MEMORANDUM

Date: March 18, 2021
To: ASRP Steering Committee
From: ASRP Science and Technical Review Team
Re: A Prioritization and Sequencing Plan to Guide Implementation of the ASRP

Executive Summary

This memorandum provides recommendations developed by the Science and Technical Review Team (SRT) on implementing the Aquatic Species Restoration Program (ASRP). Phase I of the ASRP produced three additive scales of restoration (scenarios) to address species habitat protection and restoration, which are identified as Scenarios 1, 2, and 3 (ASRPSC 2019). Phase I of the ASRP concentrated on scenario development, and now the focus of the program shifts to implementation. In 2020, the ASRP Steering Committee asked the SRT to develop a prioritization and sequencing scheme that achieves the goals of the ASRP through implementation of a "science-based roadmap for restoring habitat and protecting intact ecosystems of aquatic species along the rivers and streams in the Chehalis Basin" (ASRPSC 2019). This memorandum describes the SRT's recommendations to the ASRP Steering Committee.

Developing a prioritization and sequencing scheme for ASRP implementation involved several steps. The first was to address a need to refine Scenario 3 by incorporating results of studies and analyses that became available since the ASRP Phase I document (ASRPSC 2019) was published. For salmon and steelhead, the refinement was based on additional habitat modeling (the Ecosystem Diagnosis and Treatment [EDT] model and a life-cycle model developed by the National Oceanic and Atmospheric Administration [NOAA model]) and updated information on salmon and steelhead population trends developed by the Washington Department of Fish and Wildlife (WDFW). For non-salmonid fishes and amphibians, refining Scenario 3 was based on the latest results of research conducted by the WDFW on these species and their habitats. Using this information, the SRT prioritized the locations, type, and timing of protection and restoration actions using the refined scenario among the ASRP's 10 ecological regions and allocated them into three 10-year implementation periods. The recommendations also considered additional factors that could influence ASRP success such as the effects of invasive species on native species, hybridization among spring-run and fall-run Chinook salmon (*Oncorhynchus tshawytscha*), and restoration conflicts between species. The recommendations focus restoration activities on 554 stream miles of habitat for fishes and amphibians and 56 acres of wetland protection and restoration for Oregon spotted frog (*Rana pretiosa*). The recommended activities are not distributed evenly or randomly among the regions or implementation periods.

Based on this approach, the following activities are recommended:

- **Near-Term Implementation Period (Years 1–10; Figure 1):** The near-term period is focused on locations and factors that will provide rapid habitat benefit to three species currently most at-risk: spring-run Chinook salmon, Oregon spotted frog, and coastal tailed frog (*Ascaphus truei*). A total of 33 geospatial units (GSUs) are prioritized, covering 235 stream miles of habitat in seven ecological regions. This includes spring-run Chinook salmon habitat in the Cascade Mountains and Willapa Hills ecological regions, coastal tailed frog habitat in the Willapa Hills Ecological Region, and protection and restoration of 56 acres of wetlands habitat for Oregon spotted frog in the Black River Ecological Region. The habitat of these three species were selected for focus, but it is important to recognize that their habitats are co-occupied by many additional native aquatic species that will also benefit from these early restoration actions. Restoration in some upper reaches of sub-basins is emphasized due to these species' distributions, and restoring ecological processes here also promotes resiliency through promoting hyporheic and floodplain water storage that then supplements low flows to downstream reaches.

  In addition, restoration in the Olympic Mountains Ecological Region is targeted to protect unique habitats and restore high-priority core habitats for multiple species. Long-lead-time actions should be initiated to restore riparian buffers in several ecological regions and to transition the forested Chehalis River tidal surge plain further upstream in the Estuary Ecological Region (this habitat is projected to be lost due to sea level rise in the future).

  Additionally, there is recognition that the ASRP needs to take significant immediate action to address the effects of ongoing trends that are degrading habitat, such as climate change and population growth. Accordingly, the stream mileage recommended for restoration is larger in the near-term period than the remaining implementation periods and actions that address the future effects of climate change and human population growth are emphasized in the near-term period. Finally, 10 targeted learning actions are recommended in the near-term period to gather critical information needed to further inform ASRP implementation through time.
- **Mid-Term Implementation Period (Years 11–20; Figure 2):** In the mid-term period, the recommendations continue a focus on long-lead-time actions and protecting and restoring productive core habitats that support multiple species. The spatial distribution of the recommended actions broadens away from a focus on the upper basin to include more regions. Habitat restoration actions in the Grays Harbor estuary are initiated and restoring access to quality habitat through passage barrier corrections is emphasized. A total of 28 GSUs are prioritized, covering 198 stream miles of habitat in nine ecological regions. Similar to the near-term period, numerous actions are recommended to address the effects of future climate change and human population growth in the region. Targeted learning may continue in the mid-term period depending on results of studies conducted and actions taken in the near-term period.

- **Long-Term Implementation Period (Years 21–30; Figure 3):** In the long-term period, the trend of broadening the spatial distribution of the recommended actions continues such that the remaining areas of focus are addressed. Actions are directed at restoring productive core habitats throughout the Chehalis Basin that support multiple species and restoring connectivity among aquatic habitats through barrier corrections. A total of 24 GSUs are prioritized, covering 121 stream miles of habitat with an emphasis on seven ecological regions. This includes restoring a chain of quality habitats in the Lower and Middle Chehalis River ecological regions using a "nodes" concept. This concept utilizes in-channel structures such as engineered logjams to improve habitat conditions in the mainstem channel and promote connectivity between mainstem channel, floodplain, and off-channel habitats to benefit multiple native amphibian, resident fish, and anadromous fish species. Approximately 21 miles of river are targeted for restoration within five Lower and Middle Chehalis River GSUs. Similar to the near-term and mid-term periods, numerous actions are recommended that address the effects of future climate change and human population growth in the region.

In summary, these recommendations for prioritizing and sequencing protection and restoration actions are made to address the habitat needs of at-risk species and restore and protect productive habitats and habitat-forming processes that support multiple aquatic species. The habitat changes will promote the resiliency of aquatic species to ongoing climate change and human population growth stressors. They also plan for additional studies needed to inform ASRP implementation through time. The recommendations are based on science and are designed to achieve ASRP success. However, successful implementation of the ASRP depends on many factors outside the scientific recommendations. These include funding availability, landowner willingness, and additional factors discussed in this memorandum. This memorandum also identifies several policy aspects of ASRP implementation that will affect success of the program. These include integrating ASRP priorities with land-use planning decisions, considering potential changes to headwater stream buffers through an ongoing re-evaluation of Forest Practices Rules (WDNR 2005), integrating the ASRP with watershed plans, and updating hatchery programs to better align with ASRP goals in specific watersheds.

Figure 1
Years 1 - 10 Near-term Priorities for ASRP Implementation

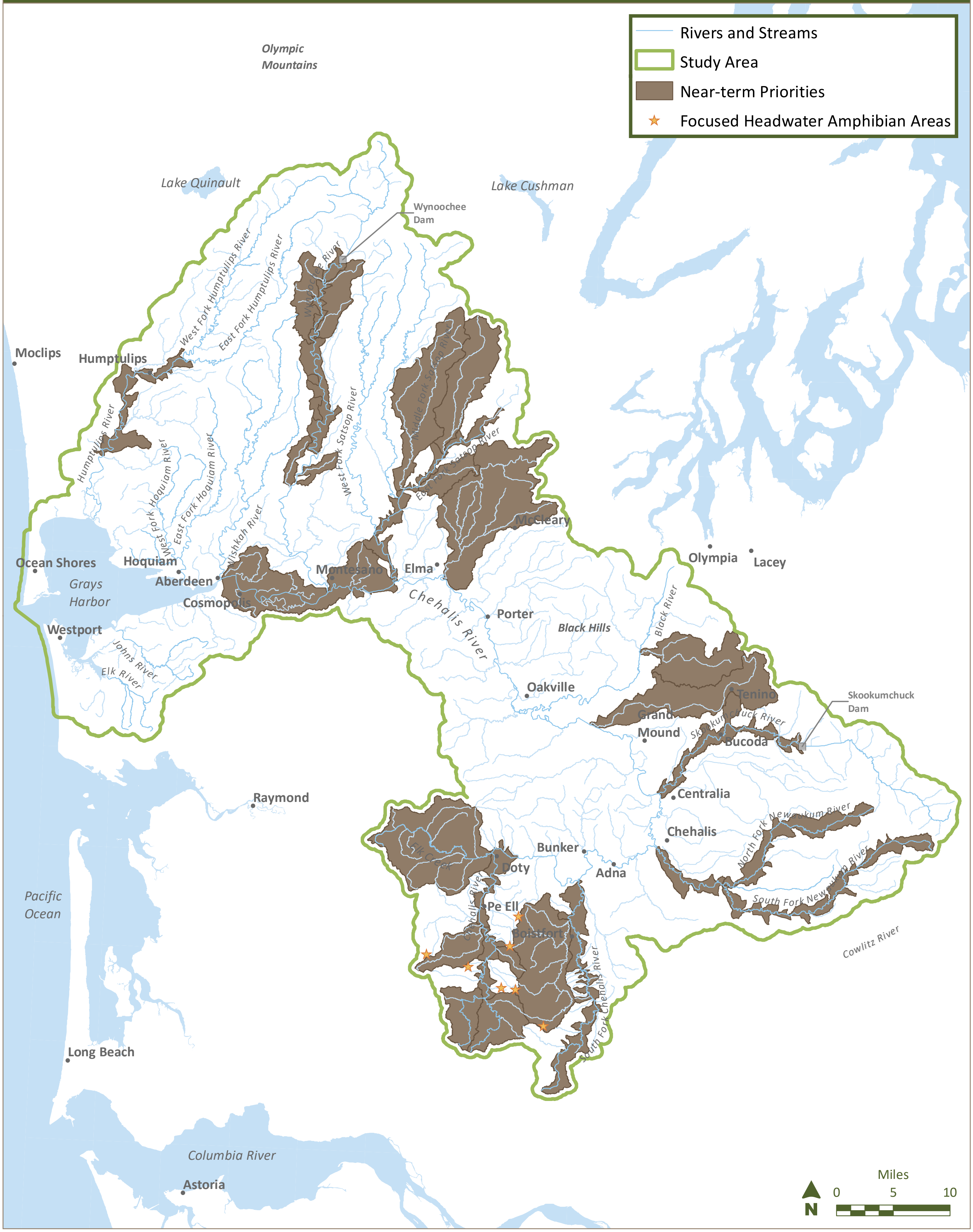
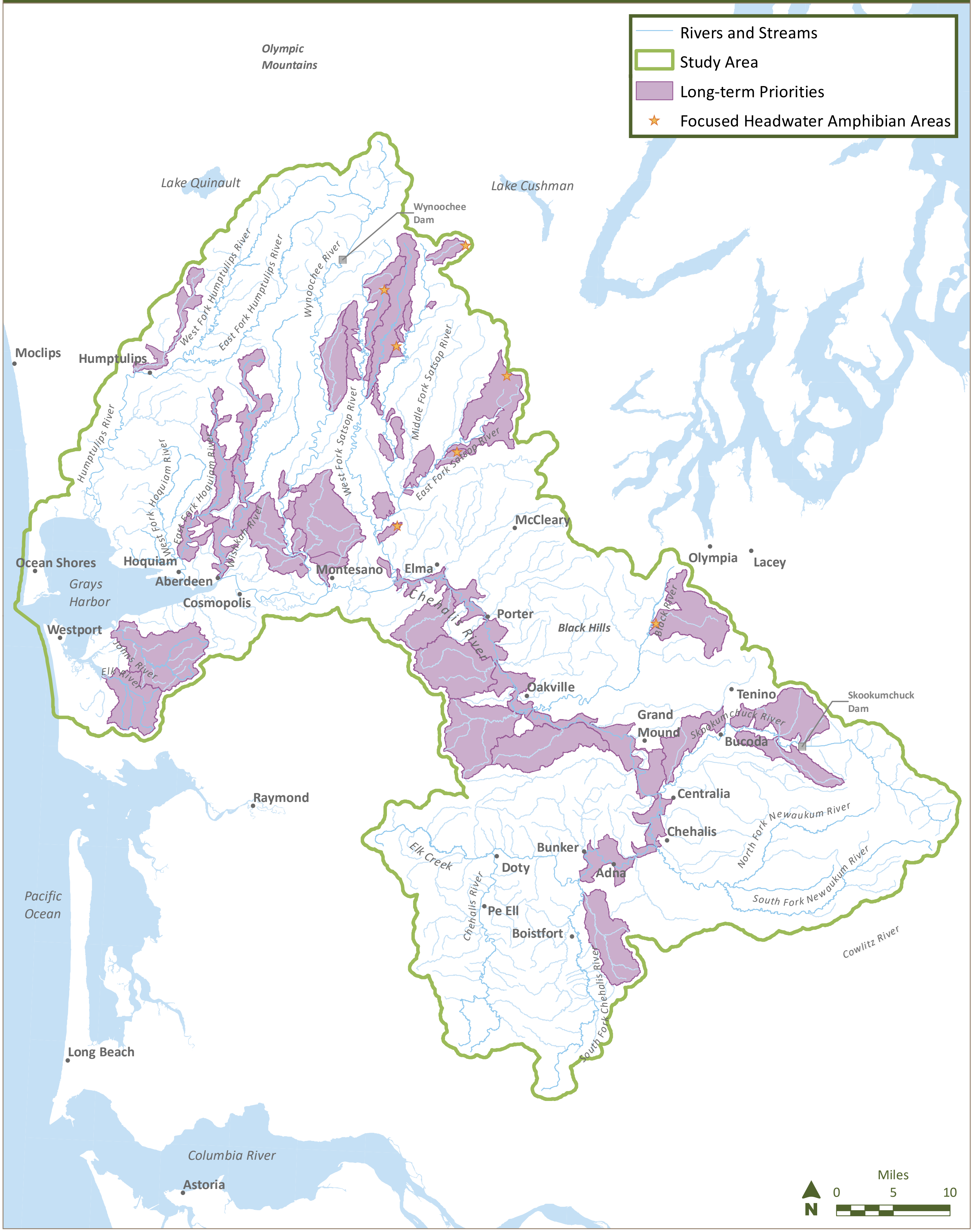


Figure 2
Years 11 - 20 Mid-term Priorities for ASRP Implementation

Figure 3
Years 21 - 30 Long-term Priorities for ASRP Implementation



I. Introduction

This memorandum provides science-based guidance developed by the Science and Technical Review Team (SRT) on how to accomplish the vision and goals of the Aquatic Species Restoration Program (ASRP). Phase I of the ASRP was completed in 2019 and outlines a "science-based roadmap for restoring habitat and protecting intact ecosystems of aquatic species along the rivers and streams in the Chehalis Basin" (ASRPSC 2019). Phase I advanced three additive scales of restoration (scenarios) to address species habitat protection and restoration across the Chehalis Basin. Phase I of the ASRP concentrated on scenario development and evaluation; subsequently, the focus of the program has shifted to implementation. In 2020, the ASRP Steering Committee asked the SRT to develop a prioritization and sequencing scheme that achieves the goals of the ASRP. This memorandum describes the SRT's recommendations to the ASRP Steering Committee.

The recommendations are organized into three 10-year implementation periods—labeled as near-term, mid-term, and long-term periods—that together form a 30-year implementation time frame. Ten-year time periods were selected to support project planning and implementation purposes and in this context are viewed as being flexible, not rigid, delineations. Ten-year time periods were also selected to allow enough time for biological responses to develop and for ASRP monitoring to quantify and document the biological responses. Selection of a 30-year implementation time frame assumes the funding to be provided will be sufficient to support the schedule. The selection was made understanding the effects of the ASRP will continue beyond the 30-year time frame (e.g., riparian plantings will grow, in-channel wood structures will retain wood and gravel, and monitoring and adaptive management activities will continue as appropriate).

The vision of the ASRP is to "protect and restore habitat in the Chehalis Basin in order to support healthy and harvestable salmon populations, robust and diverse populations of native aquatic and semi-aquatic species, and productive ecosystems that are resilient to climate change and human-caused stressors while honoring the social, economic, and cultural values of the region and maintaining working lands" (ASRPSC 2019). To develop a plan for prioritizing work, the ASRP Steering Committee provided the following specific goals for restoration of aquatic habitat in the Chehalis Basin (ASRPSC 2019):

- Protect and restore natural habitat-forming processes within the Chehalis Basin watershed context.
  - Protect and restore natural riverine processes including channel migration, sediment and wood transport, and floodplain connectivity.
  - Protect and restore riparian processes and functions including cover, shade, inputs of large wood, leaf litter and insect inputs to the aquatic food web, sediment and erosion functions, nutrient and pollutant trapping and filtering, and floodplain processes.

- Increase the quality and quantity of habitats for aquatic species in priority areas within the Chehalis Basin.
  - Significantly increase the quality of and access to instream habitat for aquatic species (including habitat needs for migration, reproduction, rearing/feeding, and overwintering habitats).
  - Protect and enhance existing functioning core habitats for species across their life history trajectories.
  - Increase habitat complexity and diversity.
  - Protect and restore native riparian, floodplain, off-channel, and wetland habitats.
  - Minimize suitability for invasive species within instream and riparian habitats.
- Protect and restore aquatic species viability within and across the Chehalis Basin considering viable species population parameters.
- Increase watershed resilience to climate change by protecting and improving natural water quantity and timing and water quality.
- Build recognition of and support for ASRP actions and the ways the ASRP supports resilient human communities (via elements such as water conservation, floodplain preservation, citizen science participation, centralized data, and other features).

The SRT recognizes that prioritization and sequencing are not derived wholly from a scientific analysis of data and reflect three equally important elements: science, policy, and implementation feasibility. The recommendations in this memorandum were coordinated with the ASRP Implementation Planning Team and Steering Committee as they were developed. Policy aspects of ASRP implementation that stem from the scientific guidance were identified and communicated to the ASRP Steering Committee as they became evident and are summarized in Section V of this memorandum for further consideration.

