U.S. Fish and Wildlife Service – Pacific Region

Environmental Risk Assessment Team for National Fish Hatcheries

Quilcene National Fish Hatchery

Climate Change Vulnerability Assessment

December 2016

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This report was written and prepared by U.S. Fish and Wildlife staff: Bill Gale, Mid-Columbia Fish and Wildlife Conservation Office, Leavenworth, Washington; Patty Crandell, Kyle Hanson, and Doug Peterson, Abernathy Fish Technology Center, Longview, Washington; Denise Hawkins, Western Washington Fish and Wildlife Conservation Office, Lacey, Washington; Ron Wong and Dan Magneson, Quilcene National Fish Hatchery, Quilcene, Washington; and Don Campton, Regional Office, Portland, Oregon, with assistance from the Hatchery Evaluation Team for the Quilcene National Fish Hatchery. Representatives from the Jamestown S'Klallam Tribe, the Lower Elwha Klallam Tribe, the Port Gamble S’Klallam Tribe, the Skokomish Indian Tribe, the Suquamish Tribe, Northwest Indian Fish Commission, Point No Point Treaty Council, NOAA Fisheries, U.S. Fish and Wildlife Service (National Refuge System, Ecological Services), Washington Department of Fish and Wildlife, Jefferson County (WA) Public Health Department, the City of Port Townsend (WA), and other stakeholders and partners participated in this process and provided valuable comments. Andrew Goodwin, U.S. Fish and Wildlife Office (Regional Office) and Chris Pasley, U.S. Fish and Wildlife Service (Winthrop National Fish Hatchery), contributed to finalization of the report presented here. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife.

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SUMMARY

Background

Episodic environmental events (droughts, floods, wildfires, summer heatwaves, etc.) have occurred historically throughout the Pacific Northwest. Since the 1970s, our scientific understanding of the relationships of these events to global oceanic and atmospheric conditions has increased substantially. For example, winters in the Pacific Northwest tend to be warmer and dryer than average during *El Niño* events when sea surface temperatures (SSTs) in the equatorial eastern Pacific Ocean are significantly warmer than normal. Conversely, winters in the Pacific Northwest tend to be cooler and wetter than average during *La Niña* events when SSTs in the equatorial eastern Pacific Ocean are significantly cooler than average. As a consequence, drought-like summer conditions are more likely during an *El Niño*, while winter/spring floods are more likely during a *La Niña*.

More recently, functional relationships among atmospheric chemistry, heat retention by the atmosphere, mean air temperatures and precipitation have been established (IPCC 2007; 2014). Physics-based, thermodynamic *General Circulation Models* (GCMs) of global atmospheric temperatures and precipitation have been developed that quantify those relationships mathematically. As a result, dynamic changes or trends in atmospheric parameters (e.g., mean concentration of carbon dioxide in the atmosphere, solar radiation intensity, etc.) can be modelled forward in time to project expected mean values for air temperature and precipitation at both global and regional scales. Such projections can then be used by resource managers to prepare for future environmental conditions and extreme environmental events that may have a higher likelihood of occurring in the future (e.g., next 20-40 years).

This series of reports for National Fish Hatcheries (NFHs) in the Pacific Region of the U.S. Fish and Wildlife Service (Service) represents the Service's attempt to use the best available science to prepare for future climate conditions and environmental events that could pose a risk to the infrastructure and/or programs at our NFHs. These reports and their underlying analyses are motivated by long-term trends in climate and the increased likelihood of extreme weather events that could significantly impact Service programs and hatcheries in the Pacific Region.

Purpose

The Pacific Region Fish and Aquatic Conservation (FAC) Program is addressing future environmental risks associated with climate change by conducting an extensive evaluation of the vulnerability of its NFHs. The NFH Environmental Risk Assessment Team (Assessment Team), with input from many employees of the FAC Program, initiated quantitative assessments of climate change vulnerabilities in 2011 with a pilot facility, Winthrop NFH (USFWS 2013).

The Assessment Team is focused on NFH vulnerabilities at the local hatchery and watershed levels, recognizing that, although other agencies would be evaluating climate change vulnerabilities in other areas that influence the viability of anadromous salmonid fishes (e.g., freshwater migration corridors and the marine environment), no other entity would be evaluating the vulnerability of U.S. Fish and Wildlife Service (Service) facilities and programs to a changing climate.

Definitions

The ***vulnerability*** of a species or system to an *environmental disturbance* such as climate change is a function of four components: sensitivity, exposure, impact, and adaptive capacity.

Sensitivity is the degree to which a system or species is likely to be affected by an environmental disturbance. ***Exposure*** is the magnitude or degree to which a system or species is expected to be subjected to an environmental disturbance. ***Impact*** is the combination of sensitivity and exposure of a system or species to an environmental disturbance. ***Adaptive capacity*** is the ability or *capacity* of a system or species to adjust or *adapt* to the impact of an environmental disturbance. ***Vulnerability*** of a species or system is an *impact* that cannot be adequately addressed by existing *adaptive capacity*.

Methods

This report elucidates the vulnerability components for existing fish culture programs at Quilcene NFH based on published climate change projections for the 2040s and information provided by the NFH staff and the Service's Hatchery Evaluation Team (HET).[1] The analyses and outputs described in this report were derived from downscaled temperature, precipitation, and hydrologic projections in the Big Quilcene River basin for the 2040s decade based on an ensemble of 10 GCMs and the *A1B emission scenario* (IPCC 2007; UW-CIG[2]). Based on the results of our analyses, expert opinions from the HET, NFH staff, co-managers representing other agencies and Tribes, stakeholders, and partners were then used to evaluate the NFH's potential adaptive strategies and vulnerabilities to climate change.

Sensitivity of Quilcene NFH

Quilcene NFH propagates one species, coho salmon (*Oncorhynchus kisutch*). Current sensitivities at the NFH include: flooding in the winter and spring, surface water shortages in the summer, high rearing densities and reduced water quality in the spring and summer, risk of disease, harmful algal blooms at saltwater net pen rearing sites, and the risk of forest fires.

[1] The Hatchery Evaluation Team consists of the hatchery manager and other technical staff of the Service who coordinate activities at a hatchery including, but not limited to, (a) scheduling of major activities, (b) biosampling of fish and tissues for fish health and other assessments, and (c) marking and tagging of juvenile fish prior to release.
[2] Climate Impacts Group, University of Washington, Seattle, Washington: http://warm.atmos.washington.edu/2860/.

Exposure of Quilcene NFH

Water temperatures are projected to increase through the 2040s, and surface water flows at Quilcene NFH are projected to be altered significantly by future climate-related shifts in mean air temperatures when compared to the 2004-2012 historical averages.

The Big Quilcene River surface water temperatures are projected to be warmer in all months, with increases ranging from between 0.4 °C (November) to 2.6 °C (June) when compared to historical averages.

The magnitude of seasonal flows is projected to be quite different in the future, especially in the Big Quilcene River, where mean flows by the 2040s are projected to increase 20-30% in the late fall and winter (November-March) and decrease by 25-42% in the summer (May-August).

Minor increases in the severity of summer drought are possible, but large increases in the magnitude of winter floods are likely.

Impact of climate change on Quilcene NFH

The projections for larger floods – as soon as the 2020s – suggest an increased risk of damage to NFH facilities and water intake structures. Climate change effects are projected to impact both water temperature and availability at the NFH.

Projected increases in surface water temperatures indicate that the NFH should remain thermally capable of propagating Pacific salmon. No upper or lower physiological thresholds will be exceeded, indicating that increasing water temperatures are not likely to preclude culture of coho salmon at Quilcene NFH. However, exposure to increasing temperatures is expected to increase juvenile growth rates, induce chronic stress, decrease immune effectiveness in individual fish, and increase disease risks for the population.

By the 2040s, the projected decreases in discharge for the Big Quilcene River for August and September, when combined with the requirement to maintain minimum (50 cfs) instream flows in the Big Quilcene River before a second water right can be exercised, will likely necessitate serial reuse of water for those months. Hydrologic projections suggest that serial reuse of water at Quilcene NFH may have to be initiated in July. The fish culture *density index* is predicted to increase throughout the rearing period and exceed the threshold guideline value for coho salmon (DI = 0.2) in the spring immediately prior to release of smolts.

Other modeling efforts suggest that the frequency and duration of harmful algal blooms in Puget Sound and Quilcene Bay will increase under the A1B emissions scenario. Harmful algal blooms are known to cause extensive mortality in juvenile salmon and may impact the NFH's ability to transfer yearling coho salmon to saltwater net pens in the spring for 1-2 months of rearing prior to release.

Adaptive capacity of Quilcene NFH

The Assessment Team, NFH staff, and HET worked collaboratively with co-managers, stakeholders, and partners to integrate current sensitivities and projected impacts of climate change on Quilcene NFH with details about the NFH's program and facilities. The information obtained provides an assessment of the NFH's adaptive capacity.

Flooding in the winter and spring may increase physical risks to Quilcene NFH infrastructure including (a) water intake structures on the Big Quilcene River, (b) low flow structures in the Big Quilcene River channel, and (c) other structures that may be blocked by gravel deposited from Penny Creek. Obtaining increased flexibility for release timing of smolts together with developing a *comprehensive plan* to address flooding and its impact on NFH infrastructure at the confluence of the Big Quilcene River and Penny Creek - and phasing planned improvements so that infrastructure can't be affected during high water - are possible means to adapt to potential flooding impacts.

Water available to the Quilcene NFH from the Big Quilcene River is projected to be reduced in the summer and may be further affected by senior water rights users upstream of the hatchery and minimum instream flow restrictions. Possible options to address these impacts include installing a recirculating water aquaculture system, drilling a new well, purchasing water from upstream senior water rights users, or convincing upstream senior water rights holders to increase their self-imposed minimum flows, thereby increasing downstream flows at the hatchery and potentially reducing restrictions on the hatchery's second water right.

Reduced water quality due to projected increases in (a) water temperature, (b) mean fish weights, and (c) fish density indexes are expected to increase fish health risks, potentially reduce survival, and increase handling stress. Improving shade covers over outside raceways, delaying egg hatch and fry emergence through chilling water, reducing feeding rations, improving Big Quilcene River riparian habitat, releasing fish early at a target release size, allowing early growth in combination with early marking, and obtaining flexibility in marking dates were suggested by Service staff, comanagers, and partners as means to address projected impacts. Studies to assess water management, compare adult survival of the two release types (net pen vs. on station), and determine maximum rearing capacity under future environmental conditions should be performed.

Harmful algal blooms may have an indirect effect on Quilcene NFH's coho salmon program when transfers of fish to saltwater net pens are delayed or cancelled causing fish to be crowded at the NFH. Options for moving net pens or reducing or abandoning their use - in conjunction with the studies listed above - will help to address these impacts.

Vulnerability of Quilcene NFH to climate change

Increases in the frequency and intensity of floods in the late fall, winter, and spring are considered to be the greatest infrastructure vulnerabilities of Quilcene NFH to the future effects of climate change. Specific concerns include the vulnerability of fish passage facilities, effects of gravel deposition, erosion affecting water diversion structures, flooding of the main road into the hatchery (Fish Hatchery Road), and the potential vulnerability of the U.S. Highway 101 bridge across the Big Quilcene River.

Coho salmon reared at Quilcene NFH are considered biologically vulnerable to accelerated growth rates associated with warmer water temperatures projected for the 2040s. Faster growth rates are expected to (a) increase rearing densities that reduce water quality and increase disease risks, and (b) increase maturation rates of males, and potentially females, yielding a higher frequency of fish that mature sexually at two years of age instead of the desired three years of age. Coho salmon smolts transferred to saltwater net pens prior to release are also vulnerable to increasing frequency and duration of hazardous algal blooms in marine waters, either directly via mortality in saltwater or indirectly via retention at Quilcene NFH where rearing densities and disease risks would increase if current protocols are retained. However, higher temperatures that could cause some mortality are not likely to preclude culture of coho salmon at Quilcene NFH based on upper temperature, physiological thresholds for the species.

Biological and environmental uncertainties

Many biological and environmental uncertainties are associated with climate change and future conditions at Quilcene NFH. Environmental uncertainties include the effects of sea level rise, ocean acidification, and reduced water quality in Puget Sound environments. The more important biological uncertainties are associated with the effect of climate change on the distribution, prevalence, and virulence of pathogens including responses of enzootic pathogens, potential immigration/introduction of novel pathogens, and incidence of harmful algal blooms. The consensus at this time is that increases in mean water temperatures will likely increase the risk and impact of fish disease within the NFH environment. These impacts could also affect native fish populations and local ecosystems in unpredictable ways. A study to determine the pathogen loads and disease impact of adult salmon and steelhead migrating upstream of the water intake for the hatchery in the Big Quilcene River may help with understanding those risks and disease management.

Recommendations

We provide eight recommendations to help prepare the Service and co-managers for the projected effects of climate change at Quilcene NFH. (p.41).

