissioned, abandoned, and derelict farm sites

Although rare, abandoned and derelict farm sites pose a threat to wildlife and habitats when unattended gear is left behind. In 2017 a Hawaiian Monk Seal drowned in a partially decommissioned sea cage in Hawaii. In British Columbia in November 2016 a humpback whale entangled by a mooring line from a decommissioned pen but was released (Price et al. 2016). Incorporating shut down procedures for net pen operations, including retrieval of all gear, must be accounted for in company operating plans.

Debris caused by catastrophic events – cage loss

While catastrophic events that result in gear loss rarely occur, detailed recovery plans must be included in company policies with an emphasis on immediate action to remove as much of the facility from the surface while the structure is still floating. Catastrophic events are likely to lead to extensive debris fields on the ocean bottom that require costly, time-consuming cleanup, as discussed below.

What are the impacts of marine debris?

Marine debris is an environmental, health, aesthetic, and economic problem. Marine debris can kill or maim unsuspecting wildlife. Entanglement and ingestion are the primary forms of direct damage to wildlife caused by marine debris. Other threats to wildlife and habitats from marine debris include smothering of the seabed and disturbance of benthic communities by mechanical scouring. Marine debris can cross oceans, potentially introducing non-indigenous species to new regions. Medical and sanitary wastes constitute a health hazard and can seriously injure people. (UNEP 2009) Every year, marine debris results in tremendous economic costs and losses to individuals and communities around the world. It can spoil, foul, and destroy the beauty of the ocean and the coastal zone.

Ecological Impacts

Marine debris may cause adverse impacts to aquatic ecosystems, such as coral reefs, wetlands, fish habitats, beaches, and migratory species breeding grounds and corridors (NOAA MDP 2016). Marine wildlife is impacted by marine debris through entanglement, ingestion,

⁹² <https://www.cbc.ca/news/canada/nova-scotia/colwell-aquaculture-aquaculture-fish-farming-cooke-minister-colwell-1.4494969>

bioaccumulation, changes to the integrity and functioning of habitats, and the spread of invasive species (Derraik 2002, NOAA MDP 2013, 2014, Vegter et al. 2014). Impacts on wildlife have received considerable attention with an ever-increasing list of species documented to sustain negative effects from debris interactions (Smith and Edgar 2014).

Derelict fishing gear has a significant impact on habitats and fisheries. Abandoned nets, plastic tarps, fishing gear, and other debris may smother and crush sensitive ecosystems and their bottom dwelling species (NOAA MDP 2013, 2015). Derelict gear may ghost fish, which occurs when marine species become trapped in lost or abandoned pots or nets that continue to catch prey without being retrieved by fishermen (Bullimore et al. 2001, Pawson 2003, Matsuoka et al. 2005, NOAA MDP 2015). Because ghost fishing does not discriminate, target and non-target species, as well as local and migratory species including those protected under the Endangered Species Act (ESA), may be captured (Laist 1987, Derraik 2002, Seitz and Poulakis 2006, NOAA MDP 2015). Animals captured in derelict traps also serve as attractants for other animals resulting in a self-baiting fishing cycle (NOAA MDP 2013).

Fishing nets, line, rope, and other debris entangles, disfigures, and drowns wildlife by encircling or ensnaring the animals. Animals may incur lacerations or other wounds from debris, potentially leading to infection and debilitation (Page et al. 2004, NOAA MDP 2015). When marine species become entangled within debris, their mobility is limited. Constricted movement may inhibit the animal's ability to collect food or breathe and may lead to starvation, suffocation, exhaustion, and increased predation (NOAA MDP 2013, 2015).

Although large debris items, such as derelict fishing gear, may have severe and highly visible impacts, smaller debris items are also hazardous to wildlife (NOAA MDP 2013). Ingestion may occur accidentally, but often animals feed on marine debris because it resembles their food (Gramentz 1988, Carson 2013). Once ingested, these materials may cause malnutrition or starvation because they may collect in the animal's stomach and lessen the appetite. Ingestion of sharp objects may damage the mouth, digestive tract, or stomach lining, and cause nutrition loss, infection, sickness, starvation, and death (Redford et al. 1997, Derraik 2002). Ingested items also may block air passages and cause suffocation. In addition, some debris items may leach harmful chemicals when consumed.

There are several additional indirect impacts of marine debris. An indirect impact of marine debris on shoreline habitats occurs on beaches as a result of debris reduction and removal efforts. Mechanical beach raking, accomplished with a tractor or human labor, is used to remove debris from the shoreline and may help to remove floatable material from beaches and marine shorelines. Beach raking may also be harmful to aquatic vegetation, nesting birds, sea turtles, and other types of aquatic life (NOAA 2008). Such practices can harm nesting birds by destroying potential nesting sites, crushing nests and chicks, and removing the natural wrack-line feeding habitat. To minimize this impact, beach raking should not be conducted during nesting season (FWS 1996). Hurricanes and tsunamis often mobilize marine debris, impacting various species and habitats as it moves throughout the water column. Marine debris may also indirectly damage the environment if it causes vessel accidents that spill oil or hazardous materials. Indirect impact

also occurs through alien species transport and the introduction of invasive species with the potential for ecosystem and economic harm (NOAA MDP 2013, 2017).