The prioritization and sequencing recommendations strive to strike a balance among multiple factors including protection and restoration, restoration action types, geographic patterns (upper reaches and lower reaches of a watershed, tributaries versus mainstem, mainstem versus off-channel and floodplain, and upper basin and lower basin), and conflicting restoration needs among species. The SRT identified several guiding principles (Section II) that were designed to achieve the ASRP vision and goals and considered additional factors that could affect species performance (Section IV). All this information was used to develop recommendations for each implementation period that were organized under specific objectives (Section III).

Recommendations were developed recognizing that changes to the implementation schedule may arise due to funding availability, implementation opportunities, or new information. An example would be a landowner that unexpectedly indicates their willingness to participate in a conservation easement in a highly productive reach of core habitat that supports multiple species. These opportunities should not be overlooked simply because they were not a recommendation identified in this memorandum. ASRP implementation should be guided by science but flexible enough to take advantage of significant opportunities.

Appendices to this memorandum provide additional information on the following topics:

- Hybridization between spring- and fall-run Chinook salmon (Appendix A)
- Fish passage barriers (Appendix B)
- Targeted learning studies to improve restoration effectiveness and adaptively manage ASRP implementation (Appendix C)
- Review of conditions in the estuary (Appendix D)
- Invasive species and challenges they pose for native species (Appendix E)
- Restoration opportunities related to sediment wedges (Appendix F)
- Cold-water thermal refuges for salmonids and other aquatic species (Appendix G)
- Freshwater mussels (Appendix H)
- Differing habitat requirements of focal aquatic species and the potential for conflicts in protection or restoration efforts (Appendix I)
- Factors external to the ASRP that may affect the success of implementation and effectiveness of restoration actions (Appendix J)

II. Guiding Principles

Based on the ASRP vision and goals, the following four overarching principles were identified and used to focus the scientific recommendations and guide the selection of actions and priorities among the three time periods.

Principle 1: Address currently degraded habitat conditions and increase resilience to future climate change and human population growth by restoring physical and biological processes that create and maintain aquatic habitats and determine species performance. This principle focuses ASRP actions on the restoration of the physical and biological processes that create and maintain habitat conditions and affect species performance over time. Physical processes allow streams and rivers to adjust to changing environmental conditions; create diverse habitats for native species; and integrate riverine, riparian, and floodplain environments. Biological processes affect how species respond to habitat conditions. Restoration actions that increase species resilience might include habitat actions targeted at minimizing hybridization between spring- and fall-run Chinook salmon, competition and predation by non-native species (fishes and bullfrogs), and interactions between hatchery- and natural-origin fish.

Maintaining and restoring natural physical and biological processes is critical for restoring habitat and creating resiliency in the face of the effects of future climate change. In the Chehalis Basin, climate change is expected to shift precipitation patterns and increase air temperature over the next several decades (Mauger et al. 2016) and raise sea levels in Grays Harbor and the lower Chehalis River (Sandell and McAninch 2013). This will increase the strength and frequency of winter storm events with impacts on flooding and stream bed scour, increase summer and fall water temperatures, reduce summer flow and wetted width, and move the existing tidal surge plain farther upstream. Some changes due to climate may already be underway. The SRT considered actions that address changes in geomorphology, groundwater, hyporheic flow, hydrology, channel incision, and water supply associated with projected climate change when developing its recommendations because these directly affect physical, habitat-forming processes.

Continued human population growth is anticipated in the Chehalis Basin. This will likely expand existing urban centers, including the Chehalis-Centralia area and Interstate 5 corridor and areas around Olympia, along with a more limited urban expansion in the Aberdeen area and dispersed rural residential development throughout the basin. Increased human development will increase groundwater extraction, reduce wetland and floodplain habitats, increase pollutants, and directly degrade streams in urban environments (Meyer et al. 2005; Walsh et al. 2005).

Principle 2: Prioritize habitat protection and restoration based on species distribution and environmental requirements. This principle provides a means to prioritize ASRP restoration actions and protection opportunities. While each species has distinct habitat requirements, considerable overlap exists in habitat specifications among species within a biological community that occupies the same habitat. Species habitat requirements can be used to narrow the focus of ASRP implementation on specific habitats and geographic areas to result in demonstrable changes in populations. For example, the SRT recommends that unique environments that are at risk of degrading from development be protected and restored and actions that require a long lead time (reforestation and riparian plantings) be implemented in the near-term implementation period.

Principle 3: Sequence restoration based on species performance and current status. This principle provides a basis for the sequencing of ASRP actions. Aquatic species across the Chehalis Basin vary in their habitat requirements, current and historical abundance, and recent trends in abundance. Some species in the Chehalis Basin are at low abundance and therefore at elevated risk as a result of changes in physical habitat and biological processes, while others are relatively abundant. Even for abundant species, some populations in specific areas of the basin are declining due to local habitat conditions. The status of species and populations is used to focus initially on protection and restoration of habitats for those species and populations at risk in the near term. The focus then shifts to the restoration of habitats for more robust species in the mid- and long-term periods.

Principle 4: Employ targeted learning projects to improve restoration effectiveness and adaptively manage ASRP implementation. The fourth principle focuses on the need to refine and improve the effectiveness of restoration actions by conducting targeted research. Experimental projects may focus on key restoration questions such as the effectiveness of beaver dam analogs to separate spawning spring and fall-run Chinook salmon to limit interbreeding or the use of wood structures to store sediment to locally reduce stream temperatures (sediment wedges). The SRT recommends these projects be conducted in the near term to inform actions and adaptive management in the mid- and long-term periods.

III. Recommendations

The ASRP Phase I Scenario 3 included restoration in 69 of the 178 geospatial units (GSUs) that encompass the basin. Organizing the basin into discrete units was needed to analyze ASRP actions at a local scale. A GSU is typically a major segment of a river; an entire small tributary sub-basin; or a sub-watershed and its entire stream network within a large sub-basin (such as the Satsop River sub-basin). Developing the implementation recommendations involved several steps.

First, Scenario 3 was refined using the process outlined in Ferguson et al. (2020). This was needed to consider and incorporate results of new analysis and data that became available after the ASRP Phase I document (ASRPSC 2019) was published. For salmon and steelhead, the refinement was based on results of habitat analyses using the Ecosystem Diagnosis and Treatment (EDT) model and the life-cycle model developed by the National Oceanic and Atmospheric Administration (NOAA model). The EDT model organizes habitat for these species in the Chehalis Basin into 178 GSUs. The individual GSUs are shown in Figure 2 of Appendix C in the ASRP Phase I document (ASRPSC 2019). The SRT reviewed changes in habitat expected to occur from restoration and protection; estimated changes in abundance for each species; and the number, location, and passage rating of barriers in the EDT model in each GSU. The NOAA model results were used to identify sub-basins with the potential for significant restoration and the potential to change habitat conditions associated with specific types of actions for each species (e.g., the reduction in temperature expected with increased shade). The actions reviewed in the NOAA model included shade, increased gravel due to wood, acres of floodplain created, beaver ponds, and fine sediment reduction. The SRT also reviewed updated information on salmon and steelhead population status and trends in each ecological region and sub-basin developed by the Washington Department of Fish and Wildlife (WDFW). For non-salmonid fishes and amphibians, refining Scenario 3 was based on the latest research conducted by WDFW on these species and their habitats. Using this information, the SRT identified key GSUs that were not in Scenario 3 that should be restored or were in the scenario but should be replaced with another (better) GSU. This effort produced a refined Scenario 3.

Second, the SRT prioritized the locations, types, and timing of restoration actions in the refined scenario among the ASRP's 10 ecological regions and allocated them into the near-term, mid-term, and long-term 10-year implementation periods. Restoration actions and priority locations were assigned to the different implementation periods based on objectives developed from the four guiding principles discussed previously. This was done to ensure the recommended actions were focused, prioritized, and sequenced in manner that achieves the ASRP vision and goals. Nine objectives were developed (e.g., protect unique habitats) and are used to organize the recommended actions under each implementation period discussed next. Not all objectives are prioritized in each implementation period. The recommendations were also based on a review of additional factors the SRT considered important because of their potential influence on ASRP success. These included biological processes such as effects of invasive species on native species, hybridization among spring- and fall-run Chinook salmon, several aspects of habitat such as thermal refuges, factors pertaining to specific species such as freshwater mussels or conflicts between species that Implementation Teams need to be aware of, and recognition of uncertainty in the scientific information. Invasive species are defined as non-native species that have been introduced into the Chehalis Basin or Grays Harbor. These include fishes (e.g., smallmouth bass [*Micropterus dolomieu*]), invertebrates (e.g., European green crab [*Carcinus maenas*]) or plants (e.g., Japanese knotweed [*Reynoutria japonica*]). Invasive species are discussed in detail in Appendix E.

Third, the prioritized and sequenced restoration actions were reviewed as a spatially (sub-basin and ecological region) and temporally (implementation periods) explicit road map. This review was done by placing the actions in an Excel spreadsheet, hereafter referred to as the GSU spreadsheet. This step translated the recommendations into the spatial and temporal layout that is linked to the objectives for each period (e.g., protect unique habitats), producing a tool that Implementation Teams can use during project planning and program implementation.

The resulting suite of implementation recommendations focus restoration activities on 554 stream miles of habitat. The activities are not distributed evenly or randomly among the regions. For example, while the recommendations include actions in all 10 ecological regions in the basin, the stream miles targeted for protection and restoration are located in slightly less than half of the 178 GSUs in the EDT model. The type of restoration, its location, and the intensity of effort recommended were chosen to achieve the selected objectives for a variety of species and thus to meet the goals of the ASRP. In addition to restoration in streams, 56 acres of wetland protection and restoration actions targeting amphibians are recommended to support Oregon spotted frog habitat requirements.

Several key patterns in the recommendations stand out, such as the following:

- The stream mileage recommended for restoration is largest in the near-term period and smallest in the long-term period. This is based on the status of selected at-risk species and a recognition that actions need to occur now to address ongoing trends that can further degrade habitat, such as climate change and population growth.
- Restoration in upper reaches of watersheds is emphasized initially due to the distribution of at-risk spring-run Chinook salmon and two frog species targeted as priorities for restoration. Restoration of ecological processes in upper reaches also translates to downstream benefits from aspects such as water storage and temperature moderation. In the later implementation periods, protection and restoration actions are distributed more broadly within the basin.
- Ten targeted learning actions are recommended to gather critical information needed to further inform ASRP implementation.

- Restoration in the Estuary Ecological Region is identified and includes actions in the near- and mid-term implementation periods.

Near-Term Period (Years 1–10)

A total of 33 GSUs are prioritized for restoration in the near-term period, covering 235 stream miles of habitat in seven of the ecological regions.[1] The recommended actions selected by the SRT for implementation in the near-term period are described as follows, organized by the relevant objectives.

Objective: Protect unique habitats.

Unique habitats were identified for protection in the near-term period in the following three areas:

- The East Fork Satsop River and its tributaries in the Olympic Mountains Ecological Region include the following GSUs: Upper East Fork Satsop Mainstem, Decker, Bingham, and Dry Run. This is a unique glacial outwash-dominated spring-fed system of highly productive habitats that supports multiple species. Similar habitats are not seen elsewhere in the basin. Dry Run Creek is included because of its highly porous glacial outwash gravels that naturally lead to seasonal subsurface flow while supporting populations of coho (*Oncorhynchus kisutch*) and chum salmon (*O. keta*). Implementation Teams should look in these GSUs for opportunities to protect these unique habitats.
- Wetlands in the Black River Ecological Region are unique habitats that support Oregon spotted frog. The range of this species in the basin is limited to the Black River, where it is largely restricted to the upper basin reaches of Black River tributaries. The following GSUs in the Black River Ecological Region were targeted for protection: Lower Black Mainstem, Upper Black Mainstem, Lower Black Tributaries, Upper Black Tributaries, Dempsey, Beaver, and Waddell. Oregon spotted frog depends on unique warm-water wetland habitats that need protection via acquisition, protection from encroachment by invasive predators, and restoration to maintain emergent marsh plant communities. Implementation Teams should look in these GSUs for opportunities to protect the unique wetland habitats.
- The Chehalis River tidal surge plain is forested and shrub-dominated tidal wetland habitat through which all Chehalis River anadromous fish migrate as adults and juveniles. The surge plain is expected to shift upriver in the future due to sea level rise resulting from climate change, indicating a need to protect and restore areas of potential future inundation now. The existing

[1] Note that the Chehalis Basin is organized into 10 ecological regions for the ASRP, but the GSU spreadsheet for this effort combined the Lower and Middle Chehalis River ecological regions. The number of ecological regions described in this memorandum in the near-term, mid-term and long-term implementation periods refers to all 10 ecological regions, hence the small differences when reviewing the organization of the GSU spreadsheet.

forested surge plain is largely in public ownership now and should be protected while development of a new surge plain is underway. Development of a new surge plain is described later under the "initiate long-lead-time actions" objective.

Objective: Prioritize restoration of core habitats for at-risk species.

Restoration of habitats that support at-risk species was targeted in areas where habitats are currently degraded but still support these species. For example, some reaches have intact and functional riparian environments, where restoration does not depend on riparian forest growth that requires decades to provide benefits. It is expected that initial work focused in such areas will accelerate attaining meaningful results on the ground that, in turn, can begin to provide benefits quickly. The actions are designed to restore processes that create and maintain core aquatic habitats and determine overall species performance. The following three at-risk species are the focus of near-term habitat restoration actions due to their current status and location in areas where restoration will benefit multiple species:

- **Spring-Run Chinook Salmon**. A total of 118 miles of restoration is recommended in 11 GSUs in the Cascade Mountains and Willapa Hills ecological regions to respond to habitat needs of spring-run Chinook salmon. This species[2] was selected to guide restoration in the near-term period because it represents the anadromous salmonid in the basin with the most limited distribution and greatest declining trend in abundance. Also, the timing of the adult spring-run Chinook salmon life stage is unique, where adults migrate into freshwater early and hold prior to spawning. This results in adults being exposed to warm, low-flow conditions during summer; disturbance from human activities; and possibly illegal harvest. Spring-run Chinook salmon also appear to be exposed to significant risk of hybridization with fall-run Chinook salmon (see Appendix A). Spring-run Chinook salmon face increased risk of further declines in abundance under future climate change due to these factors.

  Although the two ecological regions targeted represent the uppermost portion of the Chehalis Basin, the GSUs are not the headwaters of the streams and rivers. Rather, they reflect the distribution of spring-run Chinook salmon, which does not extend into the headwaters of these systems that provide habitat for other fish species and amphibians.[3] Because the location of the selected GSUs is below the headwaters and lower in these systems, the restoration actions

[2] Spring- and fall-run Chinook salmon are two distinct run types of the same species (*Oncorhynchus tshawytscha*), based on their river entry and spawning timing. Recent research has found that they are also distinct genetically (Prince et al. 2017). However, for simplicity, each will be referred to as a separate species.

[3] Headwaters encompass the upstream portions of drainage systems that vary depending on local topographic gradients. Headwaters in the Chehalis Basin that lie in moderate to steep topographic gradients are the core habitat for stream-breeding amphibians, most prominently coastal tailed frog. Headwaters are largely in first- to fourth-order streams as described in the National Hydrography Dataset and are fish-bearing in their downstream portions. In contrast, headwaters in the Chehalis Basin that occur in low-gradient topographies are the core habitat for Oregon spotted frog, a species that dwells in marshes associated with this low-gradient headwater network.

implemented in the 11 GSUs will benefit numerous other native fishes and amphibians that co-occur in these habitats.

Implementation Teams should also seek ways to maintain and increase summer flow conditions in these rivers to support adult spring-run Chinook salmon holding prior to spawning.

Few or no physical barriers exist in these GSUs that affect current spring-run Chinook salmon distribution other than potential thermal barriers. Therefore, fish passage barrier corrections for anadromous salmonids is not a priority action in these GSUs in the near-term period.

Spring-run Chinook salmon distribution is currently centered in the Skookumchuck and Newaukum rivers, which are considered spring-run Chinook salmon core spawning areas. Spring-run Chinook salmon also occupy the upper Chehalis River and South Fork Chehalis River, though at very low numbers. Spring-run Chinook salmon historically inhabited the South Fork Chehalis River but have not been observed in recent years based on spawning ground surveys.[4] Based on the available information, historical spawning occurred in the upper mainstem of the South Fork Chehalis River and the lower reaches would have been used for adult migration and holding and juvenile rearing. While many GSUs are given a high priority for implementation in the near-term period for spring-run Chinook salmon, the highest-priority action is to restore existing habitats in the core production areas (i.e., Skookumchuck, Newaukum, and upper Chehalis rivers).

Re-establishing habitat conditions in the South Fork Chehalis River that support spring-run Chinook salmon is prioritized as part of restoring core habitats for at-risk species because this area represents the only significant-sized basin in the upper Chehalis Basin outside the Skookumchuck, Newaukum, and upper Chehalis rivers that is available to spring-run Chinook salmon. Actions are needed to expand the distribution and spatial structure of spring-run Chinook salmon and increase overall abundance and population resilience to environmental variability. However, the feasibility of re-establishing conditions in the South Fork Chehalis River that once supported spring-run Chinook salmon is uncertain. Therefore, the SRT has identified the following projects that should be considered for implementation in the near-term period in three GSUs in this river:

- Increase summer and early fall flows in the Lower South Fork Chehalis Mainstem GSU by acquiring upstream water rights or implementing water conservation measures. Groundwater and hyporheic inflow to stream channels can provide refuge for adult salmon

[4] Some newly emerged fry captured in 2020 in both the South Fork Chehalis River and the upper Chehalis River (upstream of the South Fork) were genotyped by the University of California, Davis genetics lab as homozygous spring-run Chinook salmon, confirming that some spring-run Chinook salmon are still being produced in these areas, though at very low numbers. A technical report is in preparation by the Quinault Indian Nation in collaboration with Dr. Mike Miller (University of California, Davis).

from high summer water temperatures. These inflows can be enhanced by reductions in groundwater extraction and water withdrawals.