Conclusions

1. Quilcene NFH will be increasingly vulnerable to major floods in late fall, winter and spring as a consequence of climate change.
2. Infrastructure modifications to the water intakes for the hatchery and the main channel of the Big Quilcene River - between the water intake and the effluent outflow of the hatchery - could mitigate for increasing flood risks.
3. Quilcene NFH will most likely be able to continue propagating coho salmon through the 2040s, although increased growth rates resulting from increasing mean water temperatures will likely increase fish rearing densities and disease/mortality risks under current culture protocols.
4. Adjustments to current fish culture protocols and the total number of fish reared at Quilcene NFH could mitigate for increasing growth rates, densities, and disease risks.
5. Major biological and environmental uncertainties exist regarding the effects of climate change on (a) survival and growth of Pacific salmon in the marine environment and (b) the prevalence and impacts of fish pathogens and disease at Quilcene NFH and regionally.

INTRODUCTION

"As a Service and Department, we must act decisively, recognizing that climate change threatens to exacerbate other existing pressures on the sustainability of our fish and wildlife resources. We must act boldly, without having all the answers, confident that we will learn and adapt as we go. And most importantly, we must act now, as if the future of fish and wildlife and people hangs in the balance — for indeed, all indications are that it does." - Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change (USFWS 2010a).

The U.S. Fish and Wildlife Service (Service) has charted a course for its climate change efforts by identifying specific mitigation, engagement, and adaptation priorities (USFWS 2010b, c). One of the Service's adaptation priorities includes the development of vulnerability assessments for Species and Habitats, National Wildlife Refuges, and National Fish Hatcheries. The Hatcheries assessment reads as follows: *complete development of a model to assess vulnerability of National Fish Hatcheries including testing of the model.* Responsibility for this task was assigned at the national level, and a qualitative-assessment template was developed in the Headquarters Office and distributed to all National Fish Hatcheries (NFHs) in 2011. The results and conclusions of the qualitative vulnerability assessment for Quilcene NFH, including comprehensive information about the assessment and detailed methods unique to the Pacific Region, are described in Appendix A.

Although a *qualitative* assessment was completed, tremendous interest was expressed by Field Offices, the Fish and Aquatic Conservation Program (FAC), and the Regional Directorate in the Pacific Region to conduct more rigorous *quantitative* vulnerability assessments. The fish culture programs at Winthrop NFH were chosen by the FAC to serve as a pilot evaluation for the Region (USFWS 2013) with assessments for the other NFHs performed in phases. The document presented here describes the results of the quantitative climate change vulnerability assessment for Quilcene NFH.

Vulnerability Assessments: An Introduction to Concepts

The vulnerability of a species or system to an environmental disturbance like climate change can be thought of as a function of four key factors: sensitivity, exposure, impact and adaptive capacity (Figure 1).

Sensitivity is the degree to which a system or species is likely to be affected by an environmental disturbance like climate change. For example, a hatchery that is currently lacking adequate water in the summer months would be highly sensitive to prolonged periods of low summer flow conditions due to climate change. We assess sensitivity here as the current biomass capacity and productivity limitations of rearing coho salmon to the smolt age of development at Quilcene NFH.

Exposure is the magnitude or degree to which a system or species is expected to be subjected to climate change. We describe the climate change exposure anticipated in the Big Quilcene River (BQR) basin and the Quilcene NFH based on statistically downscaled climate change projections in the 2040s.

Impact is the combination of sensitivity and exposure of a system or species to climate change. To achieve a quantitative understanding of potential climate impacts to the coho salmon program at Quilcene NFH, we developed biological models that describe how fish growth and associated culture indices (density indices and flow indices) may change in the future due to climate change.

Adaptive capacity is the ability or capacity of a system or species to adjust or adapt to the impact of climate change. As part of our assessments, we considered adaptive strategies that might be useful in the future to mitigate for the effects of climate change; however, additional work is needed to assess the practicality and economic cost of employing those strategies. We discussed the potential impacts of climate change with the Hatchery Evaluation Team (HET; see footnote on page 2) for Quilcene NFH, co-managers, stakeholders, and partners, and have explored with them available strategies to respond to the projected impacts of climate change. Chillers or alternate cool water sources to delay hatching and emergence of fry exemplify ways to mitigate for the impact of increased water temperatures on growth rates of fish in a hatchery.

Consideration of the combined effect of future climate impacts that cannot be adequately addressed by exiting adaptive capacity leads to an understanding of the ***vulnerability*** of a given system or species to climate change. We describe the potential climate impacts that, most likely, cannot be adequately addressed by existing adaptive capacity as vulnerabilities to the coho salmon program at Quilcene NFH.

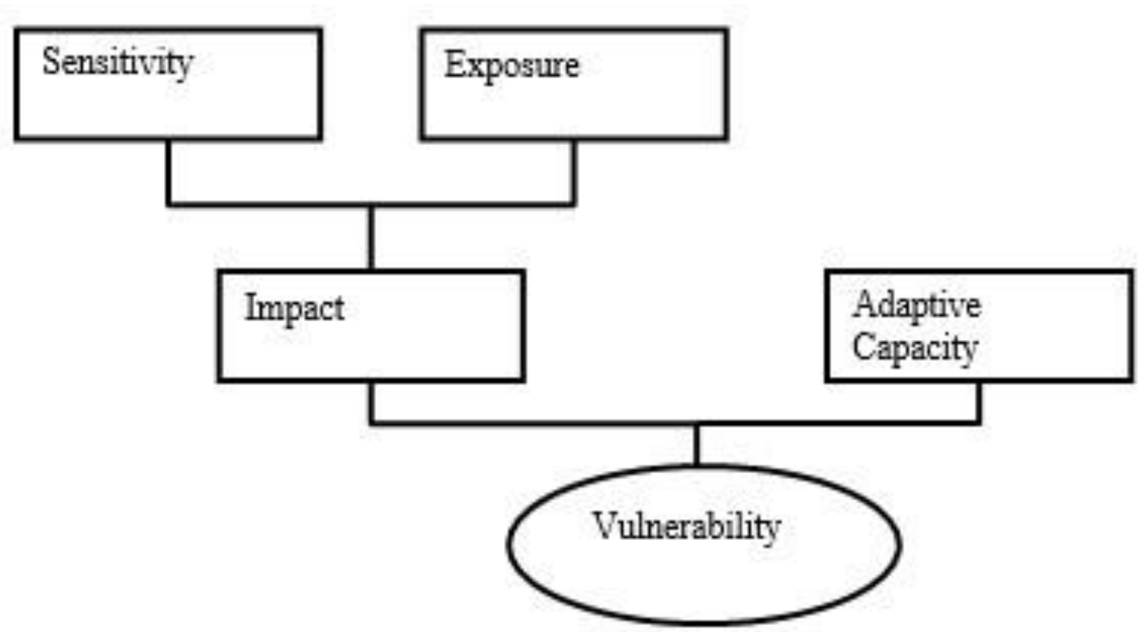

Figure 1. Key components of a vulnerability assessment.

NFH Vulnerability Assessments help determine:

- Which regional programs and species will be most affected by climate change.
- What aspects of a NFH's facilities and programs will be most affected by climate change.
- Why specific hatchery programs/species are most vulnerable to climate change.

This information will allow us to determine the most appropriate management response to climate change now and in the future.

NFH Vulnerability Assessments help us to:

- Establish practical/informed management and planning priorities.
  - What should we be doing differently?
- Inform adaptation planning.
  - What do we need to accomplish so we can continue to meet our goals?
- Efficiently allocate resources.
  - What resources do we need to gather and how are they best distributed?

At a local (individual hatchery) level, a clear understanding of the future vulnerabilities of a NFH program to changes in climate can provide managers and biologists with the information necessary to plan for future demands and stressors as well as an ability to better determine the most appropriate management direction. At the regional level (across NFHs and programs), this understanding allows resources to be more effectively allocated in a proactive manner rather than reactive in nature. A robust vulnerability assessment provides resource managers and stakeholders with the information needed to understand which NFHs and programs are vulnerable to climate change. That understanding is expected to lead to discussions among parties as how best to address identified vulnerabilities.

Need

The Service manages 15 NFHs that annually release more than 60 million juvenile Pacific salmon and steelhead (*Oncorhynchus* spp.) in the Columbia River basin and anadromous fish waters on the Olympic Peninsula (USFWS 2009a). Collectively, more than 150 State, Tribal, Federal, and Provincial fish hatcheries in Oregon, Washington, and British Columbia annually release more than 100 million juvenile salmon and steelhead (ODFW 2011; www.wdfw.wa.gov/hatcheries/overview.html; www.pac.dfo-mpo.gc.ca/sep-pmvs/hatcheries-ecloserieseng.htm). Regionally, fisheries supported by these hatcheries annually generate billions of dollars in economic activity (Lichatowich and McIntyre 1987). For example, commercial salmon fisheries made up over eight percent of the ex-vessel value of the U.S.

commercial fisheries catch valued at $257 million (Caudill 2002).

Despite the biological, economic, and cultural significance of hatchery-origin fish, little attention has been spent evaluating how current or future trends in climate will affect hatchery operations in the Pacific Northwest (Hanson and Ostrand 2011). Increased stream temperatures, earlier timing of snowmelt runoff, and reduced snowpack have already been observed in the western U.S. (Kaushal et al. 2010; Luce and Holden 2009; Mote et al. 2008). Further thermal and hydrologic changes are projected to accelerate in coming decades (IPCC 2007) which likely will result in changes in water quality and quantity within river basins in the Pacific Northwest (ISAB 2007; Mote and Salathé 2010; Mantua et al. 2010; Elsner et al. 2010). Consequently, a clear need exists to evaluate how future environmental conditions will constrain the ability of NFHs to meet their fish propagation objectives, treaty obligations, and conservation goals. Robust and transparent evaluations are particularly important because economic and infrastructure constraints will require prioritization and difficult choices between the ability to maintain existing programs and achieving other conservation objectives.

The Service has identified quantitative, scientific assessments of the vulnerability of NFHs to climate change as a priority (USFWS 2010a, b). A methodology that considers how to integrate different types of data and contextual information (Dawson et al. 2011), and formally considers the uncertainty in climate projections at the appropriate scale (Wiens and Bachelet 2010), will help identify facility or program specific impacts and vulnerabilities to climate change and support the development of strategies to cope with expected changes.

Assessment process

A NFH Climate Change Assessment Team (Assessment Team) was created to develop a process for assessing the possible future impacts of climate change on Pacific Region NFH facilities and programs. The process described here (a) allows assessments at individual facility and program levels and (b) complements existing planning and management efforts (e.g. NFH Hatchery Review Team recommendations). This assessment process has three critical elements.

1. The first critical element utilizes output from general circulation models (GCMs)[3] downscaled to the river basin of interest. Biotic and abiotic hatchery data are integrated into a framework to provide consistent and transparent evaluations of the effects of projected climate change on NFHs within the specific river basin of interest.
2. The second element combines information generated from a mathematical modeling effort with sensitivities and operational information at the local level to produce facility specific summaries of possible impacts to facilities and fish culture programs.

[3] GCMs are large, three-dimensional mathematical models that incorporate the latest understanding of the physics, fluid motion, chemistry and other physical processes of the atmosphere to simulate weather and climate globally.

3. In the final step of the process, a team of experts - including NFH staff and the HET - work collaboratively with relevant co-managers, stakeholders, and partners to integrate projected impacts of climate change with details about the infrastructure and programs at a particular hatchery. The team of experts determines which impacts might affect facilities and programs and identify possible adaptive measures. Ultimately, impacts for which there is little or no adaptive capacity are vulnerabilities for the NFH.

The report presented here for the Quilcene NFH merges information derived from diverse sources including (a) a complex modeling process (Appendix B), (b) detailed information about the programs and infrastructure of the hatchery (Appendix C), and (c) information from meetings with individuals having professional experience and/or technical expertise directly relevant to the assessment. The results of the vulnerability assessment process are intended to be available and useful for regional, programmatic (FAC), and local (NFH) level decision making and prioritization.

BACKGROUND

Big Quilcene River watershed

Quilcene NFH is located in the Big Quilcene River watershed near the confluence of the Big Quilcene River (BQR) and Penny Creek (RM 2.8) (Figure 2). The BQR watershed is a diverse ecosystem encompassing 53,016 acres from Mt. Constance (elev. 7,747 feet) in Olympic National Park to sea level at Quilcene Bay. Within the watershed, 41,734 acres of land (79% of the watershed) are administered by the U.S. Forest Service (USFS), 6,449 acres are owned by private or municipal interests, 3,676 acres are managed by the Washington State Department of Natural Resources, and 1,158 acres lie within Olympic National Park.

Three main tributaries comprise the majority of the watershed: the mainstem BQR, originating from Buckhorn Mountain; Tunnel Creek, originating from Mt. Constance; and Townsend Creek, originating from Mt. Townsend (Figure 2). Other tributaries to the BQR include Penny Creek, Mile and a Half Creek, Three Mile Creek, and numerous unnamed streams. The watershed drains approximately 83 square miles of the eastern Olympic Peninsula via 117 linear miles of streams.

The mainstem BQR is 18.9 miles long with 81.9 miles of tributaries. However, no tributary is accessible to anadromous fish (WDFW 1975) due to a natural 15-20 foot high impassible falls at RM 7.6 of the BQR. Coho salmon most likely cannot ascend even that far due to the cumulative effect of numerous cascades and rapids between RM 5 and RM 6 (WDFW 1975; Zajac 1989); however, it is likely that steelhead can pass upstream of the cascades under certain water conditions. Collectively, those falls and cascades are the upstream limit of anadromous fish migration.