Economic Impacts

Direct economic losses from marine debris may be measured in a number of different ways, including analysis of impacts on tourism, losses in catch revenues, loss of fishing gear, damaged vessels, and human injuries (Lee 2015). Marine debris may have particularly serious economic ramifications in coastal areas dependent upon tourism by creating unsightly, dangerous beaches as well as beach closures (Oigman-Pszczol and Creed 2007). In addition, the costs associated with cleanups and proper disposal of debris may be significant and include the cost of restoring the habitat impacted by marine debris; the costs to clean piers, harbors, marinas, docks, and other waterfront areas; and the costs associated with at-sea cleanups (NOAA MDP 2013, Lee 2015).

3.11.2 Washington Specificity

Marine debris in WA in general

Marine debris is present throughout Puget Sound and comes from a variety of sources including overwater structures (piers, floats), commercial and non-commercial fishing, shipping activities, and aquaculture. Human trash from direct beach recreation activities and upland sources and trash generated from locations around the Pacific Rim are found on Washington's beaches (Ecology 2018). Plastics make up approximately 92% of the debris on outer coast beaches in Washington. Bottom trawl surveys by the Washington Department of Fish and Wildlife in Puget Sound and the Northwest Straits estimated up to 117,000 derelict nets and pots weighing 2.6 million pounds lay beneath the surface (Good et al. 2010). Thousands of full size gill nets and pots have become lost or abandoned over decades of fishing, leaving a devastating legacy to marine populations in Puget Sound (Good et al. 2010).

Several efforts to date have removed tons of nets, pots, and traps (Good et al. 2010, NOAA MDP 2018, Ecology 2018). CoastSavers estimated that over 320 tons of marine debris had been collected during the April Washington Coast Cleanup events from 2000-2012, ranging from 15 to 40 tons collected per year. The July 4th, 2015 cleanup from Moclips to Long Beach collected 115 tons of debris (Ecology 2018). Tribes, WA DNR's Restoration Program and Derelict Vessel Program, and The Nature Conservancy are working to remove lost crab pots off the Washington coast. In September 2018 NOAA released a Washington Marine Debris Action Plan that maps a way forward for coordinated marine debris prevention, removal, and research among federal, state, tribal, and non-government agencies and organizations.

Threats to wildlife and protected species

Marine debris presents a direct threat to marine wildlife and protected species in Puget Sound through entanglement and ingestion. A comprehensive assessment of species recovered from derelict gillnets in Puget Sound found 960 marine fishes (22 species), 509 marine birds (15 species), 23 marine mammals (4 species), and 65 species of marine invertebrates (Good et al.

2010). Marine mammals and birds are particularly vulnerable to entanglement and drowning. (See Section 3.9 for more information about protected species in WA)

Threats to sensitive habitats

Marine debris can cause destruction of habitats in a number of different ways, including smothering, entanglement, and abrasion, with the extent of the impact dependent on the size, quantity, composition, and persistence of the material as well as the susceptibility of the affected environment (i.e. habitat vulnerability and resilience) (Wang et al. 2016). Sensitive habitats in Washington including seagrass beds, kelp beds, rocky reefs, and native shellfish beds that provide nursery habitats, refuge, and forage area for a variety of fish are vulnerable to impacts of marine debris. The presence of floating debris can similarly undermine pelagic habitat quality by affecting species' mobility by entanglement or ghost fishing, reduce the quantity of food available because of ingestion, or alter the behavior and fitness of a species (Wang et al. 2016). (See Section 3.7 for more information about sensitive habitats in WA)

Net-pen Aquaculture Marine Debris

General Operating Requirements in National Pollution Discharge Elimination System (NPDES) permits for net-pen aquaculture in Washington specifically address marine debris prevention in daily operations, managing floating debris, and larger sources such as predator nets (Icicle Subsidiary, LLC 2008).

1. The Permittee must recover floating debris, which enters the receiving water incidental to the operation of the facility.
2. The storage of predator control or containment nets on the sea floor is prohibited. Any net accidentally dropped or lost during a storm event that is not recovered immediately shall be tagged with a float, positioned using differential GPS, and reported to the WA Department of Ecology (Ecology) within 24 hours. The net shall be recovered within 30 days from the date lost, unless Ecology allows a longer time in an individual case. Ecology shall be notified on the date the net is recovered.
3. The Permittee shall routinely, at least weekly, conduct visual inspections of exposed surface lines, shackles, and mooring points. Any defective components are to be repaired or replaced promptly.
4. At least once per year, the Permittee must conduct an inspection of the main cage structure and anchoring components above and below the water line and document any problems and maintain all components to prevent failure that could lead to fish escapements.
5. The Permittee shall conduct inspections after any major storm event or physical accident involving the pen structures or moorings, and make any necessary repairs.
6. The WA Department of Natural Resources leases specifically prohibit the lessee from depositing ballast, refuse, garbage, or waste matter, both to the leased property as well as to adjacent property. This includes nets, weights, railings, and any other materials used in net pen arrays and their operation.