- Implement large wood placement actions in managed forest areas of the Upper South Fork Chehalis Mainstem GSU (upstream of the valley) and upper portion of the Stillman GSU. This is needed especially in areas where the channel is scoured to bedrock to capture sediment, increase hyporheic flow and groundwater exchange, and increase habitat complexity. The actions will inform the evaluation of effectiveness of sediment wedges (e.g., the rate at which sediment wedges form behind engineered structures, whether filling wedges with sediment should be incorporated into restoration designs, effects on localized water temperature based on site monitoring, and how far effects of habitat improvements in upper reaches extend downstream to habitats utilized by spring Chinook salmon). These actions will also benefit other species including coho salmon, steelhead (*Oncorhynchus mykiss*), coastal tailed frog, and Western toad (*Anaxyrus boreas*).
- Based on results of early-action restoration in Stillman Creek, evaluate potential actions in the Lower South Fork Chehalis River GSU that could help support spring-run Chinook salmon, such as constructing holding pools for adults. Adults attempting to recolonize the upper South Fork Chehalis River would need to migrate out of the warm mainstem Chehalis River late in spring or early in summer, and at least some fish would likely hold in pools within the lower 10 miles prior to moving upstream to spawn. Uncertainty exists regarding whether it is feasible to create pools deep enough and sited near groundwater sources to provide thermal refugia for adult holding. Ideally, spring-run Chinook salmon should be able to access historically occupied cooler habitats in the upper watershed (in the managed forest). However, whether enough flow exists in the river today to allow fish access to the upper watershed is uncertain. Due to these uncertainties, additional effort and discussions should focus on how best to support re-establishing spring-run Chinook salmon in the South Fork Chehalis River.

- **Coastal Tailed Frog**. A total of 10.5 miles of restoration is recommended specifically for coastal tailed frog in six GSUs in the Willapa Hills Ecological Region. This frog species resides in smaller streams and co-occurs with other stream-associated species. Restoration was targeted in third- and fourth-order streams where coastal tailed frog is most abundant. Stream order is based on the National Hydrography Dataset, where the numerical value indicates the level of branching and increases with river size (e.g., first- to third-order streams are headwater streams). Although it is reduced in abundance, coastal tailed frog is also relatively widely distributed in the Chehalis Basin. Restoration actions for coastal tailed frog habitat in the Willapa Hills Ecological Region were prioritized over actions in other regions because this area has the highest amphibian species richness in the basin and thus restoration actions will benefit the maximum number of native amphibian species. Proposed restoration actions involve placing large wood pieces in stream channels and restoring riparian buffers on each bank. Therefore, restoration in this region will also benefit coho salmon and steelhead that occupy the lower portions of some of the GSUs targeted for coastal tailed frog and should create synergisms with actions to restore spring-run Chinook salmon habitat located downstream. In addition, a total of 101 miles of early riparian restoration and restoration of core habitats for other species will occur in the near-term period in habitats occupied by coastal tailed frog. These habitats are in 12 GSUs and five ecological regions (Grays Harbor Tributaries, Olympic Mountains, Black Hills, Cascade Mountains, and Willapa Hills) distributed across the basin.

Although restoration actions in the near term that target anadromous salmonids will improve habitat for coastal tailed frog, these actions may conflict with Western toad requirements. Western toad breeding and spring-run Chinook salmon adult migration, holding, and spawning timing do not overlap, but Western toad requires relatively warm side-channel habitats for breeding and larval development. Implementation Teams need to recognize the need for both types of habitats (primary and secondary channels) in GSUs selected for spring-run Chinook salmon and coastal tailed frog restoration and allocate restoration actions to support life history requirements of both the target species and Western toad. Restoring processes whereby the river moves and forms side channels and early successional habitats will be the key to promoting habitats for both species.

The long instream life history stage and the upstream migration pattern for the coastal tailed frog raises the issue of passage through road crossing structures for this species. The SRT has not yet resolved how to identify potential passage barriers for this species. Within the range of fish, most culverts within the managed forest will have been upgraded to provide fish passage under the Forest Practices Habitat Conservation Plan (WDNR 2005), but outside of the fish-bearing stream network, passage inventories for coastal tailed frog have not been completed. A plan will be developed to identify barriers that need to be removed for native fishes and coastal tailed frog due to perched or poorly designed culverts. Thus, barrier correction priorities in these GSUs are under development and are not emphasized in the near-term period.

- **Oregon Spotted Frog**. As discussed previously under the "protect unique habitats" objective, a total of 56 acres of restoration in seven GSUs in the Black River Ecological Region is recommended. The actions include restoring existing habitat and adding off-channel ponds and wetlands. Oregon spotted frog was selected as an at-risk amphibian species because its range and distribution have contracted over time, it is an umbrella species for a suite of stillwater-breeding amphibians, and the species is listed as threatened under the Endangered Species Act in Washington (and Oregon). Oregon spotted frog distribution in the Black River has diminished over time given human development in the basin, and the SRT expects this trend will continue. The objectives of restoration are to maintain the hydrologic connectivity and adequate water supply to maintain wetland habitats currently occupied by Oregon spotted frog. These efforts will also seek to limit incursion by invasive warm-water predators into these sites and restore low emergent breeding habitat lost to succession. Implementation Teams should also look in these GSUs for opportunities to further expand Oregon spotted frog range, where possible, by restoring additional habitats by improving hydrological connectivity and stability, resetting succession (i.e., reversing changes in the plant community back to low emergent vegetation), and eliminating invasive predators.

Objective: Initiate long-lead-time actions in selected GSUs including planting riparian buffers and re-establishing the forested tidal surge plain.

Several GSUs were selected for early implementation of riparian buffer restoration based on salmon species showing a strong positive response to riparian restoration (in the EDT model) and detailed analysis of riparian condition (in the NOAA model). Benefits of riparian buffers include shade and the input of material from the buffer that falls into the stream channel such as food (insects), leaf litter, and woody material. To realize the benefits, riparian plantings in the selected GSUs need to be initiated as soon as possible because tree growth, shading, and wood supply to stream channels from riparian buffers requires many decades (i.e., 80 years or more) to fully develop. The Middle Humptulips River Mainstem GSU in the Grays Harbor Tributaries Ecological Region, and the Scatter Creek and Beaver Creek GSUs in the Black River Ecological Region were selected for early riparian restoration. Implementation Teams should seek locations where sun angle (i.e., south bank) and stream orientation support effective stream shading. The GSUs selected for early riparian restoration are in addition to GSUs in the Willapa Hills and Cascade Mountains ecological regions where both riparian buffer restoration and in-channel restoration actions are prioritized for at-risk species.

The existing tidal surge plain is prioritized because the forest-shrub vegetation type is largely intact and it is a highly used and productive habitat for juvenile salmon migrating downstream. However, it is expected to transition to emergent marsh habitat under projected sea level rise later this century due to climate change. Actions need to be initiated in the near-term period to identify willing landowners in the largely agricultural area upstream of the existing surge plain and determine how to establish forested freshwater tidal swamp vegetation for a future tidal surge plain where one does not currently exist.

Objective: Restore core habitats that support multiple species.

Core habitats are the areas that currently have characteristics and natural processes that are productive and currently stable for the species of interest and are used year after year by these species (ASRPSC 2019). Besides protecting unique habitats and restoring habitats for at-risk species discussed previously that will benefit numerous species, additional GSUs were identified for restoration in the near-term period that represent core habitats that can be improved to increase the resilience of the species there. These core habitats were selected to support the vision of the ASRP (i.e., healthy and harvestable salmon populations, robust and diverse populations of native aquatic and semi-aquatic species, and productive ecosystems for multiple species). This recommendation includes a total of 50 stream miles across four GSUs in the Olympic Mountains Ecological Region (Lower Satsop Mainstem, Lower East Fork Satsop Mainstem, Middle Wynoochee Mainstem, and the Middle Wynoochee Tributaries), one GSU from the Black Hills Ecological Region (Cloquallum), and one GSU from the Willapa Hills Ecological Region (Elk Creek). These GSUs were included as near-term priorities because of their high potential to benefit from restoration, their unique features, or because they are threatened by human development. For example, the upper basin in Elk Creek contains wetlands and old-growth stands that support coho salmon. The SRT recommends that the Implementation Teams work with large landowners in the watershed to develop a protection plan for these habitats and a restoration plan for the sub-basin.

Objective: Restore connectivity through barrier removal.

Correction of passage barriers is incorporated as a key element of the ASRP to optimize habitat connectivity across the life history of targeted species, but barrier removal is not emphasized as strongly in the near-term period because few physical barriers exist in the GSUs being targeted for habitat restoration for spring-run Chinook salmon as they are currently distributed. Barrier project selection criteria for salmon and steelhead will be developed by the SRT in the near-term period and will be applied to projects proposed through the Implementation Teams to support identifying the highest-priority barriers for removal. Water crossing design guidelines developed by WDFW (Barnard et al. 2013) and Washington Administrative Code 220-660-190 provide current criteria for preferred culvert design to facilitate passage for salmonid fishes. In addition, WDFW's water crossing guidance now considers stream changes due to climate change (Wilhere et al. 2017). However, barriers affecting amphibians and resident fishes have not been surveyed, and this information is needed to inform barrier removal priorities for these species. It should also be noted that throughout ASRP implementation, barriers will also be removed or corrected through other funding sources in the basin.

Objective: Initiate restoration in upper stream reaches, focus actions on managed forests where feasible to support rapid changes in conditions, and concentrate actions to produce demonstrable changes in habitat conditions.

The recommended actions are spatially and temporally concentrated (rather than dispersed) to achieve demonstrable changes in habitat conditions above background levels. The near-term period targeted GSUs were selected because of species distributions and species assemblages in these locations. Initiating actions in upper reaches of watersheds is prioritized for the following reasons:

- These reaches are largely in managed forests where riparian buffers already exist, and in-channel restoration can take advantage of existing buffers instead of waiting for buffers to be restored and fully develop elsewhere.
- Land ownership structure is simple and likely supports the timely implementation of restoration across large areas.
- Benefits of restoration in managed forests will extend downstream due to stream gradient and hydrology.
- Cooler (upper) reaches become more important as warming occurs in the basin due to climate change.

Objective: Promote the resilience of aquatic habitats to future climate change and human population growth.

A key goal of the ASRP is to overcome, or at least substantially ameliorate, the effects of future climate change and human population growth on aquatic habitats in the Chehalis Basin to increase the abundance and distribution of native species above current levels. The priority actions described here for the near-term implementation period were selected in part because they address these known stressors to aquatic species. This includes GSUs in the Black River Ecological Region (to protect Oregon spotted frog as discussed previously); Cloquallum Creek in the Black Hills Ecological Region (for coho salmon, fall-run Chinook salmon, and steelhead); the Lower Skookumchuck Mainstem, Lower Newaukum Mainstem, South Fork Newaukum Mainstem, and North Fork Newaukum Mainstem GSUs in the Cascade Mountains Ecological Region (for spring- and fall-run Chinook salmon, coho salmon, and steelhead); and 13 GSUs in the Willapa Hills Ecological Region (for multiple species including Van Dyke's salamander [*Plethodon vandykei*], a Washington State-endemic amphibian that may be the amphibian species most vulnerable to climate change). In addition to the restoration actions identified for these GSUs, the acquisition of key habitats at risk of development are being considered in the ASRP.

Besides the actions identified here, additional studies are being conducted to identify water sources to augment summer flow that is expected to decrease under climate change and human development. A Water Use Pilot Study is underway in several geographic areas of focus (sub-basins) within the Chehalis Basin. The objectives of the study are to identify means to improve instream flow for aquatic species and identify opportunities to improve water supply for agricultural, municipal, and industrial use. This study is not a formal component of the ASRP but is being conducted through the Office of Chehalis Basin and the Washington Department of Ecology to support the ASRP and inform decisions regarding the Chehalis Basin Strategy. Also, the Chehalis Basin Partnership has updated the Chehalis Basin Watershed Management Plan to address the requirements of the Streamflow Restoration Act (Engrossed Substitute Senate Bill 6091).

Currently, non-fish-bearing headwater streams have a two-sided, 50-foot buffer on a minimum of 50% of the stream length. The Hard Rock Study (McIntyre et al. 2018) evaluated the effectiveness of the current westside riparian management zone prescriptions for Type N (non-fish-bearing) waters in maintaining key aquatic conditions and processes affected by forest practices. Results of the study demonstrated increased temperatures for streams under both the current rule as well as when the entire stream length was buffered by a two-sided, 50-foot buffer. Consequently, Forest Practices Rules are being re-evaluated. Any rule change that reduces stream temperature after timber harvest will benefit aquatic resources. However, because the Hard Rock Study treatment that buffered the entire stream length still resulted in elevated stream temperatures and because the effectiveness of any rule changes cannot be predicted, acquisitions that provide increased protection or remove portions of the headwater landscape from timber harvest should also be considered.

Achieving the full vision of the ASRP will likely require integrating ASRP priorities with ongoing land-use planning decisions because climate change and human development can offset ASRP benefits. This is discussed further in Section V.

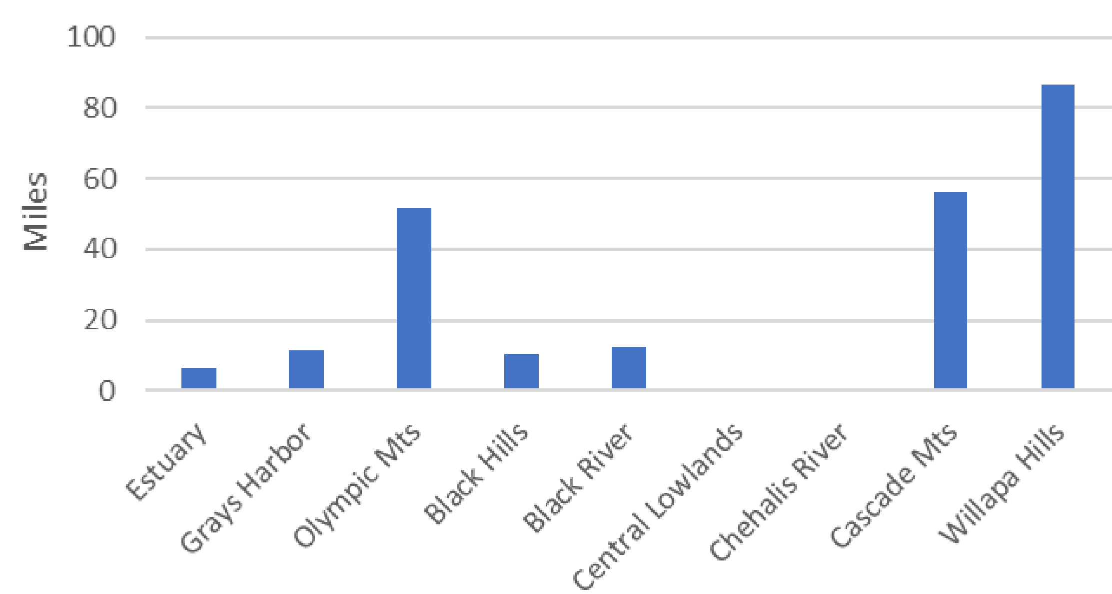
Objective: Initiate targeted learning.

Targeted learning studies were identified to improve the effectiveness of restoration actions and funds spent and adaptively manage ASRP implementation. These studies represent near-term actions that address key data gaps and uncertainties. Results of the studies will guide mid- and long-term restoration actions and are needed to achieve the full vision of the ASRP, though consideration might be given to adding some aspects into the later part of the near-term period depending on urgency. The ASRP includes a substantial monitoring and adaptive management (M&AM) effort designed to inform program progress and adaptively manage the program through time. Suggested targeted learning opportunities are described in Appendix C and will be coordinated through the ASRP M&AM Plan.

Near-Term Period Summary

The recommended near-term actions focus restoration on 235 stream miles of habitat with an emphasis on seven ecological regions and areas with spring-run Chinook salmon habitat in the Cascade Mountains and Willapa Hills ecological regions (Figure 4). These near-term actions are intended to address the acute habitat restoration needs of at-risk species, protect key unique habitats, initiate long-lead-time actions, and suggest important research topics to guide later actions. Restoration in the Olympic Mountains Ecological Region is focused on the inclusion of high-priority core habitats and unique at-risk habitat.

Figure 4
Miles of Proposed Restoration by Ecological Region in the Near-Term Implementation Period



Note the Chehalis River includes both the Lower Chehalis and Middle Chehalis ecological regions.

Mid-Term Period (Years 11–20)

Phase I of the ASRP included additive scales of restoration, Scenarios 1, 2, and 3 to address species habitat protection and restoration. Scenario 1 was intended to protect and enhance existing core habitats for all aquatic species. Scenario 2 builds on Scenario 1 to protect and enhance existing core habitat areas, with an additional focus on restoring the best opportunities to benefit multiple species and increase spatial distribution. The approach taken in developing this Prioritization and Sequencing Plan for the mid-term period was to prioritize all restoration included in Scenario 1 that was not addressed in the near-term period and the actions included in Scenario 2. In addition, habitat restoration actions in the Grays Harbor Shoreline GSU in the Estuary Ecological Region are initiated in the mid-term period. A total of 28 GSUs are prioritized for restoration, covering 198 stream miles of habitat in nine of the ecological regions. The recommended actions selected by the SRT for implementation in the mid-term period are described as follows, organized by the relevant objectives.

Objective: Initiate long-lead-time actions in selected GSUs including planting riparian buffers and re-establishing the forested tidal surge plain.

As noted previously, riparian plantings in the selected GSUs need to be initiated as soon as possible to realize the benefits because tree growth, shading, and wood supply to stream channels from riparian buffers requires decades to fully develop. Eleven GSUs in three ecological regions are prioritized for riparian plantings in the mid-term period.

Objective: Restore core habitats that support multiple species.