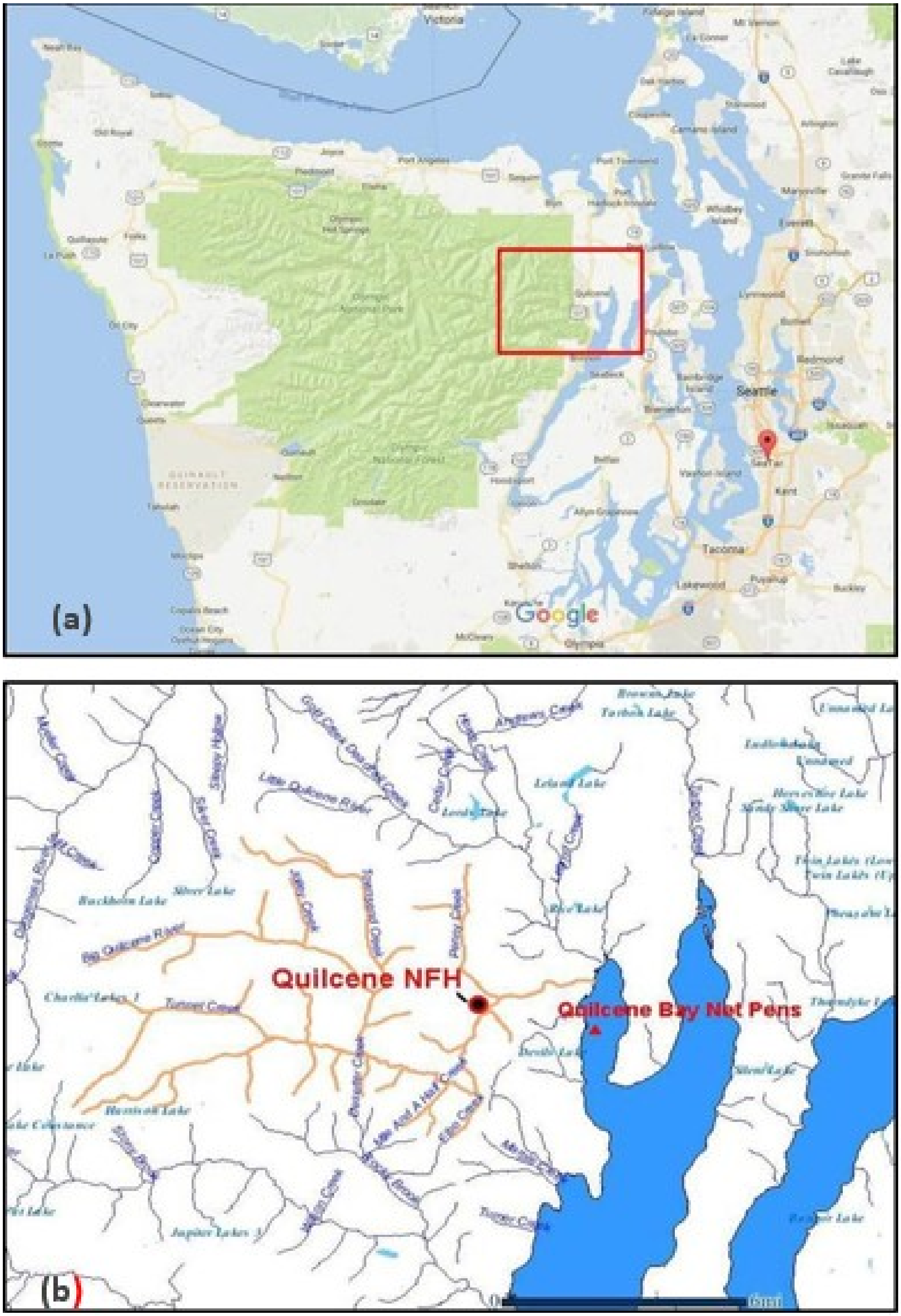

Figure 2. (a) Location of the Big Quilcene River watershed on the east slope of the Olympic Peninsula. (b) Location of the Quilcene National Fish Hatchery within the Big Quilcene River watershed (in orange; modified from http://map.streamnet.org/website/snetmapper/viewer.htm).

The headwater tributaries of the Big Quilcene River are high gradient, highly confined channels. The middle reaches below river mile 4.8 are confined moderate gradient channels with wide floodplains. The lower 2.5 miles are characterized by low gradient, unconfined channels leading into a broad alluvial fan that exits into the estuarine reaches of Quilcene Bay, the larger Dabob Bay, and Hood Canal (Figure 2).

Runoff in the Big Quilcene River watershed is transitional in nature with both snowmelt and rain driven processes. The BQR, Tunnel Creek, and Townsend Creek all have high elevation headwaters, and runoff in these tributaries is derived from both snowmelt and rainfall. The headwaters for Penny Creek are lower in elevation, and runoff is largely rainfall driven. Seasonally, runoff peaks through the winter months and remains elevated through the early summer with low flow conditions occurring in the late summer and early fall months. At Quilcene NFH, surface water temperatures in the BQR and Penny Creek are continuously measured and recorded by a computer-controlled alarm system.

As a part of Quilcene NFH's NPDES (National Pollutant Discharge Elimination System) permit requirement, surface water temperatures for BQR and Penny Creek are also recorded quarterly with a Hanna Instruments 99161 Waterproof pH/Temperature Meter. This instrument is capable of reading to within 0.1°C and is calibrated annually using a certified thermometer. BQR water temperatures range from approximately 12.8°C in the summer to 1.0°C in the winter. Penny Creek water temperatures range from approximately 11.5°C in the summer to 4.2°C in the winter. In accordance with Section 303(d) of the Clean Water Act, the BQR is listed as *impaired* for instream flow, fish and shellfish habitat, pH, bacteria, and temperature.

Coho salmon program

Quilcene NFH propagates coho salmon (*Oncorhynchus kisutch*) for harvest in tribal, commercial, and sport fisheries. In the past, 200,000 yearling coho salmon were transferred in late February and/or early March from the hatchery to saltwater net pens in Quilcene Bay (operated by the Skokomish Indian Tribe) for subsequent release in April, while 400,000 coho smolts were released into the BQR from Quilcene NFH in the late spring. However, in 2014, all 600,000 yearling coho were released at Quilcene NFH. In 2015 and 2016, 200,000 yearlings were again transferred to the net pens for release. Approximately 450,000 eyed coho salmon eggs are also transferred from Quilcene NFH to George Adams State Fish Hatchery for incubation, hatching, and early rearing. These latter fish are eventually transferred and released from saltwater net pens (operated by the Port Gamble S'Klallam Tribe) in Port Gamble Bay in November and December. Quilcene NFH also operates an isolation/quarantine building that has been used in the past for early rearing of ESA-listed steelhead. Additional information and descriptions of current rearing conditions at Quilcene NFH can be found in Appendix C.

Quilcene NFH has propagated the same population of coho salmon since construction of the hatchery in 1911. This stock of coho salmon is considered "domesticated" and managed as a segregated population for purposes of tribal, commercial, and sport harvest. The Quilcene NFH population of coho salmon is not intended to contribute to natural spawning, and was considered to have low biological significance – in terms of long-term conservation value - when reviewed by the Service's Hatchery Review Team (USFWS 2009b).

Generations of rearing as a closed artificial population have affected the life history and genetic composition of this stock. When compared to natural and hatchery populations of coho salmon in the Hood Canal region, this stock has an adult run timing that is earlier by 2-4 weeks, likely due to previous selection of early returning adults. Additionally, this stock has been comprised of three genetically distinct brood-lines, likely a result of past spawning practices that excluded two year old males (jacks) and prevented adequate gene flow among brood years of coho salmon that were spawned almost exclusively at the hatchery at 3 years of age. In 2007, in order to improve gene flow among brood years, the NFH implemented a protocol with the goal that jack males would be used in 20% of the crosses. This protocol has been in place for a number of generations, appears to be making notable progress towards reducing the genetic divergence among brood years (Smith et al. 2014), and will continue to be used in the future.

Hatchery infrastructure

The major physical facilities of the Quilcene NFH include (see Appendix C for details):

- One hatchery building supplied with surface water from Penny Creek for egg incubation and initial rearing of fish.
- One isolation/quarantine building supplied with ground water for incubating eggs from ESA-listed species.
- Thirty-nine (39), 8-by-80 foot raceways with 10 shade covers.
- Two water intake structures on the BQR: (1) a self-cleaning, NOAA-Fisheries compliant screen structure at the upper intake, constructed in 2013 and modified in 2016; and (2) and older structure constructed in 1946, located approximately 100 yards downstream of the first intake and now used as an emergency back-up.
- One 24-by-200 foot concrete pre-settling pond with two rotating drum screens for BQR water prior to delivery to the head boxes of the raceways.
- One water intake structure on Penny Creek with two, NOAA-Fisheries compliant inclined screens. The intake is divided into two diversions: one to supply water to the raceways and one as the sole source of water for egg incubation and initial rearing in the hatchery building. There is an earthen settling basin above the water intake for both the raceways and hatchery building and a subsequent concrete settling chamber for water feeding the hatchery building.
- One EPA-approved sediment pond for removing suspended solids from the effluent water of the hatchery.
- One shop building with maintenance office and built-in hazardous storage room (gasoline and diesel cans).

- Three residences for staff living on site.
- One concrete weir with a fish ladder to allow upstream passage of adult fish.
- One fish ladder to divert adult fish into raceways that are used to hold fish prior to spawning.
- Two wells: one well supplies water for the isolation/quarantine building, and the other well provides domestic water, after treatment, for staff and facilities at Quilcene NFH.

Water resources at Quilcene NFH

Quilcene NFH currently withdraws surface waters from Penny Creek and the Big Quilcene River. The hatchery also withdraws ground water from two wells located on station. A third well, across the BQR from the hatchery, is no longer used. Table 1 (p.17) summarizes the water rights of Quilcene NFH

Penny Creek

Penny Creek water was the original water source for fish rearing and egg incubation at Quilcene NFH until 1946 when a water intake on the BQR was added. Quilcene NFH has two water rights to withdraw water from Penny Creek for fish culture. Combined, these water rights allow the NFH to withdraw 25 cfs (cubic feet per second) of surface water.

Penny Creek is virtually a pathogen free water source; anadromous fish cannot ascend upstream past the water intake. Flows in Penny Creek decrease dramatically during spring and summer months. Water temperatures range from approximately 4.2°C in winter to 11.5°C in summer.

Big Quilcene River

The Big Quilcene River (BQR) is the primary water source for raceways at Quilcene NFH. The NFH has two water rights for the BQR, one dated 1946 for 15 cfs, and the other dated 1991 for 25 cfs. No restrictions exist on water use under the first right for maintaining minimum instream flows. The second water right (dated 1991) is seasonally limited and requires the hatchery to maintain minimum instream flows between the NFH intake and outfall of (a) 50 cfs from July 1 through February 28/29 and (b) 83 cfs from March 1 through June 30. This latter restriction on water use often limits the NFH to withdrawing a maximum of 15 cfs (1946 water right) and necessitates reusing water in some raceways from July through October.

The Port Townsend Paper Corporation (PTPC) and the City of Port Townsend have water rights on the BQR that precede the NFH’s 1946 water right. Their gravity-flow water diversion is located several miles upstream of the Quilcene NFH intake. That diversion provides domestic water for several towns and a PTPC paper mill. The domestic water treatment system for the City of Port Townsend does not currently have a filtration system, so water must be of designated *clarity* before it can be diverted. As a consequence, BQR water is withdrawn by upstream users only during periods of moderate to low flows when the water is clear. During winter freshets when water is murky, those users do not withdraw any water from the BQR.

The City of Port Townsend and the PTPC have imposed a minimum instream flow requirement at their water diversion on the BQR of 27 cfs year-round, even if a lack of water would require closing the PTPC paper mill. This self-imposed instream flow is now mandatory under their current water use requirements. Despite that requirement, the minimum required flow for BQR does not guarantee that the Quilcene NFH will always be able to exercise its full 1946 right of 15 cfs because some water is lost through streambed percolation between the water diversion for the City of Port Townsend/PTPC and the water intake for Quilcene NFH.

Quilcene NFH must routinely reuse water for its fish production program because of the inability to fully exercise its water rights during low flows in the BQR. It is not uncommon to use third pass (serial reuse) water for fish rearing, while returning adult fish receive fourth pass water. At no time is the NFH required to draw less than the original water right of 15 cfs. It is only when the NFH uses more than 15 cfs that the provisions of the 1991 water right must be followed. Even with the additional water right, the NFH must still reuse water between decks of raceways when rearing fish.

Water temperatures for the BQR range from approximately 1.0°C in winter to 12.8°C in summer. The BQR is listed as *impaired* for instream flow, fish and shellfish habitat, pH, bacteria, and temperature, in accordance with Section 303(d) of the Clean Water Act,

Ground Water

Quilcene NFH has two active wells. Well 1 is used for fish production in the isolation/quarantine building, and Well 6 is used for the domestic water supply. Well 1 has an original water right that dates to 1958 and authorizes the withdrawal of up to 320 gpm. This well supplies the only water for incubation and early rearing in the isolation/quarantine building. The water temperature of Well 1 ranges from approximately 7.5°C in summer to 9.2°C in winter, a reversal of typical temperature patterns. The temperature is monitored with a certified thermometer.