Cooke Aquaculture net pen collapse August 2017

On August 19, 2017, a ten-cage net pen owned by Cooke Aquaculture Pacific, LLC. (Cooke), rearing 305,000 Atlantic salmon off Cypress Island in northern Puget Sound collapsed. The collapse was preceded by an incident on July 24-25, 2017 in which the same pen moved hundreds of feet due to failed moorings (Clark et al. 2017). In response, the WA Departments of Ecology, Fish and Wildlife, and Natural Resources conducted an investigation and review of the situation (Clark et al. 2017). They found extensive biofouling on the nets contributed to significant drag resulting in mooring failures, anchor dragging, and structural failure. As a result, a recovery effort was launched to retrieve the escaped fish, the fish killed in the collapsed pens, and the damaged gear, both from the surface and the ocean floor.

The collapse offers a rare perspective into the amount and type of marine debris associated with the “worst-case” scenario associated with net pen aquaculture and thus is described in detail below.

Bathymetric images from sonar surveys following the August 2017 collapse showed anchor drag marks in the benthos and a debris field. The failure of the structure produced tons of marine debris comprised of thousands of pieces, including nets, ropes, structural metal, metal weights, plastics, and electrical cables. This catastrophic structural failure could have caused significant damage to habitats and marine wildlife if it was not properly managed and contained by being kept largely on site.

Following the collapse and immediate stabilization of the net pen, DNR required Cooke to inspect the ocean floor and remove all debris associated with the net pen structure. Cooke carried out this work in two efforts, first in September 2017 and a second effort during December 2017 – February 2018. Following the initial effort, in October 2017 DNR inspected the ocean floor using its submersible remotely operated vehicle (ROV) and found a substantial amount of debris remaining despite the initial cleanup effort. In response, Cooke initiated a second cleanup. The second clean up began with a salvage company employing its own ROV, which resulted in identification of 468 targets, thereby confirming the extent of the remaining debris problem.

Both clean-up efforts relied primarily on surface-air-supplied divers for retrieval of debris. Divers conducted the work by directly retrieving debris of a size the diver could walk or swim with. Divers placed debris of this size into a bin lowered to the bottom. Divers also secured lines to larger pieces of debris, which were hauled to the surface by crane. Sonar was used to locate larger debris and to guide the overall clean-up effort. Sonar was insufficient to identify the hundreds of smaller items, however, which could only be located, identified, and removed by diver. This work was performed in winter, at first 12 hours a day and then later 24 hours a day, beginning in mid-December and concluding in early February. All diving clean-up work was performed by an experienced salvage company hired and paid for by Cooke.

Approximately 16 acres of the seabed were surveyed and cleared of debris. Depths ranged from 70 to 100+ feet. All items recovered were inventoried and returned to shore. A total of 3,773 items were recovered and inventoried.

DNR confirmed both that the bottom had indeed been largely cleaned by deploying its ROV in May 2018 and by spot checking the inventory with the recovered materials on shore before the materials were released for disposal. DNR also viewed diver camera footage on a spot basis, which revealed the divers worked carefully to remove even the smallest-sized debris (for example, portions of zip ties). Despite this thorough effort, the May 2018 ROV survey still found three debris items in the searched area, indicating how difficult it is to clean the seabed at depth and in a high current area.

The vast majority of recovered debris clearly was associated with the net pen. The majority of the net pen related materials were associated with the July 2017 incident or August 2017 collapse. The collapse of the net pen was a violent event, sufficient to bend and rend the largest structural steel members of the net pen float system. Railings and pipes were similarly torn and crushed. The large number of pieces of debris was partly due to the violent nature of the collapse, which turned single items into multiple pieces. Among the more numerous and sizeable debris were:

- Concrete-filled 55-gallon barrels used for predator exclusion net weights (72 in number)
- Hand rails/portions of hand rails from the net pen floats (216 in number)
- A 8 foot by 10 foot section of walkway/float
- Pieces of grating (31 in number)
- Pieces of scrap steel (781 in number)
- Rope/line of various types (774 in number)
- Sections of pipe (258 in number)
- Car tires/pieces of car tire (100 in number)
- Net sections (78 in number)

Among the debris not primarily associated with the net pen were 73 crab pots/crab pot pieces.⁹³ Also in 2018, DNR restoration staff found in the eastern San Juan Islands a tub used for equipment disinfection. It had Cooke markings and likely came from the Cypress Island farm.