There is a large emphasis on restoring core habitats In the mid-term period. The recommendations include targeting 154 miles of restoration in 23 GSUs in seven ecological regions. This includes the following:

- A total of 50 miles of restoration in five GSUs in the Grays Harbor Tributaries Ecological Region
- A total of 28 miles of restoration in five GSUs in the Black River Ecological Region
- A total of 22 miles of restoration in three GSUs in the Black Hills Ecological Region
- An additional 15 miles of habitat restoration in two GSUs in the Central Lowlands Ecological Region
- A total of 13 miles of restoration in two GSUs in the Cascade Mountains Ecological Region
- An additional 4 miles of habitat restoration in three GSUs in the Willapa Hills Ecological Region

In addition to these miles and GSUs, the SRT believes that the Elk Creek sub-basin has a significant potential to produce coho salmon, and it also produces winter-run steelhead. This is why Elk Creek is identified in the near-term as a GSU to restore under core habitats that support multiple species. In addition, Elk Creek may be able to support spring-run Chinook salmon, although Chinook salmon did not utilize these habitats historically due to a natural barrier. Therefore, the SRT has identified the following actions for consideration in Elk Creek:

- Survey Elk Creek habitats above and below the natural barrier to determine if restoration of these areas will result in habitats that could support spring-run Chinook salmon. Consideration might be given to attempting to colonize Elk Creek with spring-run Chinook salmon if efforts to expand their current range are judged to be necessary.
- The fish ladder at Elk Creek was updated for adult salmon passage in 2008 or 2009 (Zimmerman 2020). Passage success of coho salmon and steelhead should be verified, and if needed, structural modifications should be implemented during the mid-term period to further improve passage conditions. In addition, the ladder has the potential to be used to separate spring- and fall-run Chinook salmon (reducing the hybridization threat) if expanding spring-run Chinook salmon range in the future to include Elk Creek is deemed necessary and feasible.

Objective: Restore estuary habitat.

The ASRP Phase I document did not specifically include the estuary beyond the tidal reaches of the Chehalis River and other tributaries to Grays Harbor (ASRPSC 2019). Beginning in early 2020, the ASRP Steering Committee requested that the SRT incorporate the estuary into the ASRP as part of its scenario refinement. Appendix D outlines the information the SRT reviewed in developing ASRP implementation recommendations for estuary habitat restoration.

Based on this review, a total of 14 miles of habitat restoration in the Grays Harbor Shoreline GSU in the Estuary Ecological Region was identified for implementation in the mid-term period. Also, as discussed under the near-term period section, the SRT recommends the forested riparian floodplain upstream of the existing forested tidal surge plain be restored and that *Spartina* distribution in Grays Harbor be surveyed and a control plan developed.

Objective: Restore connectivity through barrier removal.

Correction of fish passage barriers through replacement or removal is incorporated into the ASRP to optimize connectivity across the life histories of targeted species. Barrier project selection criteria developed in the near term will be applied to facilitate the proposal review process and identification of the highest-priority barriers for removal. The number of barrier removal projects in the mid-term period will increase compared to the near-term period because the number of barriers in core habitat GSUs is larger than the GSUs identified in the near-term period for at-risk species and protecting unique habitats. Also, barrier status and passage ratings change through time as some currently passable culverts become barriers and some barriers fill with sediment or fail; the barrier prioritization tool will be updated on a regular basis.

Objective: Promote the resilience of aquatic habitats to future climate change and human population growth.

All the actions selected for implementation in the mid-term period are intended to help address projected effects of climate change. In addition, some of the GSUs selected for implementation in the mid-term period focus on areas expected to undergo increased human population growth. These include, for example, the Mox Chehalis GSU in the Black Hills Ecological Region; the Lower Black Mainstem, Upper Black Mainstem, Lower Black Tributaries, Dempsey, and Waddell GSUs in the Black River Ecological Region; and the Hanaford and South Fork Newaukum Tributaries GSUs in the Cascade Mountains Ecological Region.

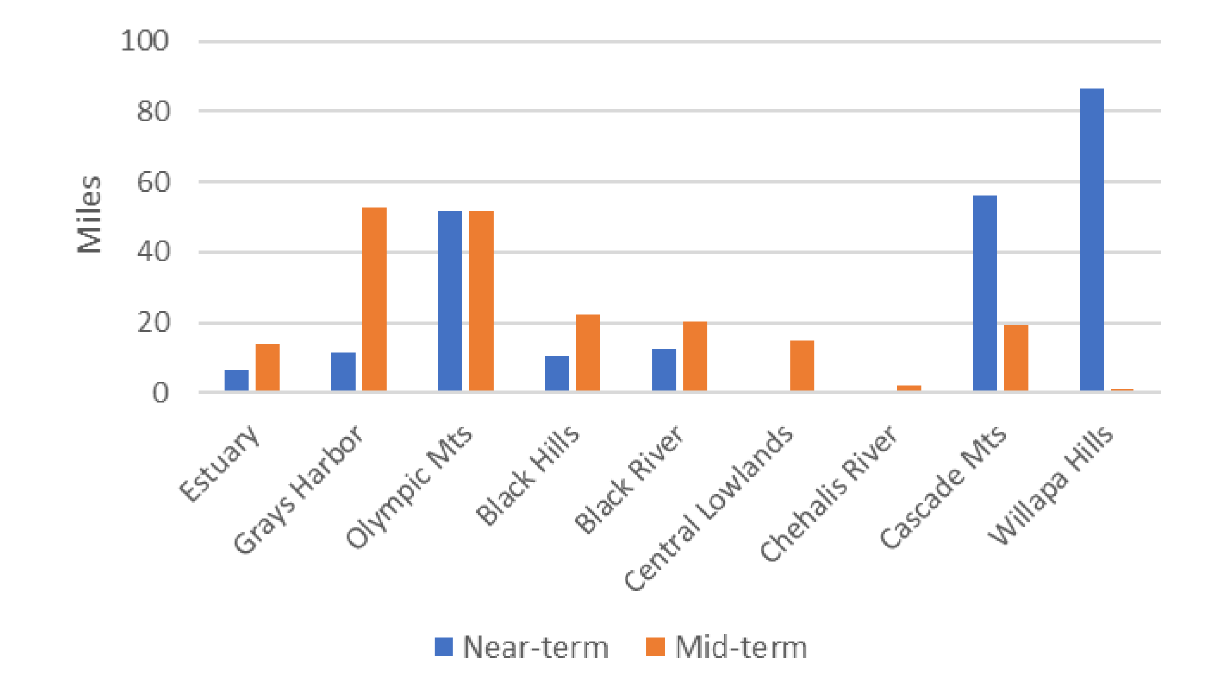
Objective: Continue targeted learning.

There will be a need to continue targeted learning projects in the mid-term period, and some aspects of targeted learning projects identified for the near-term period may continue into the mid-term period. Suggested targeted learning opportunities will be coordinated and executed through the ASRP M&AM Plan.

Mid-Term Period Summary

The recommended mid-term actions focus restoration on 198 stream miles of habitat in nine ecological regions (Figure 5). Note that many of the actions taken in the near-term period along with the effects (benefits) from the protection and restoration actions completed in that period will continue into the mid-term period, and some restoration actions completed in the near term will require maintenance in the mid-term period.

Figure 5
Miles of Proposed Restoration by Ecological Region in the Near- and Mid-Term Implementation Periods



Note the Chehalis River includes both the Lower Chehalis and Middle Chehalis ecological regions.

Long-Term Period (Years 21–30)

For the long-term period, recommended actions include restoration that continues to restore productive core habitats that support the full range of focal species addressed by the ASRP and increase the spatial structure and diversity of some species by including smaller sub-basins and population components. A total of 24 GSUs are prioritized for restoration, covering 121 stream miles of habitat with an emphasis on seven of the ecological regions. The recommended actions selected by the SRT for implementation in the long-term period are described as follows, organized by the relevant objectives.

Objective: Restore core habitats that support multiple species.

In the long-term period, actions to meet this objective are recommended in 20 GSUs in seven ecological regions. This includes in-channel and floodplain connectivity actions in five GSUs in the Lower and Middle Chehalis River ecological regions. These collective actions are referred to as “nodes” in the ASRP. The node concept utilizes in-channel structures such as engineered logjams to improve habitat conditions in the mainstem channel and improve the connectivity between mainstem channel, floodplain, and off-channel habitats to benefit multiple amphibian, resident fish, and anadromous fish species. Approximately 21 miles of river are targeted for restoration within the five GSUs.

Objective: Restore connectivity through barrier removal.

Similar to the mid-term period, barrier corrections in the long-term period will increase compared to the near-term period because the number of barriers in core habitat GSUs is larger than the GSUs identified in the near-term period for at-risk species and protecting unique habitats.

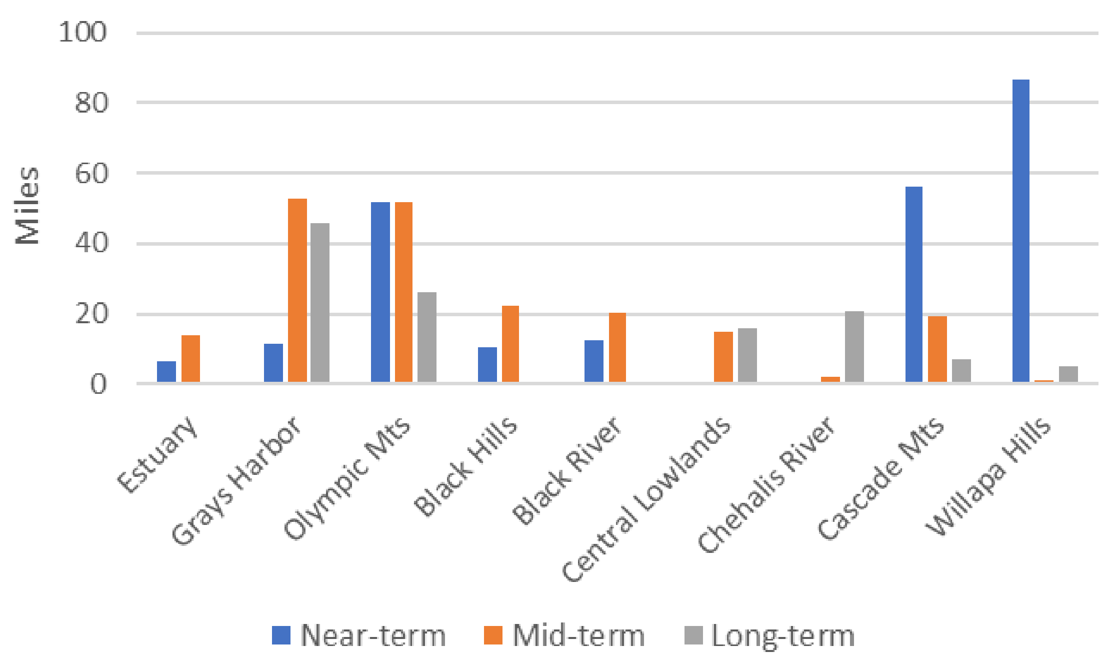
Objective: Promote the resilience of aquatic habitats to future climate change and human population growth.

All of the actions selected for implementation in the long-term period will address projected effects of climate change. GSUs selected for implementation in areas expected to undergo increased human population growth include the Skookumchuck Tributaries GSU in the Cascade Mountains Ecological Region, several GSUs in the Central Lowlands Ecological Region, and the Lake GSU in the Willapa Hills Ecological Region.

Long-Term Period Summary

The recommended long-term actions focus restoration on 121 stream miles of habitat in seven ecological regions (Figure 6). As discussed previously in the mid-term period section, many of the actions taken in the near- and mid-term periods along with the effects (benefits) from the protection and restoration actions completed in these periods will continue into the long-term period, and some restoration actions completed in the earlier periods will require maintenance in the long-term period.

Figure 6
Miles of Proposed Restoration by Ecological Region in the Three Implementation Periods



Note the Chehalis River includes both the Lower Chehalis and Middle Chehalis ecological regions.

IV. Additional Factors

The SRT considered several factors in addition to the objectives listed in Section III when developing its recommendations on ASRP implementation. These factors were discussed because of their potential to influence ASRP success. Many of the factors are identified in Appendix C for consideration as targeted learning studies and will be coordinated with the development of the M&AM Plan. Some of the factors were reviewed in greater detail and are discussed in detail in separate appendices.

Biological Processes

1. **Invasive Species:** Multiple invasive plant and animal species present unique management challenges and increase uncertainty in the response of native species to habitat restoration as restoration can also benefit invasive species. Methods and actions that reduce the impacts of invasive species on native species are limited (Appendices C and E).
2. **Hybridization:** Hybridization between spring- and fall-run Chinook salmon appears to be occurring. Opportunities exist to physically intervene to increase run separation between spring- and fall-run Chinook salmon (Appendices A and C), but uncertainty in the level of hybridization and response to this kind of intervention requires additional study.

Habitats or Habitat Features

1. **Floodplain Off-Channel Habitats:** Floodplain off-channel habitats likely support the richest freshwater assemblage of aquatic vertebrates (amphibians and fishes) in the Chehalis Basin (Appendix C). The physical and biotic complexity of these habitats will require additional efforts to design effective restoration to better understand how to control invasive species in these habitats.
2. **Sediment Wedges:** Stream water can become cooler as it flows through sediment accumulations (Appendices C and F). Sediment wedges are being studied by WDFW as part of an early grant round award for experimental actions. However, additional evaluations of sediment wedges are needed to understand the extent to which the method can be used to provide thermal refugia in different-sized streams.
3. **Thermal Refuges:** Thermal refuges or refugia are areas that allow fish and other organisms to occupy more suitable temperatures when ambient stream temperatures are either too warm or too cold for growth and survival. Appendix G outlines the information the SRT developed and reviewed when incorporating recommendation on the need for thermal refuges and the use of large wood to restore gravel accumulations.
4. **Barriers:** The SRT understands that removing barriers is an important element of the ASRP due to the immediate benefits and oftentimes excellent landowner support and has begun an effort

to develop a list of prioritized barrier removals (Appendix B). The SRT also acknowledges the need to remove barriers for resident fish and coastal tailed frog Appendix C).

Species

The SRT noted that information on eulachon (*Thaleichthys pacificus*) is limited and there is a need to evaluate eulachon population dynamics and habitat utilization (Appendix C). The SRT also identified potential conflicts between in-channel restoration for native fishes and freshwater mussels (Appendix H). The SRT recommends that Implementation Teams use the guidance developed by the Xerces Society (Blevins et al. 2019) on best management practices when developing restoration designs so the restoration is conducted in a mussel-friendly manner. Potential conflicts between restoration actions designed for different species were also identified (Appendix I).

Scientific Uncertainty

Many sources of uncertainty exist in the data, analyses, and modeling that support ASRP recommendations. For example, the SRT has high confidence and therefore low uncertainty that addressing high temperatures in the range of spring-run Chinook salmon will be critical to their future persistence. In contrast, the SRT has low confidence and high uncertainty that interventions intended to reduce the effects of invasive warm-water fishes on native species through reconnecting off-channel habitat will have the intended effect. Therefore, the potential effect of actions aimed at reducing predation impacts by invasive species in these types of habitats needs to be assessed.

A comparison of the EDT model and NOAA model outputs for fall-run Chinook salmon highlights key uncertainties associated with the effects of climate change on salmon and steelhead and therefore the effectiveness of proposed restoration strategies to address future conditions with climate change. Contrasting outputs result from a difference in the predicted effects of climate change on Chehalis River water temperature used in the two models. The SRT is continuing to evaluate the information incorporated into these models and sources of the uncertainty.

Acknowledging scientific uncertainty is critical and was used to identify targeted learning projects with the greatest chance of reducing uncertainty, improving restoration effectiveness, and supporting adaptive management of ASRP implementation.

External Factors

The success of the ASRP will also be affected by external factors that operate outside the ASRP. This is especially true for anadromous salmonids that spend most of their life in marine waters that are outside the purview of the ASRP, but where environmental conditions in the Pacific Ocean have a large effect on year-to-year variability in adult salmon and steelhead returns to freshwater. These factors are discussed in greater detail in Appendix J. The following factors need to be considered when evaluating the response of species to ASRP actions and overall success of the program:

- **Hatcheries:** Fish produced in hatcheries have lower reproductive success than wild fish, which can reduce the fitness (productivity) of a population when hatchery- and wild-origin fish spawn together.
- **Harvest:** Harvest can have a negative effect on salmon and steelhead populations with diminished productivity due to habitat degradation, contributing to declining abundance and increasing the at-risk status of some species.
- **Climate Change:** Climate change is an additional factor that must be overcome by restoration to result in positive change in species abundance and achievement of the ASRP vision.
- **Land Use:** Processes creating and maintaining aquatic habitats are fundamentally linked to upland conditions and land use. Agriculture, silviculture, and urbanization all have the potential to negatively impact aquatic environments and the native fish and wildlife species they support. Increased human development and urbanization will likely increase groundwater extraction, reduce wetland and floodplain habitats, increase pollutants, and directly degrade streams in urban environments.
- **Environmental Variation:** The abundance of salmon and steelhead populations varies widely from year to year due to variation in freshwater and marine environmental conditions, making it challenging to demonstrate substantial change as a result of restoration actions.

V. Regional Policy Issues

The SRT identified several policy aspects of ASRP implementation that stem from the scientific guidance presented, described for consideration as follows:

- **ASRP integration with land-use planning decisions.** Achieving the full vision of the ASRP will likely require integrating ASRP priorities with land-use planning decisions because human development can affect ASRP benefits. For example, water withdrawals and groundwater pumping are typical features of human population growth that can decrease streamflow and groundwater movement into nearby streams and adversely impact species and habitats targeted by ASRP actions. Regional land use planners should be aware of the potential for planning decisions that conflict with ASRP objectives. The ASRP managers should identify where key habitats selected for protection and restoration are likely to intersect with human development to minimize impacts to aquatic habitat and work with land use planners to integrate ASRP and human development priorities.
- **Headwater stream buffers.** Under current Forest Practices Rules (WDNR 2005), a two-sided, 50-foot buffer is required on a minimum of 50% of the non-fish-bearing stream length in Western Washington. Results of a recent study demonstrated that neither the current buffer prescription, nor two alternatives providing less and more buffered stream length, protected streams from increases in stream temperatures following clear-cut harvest (McIntyre et

al. 2018). Ongoing re-evaluation of Forest Practices Rules will inform potential changes in protection of non-fish-bearing streams that could impact aquatic habitats and species. During development and implementation of the ASRP, it would be beneficial to track this important issue as it develops and consider potential consequences to aquatic species and their habitats of any Forest Practices Rules change in headwater streams, as well as implications for the success of the ASRP.