Well 6 was drilled in 1997 to replace Well 3. Well 3 is located on the opposite side of the river from the NFH and had annual problems with broken pipes buried under the BQR. Well 3 is linked to a water right dated 1964 and allows the withdrawal of 19 gpm. Well 6 is the sole domestic water supply for the NFH buildings and residences and is not used for fish culture. This water is connected to the NFH’s domestic water treatment system, 12,000-gallon storage tank, buildings, residences, and fire hydrants. Water temperature of Well 6 is not monitored.

Table 1. Water rights appurtenant to the Quilcene NFH (sorted by priority date) and temperature range of sources.

Certificate Number	Source	Purpose of Use	Priority Date	Amount	Temperature Range
S202121C	Penny Creek	Fish Culture: Raceways, hatchery building	10/14/1924	10 cfs	4.2 - 11.5 °C
S207466C	Big Quilcene River	Fish Culture: Raceways	9/3/1946	15 cfs	1.0 - 12.8 °C
S2-10233	Penny Creek	Fish Culture: Raceways, hatchery building	4/7/1951	15 cfs	4.2 - 11.5 °C
G2-04876	Groundwater, Well 1	Fish Culture: Isolation/ quarantine building	4/23/1958	320 gpm	7.5 - 9.2 °C
G20727C	Groundwater, Well 3	Domestic Water: replaced with Well 6	7/29/1964	19 gpm, 4.0 acre ft.	N / A
S2-28179*	Big Quilcene River	Fish Culture: Raceways	5/16/1991	25 cfs	1.0 - 12.8 °C
G2-29679	Groundwater, Well 6	Domestic Water: Hatchery building, residences, facilities	5/19/1998	0.44 cfs, 20 gpm	Not monitored

*Water right S2-28179 has seasonal restrictions to maintain flow in BQR in the bypass reach between the water intake and outflow return for the hatchery: minimum 50 cfs from July 1 – February 28/29 and 83 cfs from March 1 – June 30 in the BQR.

SENSITIVITY

Sensitivity is the degree to which a system or species is likely to be affected by climate change. For example, a NFH already operating with maximum fish densities will be very sensitive to negative impacts of climate change that affect water quality.

We assessed and summarized known sensitivities for Quilcene NFH during current operations with the assumption that these problems are the ones most likely to be exacerbated by impacts from climate change. Additional information regarding baseline rearing conditions and water temperature data may be found in Appendix C.

Flooding in the winter and spring

Currently, the BQR is subject to occasional flooding in the winter and spring. Penny Creek deposits gravel and debris (a) into the intake settling ponds and above the fish bypass ladder on the BQR, and (b) into an eight-foot diameter corrugated metal culvert that is at risk of being blocked by debris.

The BQR intakes may be also be blocked or damaged by debris during high water events. In 2014, the upper water intake was modified to accommodate NOAA-Fisheries compliant screening, and an automatic screen cleaning system was installed. The BQR flooded in December 2014; as a result, the automatic brushes on the intake stopped cleaning, and the screens became plugged. NFH staff switched to the older BQR water intake; however, that intake also became plugged. The NFH staff then removed the dam boards from the new intake to get water into the NFH; as a consequence, the intake was out of compliance with NOAA-Fisheries fish screening criteria during the flood. The area was damaged and the automatic screen cleaning system was modified in 2016.

The main BQR channel above the NFH weir has *rip-rap* barbs to help channel flow to the center of the river, and those structures could also be affected by flooding. A concrete sill with a fish ladder and a low water dike (constructed of riprap and concrete ecology blocks) is adjacent to the BQR water intake. These structures help channel water to the BQR water intakes during low flows. The low water dike is not constructed to block water; water flows through the dike during low flows and overtops during high water.

During flood events, an eight-foot diameter culvert on Penny Creek transports large volumes of water, debris, and gravel and deposits that material upstream of the fish bypass ladder. Gravel discharged from Penny Creek accumulates above the fish bypass ladder. This gravel accumulation may hinder fish from passing the weir and using the bypass ladder during low water flows. Hatchery staff must move accumulated gravel periodically to allow fish passage.

The current weir for trapping adult fish was constructed in 1990. It acts as a physical barrier during low water flows and has virtually eliminated all volitional passage by adult fish up the

BQR during those times. Accumulated gravel above the fish bypass ladder can hinder adult fish from going upstream due the lack of access to the main channel. Gravel is removed as needed during summer and was last removed from the upstream end of the fish bypass ladder in 2016. Although the gravel can be removed, and the ladder has been modified to facilitate passage, the structure still periodically represents an obstacle to fish passage. Weir design and placement that obstructs the downstream movement of gravel has also resulted in bank erosion and poses a flood risk to the area downstream of the weir.

Surface water shortages in the summer

Low water availability at Quilcene NFH has caused some concern in the past, especially in late summer when low flows cause restrictions on the use of BQR water. Washington State's 1998 Watershed Planning Act, known as "2514" after the number of the state legislative bill that created it, made funding available for local citizen groups to assess the health of local watersheds. Inherent in this process is development of instream flow recommendations that are directed at identifying the flow at which more water could be appropriated for human uses. The BQR, the primary source of water for rearing coho salmon at Quilcene NFH, lies within Water Resource Inventory Area (WRIA) 17. The BQR, like many other area streams, may have reached its maximum appropriation potential without resulting in further impacts to stream habitats and aquatic organisms. The Service is participating in the WRIA 17 planning process as a member of the technical team to help ensure that Quilcene NFH's interests in water allocation are considered.

In the past (most recently 2006), the Quilcene NFH occasionally exceeded the provision within the NFH's existing water right for withdrawal from the BQR in order to operate the coho salmon program within the Service's recommended flow and density indices. The 1991 water right (No. S2-28170, 25 cfs) has an instream flow requirement that 50 cfs remain in the bypass area – between the water intake and outflow discharge for the NFH's - from July 1 through the last day of February, and 83 cfs remain in the bypass area from March 1 through June 30. Due to this instream flow requirement, Quilcene NFH is not permitted to withdraw more than 15 cfs (original unrestricted water right, 1946, No. S2-07466C, 15 cfs) from the BQR when the instream flow requirement is not met. The NFH can withdraw up to 40 cfs (15 +25 cfs from the first and second water rights, respectively) when water flows in the BQR exceed the required minimums during dates specified in the water right provision. Since 2007, Quilcene NFH has maintained water use in full compliance with its water rights.

In summary, water quantity may be restricted at Quilcene NFH due to the following two factors: (1) Upstream senior water rights holders (City of Port Townsend and PTPC) using all of their allotted BQR water (up to their restriction of a minimum instream flow of 27 cfs in the BQR) which may result in less than 15 cfs available for the NFH (original 1946 water right); and (2) an inability to use the 1991 water right (25 cfs) based on a requirement to leave minimum flows in the bypass reach of the BQR between the water intake and outflow of the hatchery (50 cfs from July 1 to end of February, and 83 cfs from March 1 to June 30).

Water quality: water reuse and high density indexes in the spring and summer

Current management of fish culture at Quilcene NFH complies with the NFH's water right provisions and the Service's recommended rearing thresholds for coho salmon (density index, DI < 0.2; flow index, FI < 1.0; and a 100% water exchange rate per raceway < 30 minutes).

High rearing densities approaching threshold guidelines (DI < 0.2) have been an issue at Quilcene NFH in the past, especially in late summer when less water is available and again in early spring just before yearling coho are transferred to saltwater net pens. The staff has modified rearing procedures and infrastructure when necessary to reduce stress on fish. For example, new shade structures have helped to spread fish out and allowed them to use the whole raceway rather than clumping into the shade cast along walls in the afternoon. In addition, when serial re-use is implemented, recommended loading densities are reduced by 20% in receiving ponds (Piper, 1982, pp.70). From February to April, up to 600,000 coho salmon are on station: 400,000 yearlings for on-station release and 200,000 yearlings for the Quilcene Bay net-pen program. Coho juveniles are intended to be transferred to the net pens in March, but in the past, those fish have remained on station beyond the transfer date in some years due to harmful algal blooms (HABs) in Quilcene Bay, straining fish rearing conditions at the hatchery. Water rights restrictions and DI < 0.2 guidelines have been exceeded occasionally for yearling fish during the spring when DI values have approached 0.3 and both direct-release and net-pen coho salmon were on station.

The Port Townsend Paper Company (PTPC) and City of Port Townsend have a minimum instream flow requirement of 27 cfs past their water diversion in the BQR. Even with this 27 cfs instream flow limit, the Quilcene NFH has to routinely re-use water serially between different banks of raceways to comply with its water rights, including the 1991 requirement of 50 cfs in the bypass reach from July 1 to the end of February and 83 cfs from March 1 to June 30). Serial reuse of water reduces the quality of water available to fish in downstream raceways.

Adult coho salmon typically start returning to Quilcene NFH at the end of July or beginning of August with spawning starting in October. Therefore, earliest returning adult coho salmon each year may be held for up to 4-6 weeks before they are sexually mature and spawned. Returning adult coho may be held on fourth-pass reuse water (D bank raceways) because of low flows in the BQR. Despite those water restrictions, the maximum FI does not typically exceed 0.7 with a water turnover rate of 19 minutes per raceway.

Disease risks

Bacterial coldwater disease (CWD), caused by *Flavobacterium psychrophilum*, occurs annually among coho salmon at Quilcene NFH but varies in intensity. CWD is primarily avoided by maintaining proper fish culture management practices and reducing stress. The addition of raceway shade covers has improved the rearing environment at Quilcene NFH and reduced stress. Medicated feed has been prescribed occasionally (3 of 15 years, once since 2008) to treat coho salmon for CWD at Quilcene NFH.

Fungal infections associated with marking and tagging trauma have been effectively avoided by shifting tagging to earlier in the year, from fall to late spring, when adult coho - which can shed large numbers of fungal spores into the environment – are not on station.

An electric weir, constructed to preclude adult salmon from swimming upstream of the hatchery, is no longer activated or functional at Quilcene NFH. In the past, fish biologists were concerned about infecting the water supply for the hatchery with pathogens shed by adult fish if salmonids were allowed to pass upstream of the water intake. Currently, adult fish are able to move upstream of the weir when water is high (>70 cfs). The impact or risk of disease from those fish is unknown, and there has been no effort to assess those risks to coho salmon reared at Quilcene NFH. Adult chum salmon are also a pathogen concern, but they spawn primarily in the lower reaches of the river downstream from the hatchery. Overall, disease impacts resulting from the passage of adult steelhead and coho salmon upstream of the weir are largely unknown. The HET has expressed some concern, especially if large numbers of coho salmon pass upstream; however, the HET has recommended that the weir not be electrically activated but with the caveat that no more than 800 adult coho salmon be allowed to pass upstream.

Table 2. Fish culture guidelines at Quilcene NFH.

Species	Density Index (Maximum)	Flow Index (Maximum)	Size at Release (fish/lb.)	Release Timing	Pathogens / Diseases of Concern*
Coho Salmon	0.2	1.0	15 - 17	April 20 - May 1	CWD, BKD, Fungus, *Epistylis*

* BKD (bacterial kidney disease, *Renibacterium salmoninarum*), CWD (cold-water disease, *Flavobacterium psychrophilum*), *Epistylis* sp. (protozoan parasite), and fungus (*Saprolegnia* sp.). Other potential pathogens that have been found in the system include *Aeromonas salmonicida* (causative agent of Furunculosis) and IHNV (Infectious hematopoietic necrosis virus, *Novirhabdovirus* spp.).

Harmful algal blooms

Approximately 200,000 yearling coho salmon are transferred to the Skokomish Tribe in February or March (no later than mid-March preferred) for final rearing in saltwater net pens in Quilcene Bay. Three to four weeks prior to the intended transfer date, phytoplankton sampling is initiated in Quilcene Bay by the Northwest Indian Fisheries Commission (NWIFC) and the

Skokomish Indian Tribe. Samples are collected every 1-2 weeks or more intensively if a HAB species (*Chaetoceros concavicornus* or *C. convolutus*) is detected. Transfer dates may be adjusted in accordance with the findings. One week prior to moving all of the fish, one-hundred fish are transferred to a small enclosure within a net pen and monitored by the NWIFC and the Skokomish Indian Tribe. The monitoring of the test fish includes observing their behavior for signs of distress, occurrence of mortality, and microscopic examination of the gills of a subset of fish to determine if plankton-caused damage is present. Phytoplankton samples are also collected during this period. If mortalities due to a HAB species, gill damage, or rapidly increasing levels of HABs are observed, plans to move the fish are adjusted accordingly. Coho salmon are released from the net pens in either June, when they reach 10 fish per pound, or sooner if a HAB exceeds critical levels but after April 15 to protect outmigrating ESA-listed summer chum fry. This strategy of monitoring HABs and using test fish started in 2004 and has resulted in most transfers happening in March instead of February as occurred previously.