Some of the net pen debris recovered was likely on the ocean floor prior to July 2017. This conclusion stems from the type of debris (for example, weight types not used in the structure in 2017), age, condition (corrosion, decay), amount of biofouling, and amount of sedimentation over the debris. The net pen had been moved to its location in 2010. There is no reason to think this net pen was unusual and thus it is likely that most net pens will have “operational” marine debris on the ocean floor beneath them, if only as a legacy from historical activities.

⁹³ Cypress Island Debris Recovery Project December 2017 – February 2018. Report from Global Diving & Salvage, Seattle, WA, to Cooke Aquaculture Pacific on file at WA Department of Natural Resources.

3.11.3 Permitting and regulatory authorities

Table 3.11 Permitting and regulatory authorities, relevant actions, and lead agencies

| Authority | Relevant Actions | Lead Agency |
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| <p>Chapter 43.21C RCW STATE ENVIRONMENTAL POLICY</p> | <p>Ensures government agencies give proper consideration of environmental matters in making decisions on actions proposed by private parties or governmental agencies that may impact the environment. Requires an Environmental Impact Statement be performed by WA Ecology if the action will have probable and significant adverse environmental impacts.</p> | <p>WA Ecology</p> |
| <p>Chapter 79.145 RCW MARINE PLASTIC DEBRIS Sections 79.145.010</p> | <p>Governor appointed the marine plastic debris task force which presented a state action plan in October 1988. It is necessary for the state of Washington to implement the action plan in order to:</p> <ul style="list-style-type: none"> (1) Cleanup and prevent further pollution of the state's waters and aquatic lands; (2) Increase public awareness; (3) Coordinate federal, state, local, and private efforts; (4) Foster the stewardship of the aquatic lands of the state. | <p>WA DNR</p> |
| <p>Chapter 90.48 RCW WATER POLLUTION CONTROL</p> | <p>Insure the purity of all waters of the state consistent with public health and public enjoyment thereof, the propagation and protection of wild life, birds, game, fish and other aquatic life, and the industrial development of the state, and</p> | <p>WA Ecology</p> |

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| | to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington. | |
| Chapter 90.58 RCW SHORELINE MANAGEMENT ACT OF 1971 | The SMA is intended to protect shoreline natural resources including the land, vegetation, wildlife, and aquatic habitats against adverse environmental effects. All allowed uses are required to offset adverse environmental impacts as much as possible and preserve the natural character and aesthetics of the shoreline. | WA Ecology |
| Marine Debris Research, Prevention, and Reduction Act (MDRPRA - 33 U.S.C. §§ 1952 et seq.), renamed the Marine Debris Act (MDA - P.L. 112-213, Title VI, § 603, 126 Stat. 1576, December 20, 2012). Save Our Seas Act of 2018 (P.L. 115-265 Title I §§ 101-105, 9) | Established Marine Debris Program in NOAA to conduct research, monitoring, prevention, and reduction activities. USCG obtains a report from the National Research Council on the effectiveness of international and national measures to prevent and reduce marine debris and its impact USCG maintains voluntary reporting program, reports damage to vessels and disruption of navigation as a result of marine debris and increase international cooperation to reduce marine debris. Interagency Committee (NOAA and EPA co-chair) provide a report to Congress identifying the sources of marine debris, | NOAA, USCG |

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| | <p>impact, costs, and recommendations every 2 years.</p> <p>Reauthorize and amend the MDA to promote international action to reduce marine debris.</p> | |
| <p>Coastal Zone Management Act of 1972 P.L. 92-583; 16 U.S.C. 1451 et seq. as amended</p> | <p>Provides for management of the nation’s coastal resources through the development of state coastal zone management programs and the National Estuarine Research Reserves.</p> <p>Under Section 309 of the Act, states are eligible to receive grants for reducing marine debris entering the Nation’s coastal and ocean environment by managing uses and activities that contribute to the entry of such debris.</p> | <p>NOAA, EPA</p> |
| <p>Marine Plastic Pollution Research and Control Act 33 U.S.C. 1914-1915</p> | <p>Establishes Marine Debris Coordination Committee, chaired by NOAA, to ensure the coordination of national and international research, monitoring, education, and regulatory actions addressing persistent marine debris.</p> | <p>NOAA, EPA, USCG</p> |
| <p>Marine Protection, Research, and Sanctuaries Act 33 U.S.C. 1401-1445 (Regulatory)</p> | <p>Prohibits dumping material in the ocean that would unreasonably degrade or endanger human health or the marine environment. EPA is the permitting agency for materials dumped in the ocean except for dredge materials permitted by USACE with EPA criteria and concurrence. EPA is also responsible for designating recommended ocean dumping sites for all types of materials.</p> | <p>EPA</p> |