- **Streamflow Restoration Act, Revised Code of Washington 90.94 (i.e., Hirst decision).** A decision by the Washington Supreme Court in 2016 for Whatcom County versus Western Washington Growth Management Hearings Board (referred to as the Hirst decision) required each county to determine that the impacts from proposed new domestic permit-exempt wells would not impair senior water rights (which included instream flow requirements). The Streamflow Restoration Act passed in 2018 prescribed the actions local watershed planning units needed to take to allow new permit-exempt wells to be constructed. The Watershed Management Act resulted in the formation of the Chehalis Basin Partnership (Partnership) in 1998. The Partnership completed a watershed plan and added an addendum referring to Engrossed Substitute Senate Bill 6091 describing potential actions that could mitigate for the water usage from permit-exempt wells. The addendum identifies potential projects intended to produce a net ecological benefit, which may overlap with the ASRP. As the ASRP and watershed plans move forward, there should be focused coordination to ensure the programs are integrated.
- **Hatchery program alignment with ASRP goals.** The ASRP is intended to improve the performance and sustainability of wild native species in the Chehalis Basin by restoring physical and biological processes that support those species. However, major hatchery production programs exist in the basin, which in some cases have the potential to reduce, or even negate, the benefits of restoration actions for wild fish. The SRT recognizes that these hatchery programs are intended to provide fishery benefits to both treaty Indian and non-treaty fisheries within the basin and in the ocean. The programs were primarily initiated to offset declines in wild fish production because of habitat degradation and other factors. Recently, increased hatchery production of Chinook salmon is being considered to benefit the Endangered Species Act-listed southern resident killer whales. The SRT has identified potential updates of certain parts of the hatchery programs (i.e., Skookumchuck Hatchery releases into Elk Creek as discussed previously) to better align with the direction and priorities of the ASRP. The SRT realizes that the hatchery programs in the basin were reviewed by the Hatchery Scientific Review Group (HSRG; HSRG 2004), and many of the HSRG recommendations were implemented. However, that review was done more than 15 years ago and did not envision the ASRP. Aspects of the hatchery programs that should be revisited include the following:
  - Egg and fish transfers between hatchery facilities or sub-basins that would potentially lead to reduced genetic diversity, potentially reducing the fitness and resilience of the genetically diverse natural stocks in the Chehalis basin.

- Elimination of off-station releases of coho salmon and steelhead juveniles into the Newaukum River and Elk Creek to minimize competition between hatchery and wild fish in those areas and loss of genetic structure. Approximately 100,000 coho salmon smolts and over 30,000 steelhead smolts are released annually into the stream. This legacy program results in stocked fish competing with wild coho salmon and steelhead and potentially introduces genetic risks to the endemic populations.

- It is critical that adult spring-run Chinook salmon holding in pools in the mainstem Chehalis, Skookumchuck, and Newaukum rivers prior to spawning be protected from harassment, disturbance, and poaching. Protection could be enhanced through community outreach measures to educate the public on the vulnerability of adults to pre-spawn mortality during this part of their life cycle combined with focused enforcement.

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Appendix A
Hybridization

Summary – Problem Statement and Potential Actions

Hybridization between spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Chehalis Basin appears to be a key factor contributing to the decline and low abundance of spring-run Chinook salmon in the basin. The issue arises because the spawning area of the two runs overlaps, and increasingly the spawning times overlap between the two runs. Fall-run Chinook salmon are far more abundant than spring-run Chinook salmon, and there is mounting evidence that hybridization between the two runs is occurring. The concern is heightened because of recent research indicating that the spring-run life history of Chinook salmon is a unique genetic trait that could be lost. Hybridization between the two races appears to be reducing the occurrence of the spring-run genetic trait, which may ultimately lead to elimination of the run in the Chehalis Basin. Actions should be included in the *Aquatic Species Restoration Plan* (ASRP) to reduce mixing and hybridization of the two runs. Initially, actions should be intended to increase knowledge and understanding of the extent of the issue and to assess potential remedial steps that could be taken.

Potential actions identified here are aimed at reducing the rate of hybridization between spring- and fall-run Chinook salmon in the basin. The following three types of actions are described in this appendix: 1) habitat restoration; 2) temporary use of weirs to increase spatial separation during breeding of the two run -types; and 3) temporary intervention using hatchery techniques to safeguard pure spring-run genetics during the period when habitat restoration actions are being implemented.

Background

The hybridization of species, subspecies, or varieties can undermine restoration efforts. Rates of hybridization have increased dramatically worldwide because of widespread intentional and accidental translocations of species and habitat alterations by humans (Allendorf and Luikart 2007). Hybridization has contributed to the extinction of many species and varieties through direct and indirect means. This issue can threaten aquatic species in particular, notably fish (Allendorf et al. 2001).

In the Chehalis Basin, growing evidence suggests that hybridization between spring- and fall-run Chinook salmon is increasing to such an extent that Miller (2019) believes it is an imminent threat to sustaining spring-run Chinook salmon in the basin.

This appendix provides an overview of some aspects of hybridization that should be considered in the development and implementation of the ASRP. Hybridization is a biological process that potentially can reduce or negate the effectiveness of actions meant to benefit and restore performance of native species.

Hybridization Defined

The term “hybridization” has sometimes been used solely to refer to the interbreeding of species (e.g., Grant and Grant 1992, cited in Allendorf and Luikart 2007). Allendorf and Luikart (2007) found this use of the term to be problematic, especially since it is sometimes difficult to agree on what is a species. Therefore, they adopted a more general definition given by Harrison (1990) that includes matings between "individuals from two populations, or groups of populations, which are distinguishable on the basis of one or more heritable characters." In this sense, hybrids include the products of interspecific matings, such as between steelhead (*Oncorhynchus mykiss*) and coastal cutthroat trout (*O. clarkii clarkii*) or westslope cutthroat trout (*O. clarki lewisi*; Quinn 2018) as well as intraspecific matings, such as between spring- and summer-run Chinook salmon (Fraser et al. 2020) or spring- and fall-run Chinook salmon (Kinziger et al. 2008).

Causes of Hybridization

Hybridization, as defined previously, is a biological process that occurs naturally in the absence of any actions taken by humans. It is a part of the natural evolutionary process. Because of this, the idea of interventions in this biological process by human actions can be controversial (Allendorf and Luikart 2007). However, the increasing pace of species introductions (plant and animal) and habitat modifications made by humans have caused increased rates of hybridization and heightened concerns about effects on native species. This form of hybridization has been referred to as "anthropogenic hybridization" because it is fundamentally the result of human activity.

The most easily recognized form of hybridization in species conservation occurs between native and non-native species. For fish species, well-known examples of this form of hybridization are between interior subspecies of native cutthroat trout (westslope, Yellowstone, etc.) and introduced rainbow trout (Behnke 2002). Rainbow trout are not native to the areas inhabited by these cutthroat trout subspecies. In this case, hybridization is a serious threat to the native cutthroat trout, jeopardizing the persistence of those subspecies within their historical distributions (e.g., Muhlfeld et al. [2014]). It bears noting that coastal cutthroat trout, also a subspecies of cutthroat trout, coevolved with coastal rainbow trout (both anadromous and resident), a subspecies of *O. mykiss*. In this case, hybridization between the species, which occurs naturally within the native ranges of these species, results in hybrids that are apparently less fit than either of the pure species, allowing both species to coexist and occasionally hybridize without jeopardizing either species (Quinn 2018).

Another factor that affects the rate of hybridization is habitat modification that occurs through human activity. The role of this factor is believed to be underappreciated (Allendorf and Luikart 2007)—it is likely that it has a significant effect on the rate of hybridization in many places. Allendorf and Luikart (2007) noted that some authors refer to hybridization resulting from habitat modifications as entirely natural, as it does not involve species introductions outside their native range. However, Allendorf and Luikart (2007) identify these cases as anthropogenic hybridization because they are the result of human activity. They cited various ways that habitat modifications can lead to increased hybridization, many of which involve the breaking down of mechanisms that kept the species or subspecies spatially or temporally separate during breeding prior to the modifications.

Habitat modifications or other human activity (such as overharvesting) that result in a decline in the abundance of a species can also promote hybridization among species or populations (Allendorf and Luikart 2007). This can occur, for example, because of the difficulty of finding mates of the same species or population. Miller also explains this facet of hybridization as a "numbers game"—that is, when one species or population is reduced to such low abundance that it can be easily swamped during breeding by another more abundant population (Miller 2020). In this case, even a low rate of hybridization from the perspective of the abundant population can swamp the low-abundance population. As a result, genetically distinct populations may be lost through genetic mixing. Thompson et al. (2019a) suggest that this may be occurring to Chehalis spring-run Chinook salmon as a result of hybridizing with the more abundant fall-run Chinook salmon population.

Spring- and Fall-Run Chinook Salmon

Until recently, the genetic basis that distinguishes run type within Chinook salmon populations was not understood. In earlier studies, based on the genetic markers being used, little genetic differentiation between spring- and fall-run Chinook salmon within the same river system could be identified. This changed in 2017 when the genetics lab at University of California, Davis (UC-Davis) discovered that a single genetic locus in Chinook salmon determines run type. The researchers concluded that the genetic mutation that produced spring-run Chinook occurred only once in the species' history, and that event occurred hundreds of thousands of years ago (Prince et al. 2017). These findings have now been duplicated by other labs and for other rivers (e.g., Narum et al. 2018), including in the Chehalis River (Thompson et al. 2019a). The rarity of the mutation suggests that if spring-run Chinook salmon went extinct, they would not reoccur from other run types.

Implications of the genetic basis of spring-run Chinook salmon are amplified when considering potential effects of hybridization between run types in a river system like Chehalis. Some degree of interbreeding between run types in Washington coastal rivers is expected due to the relatively small size of the rivers. This is shown by the relatively low levels of genetic differentiation between run types across most of their coastal range shown by older, conventional genetic evaluation (Waples et al. 2004; Brown et al. 2017). But maintenance of intra-run mating within the spring run type is almost certainly important for the long-term persistence of the spring-run Chinook salmon populations in these rivers (Thompson et al. 2019b).

Spatial and temporal overlap in spawning between the spring- and fall-run Chinook salmon populations in the Chehalis system appears to be increasing (Lestelle et al. 2019; Ronne et al. 2020). The situation appears to be causing increased hybridization of the run types within the upper Chehalis Basin based on recent genetic sampling (Thompson et al. 2019a; QIN [in preparation]). Consequently, a high rate of hybridization with fall-run Chinook salmon likely represents an existential threat to the persistence of the spring-run Chinook salmon population (Thompson et al. 2019a, 2019b). Without habitat separation, a meager spring run may be rapidly swamped by numerous fall-run fish.

Therefore, restoration of the ecological processes that allow for the sustained coexistence of spring- and fall-run Chinook salmon populations is critical for the full recovery of spring-run Chinook salmon viability in the Chehalis Basin. The high priority being given to restore habitats and ecological processes that would benefit spring-run Chinook salmon is intended to slow and then reverse the declining trend of spring-run Chinook salmon in the basin. This in turn should, over a period of time, decrease the rate of hybridization that is occurring.

Potential Actions to Reduce Hybridization

Potential actions identified here are aimed at reducing hybridization that is occurring between spring- and fall-run Chinook salmon in the basin. Three types of actions are described as follows:

1. **Habitat restoration.** The ASRP is largely focused on the restoration of habitat characteristics within the river basin to improve the performance of wild native species (ASRPSC 2019). In the near-term period of the plan, priority is given to restoring habitat characteristics (such as cold-water holding pools in the upper basin) that will benefit at-risk species, particularly spring-run Chinook salmon. Over time, these actions are expected to increase the population performance of spring-run Chinook salmon (both intrinsic productivity and abundance), which would make them more resistant to the adverse effects of hybridization.

   It is important to recognize, however, that these actions will take time to both implement and mature with respect to having the needed benefits to spring-run Chinook salmon. This means that other actions with more immediate effects may be needed in the intervening period.
2. **Temporary use of weirs to increase spatial separation during spawning of the two run types.** The most direct way to reduce hybridization between the two run types would be to reduce spatial and temporal overlap of the two populations when and where spring-run Chinook salmon are spawning (Miller 2019).
   A. An example of such a restoration action would be to re-employ a weir on the Skookumchuck River or to remove the dam on that river. Following construction of the dam in 1970 at River Mile (RM) 21.9, spring-run Chinook salmon were blocked from accessing their historical spawning habitat in the upper reaches of the that river. This resulted in an increase in spatial spawning overlap between the spring and fall run types that was striking enough for the Washington Department of Fisheries to construct a weir near RM 19.0 as protection for the spring run (Hiss et al. 1985). The weir was used to provide exclusive access for spring-run Chinook salmon between that site and the dam. The weir was discontinued after several years, but reinstatement was recommended by the U.S. Fish and Wildlife Service in 1985 after spawner surveys again found concerning degrees of overlap between the runs (Hiss et al. 1985).

      The concern in the Skookumchuck River was that the later-timed spawning of fall-run Chinook salmon was causing redd superimposition and mortality to the eggs of the earlier-timed spring-run Chinook salmon. No action was taken to redeploy the weir. Note that when these concerns existed, hybridization between the run types did not appear to be an issue (i.e., spawning timing between the run types was sufficiently separate). However, spawning timing of spring-run Chinook salmon in the Chehalis Basin has shifted later, now overlapping that of fall-run Chinook salmon (Lestelle et al. 2019), likely the result of increasing hybridization over time.

B. Another use of a type of weir has been proposed to be employed on an experimental basis. A proposal by the Wild Salmon Center (WSC) would use beaver dam analogs (BDAs), strategically placed in the lower ends of the major spawning areas of Chehalis spring-run Chinook salmon, to reduce spatial and temporal overlap of spawners when spring-run Chinook salmon are moving on to their spawning grounds. The BDAs are proposed as a developmental strategy for helping to restore processes that likely once helped segregate spring- and fall-run Chinook salmon spawning in the Chehalis Basin. WSC suggested that natural beaver dams likely influenced salmon access to summer holding and spawning habitat in parts of the upper Chehalis Basin.

C. Beaver dams and stream flows can interact to control salmon spawning distributions (Mitchell and Cunjak 2007; Holt 2019) and with strategic placement and timing of construction, BDAs may reduce the incidence of spring- and fall-run Chinook salmon hybridization. Few other habitat restoration activities, if any, can provide such immediate benefits to spring-run Chinook salmon in this manner. The traditional expected benefits of BDAs include increased floodplain connectivity, juvenile habitat complexity, and improved stream temperatures, but BDAs have not been previously executed with the explicit goal of helping to restore spatial structure of Chinook salmon run types. Therefore, the action proposed by WSC would be an experimental action because of the critical need to further develop and evaluate conceptual designs for applying BDAs to restore Chinook salmon spatial structure. If successful, the approach could be strategically applied in the Chehalis Basin to reduce hybridization while other more conventional restoration actions are being implemented.

3. **Intervention using conservation hatchery techniques.** The decline of spring-run Chinook salmon could continue despite other actions to increase separation in spawning of the two run types. While not the preferred strategy, the use of a conservation-style hatchery program to propagate spring-run Chinook salmon and safeguard pure spring-run genetics during the period when habitat restoration actions are being implemented may be necessary as a temporary measure pending results from other strategies. The Skookumchuck Hatchery facility could be employed for this purpose.

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Appendix B
Barriers

Phase I of the Aquatic Species Restoration Plan (ASRP) included the removal or replacement of 200, 300, or 450 fish passage barriers in Scenarios 1, 2 and 3, respectively (ASRPSC 2019). When the Science and Technical Review Team (SRT) refined Scenario 3 in 2020, the number, location, and estimated blockage associated with barriers were evaluated for sub-basins in each ecological region based on the Washington Department of Fish and Wildlife (WDFW) 2018 barrier database that was incorporated into the Ecosystem Diagnosis and Treatment (EDT) model. WDFW has developed and maintained a database on fish passage obstructions that is updated regularly and includes information on habitat conditions upstream and downstream of the obstruction. A basin-wide prioritization tool was also created for barrier projects that was spearheaded by WDFW and funded by the ASRP. The information in EDT and the WDFW prioritization tool is focused on passage conditions for salmon and steelhead though they have differing prioritization methods and outputs. The SRT understands that removing barriers is an important element of the ASRP due to the immediate benefits and is an action that oftentimes has excellent landowner support. The SRT has begun an effort to use the EDT model and WDFW tool to develop a list of prioritized barrier removals; however, due to the complexity of this effort, it remains incomplete. The SRT has identified the potential for limited removal in the near-term period of barriers associated with spring-run Chinook salmon due to the smaller number of barriers in spring-run Chinook salmon distribution. Additional barriers in the middle or lower basin may be identified and prioritized upon completing the review of the barrier information.

The SRT also acknowledges the need to remove barriers for resident fish species such as Pacific lamprey (*Entosphenus tridentatus*) and amphibians (see the targeted learning section of the near-term recommendations in Section III of the Prioritization and Sequencing Plan to Guide Implementation of the ASRP), but prioritization of these barriers for removal will need to rely on local expert knowledge due to the lack of a barrier-specific database for these species.

Culverts that present movement barriers may affect more than native fishes. In much of the headwater stream network (fourth-order streams or smaller based on the National Hydrographic Database), the dominant aquatic vertebrates are stream-breeding amphibians. For example, in an extensive survey of first- to seventh-order stream reaches above the mainstem Chehalis River in the Willapa Hills, two of the three stream-breeding amphibian groups (tailed frogs and giant salamanders) peaked in occupancy and abundance in third- and fourth-order stream reaches, whereas the third group, torrent salamanders (low-flow specialists), peaked in occupancy and abundance in first- and second-order streams (Hayes et al. 2019). Moreover, Hayes and colleagues (2006) showed that coastal tailed frog (*Ascaphus truei*) engage in seasonal upstream movements, probably at least in part in response to the process of downstream drift, to maintain their position in suitable habitat in the headwater stream network. Seasonal movements encompass distances of 0.5 kilometer (km) at a minimum but have been recorded up to 2.1 km (Hayes et al. 2006; Hayes 2007). Coastal tailed frog has an entirely stream-constrained larval period that lasts at least 2 years at all points in the Chehalis Basin, so culverts at stream crossings in the headwater network that present a barrier (such as perched culverts) may constrain coastal tailed frog movements. Also, one giant salamander species, Cope's giant salamander (*Dicamptodon copei*), rarely metamorphoses and hence typically has a completely aquatic life history (Jones et al. 2005). Movement scale for Cope's giant salamanders is largely unknown, so the degree of impediment that barrier culverts might be to Cope's giant salamanders is unknown. Culvert barriers do not act as a complete barrier to coastal giant salamanders, which regularly metamorphose; however, research shows that larvae move less frequently through stream reaches with culverts than reaches without culverts (Sagar 2004).