In the past, HABs in Quilcene Bay have prevented timely transfer of coho salmon from Quilcene NFH to the net pens. Retaining additional fish on station can result in rearing densities that exceed fish health guidelines (DI < 0.2). HAB outbreaks in Quilcene Bay may also occur after juvenile coho salmon are transferred to the net pen. Such outbreaks may pose a serious health risk to fish and can prompt an early release. Fish mortalities exceeding 50% have occurred occasionally immediately following transfer to the net pens, but those incidences occurred before implementation of the current HAB monitoring and management plan, as described above.

Forest fire risks

The Quilcene NFH is surrounded by the Olympic National Forest, and large forest fires have occurred historically in the area (Henderson et al. 1989; cited by Halofsky et al. 2011, p.65).

Sensitivity main points:

- Quilcene NFH is subject to occasional flooding from the BQR and Penny Creek in the winter and spring which may impact water intakes, water diversion structures, roads, and fish passage.
- Water availability at Quilcene NFH has caused some concern in the past, especially in late summer when low flows cause restrictions on the use of BQR water.
- The need to serially reuse water and rearing densities approaching upper threshold guidelines have been an issue in the past, especially in late summer when less water is available and again in early spring just before fish are transferred to the net pens.
- HABs in Quilcene Bay have prevented timely transfer of coho salmon to the saltwater net pens in some years. Retaining additional fish at Quilcene NFH until the blooms recede may result in rearing densities that exceed Service-recommended fish health guidelines.

- A HAB in Quilcene Bay may occur also after coho salmon are transferred to the net pens; such outbreaks pose a serious risk to fish survival and can prompt an early release.
- Quilcene NFH is surrounded by Olympic National Forest, and huge fires have occurred in the area historically, thus posing a risk to the NFH.

EXPOSURE

Exposure is the magnitude or degree to which a system or species is expected to be subjected to climate change. This is the quantified prediction of change that may occur at a particular NFH.

A detailed description of how we quantitatively assessed the exposure of Quilcene NFH to climate change and the potential impacts to the NFH are described in Appendix B. A summary of methods and results are provided below.

To assess the vulnerability of Quilcene NFH to predicted climate change, we determined whether the coho salmon program could operate under the current, fish culture paradigm following existing rearing schedules and production targets under the predicted climatic conditions for the 2040s, focusing specifically on changes in water temperature and water availability at the NFH. Our specific objectives were to: (a) determine if future environmental conditions are likely to completely preclude rearing of coho salmon, (b) identify the magnitude and timing of sub-lethal effects (altered growth rates, disease outbreaks, etc.) that may affect survival and growth, and (c) suggest general mitigation strategies given the sensitivities detected in (a) and (b). To achieve those objectives, we (a) synthesized physiological tolerance data for coho salmon at Quilcene NFH and thermal growth data for common salmon pathogens, (b) adapted a temperature-driven growth model to predict fish growth, and (c) used flow index and density index parameters (Piper et al. 1982, Wedemeyer 2001) to develop a modeling framework that integrated the effects of changing temperature and water availability within the Quilcene NFH (Appendix B). We briefly summarized the important hydrologic changes anticipated for the BQR basin upstream from the NFH based on downscaled climate projections for the 2040s and one greenhouse-gas emission scenario (A1B) of the IPCC (2007). We then used the growth model and empirical data on recent rearing conditions at Quilcene NFH to predict future mean size and biomass of coho salmon, by month, at each life history stage during the freshwater phase. We then modeled flow and density indices based on in-hatchery environmental conditions predicted for the 2040s, and used associated changes in water temperature and availability, as a basis for assessing *exposure*, and subsequently, future *impacts* and *vulnerabilities* of coho salmon at Quilcene NFH.

Methods

To derive predictions of the future climate at Quilcene NFH in the 2040s, statistically downscaled general circulation model (GCM) simulations for the A1B emissions scenario were used to generate air temperatures in the local watershed. Air temperatures were then converted to surface water temperatures in the BQR and Penny Creek – the primary water sources for Quilcene NFH – through a series of regression models. The predicted 2040s temperatures were then compared to baseline thermal rearing conditions measured at the NFH's surface intake locations from 2004 – 2012 (Table B3, Appendix B).

Results and discussion

Climate and hydrologic modeling under the A1B emissions scenario project that the BQR basin will most likely experience warmer air temperatures, higher stream temperatures, lower summer baseflows, and more extreme winter floods by the 2040s (Appendix B). Mean monthly air temperature is expected to increase an average of 1.8 °C (S.D. = 0.46) from the present (2015) to the 2040s, with the largest absolute increases predicted between July and September (Table B4). Modeling predicts that BQR surface water temperatures will be warmer in all months, with increases ranging from between 0.4 °C (October) to 2.6 °C (June) when compared to historical averages (Table B3). The most significant increases in surface water temperatures (>1.5 °C) in the BQR are predicted to occur in May, June, and July. The water temperatures in Penny Creek follow a similar pattern with predicted warming in all months, with increases of over 1 °C are predicted to occur in April, May, June, and July. Total annual precipitation is projected to be similar (historical monthly mean = 124 mm vs. 129 mm in 2040s), but seasonal precipitation is projected to decline in summer (May-September) and increase slightly in other months (Table B4). Based on the VIC modeling (Table B5), mean annual flows projected for the BQR in the 2040s (379 cfs; range = 331-429 cfs for 10 GCMs) will be similar to the modeled historical values (359 cfs). Projected mean annual flows in Penny Creek follow a similar pattern (2040s = 15 cfs; historical = 14 cfs). The magnitude of seasonal flows, in contrast, is projected to be quite different in the future, especially in the BQR (Figure B1A), where mean flows by the 2040s are projected to increase 20-30% in the late fall and winter (November-March) and decrease by 25-42% in the summer (May-August). By the 2040s, moderate increases in monthly flows during winter are projected for Penny Creek, although considerable variation exists among the 10 GCMs (Figure B1B). The shape of the hydrographs are generally similar for both time periods (Figure B1), but - in the future - the timing of the center in flow mass is earlier in the year (Figure B3), due largely to increases in fall and winter flows. Those projected increases in fall and winter flows are not due to significant increases in total precipitation during those months (Table B4) but rather to a greater proportion of the total precipitation falling as rain and less as snow (see also Figures A2f and A3f in Appendix A for the adjacent Dungeness and Skokomish River watersheds, respectively). In short, although mean annual flows will be similar between the present (2015) and the 2040s, the timing and variability of that discharge will change considerably. We expect minor increases in the severity of summer droughts, but perhaps more importantly, we expect large increases in the number and magnitude of winter floods. Those projections for larger floods – as soon as the 2020s – suggest an increased risk of damage to facilities and water intake structures at the Quilcene NFH based on previously-described *sensitivities*.

Exposure main points:

- The BQR basin is projected to experience warmer air temperatures, higher stream temperatures, lower summer base flows, and more extreme winter floods by the 2040s.
- The BQR surface water temperatures will be warmer in all months, with increases ranging from between 0.4 °C (October) to 2.6 °C (June) when compared to historical averages.
- Penny Creek will follow a similar pattern with predicted warming in all months, with increases of over 1°C predicted to occur in April, May, June, and July.
- Total annual precipitation is projected to be similar (historical monthly mean = 124 mm vs. 129 mm in 2040s), but seasonal precipitation is projected to decline in summer (May-September) and increase slightly in other months.
- The magnitude of seasonal flows is projected to be quite different in the future, especially in the BQR, where mean flows by the 2040s are projected to increase 20-30% in the late fall and winter (November-March) and decrease by 25-42% in the summer (May-August). By inference, this shift in flows is due to a greater amount of precipitation in the watershed falling as rain and less as snow in the late fall and winter.
- There may be minor increases in the severity of summer drought, but there will be large increases in the magnitude of large winter floods.
- The projections for larger floods – as soon as the 2020s – suggest an increased risk of damage to NFH facilities and water intake structures.

IMPACT

Impact is the combination of sensitivity and exposure of a system or species to climate change. A sensitive NFH may be impacted by even a small change in climate. Conversely, if the exposure is large enough, it may affect less sensitive NFHs.

Water temperature

The predicted future water temperatures in the 2040s during August and September meet or exceed the optimal spawning temperatures for coho salmon (5.7 – 11.7 °C) based on literature values. As a result, adult coho will likely experience increased risk of physiological stress during holding and spawning, especially for fish captured and spawned earlier in the season.

Juvenile coho salmon reared at Quilcene NFH will be exposed to warmer rearing conditions by the 2040s, with increases ranging between 0.4 °C and 2.6 °C projected across the rearing cycle (Table B6). Increases of more than 1.0 °C are projected for April (+1.4 °C), May (+2.1 °C), June (+2.6 °C), and July (+1.8 °C) of the first (subyearling) rearing year as well as February (+1.0 °C) of the second (yearling) rearing year and at release in April (+1.4 °C). By the 2040s, water temperatures at Quilcene NFH are predicted to approach the physiological upper thresholds for eggs and fry during October in the first rearing year. At the time of release, the predicted future water temperatures within the facility in April (8.2 °C) are predicted to remain well below the upper limit for proper smoltification (14.3 °C). Water temperatures of over 11 °C are predicted to occur during two months of both the adult broodstock and the egg/fry stage, and during four months of the juvenile stage.

No upper or lower physiological temperature thresholds for coho salmon are expected to be violated, indicating that increasing temperatures through the 2040s are not likely to preclude culture of coho salmon at Quilcene NFH. However, high water temperatures relative to physiologic thresholds are inherently stressful to all Pacific salmon, and increased exposure to higher temperatures is expected to induce chronic stress, decrease immune effectiveness in individual fish, and cause an increased potential for disease outbreaks in the population. As a result, disease risks are expected to increase for certain pathogens, although projected temperatures are below the optimal growth temperatures for common salmon pathogens, (e.g., Furunculosis, Enteric Redmouth Disease, Ich; Table B2). As a consequence, the timing of standard hatchery practices (e.g., handling, tagging, moving fish between rearing containers) that are stressful to fish may need to be changed to avoid coinciding with periods of higher temperatures anticipated in the 2040s.

While the predicted future water temperatures at Quilcene NFH may not exceed physiologic tolerances of coho salmon, warmer water temperatures will undoubtedly increase growth rates of juvenile coho salmon under current culture protocols. The largest percent increases in both mean fish weight and mean length are predicted to occur in June – August (warmest months) when mean fish weight is predicted to increase by 37.6 – 41.5%, and mean fish length is predicted to increase by 11.1 – 12.1% (Figure B10). Due to the warmer thermal environment during the entire rearing period, coho salmon smolts from the Quilcene NFH are predicted to be 34.7% heavier and 10.3% longer at release compared to historical sizes.

Water availability

Projected hydrologic changes and current instream flow requirements in the Big Quilcene River (BQR) interact to pose some important constraints on fish culture at Quilcene NFH. Modeling indicates that in certain months, Quilcene NFH will have no more than 15 cfs available from the BQR to devote to coho salmon culture because only the first water right (priority date 1946) for the NFH, which allows diversion of up to 15 cfs from the BQR regardless of river levels, will be useable. The second water right (priority date 1991) of 25 cfs from the BQR is linked to an instream flow requirement of 50 or 83 cfs before the right can be used. Currently, Quilcene NFH withdraws only 12-15 cfs during low flow conditions in August and September and relies on serial reuse to supply sufficient water to the occupied raceways. By the 2040s, the projected decreases in stream flow for the BQR for August and September, when combined with the instream flow requirement for use of the second water right, will dictate serial reuse for those months. The most pessimistic hydrologic projections suggest that the period of serial reuse may need to be expanded and initiated in July.

On a more pessimistic note, our hydrologic projections for the BQR may overestimate future stream flows near the hatchery. The city of Port Townsend (Washington) and the Port Townsend Paper Corporation (PTPC) operate a water diversion several miles upstream from the hatchery and typically divert water during base flows or when water clarity is high. Port Townsend and PTPC have a 27 cfs minimum instream flow requirement at their diversion structure, but substantially less than 27 cfs has reached the Quilcene NFH's water intake historically during the summer, which is less than our modeled flows for those months. Although our model results indicate that serial reuse of water will need to be a standard protocol in late summer, those results are projected averages or mean flows, and actual annual variations in flows at the hatchery will dictate the period of serial reuse each year.

The model-based climate scenarios further suggest that Quilcene NFH may experience small-to-modest increases in the flow index for coho salmon throughout the entire rearing period, but the flow index overall is projected to remain well below the threshold upper guideline value of 1.0. These projected increases in flow index are driven largely by faster fish growth resulting from higher water temperatures.

Density index values in the 2040s are also projected to increase throughout the rearing period and will most likely exceed the threshold guideline value of 0.2 for coho salmon during March and April immediately prior to release of smolts.