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| <p>Shore Protection Act 33 U.S.C. 2601-2609 (Regulatory)</p> | <p>Applicable to transportation and reception of municipal and commercial wastes in coastal waters.</p> <p>Vessel permitting program administered by the USCG is designed to minimize trash, medical waste, and other harmful materials deposited into coastal waters as a result of inadequate waste handling procedures by vessels transporting such waste.</p> <p>EPA in consultation with USCG is responsible for developing regulations governing the loading, securing, offloading, and cleaning up of such wastes from waste sources, reception facilities, and vessels.</p> | <p>EPA, USCG</p> |
| <p>Clean Water Act 33 U.S.C. 1251-1385, including 33 U.S.C. 1346(f) as amended by Beaches and Environmental Assessment and Coastal Health Act of 2000, P.L. 106-284, (114 Stat. 876) (Regulatory)</p> | <p>Section 402 requires EPA to develop and implement the National Pollutant Elimination Discharge System (NPDES) program. Sections 301 and 304 authorize EPA to set effluent limits on an industry-wide (technology-based) basis and on a water quality basis to ensure protection of the receiving water. NPDES program is administered by states (Ecology) with EPA oversight.</p> <p>Section 406(f) directs EPA to provide technical assistance to states and local governments for the assessment and monitoring of floatable material (marine debris).</p> | <p>EPA, USACE</p> |

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| <p>Resource Conservation and Recovery Act 42 U.S.C. 6941-6949</p> | <p>Directs EPA to develop guidelines for solid waste management plans. Administered by states with EPA assistance.</p> | <p>EPA</p> |
| <p>Pollution Prevention Act of 1990 42 U.S.C. 13101-13109 et seq.</p> | <p>Declares a national policy that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible; pollution that cannot be prevented or recycled should be disposed of in an environmentally safe manner when feasible; and disposal or other release into the environment should be the last resort and conducted in an environmentally safe manner.</p> <p>A major provision of the PPA is for federal agencies to provide matching funds for state and local pollution prevention programs through a grant program that promotes use of pollution prevention techniques by businesses.</p> | <p>EPA</p> |
| <p>National Marine Sanctuaries Act 16 U.S.C. 1431 et seq. (Regulatory)</p> | <p>Sanctuary protection and management including addressing threats to sanctuary resources.</p> | <p>NOAA</p> |
| <p>Endangered Species Act of 1973, 16 U.S.C. 1531 et seq. (Regulatory)</p> | <p>In consultation with the Secretaries of Commerce and Interior, agencies shall insure any authorized action is not likely to jeopardize the continued existence of any threatened or endangered species or result in the</p> | <p>NOAA, USFWS</p> |

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| | modification or destruction of critical habitat. | |
| Marine Mammal Protection Act 16 U.S.C. 1402 (Regulatory) | Regulate, enforce, and prevent marine mammal takes | NOAA, MMC, USFWS |
| Magnuson Stevens Fisheries Conservation and Management Act 16 U.S.C. 1801 et seq. (Regulatory) | Protect Essential Fish Habitat and Habitats of Particular Concern as well as manage bycatch which could occur from ghost fishing | NOAA |
| FAO Code of Conduct for Responsible Fisheries UNEP 2009 | The FAO Code of Conduct for Responsible Fisheries is a guidance document, stating that fishing should be conducted in accordance with the IMO's requirements (e.g., MARPOL Annex V) to protect the marine environment and prevent loss of fishing gear. This Code sets out principles and international standards of behavior for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity. The Code recognizes the nutritional, economic, social, environmental and cultural importance of fisheries, and the interests of all those concerned with the fishery sector. The Code takes into account the biological characteristics of the resources and their environment and the interests of consumers and other users. | |
| International Convention for the Prevention of Pollution from | Controls pollution from shipping by regulating the types and quantities of waste ships | |

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| <p>ships 1973 as modified in 1978 (MARPOL 73/78)</p> <p>MARPOL Annex V</p> | <p>discharge into the marine environment.</p> <p>Under Annex V, garbage includes all types of food, domestic and operational waste, excluding fresh fish, generated during normal operation of the vessel and liable to be disposed continuously or periodically. Disposal of plastics and other synthetics such as ropes, fishing nets, and plastic garbage bags anywhere in the sea is forbidden. It also obliges governments to ensure the provision of reception facilities at ports and marinas for the reception of garbage.</p> | |
| <p>The Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter 1972 (London Protocol)</p> | <p>Controls dumping of wastes at sea that have been generated on land. It prohibits dumping of persistent plastics and other non-biodegradable materials and certain compounds into the sea.</p> | |
| <p>The United Nations Convention on the Law of the Sea (UNCLOS) 1982</p> <p>Part XII, Articles 192-237</p> | <p>Sets out the legal framework within which all activities in the oceans and seas must be carried out.</p> <p>Concerns the protection and preservation of the marine environment. It sets general obligations to prevent, reduce, and control pollution from land-based sources, including rivers, estuaries, pipelines, and outfall structures; from seabed activities subject to national jurisdiction; from activities beyond the limits of national jurisdiction; from vessels; by</p> | |

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| | dumping; and from or through the atmosphere. | |
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3.12 Aesthetics

Coastal ocean stakeholders have voiced concerns about changes to an area's aesthetic value due to marine net pens. In Washington, concerns about noise, lighting, view plane and odor impacts have been raised during the Shoreline Master Program (SMP) update processes, shoreline permit appeals and during the development of this document (Ecology, 2017).