Evaluating which culverts in the headwater stream network should be addressed to remove barrier conditions for amphibians is not straightforward. It will involve not only barrier surveys but also gathering information on present species and their life history characteristics. However, perched culverts in third- and fourth-order streams should be a priority consideration for removal. In the Willapa Hills, greater specificity on headwater barrier culvert removal may be informed by stream-specific occupancy patterns from data available in a Washington Department of Fish and Wildlife database (Hayes et al. 2019), but that option is not currently available for other headwater areas in the basin. Relevant data for amphibians in the Olympic region is currently under compilation and will be available for review in 2021. Beyond that, an assessment tool specific to barrier culvert removal that addresses amphibians needs development. This may require more resolute data on some stream-breeding species.

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Appendix C
Targeted Learning Actions

Targeted learning studies can help to improve the effectiveness of restoration actions and adaptively manage Aquatic Species Restoration Plan (ASRP) implementation. These represent near-term studies that address key data gaps and uncertainties for potential inclusion in the Monitoring and Adaptive Management (M&AM) Plan. Results of the studies will guide later restoration actions and are needed to ensure the full vision of the ASRP can be achieved. The current phase of ASRP development includes completion of an M&AM Plan designed to document how the ASRP will measure the success of habitat restoration and protection, as well as inform and update project implementation to the learnings from ongoing adaptive management. The targeted learning topics listed herein will be developed and coordinated through the M&AM effort (the topics are listed, not prioritized).

Identify barriers for non-salmonids. Little information exists on how native non-salmonid species (e.g., Pacific lamprey [*Entosphenus tridentatus*] and amphibians) may be affected by passage barriers in the basin. The Washington Department of Fish and Wildlife maintains a Chehalis Fish Passage Barrier Prioritization database to help plan barrier correction projects. The database uses a metric to determine the amount of suitable habitat for salmonids on an individual species basis and assesses habitat quality as a separate score. The separate scores could be evaluated and interpreted for their significance to non-salmonid species. This has not been done nor has passage for non-salmonids at barriers been rated.

Evaluate actions to address predator fishes. Due to the high potential for predation to have significant impacts on ASRP benefits and effectiveness, evaluate the feasibility of actions to address impacts from invasive predatory fishes. Centrarchid fishes have been identified as the greatest risk to juveniles of native amphibians and native fishes in lowland stillwater habitats, a condition prominent in Chehalis River floodplain off-channel habitats. Effective actions to limit the impact of centrarchid fishes are currently lacking, and experimentally addressing hydroperiod manipulation and off-channel habitat reconnection is recommended to design restoration tools that limit centrarchid fish effects.

Evaluate actions to address American bullfrog (*Rana [Lithobates] catesbeiana*). American bullfrogs are known to be the pre-eminent risk factor for Oregon spotted frogs (*Rana pretiosa*). Bullfrogs continue to expand their distribution in the Black River system, the only stronghold for Oregon spotted frog in the Chehalis Basin, which places Oregon spotted frogs at greater risk. Methods to control bullfrogs and/or reduce habitat suitability should be evaluated through experiments to limit bullfrog predation effects.

Estimate variation in groundwater levels. Since 2015, a drought year, groundwater levels dropped and have never fully recovered in the Black River system. This was due in part to increased groundwater withdrawal, which placed wetland habitats and water resources for the highly aquatic Oregon spotted frog at risk in 2019. Model(s) based on empirical data need to be developed that estimate the variation in groundwater and surface water under various precipitation patterns to identify how these patterns affect wetland water sources and to develop appropriate restoration actions to maintain wetland sources.

Evaluate hybridization. Evaluate the extent of hybridization between spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Skookumchuck and Newaukum rivers and the feasibility of addressing hybridization if necessary. Hybridization is defined as mating between individuals from two populations, or groups of populations, which are distinguishable based on one or more heritable characters (Appendix A). Mounting evidence exists that hybridization is occurring between spring- and fall-run Chinook salmon in the Chehalis Basin, and it appears to be a factor contributing to the decline and low abundance of spring-run Chinook salmon. Hybridization between spring- and fall-run Chinook salmon occurs because the spawning area of the two runs overlaps and, increasingly, spawn timing overlaps, resulting in fish from these two salmon runs mating with each other. Improving the understanding of the current level of hybridization and studying the effectiveness of actions such as temporary weirs to increase spatial separation during breeding of the two run types are needed to assess risk, reduce the spatial and temporal overlap of spawning, and prioritize actions to address hybridization.

Evaluate sediment wedges. Evaluate the effectiveness of sediment wedges for cooling water temperatures through increased hyporheic exchange. The concept is intended to locally cool water temperatures by routing flow through the hyporheic zone (the region of sediment and porous space beneath and alongside a stream bed where shallow groundwater and surface water mix) to create thermal refugia for fish (Section IV, Additional Factors, Habitats, or Habitat Features, of the Prioritization and Sequencing Plan to Guide Implementation of the ASRP; see Appendices F and G). This method needs to be developed further to understand design requirements, the spatial and temporal extent of the changes in temperature, and whether fish adjust their distributions and favor the habitats created downstream of the wedges. Evaluations are needed to understand the extent to which the method can be used in different-sized streams to provide thermal refugia.

Improve understanding of mainstem-floodplain connectivity. The floodplain off-channel habitats (FOHs) are aquatic habitats linked to the stream network where floodplains are large enough to permit their development. These habitats likely support the richest freshwater assemblage of aquatic vertebrates (amphibians and fishes) in the Chehalis Basin, including Olympic mudminnow (*Novumbra hubbsi*), an FOH-specialized species. Knowledge of the seasonal dynamic of the hydrological and faunal exchange between FOHs and the mainstem Chehalis River is sparse but critical to understanding habitat utilization by native species and the negative influence of invasive warmwater predators on native species in these habitats. Different FOHs occur across a hydroperiod gradient from permanent to temporary. Native amphibians tend to utilize the temporary portion of this spectrum, likely due to the seasonal exclusion of warmwater exotic predators. Juvenile anadromous salmonids also utilize FOHs, especially coho salmon (*Oncorhynchus kisutch*) during fall and winter. Improved connection of FOHs and the mainstem Chehalis River has the potential to reduce warmwater exotic predator effects while improving movement, genetic exchange, and recolonization by native species. The physical and biotic complexity of FOHs will require targeted learning efforts to better understand the following: 1) the range of hydroperiods and physical conditions that minimize predation while maximizing benefit to the native species assemblage; 2) the range of connectedness of FOHs that minimizes warmwater predator abundance and benefits the native species assemblage; and 3) the dynamics of creation and loss of FOHs of different types over time that affect the landscape-scale species composition in FOHs.

Survey freshwater mussel distributions. Freshwater mussels have recently received increased conservation attention due to the valuable ecosystem functions they provide (e.g., water filtration) and results of monitoring that suggest several species and populations are declining. Baseline monitoring of freshwater mussel distribution and abundance in key areas of the Chehalis Basin is underway and should be augmented to complete a watershed-scale assessment of their distribution. An effort to determine the causes of freshwater mussel die-offs in the Chehalis Basin is ongoing and should be augmented where in alignment with ASRP goals. Information is needed on mussel distribution, abundance, and causes of die-offs to locate and protect mussel beds and minimize any detrimental effects of habitat restoration projects on freshwater mussels. In addition, the ASRP does not include restoration actions targeted to benefit freshwater mussels. The feasibility of developing additional actions, such as artificial mussel beds, should be evaluated.

Evaluate eulachon (*Thaleichthys pacificus*) population dynamics and habitat utilization. Eulachon, or candlefish, is a small, anadromous, estuary-utilizing native fish that is culturally important to indigenous peoples. Due to limited data on eulachon in the Chehalis Basin, there is a need to improve the understanding of the spatial and temporal extent of eulachon in this system and restoration actions that can be effective.

Survey smooth cordgrass (*Spartina* spp.) distribution in Grays Harbor. Smooth cordgrass is an aggressive invasive species that alters ecosystems so significantly that native biodiversity and habitats can be lost. The herbicide Imazapyr is an excellent control (i.e., eradication) method for addressing smooth cordgrass. Grays Harbor County has two different types of invasive smooth cordgrass—*Spartina alterniflora* is found in lower tidal areas and spread widely in Willapa Bay prior to eradication measures, and *Spartina densiflora* has been found in limited upper tidal areas near Ocean Shores. The understanding of smooth cordgrass distribution in Grays Harbor is very limited, but it is needed to be able to develop and apply effective control measures where appropriate to support ASRP habitat protection and restoration measures. Like Willapa Bay, controlling smooth cordgrass in Grays Harbor will raise concerns about effects to commercial shellfish beds, and accurate distribution information is needed to address these concerns.

Appendix D
Estuary

The *Aquatic Species Restoration Plan* (ASRP) Phase I document acknowledges the estuary is very important to aquatic species survival and states that although the plan did not address conditions in the estuary at that time, the estuary would be further addressed in a future phase of the ASRP (ASRPSC 2019).

Beginning in early 2020, the ASRP Steering Committee requested that the ASRP Science and Technical Review Team (SRT) incorporate the estuary into the ASRP. As a first step in this process, the SRT reviewed five existing studies and plans that included or were developed specifically for the estuary (Hiss and Knudsen 1993; Smith and Wenger 2001; Grays Harbor Lead Entity 2011; Washington Coast Sustainable Salmon Partnership 2013; Wild Fish Conservancy 2015). The primary concerns discussed in these plans included water quality issues that could affect salmon survival, including increased temperatures; loss of habitat due to dredging, filling, diking, and bank armoring; a notable lack of large wood in the estuary; the need to manage invasive species; possible food limitations; and potential future habitat loss from sea level rise and the human response to sea level rise (e.g., bank armoring). It was noted that juvenile salmon use varying parts of Grays Harbor as fish exit the Chehalis River and other Grays Harbor tributaries. It was also noted that regulatory processes are in place to monitor and improve water quality. Based on this review, there was general support among SRT members for the following approach:

- Add the estuary and the tidally influenced lower ends of tributaries that enter Grays Harbor to the mainstem Chehalis River Tidal Ecological Region (to be called the Estuary Ecological Region in future ASRP documents). The non-tidal extents of tributaries that enter Grays Harbor remain in the Grays Harbor Tributaries Ecological Region.
- Assume that the Washington Department of Ecology is addressing water quality requirements per current National Pollutant Discharge Elimination System (NPDES) permits and the ongoing cleanup and monitoring of multiple industrial sites.
- Re-evaluate the Schroeder and Fresh (1992) analysis of the survival of wild and hatchery coho salmon (*Oncorhynchus kisutch*) smolts emigrating from the Chehalis Basin and its estuary. Schroeder and Fresh reported that coho salmon survival was lower for fish originating from the Chehalis River than those from the Humptulips River and other north bay tributaries and posited the cause of the differential survival could be due to estuarine factors (e.g., pathogens and parasites, predation, or chronic physiological stress and reduced immunocompetence due to poor water quality).
- Focus on the forested tidal surge plain and adjacent upstream areas that will be inundated as sea level rises in the future due to climate change.
- Assume juvenile salmonids will enter the estuary and transit along both shorelines of Grays Harbor, and focus restoration on establishing appropriately spaced patches of high-quality habitat along each shoreline for fish to use as they rear and migrate toward the ocean.

At the request of the Steering Committee, the SRT initiated a process in June 2020 to refine Scenario 3 from the ASRP Phase I. The SRT reviewed updated information on salmon and steelhead (*Oncorhynchus mykiss*) escapement trends and the Ecosystem Diagnosis and Treatment (EDT) and National Oceanic and Atmospheric Administration (NOAA) habitat model outputs. Based on the updated information, Scenario 3 was refined by adding or deleting geospatial units (GSUs), increasing or decreasing restoration intensity, and emphasizing or de-emphasizing restoration action types (e.g., large wood placement and barrier removal) within the selected GSUs (Ferguson et al. 2020). The refined Scenario 3 identifies the Chehalis River Tidal Zone GSU in the Estuary Ecological Region as a high-priority GSU and calls for restoring 33% (7 stream miles) of the GSU through the placement of large wood, removal of fish passage barriers, and reconnection and restoration of floodplains and riparian restoration. The GSU extends from River Mile (RM) 0 to the mouth of the Satsop River at RM 20. Additional restoration of up to 21 miles of estuary shoreline, wetland, and tidal slough habitat is also included in the refined Scenario 3.

The EDT and NOAA habitat models that were used to quantitatively analyze effects of ASRP actions on anadromous salmonids did not explicitly analyze estuary habitat, and Grays Harbor itself is not a GSU in the spatial framework. The new Estuary Ecological Region includes the Chehalis River Tidal Zone GSU, plus seven additional GSUs that are sloughs and small tributaries to either the Chehalis River between RM 0 and RM 20 or Grays Harbor and the tidally influenced lower ends of tributaries that enter Grays Harbor. As part of the prioritization and sequencing exercise currently underway and at the request of the Steering Committee, the SRT continued to assess potential factors affecting the survival of fish migrating through the Estuary Ecological Region, the overall productivity of the estuary, and potential impacts of climate change on habitats within the estuary. The assessment relied on a review of the scientific literature and discussions with experts on key topics; it resulted in the following conclusions:

- European green crab (*Carcinus maenas*) and New Zealand mud snail (*Potamopyrgus antipodarum*) are two invasive species that have the potential for substantial impacts on estuary habitats. See Appendix E (Exotics: A Special Challenge for Native Species) for a more detailed discussion on these two invasive species.
- Bottom et al. (2005a) provides a detailed and comprehensive summary of the available information regarding salmon habitats and life histories in the Columbia River estuary, a large, well-studied estuary that provides important information to consider for the Chehalis Basin. The paper reviewed the effects of changes in the hydrology, habitats, and food webs, and the ecology of the Columbia River estuary on salmon population structure and life histories, along with the estuary's capacity to support juvenile salmon. Bottom et al. (2005a) concluded that restoration of estuarine habitats, particularly diked emergent and forested wetlands, along with flow manipulations to restore historical flow patterns, might significantly enhance the productive capacity of the Columbia River estuary for salmon.

- Bottom et al. (2005b) provides a detailed and comprehensive summary of the available information regarding salmon habitats and life histories in a small, coastal estuary, the Salmon River in Oregon. Changes in estuarine residency and migration patterns following the removal of dikes resulted in expanded life history variation in both Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon by allowing greater expression of estuarine-resident behaviors. The estuary has been studied since 1995 and represents a valuable long-term dataset on the effects of habitat restoration and hatchery production on salmon in the basin (Jones et al. 2018).
- McNatt et al. (2016) evaluated marsh- and channel-scale residency and movement patterns of juvenile Chinook salmon in the Columbia River estuary. Marked fish remained in marsh habitats for 2 to 4 weeks, displayed average growth rates of 0.53 millimeter per day, and frequently entered secondary channels. The authors concluded that subyearling Chinook salmon take advantage of shallow estuarine habitat in the Columbia River to a greater extent than previously documented and that these habitats provide substantial food production.
- Krueger et al. (2017) describe the results of an expert panel process established in 2009 to improve and implement a process for assessing and assigning “survival benefit units” to restoration actions in the Columbia River estuary. The panel adopted three project assessment criteria that included the certainty of success, fish opportunity improvements, and habitat capacity improvements. The panel then reviewed 55 completed projects that included 181 individual actions using the criteria. Krueger et al. (2017) concluded that fully restored tidal connection, historic channel structure, flow, and vegetation projects scored well if they were large and their locations allowed access by mainstem river fish. Projects that scored low had partial access and were small, highly engineered, and susceptible to colonization by invasive species of fish or vegetation.

These reviews resulted in the following recommendations and guidance for the Implementation Team and project sponsors for the Estuary Ecological Region:

- Re-evaluate the survival of wild and hatchery coho salmon smolts emigrating through the Chehalis Basin using updated information to inform whether survival is still lower for fish emigrating from the Chehalis River than for fish originating from other coastal watersheds.
- Restore forested riparian/floodplain areas upstream of the existing forested tidal surge plain (Chehalis River mainstem between RM 12 to RM 20) to prepare for the effects of sea-level rise on the existing forested tidal surge plain (RM 3 to RM 12) that is likely to convert to emergent marsh in the future. This is an important ecotype for juvenile salmon, and there is a need to begin now to identify where and how to develop this ecotype in the upper portion of the Chehalis River Tidal Zone GSU under future conditions.
- Multiple areas in the Estuary Ecological Region are under public or conservation ownership. This includes the large state-owned Natural Area Preserve in the tidal surge plain between RM 3 and RM 12 and the Grays Harbor National Wildlife Refuge. Also, there are a substantial number of

publicly owned areas along the south shore of Grays Harbor, including the Johns River State Wildlife Area and the Elk River Natural Resources Conservation Area. In addition, multiple conservation areas dot the remaining southern shoreline and the northern shoreline. These public- or land trust-owned lands are in good condition now and should continue to be protected. They should be considered as high-priority areas for habitat restoration in the future to manage invasive species and increase habitat complexity through the placement of large wood.