Harmful algal blooms

The current practice is to annually transfer 200,000 yearling coho salmon from Quilcene NFH to saltwater net pens in Quilcene Bay, Puget Sound (operated by the Skokomish Indian Tribe), for the final two months of rearing. HABs cause salmon mortality, which may be of even greater concern in the future if warming coastal waters result in more frequent algal blooms. If HABs preclude moving fish to saltwater net pens, then modest increases in density index values are predicted to exceed the guideline value of 0.2 at Quilcene NFH in both March and April. We did not directly model HABs in Quilcene Bay, but other modeling efforts suggest that the frequency and duration of HABs in Puget Sound will increase under the A1B emissions scenario (Huppert et al. 2009; Moore et al. 2011). HABs are known to cause extensive mortality in juvenile salmon, and up to 50% mortality has been recorded among juvenile coho salmon in the net pens after transfer from Quilcene NFH. Consequently, the current HAB monitoring program in Quilcene Bay will need to be continued, with an emphasis on identifying the environmental drivers that influence HAB events.

Impact main points:

- In the future, Quilcene NFH will likely have to contend with year-round increases in water temperature of its source water and decreased surface-water availability during summer.
- The predicted future water temperatures in August and September may exceed the optimal spawning temperatures for coho salmon (5.7 – 11.7 °C) based on literature values, so it is possible that adult coho will experience physiological stress during holding and spawning
- By the 2040s, water temperatures in October at Quilcene NFH are predicted to approach the upper physiological threshold values for the incubation and culture of eggs and fry of coho salmon relative to optimal temperatures. However, no upper or lower physiological thresholds are expected to be violated, indicating that projected temperatures alone are not likely to preclude culture of coho salmon at Quilcene NFH.
- Increased exposure to high temperatures is expected to induce chronic stress, decrease immune effectiveness of individual fish, and increase disease risks.
- Coho salmon smolts from Quilcene NFH are predicted to be, on average, 34.7% heavier and 10.3% longer at release, compared to historical sizes, due to the warmer thermal environment during the entire rearing period.
- The density index is predicted to increase throughout the rearing period and exceed the threshold guideline value of 0.2 for coho salmon during March and April immediately prior to release of smolts.
- By the 2040s, projected decreases in flows of the BQR during August and September, when combined with instream flow requirements, will dictate serial reuse for those months. Hydrologic projections suggest that the period of serial reuse may have to be expanded and initiated in July.
- Projected increases in the frequency and duration of HABs in Quilcene Bay may negatively impact the net pen rearing program.

ADAPTATION AND VULNERABILITY

The Quilcene NFH HET provided guidance and information for all parts of this assessment. For example, the HET's technical experts in fish health, culture, and biology, provided input as to how exposure due to climate change might be expected to impact NFHs as a whole. The HET's input was particularly critical for the adaptation and vulnerability sections of this assessment because HET members had the specific hatchery-related experiences necessary to determine whether Quilcene NFH *could* adapt to anticipated climate change impacts or would be vulnerable to the projected effects of climate change.

A *Workgroup* led by the Assessment Team and composed of the HET for Quilcene NFH, co-managers, stakeholders, partners and others worked collaboratively to integrate (a) the quantitative information about possible impacts of climate change on Quilcene NFH with (b) details about the hatchery's programs, facilities and capabilities. The Workgroup discussed possible adaptation strategies for Quilcene NFH and helped to clarify the vulnerability of the hatchery and its programs to the projected effects of climate change. The results of those discussions are described below.

Adaptive Capacity

Adaptive capacity is the ability or capacity of a system or species to adjust or adapt to the impact of climate change. Some NFHs will be able to adapt to climate change impacts better than others.

Staff at Quilcene NFH are experienced at dealing with environmental disturbances by adjusting infrastructure, water usage and sources, and fish culture protocols. A vulnerability assessment provides the opportunity for a proactive approach to adaptation; anticipated climate impacts can be deliberately considered, and necessary changes to infrastructure, rearing protocols, and management practices can be implemented in an organized and efficient manner.

In the past, Quilcene NFH facilities and programs have been sensitive to a variety of environmental disturbances including: (1) flooding in the winter and spring; (2) surface water shortages in the summer; (3) reduced water quality in the spring and summer resulting from high rearing densities and the need to reuse water; (4) disease; (5) harmful algal blooms in Quilcene Bay; and (6) forest fires These environmental disturbances are expected to be exacerbated by the current and future effects of climate change.

Impacts from climate change at Quilcene NFH are expected to be individually manageable, but serious consequences could occur if impacts are confounded (e.g., when water is both warmer than expected and less available). Many adaptation strategies suggested by the Workgroup (see below) do not require major changes to infrastructure; those strategies may only require changes to culture protocols or management practices. Many of the suggested adaptations provide additional management flexibility to the NFH staff in the event of an emergency or other contingency (e.g., a HAB in Quilcene Bay prevents transfer of coho salmon yearlings to saltwater net pens). Many of the adaptations described below will require discussion of possible options and agreement among Service/NFH staff, co-managers, stakeholders, and partners so that all parties are aware of actions that may be taken by the NFH to deal with climate change impacts, both in the long term and in response to episodic events like floods.

Flooding in the late fall, winter and spring

Currently, the BQR is subject to occasional flooding in the winter and spring. In the future, floods are predicted to increase in frequency and severity due to an increase in the proportion of precipitation falling as rain instead of snow with increasing likelihood of flooding in the late fall.

Impact: The BQR intakes may be blocked or damaged by debris during high water events. Debris loading and damage to the intakes could have a catastrophic impact to the fish rearing environment in the hatchery through temporary loss of water.

> ***Infrastructure adaptation***: Re-engineer the BQR water intake to minimize the likelihood of damage due to debris loading during high water events by raising the chain trolley screen mechanism (this modification was completed in 2016). Continued monitoring will be needed to ensure that this adaptation has had the expected benefit.
>
> ***Protocol and management adaptations:*** Discuss with permitting agencies and co-managers the potential need to release fish early or transfer fish to another facility if water becomes unavailable to the NFH because of flooding. Develop a comprehensive contingency plan for dealing with management options and alternatives in the event of a major flood.

Impact: The main BQR channel above the NFH weir has *rip-rap* barbs to help channel water to the center of the river. The rip-rap could be affected by flooding. During a flood, significant erosion could occur above and below the weir, destroying the rip-rap and barbs. Debris could alter river flows downstream and be directed towards the U.S. Highway 101 bridge or private land, thus posing a hazard to both. In addition, a concrete sill and low water dike (constructed of rip-rap and concrete ecology blocks) adjacent to the BQR water intake are vulnerable to high river flows and debris. Normally, water flows through the dike during low flows and overtops the dike during high flows. If the concrete sill or low water dike fails, then water could be directed away from the BQR water intakes.

> ***Infrastructure adaptation:*** Re-engineer rip rap, weir, and water intake so that they can't be affected during high water events. Ensure that potential debris from the NFH, in the event of a catastrophic failure, won't damage or direct flood water towards the U.S. Highway 101 bridge or private land.
>
> ***Protocol and management adaptations:*** None proposed.

Impact: During flood events, Penny Creek transports large volumes of water, debris, and gravel through an eight-foot diameter, corrugated metal culvert and into the intake settling ponds and above the fish bypass ladder. This accumulated gravel can impede fish from using the bypass ladder and, thus, gaining access to the BQR main channel upstream of the weir. When the water subsides, the accumulated gravel above the bypass ladder blocks fish passage upstream to the BQR's main water channel. Gravel discharged from Penny Creek – which fills the water intake and bypass ladder - could be a larger and more common problem with greater and more frequent floods. In addition, the eight-foot diameter culvert could be completely blocked by debris during flooding. If the culvert is blocked, flooding will threaten the main entrance into the hatchery (Fish Hatchery Road) from U.S. Highway 101, the hatchery office, and other structures. The water intake from Penny Creek – the only source of water for incubating eggs and young fry in the hatchery building - is dangerous to clean during flooding, thus posing a human health and safety hazard.

> ***Infrastructure adaptations:*** (1) Re-engineer the area where gravel is deposited from Penny Creek so that gravel and debris are discharged into the BQR downstream of the bypass ladder and not upstream of the bypass ladder. The gravel should be channeled below the fish ladder to allow it to be to be dispersed into the BQR. (2) Re-engineer, or replace with a bridge, the culvert on Penny Creek to ensure free passage of debris during high water and flood events.

> ***Protocol and management adaptation:*** Develop a *comprehensive plan* to address future flooding and its potential impact on the entire water intake infrastructure at the confluence of the BQR and Penny Creek and then stage improvements. The water intake and culvert on Penny Creek, along with the fish ladders, rip-rap, water intakes, and weir on the BQR, are functionally tied together. Consequently, the comprehensive plan should cover all aspects of the water infrastructure for Quilcene NFH. The plan should also address concerns about fish passage, gravel deposition, and erosion affecting water diversion structures and rip-rap. In addition, the plan should consider how to best to protect the U.S. Highway 101 bridge, nearby private property, and Fish Hatchery Road. All these structures are functionally tied together, and a major alteration would ideally mitigate for all future infrastructure risks associated with climate change and the increased likelihood and intensity of major floods at Quilcene NFH

Surface water shortages in the summer

Water shortages have caused concern in the past, especially in late summer when low water flows caused restrictions on the use of BQR water. In the future, water is predicted to be less available in the summer due to an increase in the proportion of precipitation falling as rain instead of snow, resulting in a decreased snow pack in the spring and summer. Water flows in Penny Creek during spring and summer months are not sufficient to make up for lost BQR water for Quilcene NFH.

Impact: Water availability from the BQR may be reduced in the summer due to (a) overall decreases in summer stream flows, (b increased withdrawals by senior water rights users upstream of the hatchery, and (c) existing, minimum instream flow restrictions.

> ***Infrastructure adaptations:*** (1) Install a recirculating aquaculture system with appropriate water conditioning infrastructure to replace or supplement raceways; (2) Obtain ground water rights and drill another well. [Note: Much uncertainty exists regarding the efficacy of drilling additional wells. Ground water is available in the BQR basin for agriculture, but ground water at Quilcene NFH may not be useable due to salt water intrusion; indeed, NFH staff doubt much more groundwater is available at the hatchery. Moreover, the effect of climate-related changes in BQR and Penny Creek

discharges on available groundwater resources is unknown. We did not model the dynamics of the groundwater source available to Quilcene NFH or explore whether it could be used to mitigate for expected reductions in surface water availability. Consequently, it is difficult to evaluate whether well water could compensate for reductions in surface water flows; for example, groundwater availability could decrease in concert with surface flows if less surface water is able to percolate into the ground.]

Protocol and management adaptations: (1) Buy water from upstream senior water rights users such as the PTPC or the City of Port Townsend. (2) Discuss increasing the self-imposed minimum flows of 27 cfs with upstream senior water rights holders. This would leave more water in the BQR for the NFH.

Water quality: Increase in water temperatures and fish densities in the spring and summer

Reduced water quality associated with high fish densities has been an issue in the past, especially in late summer when less water is available and again in early spring just before yearling fish are transferred to saltwater net pens. Consistently higher water temperatures have been identified as one impact of climate change. Higher water temperatures are expected to result in larger fish at a specific age under current culture protocols.

Impact: Higher water temperatures will increase fish growth rates which are expected to increase density indexes, increase disease risks, and decrease water quality. Water temperature increases are predicted for BQR and Penny Creek water for every month of the year. Increasing temperatures lead to increases in mean fish size and biomass density in raceways, quantified by increasing density indexes, which in turn increases the risk of disease. Water quality for coho salmon in raceways is already considered poor or sub-optimal in the summer and spring because of high ration requirements and feed usage, increased water temperatures, and serial reuse of water, especially in summer. In the spring, high density indexes occur if transfer of fish to the saltwater net pens is delayed or cancelled, resulting in increased total biomass at the hatchery. Delays or prohibition of transferring fish to the net pens may happen more frequently in the future because the incidence and duration of HABs are expected to increase with warmer temperatures.

Infrastructure adaptations: (1) Add additional shade covers to open raceways, tanks, intake areas, etc. (2) Install chillers in the hatchery building to delay egg hatching and fry emergence, thereby decreasing the period of time for growth while retaining the same mean size and date of release. (3) Install chillers for raceways. [Note: Chillers may be impractical for high-volume, single pass raceways.] (4) Install a recirculating water aquaculture system with appropriate water conditioning infrastructure to replace raceways. (5) Restore upstream riparian habitat to help cool BQR water. (6) Consider infrastructure changes whenever reassessing water management practices.

Protocol and management adaptations: (1) Reduce feed rations to decrease growth and retain same mean size and date of release. (2) Evaluate water management capabilities and determine the appropriate program size and number of coho salmon that Quilcene NFH can propagate without exceeding recommended density index thresholds and water right restrictions. This proposed strategy, by itself, would most likely reduce the total number of fish reared at Quilcene NFH and would require discussions with co-managers. (3) Determine whether cold groundwater is available for rearing. While colder groundwater could conceivably be used to slow fish growth, this has not yet been attempted at Quilcene NFH. The volume of well water currently available to the facility (~320 gpm to an isolation/quarantine building) is not sufficient to replace the surface water required for full production of coho salmon at Quilcene NFH as each of up to 24 raceways has a target inflow of 600 gpm. (4) Determine whether reducing the total number of fish reared at Quilcene NFH and releasing an intermediate number of fish on station (less than 600,000 but greater than 400,000) would result in the same (or greater) number of adults returning as the current release procedures (400,000 fish on station and 200,000 from net pens). There is some indication that fish reared at the NFH have higher survival (i.e., smolt-to-adult return rates) compared to the fish transferred to the net pens. If an intermediate number would be acceptable to co-managers, reduce the total number of fish reared and released. (5) Release fish earlier. This strategy would require discussions with NOAA Fisheries and co-managers to ensure ESA-listed fish species would not be affected. It would require changing the HGMP (Hatchery Genetic Management Plan) for the coho salmon program but would help keep densities from exceeding management guidelines in the spring.