Washington's Shoreline Management Act directs SMPs to include, when appropriate, a conservation element "for the preservation of natural resources, including but not limited to scenic vistas, aesthetics..." (RCW 90.58.100(2)(f)). The Washington Administrative Code (WAC) and local SMPs specifically require aquaculture installations and operations to minimize any aesthetic impact.

For example, the Kitsap County SMP requires over-water aquaculture structures to be designed and maintained to minimize visual impacts and establishes height limits. Aquaculture applications must include a visual assessment that demonstrates visual impacts within 1,500 feet of the proposed project site. Net pen facilities "shall be located no closer than 1,500 feet from the OHWM, unless a specific lesser distance is determined to be appropriate based upon a visual impact analysis or due to potential impacts to navigational lines" (22.600.115 Aquaculture)

Visual impacts

Facilities currently located in Puget Sound are found in a range of landscapes, from remote to industrial areas, and also near residential neighborhoods. To identify how aquaculture facilities affects view planes, Ecology commissioned the Aquaculture Siting Study (Ecology 1986), a comprehensive study of visual impacts of Washington aquaculture practices. Distance from shore, vertical profile, size, colors, materials used and solar orientation all affect the potential visual impact. The degree of visual impact is highly variable, being dependent on the surrounding landscape, facility design, and attitude of the viewer. The study further notes that at a distance of 1,500-2,000 feet from shore, most facilities would appear as a line on the horizon.

Visual impacts may be mitigated by changes in design and location during the local shoreline permitting process. Height and distance offshore can be modified to reduce visibility. Concentrating the use and related overwater structures in one location instead of multiple locations may also minimize the visibility of facilities from residential or other high use areas. Ecology recommends local governments rely on flexible standards that incorporate the 1,500-2,000 foot distance to address visual impacts from net pens and other aquaculture overwater structures.

Local governments may require a visual impacts assessment for aquaculture proposals. Visualizations include plans, maps, wirelines, photographs, and photomontages. Different types of visual tools are likely to be used at different stages in the permitting process. This information can inform permitting authorities, local communities, and the wider public about what change is likely if the planned development takes place (Scottish Natural Heritage 2018).

Noise

Noise pollution is regulated by local governments⁹⁴ as well as the WA Department of Ecology (Ecology). Ecology’s administrative code establishes maximum permissible noise levels (Figure 3.12). However, local jurisdictions have authority to implement local noise ordinances which differ from Ecology’s. The EDNA (environmental designation for noise abatement) of an area determines the allowable amount of noise. Sources of noise from net-pen farms are varied and may include vessel motors, generators, feeders, cleaning equipment, and employee voices.

Figure 3.12 Maximum permissible environmental noise levels

WAC 173-60-040: Maximum permissible environmental noise levels

(1) No person shall cause or permit noise to intrude into the property of another person which noise exceeds the maximum permissible noise levels set forth below in this section.

(2)(a) The noise limitations established are as set forth in the following table after any applicable adjustments provided for herein are applied.

| EDNA of noise source | EDNA of receiving property | | |
|----------------------|----------------------------|---------|---------|
| | Class A | Class B | Class C |
| Class A | 55 dBA | 57 dBA | 60 dBA |
| Class B | 57 | 60 | 65 |
| Class C | 60 | 65 | 70 |

(2)(b) Between the hours of 10:00 p.m. and 7:00 a.m. the noise limitations of the foregoing table shall be reduced by 10 dBA for receiving property within Class A EDNAs.

(2)(c) At any hour of the day or night the applicable noise limitations in (a) and (b) above may be exceeded for any receiving property by no more than:

- (i) 5 dBA for a total of 15 minutes in any one-hour period; or
- (ii) 10 dBA for a total of 5 minutes in any one-hour period; or

Odor

Odors associated with finfish net-pen operations can come from feed, air-drying, biofouling, or dead fish. The degree of effect is dependent upon the source, local wind conditions, and other uses of the area. Conscientious management practices can minimize the potential for offensive

⁹⁴ Washington Department of Ecology. Noise Pollution. Available at: <https://ecology.wa.gov/Regulations-Permits/Laws-rules-rulemaking/Noise-pollution> Accessed 16 October 2018

odors to develop. Examples are storing feed so it remains dry to keep the odor from spreading, promptly removing dead animals and taking the carcasses to an appropriate disposal site, and air drying equipment in designated areas.

Impacts to aesthetics will vary based on the farm's location, size, and number of other users of an area. What appears to be critical in minimizing impacts, particularly noise and odor, is implementing and practicing a site specific, good-neighbor policy.