- Restoration actions on publicly and privately owned lands should strive to establish patches of high-quality marsh, slough, or forested tidal swamp habitat along each shoreline for fish to use for foraging as they rear and migrate toward the ocean. Patch spacing criteria have not been discussed or adopted by the SRT at this time. Spacing should allow movement between patches to occur within a 1-day period, based on fish swimming speed and current velocity, to allow fish to move between patches of good habitat and then stop to feed.
- Krueger et al. (2017) describe a process for assessing and assigning survival benefits to proposed projects. Estuarine habitat restoration projects should incorporate the results of this expert panel process when developing project designs, and project reviews should consider incorporating the scoring criteria (certainty of success, fish opportunity improvements, and habitat capacity improvements) into ranking criteria.
- Remove abandoned creosote-treated piles to improve water and sediment quality and restore more natural sediment erosion and deposition processes. Piles are most predominant in the lowest reach of the Chehalis River and along the Aberdeen and Hoquiam shorelines, and these should be considered the top priority because all salmon and steelhead migrating out of the Chehalis River must pass through this industrialized area. The total number of piles that should be removed has not been discussed or adopted by the SRT, and it is not a science question per se. Rather, the details of pile removal are a policy decision to balance this action compared to other proposed actions in consideration of available funding and the potential to substantially reduce contamination from these legacy structures.
- Hydrologic reconnection is the primary strategy for ecosystem restoration in the Columbia River estuary, and specific restoration actions include breaching dikes and levees and removing or upgrading tide gates (Krueger et al. 2017). These actions afford varying degrees of hydrologic improvement, and restoration of tidal channels behind the gates is often integrated as part of the hydrologic improvements at a project site. Therefore, projects in Grays Harbor that remove tide gates and restore or improve access to productive, shallow tidal channels in which juvenile salmonids can occupy and feed are considered high-priority actions.
- Separately, or in conjunction with tide gate removals, restore lower floodplains and marshes at tributary mouths such as those located along the north and south shores of Grays Harbor. The goals are to increase the amount and complexity of shallow water habitats and food production in those habitats (for juvenile salmon to occupy these sites and grow until moving to the next

site) and provide a greater a mosaic of opportunities along both shorelines whereby juvenile salmon entering Grays Harbor can transition from site to site in a timely manner.

- Remove riprap, hardened shorelines, and fill in the Aberdeen/Hoquiam area and restore the sites to more productive, natural vegetation, including the development of shallow shorelines and cover and structure where feasible.

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Appendix E
Invasive Species: A Special Challenge for Native Species

In the Chehalis Basin, non-native species (hereafter invasive species) are an existing part of the established biota. Whether introduced intentionally or accidentally, invasive species have become integrated into local ecosystems. As a result of this integration, physical and biotic processes have been altered with diverse consequences for the native biota. A number of these consequences are known, others are suspected, and still others likely remain unrecognized. In addition, climate change may exaggerate the impacts of invasive species via various pathways, including but not limited to the expansion of invasive species distributions and greater competition or predation effects.

Regardless of the invasive species involved, an action plan should guide management. Action plans should be species-specific, but overarching objectives exist that characterize all plans. Below, those overarching objectives are generalized, drawing on the *Salish Sea Transboundary Action Plan for Invasive European Green Crab* (Drinkwin et al. 2019). These generalized objectives are as follows:

1. Collaboratively manage the response to the target invasive species among the most entities possible. The larger the partner base, the more the distribution of effort to respond will be equitable, if the management hierarchy is efficient and well structured.
2. Prevent human-mediated introduction and spread of the target invasive species. This objective lies largely in the realm of policy and requires coordination among policymakers and diverse stakeholder groups.
3. Detect invasive species at the earliest invasion stage possible because control and eradication is least costly, most efficient, and most likely to be completed at this stage.
4. Rapidly eradicate or reduce newly detected populations of invasive species. Rapid response reduces the time over which invasive species populations can expand, wherein they become progressively more difficult to control.
5. Control persistent infested site populations to eliminate or minimize environmental, economic, or human resource harm.
6. Conduct research to develop effective management strategies. For invasive species for which management strategies exist, increasingly effective strategies should be sought.

For those invasive species known to negatively affect the native biota, actions to reduce or eliminate them or their effects will likely be necessary to reduce the risk to native species and to prevent their extirpation. Invasive species known to negatively affect the native aquatic biota in the Chehalis Basin include the following:

1. **Centrarchid fishes.** Six centrarchid fish species exist in the Chehalis Basin aquatic habitats. These include rock bass (*Ambloplites rupestris*), bluegill (*Lepomis macrochirus*), pumpkinseed (*Lepomis gibbosus*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*) and black crappie (*Pomoxis nigromaculatus*; Holgerson et al. 2019). To date, study of centrarchids has focused on their distribution in floodplain off-channel habitats, where all species were recorded except smallmouth bass. Largemouth bass was the most abundant centrarchid in floodplain off-channel habitats. However, from 2019 to 2021, John Winkowski

and Julian Olden began a study in the larger river network, especially the mainstem Chehalis River and the lower portion of its major tributaries that focuses on smallmouth bass (Winkowski 2020). The two *Micropterus* bass species are treated separately because they may represent the dominant problems in the off-channel and large river habitats, respectively.

A. Smallmouth bass are likely the dominant centrarchid in the riverine mainstem Chehalis River, a condition indicated by the sport fishery for some decades (Holt 2018; Gordon 2018), but the nature of smallmouth bass dominance in the mainstem Chehalis River and their degree of impact on native fishes (including salmonids) is poorly understood. Smallmouth bass predation on juvenile salmonids can be seasonally significant (Erhardt et al. 2018; Fritts and Pearsons 2004; Tabor et al. 1993, 2007; Tiffan et al. 2020; Zimmerman 1999), so evaluation of their impacts on native fishes, including salmonids, in the mainstem Chehalis River is crucial in part because it could reduce or negate gains from *Aquatic Species Restoration Plan* (ASRP) restoration actions applied in the rest of the system. This is because all juvenile salmonids that rear in the Chehalis River and its tributaries must pass through some length of the mainstem during their seaward migration, where their numbers could be depleted by smallmouth bass and perhaps other invasive species that occupy the mainstem. A current study designed to inform this data gap, called the "Ecology of Non-Native Fish Study," is a multiyear study with the objectives of quantitatively describing ecological characteristics of non-native species (primarily focusing on smallmouth bass) to provide key information for restoration and conservation planning. To date, a year of data on each of spatial distribution (2019) and predation (2020) has been collected, and the plan is to repeat this effort across a range of scenarios (e.g., stream temperature and smolt outmigration abundances). This study will also consider integrated studies addressing the overall abundance, movement behavior, and juvenile rearing/recruitment success of smallmouth bass.

   Potential Actions: Currently, actions to address the problem of invasive species in the mainstem Chehalis River, notably smallmouth bass, are highly uncertain due to lack of data on the response of smallmouth bass to management actions.

   <u>Temperature.</u> In the John Day River system, Lawrence and colleagues (2012) pointed out that the dominant influence of water temperature on smallmouth bass distribution suggests that managers may be able limit future upstream expansion of bass into salmon-rearing habitat by concentrating on restoration activities that mitigate climate- or land-use-related stream warming. The challenge with this suggestion is how to implement such restoration in the large river habitat of the Chehalis system.

   <u>Nest Destruction.</u> Work in British Columbia has studied the effects of smallmouth bass nest destruction on their population dynamics. Hence, the opportunity may exist to experimentally investigate nest destruction techniques in areas of the Chehalis Basin, such as the upstream invasion edge sites identified in the ongoing "Ecology of Non-Native Fish Study." This could answer the question of whether smallmouth bass nest destruction at

their upstream invasion front could limit their future upstream expansion. It cannot be overemphasized that the invasive species problem in the Chehalis large river habitat is a crucial one that needs to be addressed to ensure that restoration actions outside the mainstem are effective. One further reason for this is that selected basic restoration tools, such as the addition of large wood, which can create foraging and refuge habitat for juvenile salmonids (Fausch and Northcote 1992; Jones et al. 2014; Hafsa et al. 2014), is also a habitat that basses can use as cover (Dauwalter and Fisher 2008; Schenk et al. 2014) and from which they may ambush prey. Hence, large wood additions may favor invasive species to the detriment of native fishes.

Other potential actions exist that could influence invasive species in the Chehalis system, but these overlap with management policy. These were summarized by Carey and colleagues (2011) as follows:

i. **Liberalize harvest.** Such action could reduce population size (Barfoot et al. 2002), but the magnitude of the beneficial effect on native species is uncertain because harvested sizes may not sufficiently overlap with the size range doing the detrimental predation; most smallmouth bass anglers practice catch and release that could limit the effectiveness of such action (Aday et al. 2009; Isermann et al. 2013), and what mortality may occur from hooking is low (Clapp and Clark 1989).

ii. **Enact regulations changing take size limits.** Regulations changing size limits altered largemouth bass size distributions in Minnesota despite the prior noted catch-and-release practices (Carlson and Isermann 2010). However, in the Yakima River system, Fritts and Pearsons (2006) found that rates of predation on salmon may be greater among smallmouth bass sizes that bass anglers do not target (<250 millimeters [mm]). WDFW is reviewing whether to remove bag limits and size restrictions on basses taken in riverine and floodplain habitats of the Chehalis system beginning in 2022 as a way of reducing impacts on native fishes. If this occurs, it will be imperative to evaluate how effective this change was in reducing centrarchids and their predation on native salmonids. That evaluation could be one of the targets of the “Ecology of Non-Native Fish Study.”

Actions tied to policy face special issues. As a non-native sportfish, smallmouth bass (and other non-native sportfish) creates a conflict for state and federal agencies charged with simultaneously conserving native or Endangered Species Act (ESA)-listed species and providing angling opportunities. Further, giving the recreational community an active role in resolving this conflict is critical to the success of management actions. Moreover, anglers, outfitters, professional guides, recreational groups, and others can also provide important input on populations of non-native fishes and determine locations of principal fisheries. Lastly, management actions will require sustained efforts in education and enforcement.

B. Off-channel aquatic habitats in the floodplain of the mainstem Chehalis River have a rich assemblage of non-native centrarchid fishes (Holgerson et al. 2019). Largemouth bass, arguably the most abundant of the group in those habitats, is ranked among the 100 worst alien invasive species globally (Lowe et al 2004). However, bluegill and pumpkinseed are also dominant species in this assemblage. Modeling has revealed that this centrarchid fish assemblage has the most negative effect on native amphibian occupancy among many characteristics measured in floodplain off-channel habitats (Holgerson et al. 2019).

A negative effect on native fishes, including Olympic mudminnow (*Novumbra hubbsi*), is suspected but not yet verified. This centrarchid assemblage, or portions of it, also occur in selected stillwater habitats across the Black River system, but understanding of their distribution outside of specific glacial outwash lakes and ponds is limited.

Potential Actions:

Removal. In seasonally surface-connected aquatic systems like the Chehalis River mainstem floodplain and its major tributaries, and much of the Black River system, removal may not be an attainable option because surface connectivity and high flows would reintroduce the undesired assemblage seasonally. This would make removal efforts perpetual and would need to be implemented on a short (annual) time cycle. Given the very large footprint over which these invasive species occur across Chehalis Basin floodplain off-channel habitats, this would probably be excessively costly and infeasible to complete, even in a few years. Removal might be applicable in those instances where an occupied aquatic habitat lacks seasonal connectivity to other invasive species-occupied surface waters (Maezono and Miyashita 2004; Pollard et al. 2017); however, those instances are infrequent in the lowland Chehalis River. Where implementation is possible, invasive species removal can be both more effective and less costly than certain types of flow restoration (Jane et al. 2010). Where complete removal is not possible, it may be possible to focus on the size class or life stage that best limits or reduces population growth. Size class- or life stage-specific analyses would be needed to identify the suitable size class or life stage (see Potential Actions under Section 2, American bullfrog, for examples) before selecting partial removal as an intervention tool.

Habitat Alteration. A likely better option is to modify habitat in a manner that disfavors invasive species and favors the native species assemblage. This option is the basis of an experimental off-channel reconnection project that seeks to seasonally increase stage variation, contract the water temperature profile (especially for the high temperature range), and increase the dissolved oxygen profile. One should recognize that even if this option works, it can be expected to confer an advantage on some of the native fish assemblage, but not amphibians. In a landscape where native amphibians survive with invasive species because they largely use non-permanent aquatic habitats for reproduction and rearing, providing a better hydrologically connected permanent hydroperiod habitat would likely not provide an advantage for amphibians.

Drying or Screening. Other focused options may exist in habitats that can be dried down via pumping, to remove the invasive species, and hold and replace the native assemblage if refilling is possible. This option is unlikely to work except in aquatic habitats that are relatively small due to the pumping and refilling need. Screening out invasive species might be an option in selected habitats, but screening should not interfere with fish passage for the native assemblage, thus limiting applicability.

Suffice it to say a technology that can target a particularly invasive species, or an assemblage of related invasive species, does not currently exist. If a pathogen or parasite existed that could effectively do that job, one would have to guarantee that it could not make the undesired jump to native species.

Selected actions linked to policy may be effective (see Potential Actions under Section 1A that pertain to basses).

2. **American bullfrog (*Rana* [*Lithobates*] *catesbeiana*).** The highly aquatic American bullfrog, native to eastern North American, is ranked among the 100 worst invasive species globally (Lowe et al. 2004) and presents a high risk, notably in concert with centrarchid fishes, for the federally threatened and Washington state-endangered Oregon spotted frog (*Rana pretiosa*). Oregon spotted frog have an entirely aquatic life history, which results in greater overlap with the fully aquatic warmwater predator assemblage (bullfrogs and centrarchids and other warmwater fishes) than any other native stillwater-breeding amphibian.[1] Bullfrogs, along with the basses (especially largemouth bass), also present a high risk to the state endangered western pond turtle (*Actinemys marmorata*; Holland 1984). The western pond turtle is probably extirpated from the Chehalis Basin, but its re-introduction, one of the goals of the recovery plan for Washington State (Hays et al. 1999), will have to address issues of site suitability as influenced by these invasive species.

   Potential Actions: Actions that might address bullfrogs, as inhabitants of permanent hydroperiod aquatic habitats, are similar to those that might address centrarchid fishes in off-channel habitats in the mainstem Chehalis River (see those Potential Actions under Section 1B).

   <u>Removal.</u> Documentation of bullfrog removal is infrequent (Adams and Pearl 2007). Success has been realized at a few sites, but it requires constant vigilance to exclude recolonizers and the sites from which removal was successful are small and relatively isolated (Orchard 2011). Kamoroff and colleagues (2019) described a successful removal touted as being landscape-scale, but this was actually at the margin of its geographic range with limited bullfrog distribution and monitoring potential recolonizers did not present an excessive cost. Eradication has had only short-term success at some sites (Schwalbe and Rosen 1988; Rosen and Schwalbe 1995) and has failed at one small site (Banks et al. 2000). For bullfrogs, strong density dependence in the larval and post-metamorphic stages of their life history (Doubledee et al. 2003; Govindarajulu et al. 2005) hampers their direct removal if removal cannot be complete (Adams and Pearl 2007). For example, partial tadpole removal can boost survival and developmental rates of juveniles due to reduced density-dependent competition (Govindarajulu et al. 2005). Incomplete adult removal

[1] In contrast, all other native stillwater-breeding amphibians in western Washington seasonally move into uplands.

leads to higher survival of post-metamorphic juveniles because of reduced cannibalism (Govindarajulu et al. 2005). Further, bullfrog life history and demography vary among sites and regions (e.g., Viparina and Just 1975; Cecil and Just 1979), so control prescriptions will have to address this variation (Govindarajulu et al. 2005). Clearly, understanding bullfrog populations in areas targeted for removal is needed before removal can be implemented effectively. If little chance exists for removal to be complete, direct removal is not recommended (Adams and Pearl 2007), but if one were to use it as a control rather than an eradication option, prospective demographic perturbation modeling shows that culling juveniles in the fall is the most effective method of several alternatives evaluated in reducing bullfrog population growth rate (Govindarajulu et al. 2005). Still, this method is largely untested, and it retains the relatively high cost associated with repeated removal of the juvenile cohort. As with centrarchids, removal is likely an impractical choice at most sites in the Chehalis Basin, which have extensive spatial or temporal hydrological connections. Overland movement of bullfrogs during rains or even during nights without rain is also an option for bullfrogs.

Habitat Alteration. An alternative and potentially better option than removal could be to modify habitat in a manner that disfavors invasive species and favors native species (Adams and Pearl 2007). One way in which this might occur is to exploit life history features that differ enough between bullfrogs and native species that they could be a point of focus or manipulation. At least three such features exist, as follows: 1) hydroperiod; 2) stage (water level) variation; and 3) temperature. Adams and Pearl (2007) pointed to hydroperiod as the obvious example because bullfrogs must overwinter at least once as larvae in the Washington State portion of their introduced range (Adams 2000). This means that in Washington, bullfrogs must reproduce and rear in permanent aquatic habitats. This is the basis of suggestions to dry out aquatic habitats (Beja and Alcazar 2003; Maret et al. 2006) or design aquatic habitats that will dry out (Ferreira and Beja 2013), which are alternatives that can also seasonally eliminate invasive fishes (Maret et al. 2006). The native fauna (mostly amphibians) that utilize aquatic habitats require different hydroperiods (Holgerson et al. 2019), so drying and non-permanent hydroperiod pond designs may require species-specific prescriptions that encompass an understanding of inter-year climatic variation. Drying may not be an option for some species, like Oregon spotted frog, which must have permanent aquatic habitats, or native amphibians with larvae that regularly overwinter, such as the northwestern salamander (*Ambystoma gracile*).

The second feature, stage variation, is an option that arises from the observation that bullfrogs appear less tolerant of hydrological disturbance than native species. In particular, high water years in which flow and stage variation are greater seem to disfavor bullfrogs over native amphibians (Kupferberg 1996a, 1996b, 1997). This idea is the basis of an experimental off-channel reconnection project that seeks to seasonally increase stage variation, a condition that can also potentially contract the water temperature profile (especially in the high temperature range); the latter could disfavor a warmwater-adapted invasive species like the bullfrog. One should recognize that even if this option works, it can be expected to confer an advantage on some of the native fish assemblage, but generally not native amphibians. In a landscape like the Chehalis Basin where native amphibians survive with invasive species because they preferentially use non-permanent aquatic habitats for reproduction and rearing (Holgerson et al. 2019), a better connected permanent hydroperiod habitat is unlikely to be an advantage. The third feature, temperature, is an option that depends on the warmer water requirements of bullfrogs relative to that portion of the native aquatic fauna requiring cooler water temperatures. As noted previously, the experimental off-channel reconnection option could contract the water temperature profile, but such off-channel sites may have to be deep enough to maintain cool water below a thermocline that might typically develop during the summer.