Impact: Increasing water temperatures may result in increased mortalities, stress, and risk of disease among juvenile coho salmon as a result of mark and tagging activities. Currently, juvenile coho are “mass marked” between late May and mid-June at approximately 5-6 months of age post-hatch.

Infrastructure adaptation: Acquire a fish marking *autotrailer* for the Olympic Peninsula NFHs to allow them to adjust their mark-and-tagging schedules as needed.

Protocol and management adaptations: (1) Mark and tag fish earlier in the season when they reach a mean size that will allow them to be marked and when water temperatures are not warmer than current temperatures in late May to mid-June. Figure B6 suggests those threshold water temperatures will most likely occur in mid-April by the 2040s. However, winter-type weather in mid-spring may present a number of technical difficulties if air temperatures drop below freezing (e.g., the need to keep hoses and equipment from freezing in icy conditions). (2) Mark and tag fish later in the year in the fall after temperatures have cooled. This latter strategy would require discussions with other National Fish Hatcheries that share the tagging trailer and personnel.

Disease risks

The prevalence of pathogens and disease are expected to increase in response to decreases in surface water flows in summer, increases in water temperatures, and declines in overall water quality under projected climate change. In addition, adult fish are currently able to move upstream of the weir when water is high and thereby shed pathogens into the water supply of the hatchery. The impact of adult fish upstream of the water intake for the hatchery on the risk of disease for fish at Quinault NFH is unknown.

Impact: Increased water temperature and reduced water quality are expected to increase the prevalence and potential severity of infectious diseases for coho salmon at Quilcene NFH.

> ***Infrastructure adaptations:*** See infrastructure adaptation strategies above for reducing growth rates and density indexes to improve water quality.
>
> ***Protocol or management adaptations:*** (1) Increase use of drugs and chemicals labelled to treat diseases in Pacific salmon. [Note: Increased use of drugs and chemicals is not desirable and may not be possible in all instances; see *Coho salmon vulnerabilities* in the following Vulnerabilities section.] (2) Conduct an experiment to determine the impact of migrating salmonids upstream of the water intake for the hatchery on disease risk to fish in the raceways. Depending upon results, possibly control the numbers of coho salmon allowed to swim upstream from the NFH.

Harmful algal blooms

Harmful algal blooms (HABs) are predicted to increase in the future. HABs may have an indirect effect on the program when transfers to the net pens are delayed or cancelled, thus increasing density indexes at the hatchery. Increased incidence and duration of HABs are expected to increase mortality rates of coho salmon transferred to the saltwater net pens.

Impact: HABs prevent or delay transfer of fish to net pens and/or cause increased mortality rates for fish that are transferred.

> ***Infrastructure adaptation:*** (1) Rear all fish at Quilcene NFH (2) See adaptations listed above for water quality impacts related to increasing temperatures.
>
> ***Protocol and management adaptations:*** (1) Find other net pen sites that may be less affected by HAB or another rearing location. (2) Release fish from net pens earlier than current protocols dictate. This latter strategy would require discussions with co-managers and changes to the HGMP for coho salmon to provide more flexible release dates.

Forest fire risks

The Quilcene NFH is surrounded by the Olympic National Forest, and huge fires have occurred historically in the area.

Impact: A forest fire may destroy the Quilcene NFH and the surrounding watershed, and may pose a human health and safety risk to staff.

> ***Infrastructure adaptations:*** (1) Continue to remove inflammable materials from around structures. (2) Replace burnable materials with fire resistant materials when feasible.
>
> ***Protocol and management adaptation:*** Coordinate more closely with US Forest Service. The Quilcene NFH staff already coordinates with the local US Forest Service office regarding communication, planning and preparation for forest fires. The hatchery staff is already doing what they can to minimize fire risks to the facility. The US Forest Service monitors the area for lighting strikes.

Adaptive Capacity main points:

- Flooding in the winter and spring may affect Quilcene NFH water related infrastructure including BQR intakes, BQR channel and low flow structures, and other structures that may be blocked by gravel deposited from Penny Creek. Developing a *comprehensive plan* is desired to address future flooding and its potential impact on the entire water intake infrastructure at the confluence of the BQR and Penny Creek. Increasing management flexibility to allow early release or transfer of fish would also help to address these impacts.
- Water available from the BQR is projected to be reduced in the summer due to climate change and may be further affected by senior water rights users upstream of the hatchery and existing minimum flow restrictions. New infrastructure such as a recirculating aquaculture system or a new well could assist with reducing impacts of reduced surface water availability. Other options such as (a) purchasing water from upstream senior water rights users or (b) negotiating with them to increase their self-imposed minimum flows above 27 cfs in the BQR are other possible means to address projected, water shortage impacts.
- Reduced water quality due to projected increases in temperature and density may impact fish health and survival and increase handling stress during rearing and marking. Additional shade covers, delayed egg hatch and fry emergence through chilling of water in the hatchery building, reduced feed rations, restoration of BQR riparian habitat, earlier release of smolts, earlier marking of fish in the spring or later marking in the fall, including greater flexibility in actual marking dates in response to specific annual conditions, are possible means to address impacts from increasing water temperatures. Studies to (a) assess water management options and strategies, (b) compare smolt-to-adult return rates of net-pen vs. on-station released fish, and (c) determine maximum rearing capacity at Quilcene NFH under climate change projections should be performed to properly address these impacts.
- Harmful algal blooms (HAB) are predicted to increase in frequency and duration in the future. HABs affect the coho salmon program when transfers of yearling fish to saltwater

net pens are delayed or cancelled, thus resulting in higher than desired density indexes cat the hatchery. HABs may directly cause mortalities at the net pens. Studies to (a) assess water management options at Quilcene NFH, (b) compare smolt-to-adult return rate of net-pen vs. on-station released fish, and (c) determine maximum rearing capacity at Quilcene NFH under climate change projections should be performed to properly address these impacts. Depending upon the results of those studies, options for obtaining flexibility in releasing fish from the net pens and/or reducing or abandoning the use saltwater net pens altogether should be considered.

- Considerable uncertainty exists concerning the effect of climate change on the future distribution, prevalence, and virulence of salmon pathogens at Quilcene NFH. Climate change will likely increase disease risks and impacts to coho salmon reared at Quilcene NFH environment. A study to determine the disease risks and impact of adult salmonids that have migrated upstream of the water intake for the hatchery may help with disease management to address those risks and impacts.

Vulnerability

Vulnerability is the effect of climate change impacts that cannot be adequately addressed by existing adaptive capacity. Vulnerability provides a summary of sensitivity, exposure, and adaptive capacity for a particular NFH.

While the changes expected in the natural environment due to climate change are significant, adaptation strategies may be employed to mitigate for much of the impact on the coho salmon rearing program at Quilcene NFH. The maximum change in monthly average temperature of surface water sources is expected to be relatively high in the summer (>2°C), but no upper or lower physiological thresholds are projected to be violated, indicating that temperatures that cause mortality are not likely to preclude culture of coho salmon in Quilcene NFH.

Vulnerabilities of facilities and fish health at Quilcene NFH may be reduced by changing Quilcene NFH's infrastructure, increasing the ability of hatchery staff to adaptively manage through enhanced communication with partners, stakeholders, and co-managers, or simply adjusting rearing practices. Studies to assess water management, compare adult survival of the two release types (net-pen vs. on-station), and determine maximum rearing capacity for coho salmon at Quilcene NFH under projected climate change conditions should be performed in order to implement appropriate adaptive strategies.

Infrastructure vulnerabilities

The Workgroup identified flooding in late fall, winter, and spring as a major climate change vulnerability of Quilcene NFH. Flooding not only poses a threat to the physical infrastructure of the hatchery but can also block or divert water away from water intake structures. A *comprehensive plan* should be developed and implemented to address flooding and its impact on

NFH infrastructure, particularly at the confluence of BQR and Penny Creek. Flooding in 2014 caused major damage to the NFH intake, and projections for more frequent and larger floods suggest an increased risk of damage to facilities and water related structures in the future. The Penny Creek intake and culvert and the BQR fish ladder, rip rap, intakes, and weir are functionally tied together; consequently, the proposed plan needs to include engineering staff and should cover all aspects of the NFH's water infrastructure. The plan should also address concerns about fish passage, gravel deposition, and erosion affecting water diversion structures and rip rap. It should consider how to best to protect the U.S. Highway 101 bridge, nearby private property, and Fish Hatchery Road (the main entrance) which are all vulnerable to projected climate change impacts and flooding.

Quilcene NFH is also vulnerable to year-round increases in water temperature of its source waters, decreased surface-water availability during the summer, and instream flow requirements in the BQR that could confound decreased surface water availability. Facility changes could address anticipated declines in Quilcene NFH's water quantity and quality by reducing the amount of water needed (e.g., install a recirculating-water aquaculture system with appropriate water conditioning infrastructure to replace raceways), increasing the amount of water available (e.g., install a well if possible), and/or chilling water to slow development of embryos or fish to maintain fish density indexes within prescribed guidelines. Operationally, the NFH could attempt further serial reuse during periods of lower water availability. However, the current reuse protocols are fairly complex, and the effects of additional modifications on fish health are unknown. The purchase of a marking autotrailer would also reduce vulnerabilities associated with higher water temperatures, higher rearing densities, and disease risks – including mortalities - by providing added flexibility and efficiency as to when fish are marked. The trailer could be shared with other Olympic Peninsula NFHs.

Coho salmon vulnerabilities

Faster growth rates associated with increasing temperatures are expected to affect coho salmon at Quilcene NFH in two ways under current culture protocols: (1) increased growth rates and rearing densities that reduce water quality and increase disease risks, and (2) increased maturation rates of males, and potentially females, at two years of age. Simple changes in rearing practices may be implemented by hatchery staff to help mitigate those impacts due to climate change. Densities may be controlled through growth modulation using reduced rations to retain a consistent release size and date. However, ration levels would also need to be maintained at a level sufficient to ensure fish condition and health.

Coho salmon are also vulnerable to increasing frequency and duration of HABs in marine waters, both directly via mortality in the marine environment and indirectly via increased densities for fish retained on station that would otherwise be transferred to saltwater net pens.

Much uncertainty is associated with future disease impacts of climate change to coho salmon at Quilcene NFH. Disease risks are expected to increase, particularly during summer with elevated water temperatures and reduced surface flows. The parasite *Ichthyophthirius multifiliis* (Ich) may be especially problematic under projected future conditions. In general, chemical or drug treatments can be applied at first observation of disease symptoms with a high degree of success. However, the most efficacious parasiticide and fungicide, formalin, is highly regulated, associated with both human safety and environmental concerns, and is expensive. In addition, while there are antibiotics labelled for bacterial diseases in fish, concerns about antibiotic resistance, environmental impacts, toxicity in fish, and cost greatly restrict the use of those drugs. The chronic use of drugs to mitigate the impact of climate change on infectious diseases in fish is not an option acceptable to the Region's veterinarians or hatchery managers. Hence, disease risk is considered a significant vulnerability from climate change, not just to coho salmon at Quilcene NFH, but to most other populations of salmonid fishes propagated by NFHs in the Pacific Region (Appendix A)

Vulnerability main points

- Quilcene NFH is vulnerable to increased frequency and magnitude of major floods in the late fall, winter, and spring based on climate change projections. Infrastructure changes to protect the NFH from winter flooding (such as redesigning the intake and other structures) may be expensive to implement but may be necessary to reduce vulnerabilities and should be carefully planned.
- Coho salmon propagated at Quilcene NFH are vulnerable to higher rearing densities, higher proportions of fish maturing at two years of age, and fish health risks associated with warmer water temperatures in both the hatchery and marine environments. These latter climate-related impacts may be reduced by simple changes in rearing practices and increased adaptive management flexibility via communicating proactively with co-managers, stakeholders, and partners. However, the ability to increase the use of drugs and chemicals to treat potential increases in the prevalence or severity of infectious diseases is questionable.

BIOLOGICAL AND ENVIRONMENTAL UNCERTAINTIES

Effect of Climate Change on the Marine Environment

Predicting the future effects of climate change on marine ecosystems is extremely difficult, although many effects have been documented and postulated (see review by Hoegh-Guldberg and Bruno 2010). Global mean temperatures have risen approximately 0.2 ^{o}C over the past 30 years with most of that heat energy absorbed by the oceans. The oceans have also absorbed approximately one-third of all anthropogenic CO_2, thus reducing the mean pH of the oceans globally.

Continued warming of the upper layers of the oceans is expected to increase temperature stratification, thus decreasing dissolved O_2 concentrations in deeper waters and potentially reducing nutrient availability in the phototrophic zone. Indeed, total phytoplankton production has decreased by more than 6% since 1980 with over 70% of this reduction concentrated at higher latitudes, particularly in the Pacific Ocean and Indian Ocean gyres.