References

Scottish Natural Heritage. 2018. Visualisations for aquaculture. Available at: <https://www.nature.scot/sites/default/files/2018-02/Visualisations%20for%20Aquaculture%20-%20Guidance%20%20Note.pdf> Accessed 24 June 2019

WA Department of Ecology (Ecology). 1986. Aquaculture Siting Study. Prepared by EDAW, Inc. and CH₂M/Hill. Available at: <https://fortress.wa.gov/ecy/publications/documents/8610.pdf> Accessed 25 June 2019

WA Department of Ecology (Ecology). 2017. Shoreline Master Program Handbook (11-06-010). Available at: <https://fortress.wa.gov/ecy/publications/summarypages/1106010.html> Accessed 24 June 2019

Glossary

Anthropogenic: Caused or influenced by humans

Antibiotic: A drug which kills or inhibits the growth of bacteria

Antifoulants: Chemicals used to control or eliminate the growth of marine organisms which attach to aquaculture cages, ropes, and structures

Antinutritional factors: Substances that when present in animal feed or water reduce the availability of one or more nutrients

Aquaculture: The culture and/or farming of food fish, shellfish, and other aquatic plants and animals in fresh water, brackish water or salt water areas. Aquaculture practices may include but are not limited to hatching, seeding or planting, cultivating, feeding, raising, harvesting of planted crops or of natural crops so as to maintain an optimum yield, and processing of aquatic plants or animals. WAC 332-30-106 Definitions⁹⁵

Aquatic farm (aquaculture farm, fish farm): According to state regulations, aquatic farm is any facility or tract of land used for private, commercial culture of aquatic products. Each geographically separate facility or tract of land used for commercial culture constitutes a separate farm. WAC 220-370-040 Aquatic farm—Definition⁹⁶

Aquatic farmer: A private sector person who commercially farms and manages the cultivating of private sector cultured aquatic products on the person's own land or on land in which the person has a present right of possession. RCW 15.85.020⁹⁷

Assumed Pathogen Prevalence Level (APPL): The percentage of a population that is expected to be carrying a detectable level of a specific pathogen

Bathymetry: The study of underwater depth of lake or ocean floors

Benthic: Of or relating to or happening on the sea floor

Benthos: Organisms that live in or on the sediment in aquatic environments

Biodeposition: The excretion of feces and pseudofeces onto the sediment below

Biodiversity: The variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and ecosystems

⁹⁵ WAC 332-30-106 Definitions. <http://apps.leg.wa.gov/wac/default.aspx?cite=332-30-106>

⁹⁶ <http://apps.leg.wa.gov/wac/default.aspx?cite=220-370&full=true>

⁹⁷ <http://app.leg.wa.gov/RCW/default.aspx?cite=15.85.020>

Biofouling: The undesirable accumulation of microorganisms, plants, and animals on surfaces immersed in sea water

Biomass: The total mass of all living material in a defined area, habitat, or region

Biosecurity: The exclusion, eradication, or effective management of risks posed by introduced pests and species

Brackish: Water that is slight to moderately saline. The salinity of brackish water varies from 0.5 to 16psu and is therefore oligohaline to mesohaline water

Carrying capacity: In aquaculture, the maximum quantity of fish that any particular body of water can support over a long period without negative effects to the fish and to the environment

Cetacean: Marine mammals of the Order Cetacea including whales, dolphins, and porpoises

Conservation status: Measure of the risk of extinction for species protected under state, federal, and international laws

Critical habitat: Specific geographic areas that contain features essential to the conservation of an endangered or threatened species and that may require special management and protection under the Endangered Species Act

Cumulative effect: Ecological effects in the marine environment that result from the incremental, accumulating, and interacting effects of an aquaculture development when added to other stressors from anthropogenic activities affecting the marine environment (past, present, and future activities) and foreseeable changes in ocean conditions

Detritivore: Organism that feeds on dead particulate organic material including decomposing plants and animals as well as feces

El Niño: An irregularly recurring flow of unusually warm surface waters from the Pacific Ocean toward and along the western coast of South America that prevents upwelling of nutrient-rich cold deep water and that disrupts typical regional and global weather patterns - compare La Niña.

Enhancement pens (restoration pens): A net pen used to propagate native fish for their eventual release as part of an enhancement or restoration project

Essential fish habitat: All types of aquatic habitat including coral reefs, kelp forests, bays, wetlands, rivers, and even areas of the deep ocean that are necessary for fish reproduction, growth, feeding, and shelter

Facility (site): The physical structure(s) associated with an aquatic farm at a single location. May include one or more net-pen arrays. A National Pollutant Discharge Elimination System (NPDES) permit is issued for each facility (site).

Fallowing: The practice of relocating marine fish cages or delaying restocking of cages to allow the sediment below to undergo natural recovery, both geochemically and ecologically, from the impacts of nutrient loading.