Although the effects of sea-level rise and ocean acidification on nearshore estuarine ecosystems can be assessed to some extent, the overall effects of climate change on the trophic dynamics of marine ecosystems and salmon productivity are major uncertainties (Schindler et al. 2008). Modeling efforts to date do provide some insights regarding projected effects of climate change on marine survival and productivity of Pacific salmon in the North Pacific Ocean. Based on the A1B emission scenario, summer habitats in the North Pacific Ocean are projected to decrease by 86% for Chinook salmon, 45% for sockeye salmon, 36% for steelhead, and 30% for coho salmon by the year 2100 (Abdul-Aziz et al. 2011). A general decline since the mid-1970s in the marine abundance of coho salmon and Chinook salmon in the eastern North Pacific Ocean has been attributed to climate-related changes (Irvine and Fukuwaka 2011). Peterson et al. (2010) report that the abundances of yearling Chinook salmon (but not coho salmon) in the California Current were negatively correlated with marine temperatures which influence coastal upwelling and zooplankton abundance. In general, warm ocean conditions associated with the Pacific Decadal Oscillation suppress upwelling and reduce marine survival and productivity of Pacific salmon in the Pacific Northwest (Mantua et al. 1997; Scheuerell and Williams 2005; Mantua 2009). On the other hand, climate change is projected to increase the incidence and intensity of Pacific storms in the Gulf of Alaska, and stronger onshore winds are projected to increase upwelling and nutrient turnover rates in the eastern North Pacific Ocean.

The interaction effects of climate-change increases in ocean temperature, ocean acidification, and onshore winds are major uncertainties with respect to marine primary production and marine food webs. These uncertainties confound attempts to assess the vulnerability of Pacific salmon populations to climate change in specific watersheds (e.g., Columbia River) and sub-basins (e.g., Big Quilcene River). Consequently, much research and monitoring are necessary to understand the future effects of climate change on the marine survival and productivity of Pacific salmon and steelhead originating from rivers in the Pacific Northwest.

Effect of Climate Change on Pathogen Prevalence and Fish Disease

The incidence and severity of infectious diseases in fish are affected by the immune status of the fish, the virulence of the pathogen within the fish, and the density of the pathogen in the fish’s environment. Serious disease outbreaks usually occur when the fish’s immune status is compromised at a time when (a) the pathogen is well within it optimal temperature range and (b) conditions are such that the density of the pathogen in the environment is high.

Basic metabolic rates, physiological homeostasis, and immune function of fish are direct functions of water temperatures. Water temperatures in the upper range of physiological tolerance will stress and ultimately compromise the immune system of fish (Wedemeyer 1970, 1996). At the same time, elevated temperatures may match the optimal ranges for (a) fish parasites like *Ichthyophthirius multifiliis* (Ich) or *Ceratomyxa shasta*, (b) bacterial pathogens like *Aeromonas salmonicida* (furunculosis) or *Flavobacterium columnare* (columnaris), and (c) pathogenic fungi. All species of salmonid fishes are particularly vulnerable to Ich at elevated water temperatures.

Reduced stream flows in summer, like those projected for the Big Quilcene River, can also increase disease risks to fish reared on surface waters in a hatchery. Reduced flows may increase pathogen density by reducing dilution, increasing fish-to-fish contact by elevating density indexes, and by increasing nutrient loads to favor the growth of non-obligate bacterial and protozoan pathogens that can propagate in the environment without a fish host. Thus, while either increased temperatures or reduced flows might trigger an outbreak of infectious disease, the combination of both factors can often be devastating.

A recent example of this synergistic interaction among water temperature, flow, and disease occurred in 2002 on the Klamath River, California, where over 33,000 adult salmonids, primarily Chinook salmon, died during their upstream migration at a time of low water flows and warm water temperatures. Pathology reports concluded that the fish died from Ich and columnaris (*Flavobacterium columnare*) and not directly from high water temperatures which reportedly did not exceed the physiological tolerances of the fish themselves (CDFG 2004) but may have compromised their immune systems. Both Ich and columnaris are caused by warmer water pathogens that are most devastating when salmon are exposed to temperatures above their physiological optima, as occurred in the Klamath River in 2002.

At Service hatcheries in the Pacific Region (Idaho, Oregon, and Washington), serious outbreaks of Ich, columnaris, furunculosis, fungal diseases, and *C. shasta* strongly correlate with water temperatures in the range of 13-20 °C. In the summer of 2015, Chinook salmon juveniles experiencing high mortality at 18 °C (despite disease treatments) at one hatchery (Warm Springs NFH) completely recovered within 10 days after they were transferred to another facility (Little White Salmon NFH) with water temperatures of 9 °C.

The effect of elevated water temperatures on viral pathogens of salmon is less clear than for bacteria, fungi, or parasites. The two most significant fish viruses in the Pacific Northwest, IHNV and VHSV[4], only produce disease at temperatures below 15 °C, and those viruses are unable to propagate at higher temperatures, even in vitro where host immunity is not a factor.

[4] Infectious hematopoietic necrosis virus (IHNV) and Viral hemorrhagic septicemia virus (VHSV)

However, low flows and high temperatures might weaken fish physiologically during warm seasons, thus predisposing them to viral infections when temperatures cool.

The potential for new pathogens to emerge or spread to new areas as the climate changes is unknown and a major uncertainty. Organisms not currently impacting salmon health may become problematic in the future when their fish hosts or environments are altered. For example, the parasite *C. shasta* has recently become much more problematic in the Deschutes River system, a circumstance that is likely attributable to recent changes in reservoir management that subsequently affected river flows and downstream water temperatures.[5]

Although the potential for elevated water temperatures and decreased flows to increase the prevalence and severity of disease in Pacific salmon is difficult to quantify, recent parasite and bacterial disease outbreaks at Service hatcheries affected by low flows and high temperatures in the summers of 2015 and 2016 clearly demonstrate the potential for climate change to increase risks of infectious disease and fish mortality. In general, climate-induced increases in the prevalence of pathogens in existing habitats, and the spread of those pathogens to new habitats, are expected to reduce the abundance and viabilities of many fish species within their native geographic ranges (Harvell et al. 2009). Overall increases in water temperatures resulting from climate change are expected to (a) increase physiological stress and reduce immune effectiveness in salmon and steelhead and (b) increase the propagation and transmission rates of aquatic parasites and pathogens (Marcogliese 2008). Despite these expectations, a great deal of uncertainty exists concerning the future magnitude and mechanisms of climate-induced changes to pathogen prevalence and disease throughout the Pacific Northwest.

Fish health and hatchery staff clearly recognize these increasing disease risks and uncertainties associated with climate change (Appendix A). Additional research and enhanced monitoring and evaluation efforts will most likely be needed to better understand how climate change will affect the future distribution, prevalence, and virulence of fish pathogens throughout the Pacific Northwest.

RECOMMENDATIONS

Presented below is a summary of key information needs and work efforts suggested by the Assessment Team. This information would allow a more comprehensive understanding of adaptive capacity of the hatchery as well as provide information pertinent to other NFH programs on the Olympic Peninsula. Many of the anticipated problems may be minimized by proactive communication with co-managers, stakeholders, and partners. Quilcene NFH will be encountering challenges due to climate change and will need to be able to adaptively manage in a

[5] http://www.thedalleschronicle.com/news/2014/aug/23/parasite-driven-disease-hits-klamath-salmon-hard-f/

nimble manner in order to maximize success. Many of the actions described below may increase the ability of the Service to adapt and respond to the impacts of climate change at Quilcene NFH.

1. **Gather data and perform studies to provide accurate information for making decisions, including:**
    a. Compare survival of fish released from the NFH and from net pens. If rearing a moderate number (e.g., 400,000 - 500,000) of coho salmon exclusively at the NFH is shown to cause no decrease in the number of fish returning, the NFH could avoid exceeding density index thresholds at the end of the rearing schedule by rearing fewer fish.
    b. Perform a water resource inventory assessment for the NFH.
    c. Determine maximum rearing capacity at the NFH under climate change.
    d. Conduct a study to determine impact of passing migrating salmonids upstream of the hatchery on disease risk to fish in the hatchery.

2. **Develop or acquire access to additional water resources for Quilcene NFH.** Reductions in water availability may be resolved through discussions with upstream senior water rights users by offering to purchase water or asking them to increase the self-imposed minimum flows during a low water emergency at the NFH. The NFH could also pursue actions such as seeking additional water rights or attempting to re-negotiate the instream flow requirements for the BQR. As a last resort, the NFH should investigate acquiring new infrastructure such as recirculating aquaculture systems or an additional ground water source. The NFH could also seek additional water rights or attempt to re-negotiate the instream flow requirements for the BQR, although competing water demands in the basin may present a challenge.

3. **Begin communication with co-managers and permitting agencies about the need for flexibility in rearing practices and protocols.** After appropriate information has been collected about water management, adult survival and rearing capacity, begin discussions with co-managers and permitting agencies about the following topics: (1) Releasing fish from the NFH earlier than scheduled when fish are threatened due to poor water quality, high densities, floods resulting in a loss of water in the winter, and other water related emergencies. An early release may also be necessary from net pens due to a HAB that is causing mortalities; (2) Changing or ceasing the rearing of coho salmon in saltwater net pens; (3) Implementing changes to rearing practices as necessary to alleviate climate change impacts on water quality.

4. **Begin communication with co-managers about options and alternatives for rearing fish in saltwater net pens.** Given that the frequency of HABs in Puget Sound are expected to increase throughout much of the year, the NFH may also need to discuss, with comanagers, alternatives to the current practice of moving fish to saltwater net pens.

Options may include (a) abandoning the net pen rearing site and rearing fish at another location or (b) reducing the number of fish reared at Quilcene NFH.

5. **Develop a comprehensive plan to address flooding and its impact on NFH infrastructure at the confluence of BQR and Penny Creek.** Within Quilcene NFH's deferred maintenance, include a request for the design and phased construction of water related infrastructure at the confluence of BQR and Penny Creek that will be able to withstand projected increases in extreme flooding.

6. **Understand climate change impacts in the Hood Canal area that may affect fish rearing and spawning.** Now that the effects of climate change on fish culture conditions at Quilcene NFH are better understood, the logical next step for the vulnerability assessment process is to understand the impact of climate change on the freshwater spawning and juvenile rearing conditions for naturally-spawning fish within the BQR basin and the Hood Canal area. This challenge should be a collaborative effort and include regional co-managers, stakeholders, and other partners. Linking an assessment of climate change vulnerabilities for natural populations of fish with ongoing planning efforts on the Olympic Peninsula may result in a more comprehensive and powerful evaluation.

7. **Hatchery staff, members of the HET, and regional Service personnel should become involved with efforts to understand climate change impacts in the marine environment that may affect migrating fish and natural populations in the Hood Canal area.** For example, harmful algal blooms are expected to increase in duration with possible impacts on migrating smolt and adult salmon as well as fish transferred to saltwater net pens. According to Moore et al. (2011):

   > "Climate change projections from global climate models [aka *general circulation models*] and regionally downscaled climate models for the Pacific Northwest are used to evaluate scenarios for the future HAB-WOO[6]. Under a moderate greenhouse gas emissions scenario (i.e., A1B), the annual HAB-WOO for *A. catenella* in Puget Sound is projected to increase by an average of 13 days by the end of the 21st century. Furthermore, the annual HAB-WOO may begin up to 2 months earlier in the year and persist for up to 1 month later in the year compared to the present day."

   This effort to understand the impacts of climate change on the nearshore marine environment in Hood Canal should include regional co-managers, stakeholders, and other partners.

[6] HAB-WOO: *Harmful Algal Bloom Windows of Opportunity* are annual time periods when a combination of weather conditions occur that are beneficial to the production of HABs.

8. **Implement hatchery reform recommendations for Quilcene NFH (USFWS 2009b).**

CONCLUSIONS

1. Quilcene NFH will be increasingly vulnerable to major floods in late fall, winter and spring as a consequence of climate change.
2. Infrastructure modifications to the water intakes for the hatchery and the main channel of the Big Quilcene River - between the water intake and the effluent outflow of the hatchery - could mitigate for increasing flood risks.
3. Quilcene NFH will most likely be able to continue propagating coho salmon through the 2040s, although increased growth rates resulting from increasing mean water temperatures will likely increase fish rearing densities and disease/mortality risks under current culture protocols.
4. Adjustments to current fish culture protocols (e.g., incubation chilling, feeding modulation) and the total number of fish reared at Quilcene NFH could mitigate for increasing growth rates, densities, and disease risks.
5. Major biological and environmental uncertainties exist regarding the effects of climate change on (a) survival and growth of Pacific salmon in the marine environment and (b) the prevalence and impacts of fish pathogens and disease at Quilcene NFH and regionally.

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APPENDICES

Appendix A. Qualitative Assessments of Climate Change Vulnerability of National Fish Hatcheries in the Pacific Region, Quilcene National Fish Hatchery.

Appendix B. Modeling the Potential Effects of Changed Water Availability and Temperature on Pacific Salmon Culture Programs at Quilcene National Fish Hatchery.

Appendix C. Baseline Information and Data for Quilcene National Fish Hatchery, 2011.