Finfish: Any fish within the Class Actinopterygii. This Class includes over 96 percent of all fish including salmon, sablefish, herring, and sturgeon.⁹⁸

Genetic modification: An organism in which the genetic material has been altered by means of gene or cell technologies

Habitat exclusion: The exclusion of one or more animal species from an existing habitat due to the introduction of a new activity

Harmful algal blooms (HABs): Occur when colonies of algae, simple photosynthetic organisms that live in the sea and freshwater, grow out of control while producing toxic or harmful effects on people, fish, shellfish, marine mammals, and birds

Hypoxia: Although there are many definitions of hypoxia, generally, it can be defined as the level of DO in which fish make a physiological adjustment to maintain oxygen level to tissues. From a physiological perspective, environmental hypoxia can be defined as any water oxygen level that decreases the arterial blood oxygen concentration; such a decrease has the potential to decrease the arterial oxygen transfer factor. For Atlantic salmon, oxygen levels falling below the critical point of 6 mg/L are considered hypoxic and could have detrimental effects.

Integrated multi-trophic aquaculture (IMTA): The cultivation of fed aquaculture species (finfish) with organic extractive aquaculture species (shellfish and seaweed) for a balanced ecosystem management approach that takes into consideration site specificity, operational limits, and food safety guidelines and regulations

Intertidal: The area between that is above water at low tide and below water at high tide

Iteroparous: Reproductive strategy in species characterized by multiple reproductive cycles over the course of its life

La Niña: An irregularly recurring upwelling of unusually cold water to the ocean surface along the western coast of South America that often occurs following an El Niño and that disrupts typical regional and global weather patterns especially in a manner opposite to that of El Niño

Micronutrient: A chemical element or substance required in trace amounts for the normal growth and development of organisms

Microscopic pathogens: A disease agent such as bacteria or viruses

⁹⁸ List of Orders of Living Fishes, found in “Biology of Fishes” Second Edition. Carl E. Bond Saunders College Publishing 1996. ISBN 0-03-070342-5

Naïve: An organism that has not been previously subjected to something. Not previously exposed to a particular pathogen or antigen, therefore has not developed an Immune response; Not previously exposed to a particular condition

Net pen: A singular, netted, in-water cage used for both commercial and non-commercial finfish aquaculture, in both fresh and salt water

Net-pen array (array, raft): Multiple net pens physically connected via a shared mooring system. Arrays are typically made up of 6-12 net pens connected via a central walkway and/or a single feeding system that services all net pens in the array.

Operation: The activities that take place at a facility

Pelagic: Relating to living or occurring in the open water areas of lakes or oceans

Photomontage: An image that combines a photograph of an existing baseline view with a computer rendered image of a proposal. Thus photomontages illustrate the likely view of the aquaculture proposal as it would be seen in a photograph.

Phytoplankton: Photosynthetic microscopic plants that live suspended in the water column

Shellfish: Species belonging to the subphylum Crustacea or class Bivalvia and include crabs, oysters, clams, and mussels

Siting: The selection of a facility location and placement of that facility

Smoltification: The series of physiological changes where juvenile salmonid fish adapt from living in fresh water to living in seawater. Physiological changes during smoltification include altered body shape, increased skin reflectance, and increased Na^+/K^+ -ATPase in the gills.

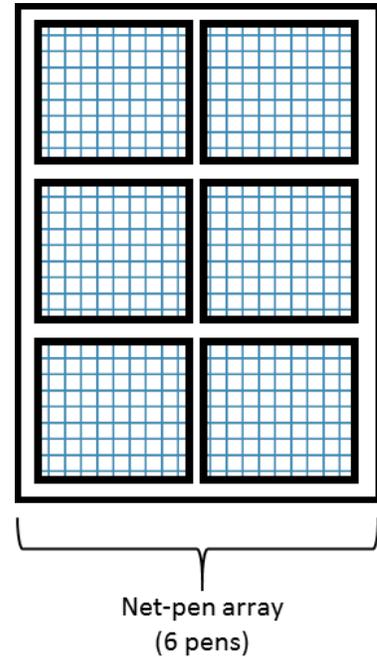
Stratification: The layering of water caused by differences in temperature and salinity

Stressor: An environmental or biotic factor that exceeds the natural levels of variation and causes disruption to an organism

Therapeutant: Chemical substances (vaccines, antibiotics, or pesticides) used on fish farms or aquaculture operations when necessary to keep aquatic animals healthy while they are raised

Trophodynamics: The dynamics of nutrition or metabolism. Relationships within a community, energy flow, and linkages between biota and the environment

Water column: A vertical expanse of water from the ocean surface to the ocean floor



Withdrawal Time: The withdrawal time is the period following drug treatment during which the animal may not be offered for slaughter and during which products from this animal may not be offered for sale. The withdrawal period is based on residue studies conducted under the labeled conditions of use (type of animal, dosage, route of administration) to ensure that residues above levels that have been shown to be safe will not be present in animal products used as human food.