Habitat Structure. Habitat structure could facilitate co-existence between bullfrogs and the native aquatic fauna. Adams and Pearl (2007) pointed out that habitat characteristics can mediate the interaction between species. Prominent among these is habitat complexity that can facilitate prey survival (Crowder and Cooper 1982; Sredl and Collins 1992). In Chehalis River floodplain off-channel habitats, studies have already discovered that at least intermediate vegetation densities seemed to reduce the strong negative effect of centrarchid fishes on amphibians (Holgerson et al. 2019). Yet a parallel effect for bullfrogs was not evident (Holgerson et al. 2019). If a structural habitat feature exists that could attenuate a negative effective of bullfrogs, it is not currently known. Currently, co-existence between bullfrogs and the entire suite of stillwater-breeding amphibians except Oregon spotted frog appears to be occurring (Holgerson et al. 2019), though Adams and Pearl (2007) forward the valid caution that since the data is a temporal snapshot, it prevents recognizing any kind of trend. The high niche overlap between bullfrogs and Oregon spotted frogs make it unlikely that a habitat component exists that could allow coexistence between these two species.

Hydroperiod manipulation is likely one action for which there is enough confidence to apply and expect some level of attenuation of bullfrog effects, but even hydroperiod needs to be much better understood for how its length and timing most effectively attenuate bullfrog effects and how other native species may be affected (Adams and Pearl 2007). Note that though bullfrogs still currently overwinter at least once as tadpoles in Washington, the length of larval development has shrunk as the warm season is lengthening with climate change. Historically, bullfrogs overwintered at least once as larvae in Oregon, but their ability to metamorphose in seasonal aquatic habitats has become evident in Oregon (Cook 2011; Cook et al. 2013). If bullfrogs become able to regularly metamorphose in such habitat, the ability to use hydroperiod as a control option will be reduced or eliminated. In short, enough uncertainty exists for any potential action to control bullfrogs or attenuate bullfrog effects to apply them in other than an experimental setting with monitoring to determine effectiveness.

3. **European green crab (*Carcinus maenas*).** First discovered in Washington in Grays Harbor and Willapa Bay in 1998 (Figlar-Barnes et al. 2002), European green crab is native to the eastern Atlantic Ocean and Baltic Sea and ranked among the 100 worst invasive species in the world

(Lowe et al. 2004). A rapid colonist, European green crab has invaded several coastal locations, including South Africa, Brazil, Australia, and both coasts of North America (Klassen and Locke 2007). An efficient predator, it feeds on diverse prey, including clams, oysters, mussels, marine worms, and small crustaceans, which is a plasticity that gives it the potential to alter ecosystems (Klassen and Locke 2007). European green crab also preys on juvenile crabs and shellfish, so its northward spread to the Washington coast and Salish Sea could put Dungeness crab, clam, and oyster fisheries at risk and threaten aquaculture operations in the Pacific Northwest and British Columbia (Mach and Chan 2014). However, a 2011 analysis concluded that past and present economic impacts on West Coast shellfisheries from European green crab are minor, though losses could increase significantly if European green crab densities increase or it expands its range northward into Alaska (Grosholz et al. 2011). That analysis is nearly 10 years old, and in Washington, concern elevated in 2016 when numbers of European green crab were found in Puget Sound, which led to significant state-level funding to identify its distribution. Concern regarding shellfisheries is high because European green crab is strongly suspected in the collapse of the soft-shell clam industry in Maine (Glude 1955). European green crab has also been linked to the decline of eelgrass (*Zostera marina*) meadows, resulting in effects that cascade onto their associated fish assemblages (Matheson et al. 2016). Further, work in California has shown that European green crab may depress food resources for native fish and bird species (Estelle and Grosholz 2012).

Grays Harbor is one of three locations within the WDFW Coastal "Response Action Areas" for European green crab (i.e., known hotspots for the species). Competition with Dungeness crab and the destruction of marsh and eelgrass habitats important to juvenile salmonids are considered the potential crucial impacts in Grays Harbor, but data are lacking. Where historic data exist, European green crab appears to have been detected sporadically, but recently, regular detection is the pattern. Uncertainty exists because effort across years has not been equivalent. If this change is real; climate and ocean conditions may be responsible. Some suspicion exists that El Niño years, which are increasing in frequency, are linked to more European green crab detections.

Potential Actions:

<u>Monitoring.</u> For the Chehalis Basin and Grays Harbor in particular, evaluation is needed of critical habitats for protection and developing control efforts to keep European green crab numbers low. Whether yet-to-be developed control efforts for European green crab would be effective is uncertain. Washington Sea Grant, WDFW, and Quinault Indian Nation (QIN) are currently monitoring spatial and ultimately the temporal distribution[2] trends in the estuary, effects on the aquatic community, and refinement of trapping surveys. Continuation of those efforts is critically important for restoration design under the ASRP. Puget Sound has a large

[2] This monitoring includes determining how far up the Chehalis system European green crab extend and how much this will change with sea-level rise.

citizen science monitoring effort for European green crab; a similar effort could greatly benefit monitoring in Grays Harbor or enlisting further partners.

Biological Control. Biological control is unexplored for European green crab. In an extensive parasite survey of European green crab in Australia, Gurney and colleagues (2004) found two tapeworms, *Dollfusiella martini* and *Trimacracanthus aetobatidis*, whose larvae exist in the digestive gland. They found *D. martini* only in low population levels of European green crab, which suggests either *D. martini* has an impact on European green crab survival or parasite presence reflects high predation pressure on European green crab. Rigorous evaluation would be needed to assess whether *D. martini* would be an effective biological control. Biological control is fraught with uncertainties, the most important reasons are the possibility of the parasite jumping to commercially important species where it has serious negative effects or, over time, the parasite evolves into a less virulent form, reducing or eliminating its value as a control agent.

4. **New Zealand mud snail (*Potamopyrgus antipodarum*).** New Zealand mud snail is a tiny (≤12 mm)[3] euryhaline[4] snail (Zaranko et al. 1997; Levri et al. 2007) with great flexibility in its reproduction,[5] which facilitates its rapid colonization (20 to 50 kilometers per year) of a range of aquatic habitats (Leppäkoski and Olenin 2000). Moreover, rapid colonization and reproduction can lead the New Zealand mud snail to dominate carbon and nitrogen metabolism in productive streams (Hall et al. 2003). New Zealand mud snails also have ability to survive gut passage of some predators that consumed them (Bruce et al. 2009). New Zealand mud snail was first discovered in the Chehalis system in the surge plain near the Blue Slough access area on Washington Department of Natural Resources (WDNR) land on July 24, 2013 (Johannes 2013). As a result of this discovery, several entities (including WDFW, WDNR, the Confederated Tribes of the Chehalis, and QIN) cooperated to support Johannes in additional surveys in this vicinity in 2013; these surveys encompassed Peels and several other nearby sloughs (Johannes 2013). In 2015, New Zealand mud snail was found at Duck Lake near Ocean Shores (WDFW Aquatic Invasive Species database). No surveys for New Zealand mud snail have been conducted in the Chehalis system since 2015, but at the rate of spread described by Leppäkoski and Olenin (2000), New Zealand mud snail could have significantly expanded its range in the Chehalis Basin.
Potential Actions: Potential actions for New Zealand mud snail face several of the same issues that were noted for European green crab, including the need to develop adequate monitoring for species detection and limited options for control or actions that reduce the effects of the invasive species. Physical removal was discussed as an option immediately after the Blue Slough discovery in 2013, but surveys showed removal would be futile because of the relatively large

[3] This is its size in its introduced range; in its native range, it reaches 12 mm (Levri et al. 2007; Zaranko et al. 1997).
[4] Optimal salinity is near or below 5 parts per thousand (ppt), but New Zealand mud snail is capable of feeding, growing, and reproducing at salinities of 0 to 15 ppt and tolerates 30 to 35 ppt for short periods (Costil et al. 2001; Gerard et al. 2003; Jacobsen and Forbes 1997; Leppäkoski and Olenin 2000; Zaranko et al. 1997).
[5] New Zealand mud snail is ovoviviparous, exhibiting mostly sexual reproduction in its native range and mostly parthenogenetic reproduction across its broadly introduced populations.

area over which the species was already established, and the small size of individuals made ensuring complete detection unfeasible (Pleus 2018). Moreover, efforts to marshal resources for monitoring and possible control actions fell through. Using saltwater to backflush a New Zealand mud snail infestation in freshwater Capitol Lake, LeClair and Cheng (2012) observed an approximately 20% increase in mortality in New Zealand mud snail exposed to 27 to 28 parts per thousand (ppt) saltwater. This kind of action would be limited to situations where saltwater was concentrated enough and could inundate long enough to induce mortality. Richards and colleagues (2004) originally discovered that freezing was a potentially useful option to control New Zealand mud snail. This option was applied during a drawdown of Capitol Lake prior to freezing conditions at night, which resulted in significant New Zealand mud snail mortality (Pleus 2018). Again, this kind of action would be limited to situations where manipulating water levels via drawdown was possible during an episode of freezing conditions. Richards and colleagues (2004) also showed that New Zealand mud snail is vulnerable to desiccation under higher temperature conditions. Beyond the original experimental application of Richards and colleagues, the desiccation option has not been applied in the field. The application of this option is dependent on the ability to drawdown water levels under conditions of sufficiently high temperature, which makes this option limited in general application for the Chehalis Basin. Hence, no effective tools currently exist to control New Zealand mud snail.

5. **Invasive plants.** Many invasive plant species have become established in the Chehalis Basin, but some are regarded as greater threats than others. The Integrated Aquatic Management Plan for the Chehalis Basin prioritized five invasive plant species as critically in need of attention (Simon and Peoples 2006). All five are on the Washington State Quarantine List[6] (WSNWCB 2020a). Control of invasive plants is complex. The preferred approach for weed control is Integrated Pest Management (IPM; King County NWCP 2014). IPM involves selecting from a range of possible control methods to best fit the management requirements of each specific site. The goal is to maximize effective control and minimize negative environmental, economic, and social impacts. The IPM approach is multifaceted and adaptive. Control methods are selected that reflect the available time, funding, and labor of the participants; the land use goals; and the values of the community and landowners. Management will require dedication over a multiyear timeline and, as appropriate, should allow for flexibility in method.

   The five focal invasive species in the Chehalis Basin Integrated Aquatic Management Plan (Simon and Peoples 2006) are as follows:

   A. **Brazilian elodea (*Egeria densa*).** South American in origin,[7] it belies its standard English name. Brazilian elodea is a rooted perennial freshwater aquatic plant in the family *Hydrocharitaceae* originally sold in the aquarium trade (Getsinger 1982; Washington

[6] It is prohibited to transport, buy, sell, offer for sale, or distribute plants or plant parts of quarantined species into or within the State of Washington or to sell, offer for sale, or distribute seed packets of seed, flower seed blends, or wildflower mixes of quarantined species into or within the state of Washington (Washington Administrative Code 16-752).
[7] The geographic range of native populations extends from the state of Minas Gerais in Brazil to the Rio Plata in Argentina (Curt et al. 2010).

Invasive Species Council 2016). It typically develops submerged beds, which when dense can choke out native vegetation. As of 1993, Brazilian elodea was listed as a Class B noxious weed in Washington State.[8] Characteristics that contribute to its invasive success are fast growth, adaptability to a range of light regimes, flexibility in nutrient uptake from the water column and sediments, high productivity in environments with low-to-modest nutrient levels, a broad phenotypic plasticity, dispersal facilitated via vegetative fragments, and rapid colonization of disturbed sites (Getsinger 1982; Yarrow et al. 2009). Portions of the Chehalis Basin within Grays Harbor and Lewis counties have a modest area infested with Brazilian elodea (10 to 100 acres); some of Thurston County within the Chehalis Basin also has limited infested area (less than 10 acres).

Potential Actions:

Removal. Brazilian elodea is a challenge to control. Stems and rhizomes fragment easily, which can establish new plants from the fragments. Fragments as small as 8 centimeters can establish new plants (Pennington and Sytsma 2016), but the low-end size large enough to establish new plants is probably smaller. Hence, mechanical methods like cutting, harvesting, and underwater tilling are generally not recommended because these methods can increase infestation via fragmentation. For example, mechanical control was applied to two small reservoirs in Spain over 4 years using a 1.5-meter ad hoc-designed rake (Curt et al. 2010). This method was "utterly ineffective" because it enhanced Brazilian elodea growth rather than reducing its biomass (Curt et al. 2010). To achieve adequate control, the general notion is that the entire plant should be removed. Small populations can be hand-pulled, but only if all plant parts can be removed.

Barriers. An opaque bottom barrier can be used to suppress growth in small, discrete areas like at a boat launch or swimming area (King County NWCP 2014). Barriers need regular cleaning because plants, including Brazilian elodea fragments, will root in the sediment that falls on top of barriers. This approach is impractical for large-scale infestations.

Biological Control. Few biocontrol agents exist. Grass carp (*Ctenopharyngodon idella*), a cyprinid freshwater fish of Asian origin that is herbivorous, can be used to consume Brazilian elodea, but this control method is limited to certain situations. In Washington State, triploid (non-reproductive) grass carp may be planted only in selected lakes or ponds after the required permits and documents are approved (WDFW 2020). The suite of permit requirements limits planting of triploid grass carp to either isolated waterbodies or waterbodies with outflows that can be screened in a manner to sequester the grass carp within that waterbody. In either case, the waterbody must not be exposed to seasonal inundation that would allow grass carp to escape. Hence, most off-channel aquatic habitat in the Chehalis River floodplain would be not qualified for the use of this control option.

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[8] Class B noxious weeds are non-native species whose distribution is limited to portions of Washington State (Washington State Noxious Weed Control Board: https://www.nwcb.wa.gov/classes-of-noxious-weeds).

Nachtigal and Pitelli (2000) discovered a *Fusarium* fungus (tentatively identified as *F. graminearum*; R. Pitelli in Cuda et al. [2008]) from naturally diseased shoots of the two *Egeria* species. Pathogenicity work revealed that the fungus compromises stem and leaf tissue, leading to total breakdown. Propagation on sterilized rice grains was the best inoculum. This fungal inoculum killed *Egeria* plants at the rate of 0.5 gallons per liter and could be stored for over 8 months at 4°C. Specificity of the fungus was tested on 14 cultivated species and 11 aquatic plants, but only *Hydrilla* (*Hydrilla verticillata*) and the two *Egeria* species tested developed symptoms. The control potential of this fungus seems promising and needs further investigation (Nachtigal and Pitelli 2000); to date, this study has not occurred.

More recently, Walsh and colleagues (2013) found an undescribed species of ephydrid leaf-mining fly in the genus *Hydrellia*, currently the only known specialist herbivore on Brazilian elodea throughout its native distribution in Argentina. This leaf-mining fly caused heavy defoliation in both the laboratory and the field. In the field, this fly was found exclusively on *E. densa*, but in the laboratory it also developed on two other species of *Hydrocharitaceae*: *E. naias*, and *E. callitrichoides*. Significant oviposition and feeding were only observed on its primary natural host, and to a lesser degree on *E. naias*. Field studies reveal that this *Hydrellia* is present in the field year-round. It may be a suitable biocontrol candidate for *E. densa*, but it would have to be tested to ensure it would not damage the native hydrocharitacid species widespread in the Pacific Northwest, *E. canadensis*.

<u>Herbicide.</u> Herbicide use is another option that Brazilian elodea's habitat complicates. For a submergent invasive species, such as Brazilian elodea, herbicides applied are suspended in water and may be moved away from target plants by local water movement before the plant absorbs enough herbicide to cause damage. For this reason, specific concentration and exposure time (CET) recommendations have been developed for many herbicides and target weeds (Getsinger et al. 2011). This also means that knowledge about local water circulation patterns is critical when trying to achieve the desired CET during herbicide applications. The Ecology Aquatic Plant and Algae General Permit (Ecology 2019), which controls herbicide applications, lists 19 formulations of 17 herbicide active ingredients permitted for use in aquatic habitats. Of these, only two, diquat and fluridone, can be strongly characterized as being effective in suppressing Brazilian elodea (Glomski et al. 2005; King County NWCP 2014). Of the 17 remaining formulations of herbicides, six are not recommended, and the remainder have either poor control activity on Brazilian elodea or are data deficient. Other active ingredients exist that show excellent activity in suppressing Brazilian elodea, for example, certain formulations of copper sulfate (Ware and Gorman 1967), but these are not allowed for aquatic use in Washington State.

B. **Purple loosestrife (*Lythrum salicaria*).** Purple loosestrife, a species of aquatic margins ranked among the 100 worst invasive species in the world (Lowe et al. 2004), can develop dense monocultural thickets that exclude other vegetation (King County NWCP 2011). In

Washington State, purple loosestrife is a Class B noxious weed. Purple loosestrife alters wetland ecosystems by replacing beneficial native plants; water-dependent mammals, waterfowl, and other birds abandon wetlands when purple loosestrife displaces their food resources, nesting material, and shelter. Introduced to the United States in the early 1800s at northeastern ports from ship ballast obtained from European tidal flats, purple loosestrife arrived in marine estuaries in the Pacific Northwest in the early 1900s. Commonly cultivated for the horticultural trade, beekeepers prized it in the mid-1900s (King County NWCP 2011). First collected in Washington State in 1929, deliberate planting and escape from cultivation likely aided its spread. Purple loosestrife occurs over diverse freshwater and brackish wetlands, lake and river shorelines, ponds, shallow streams and ditches, wet pastures, and other wet places. It can grow on moist or saturated soils or in shallow water, and it tolerates a broad pH and nutrient range. Mode of spread is primarily by seeds but also by fragmentation of stems and roots. Mature plants can produce an estimated two to three million pepper-sized seeds annually, which remain viable after 2 years in water.

Potential Actions:

Removal. Small purple loosestrife infestations can be effectively hand-pulled or dug up if conditions allow (King County NWCP 2011). Isolated plants should be carefully removed to avoid infesting more area. Larger infestations will require site-specific strategies. In general, work should progress from least to more heavily infested areas. In any stream network, work upstream to downstream. Cutting alone is not an option; new plants will grow from the roots.

Mulching. Sheet mulching or solarization using black plastic, landscape fabric, or cardboard and 6 inches of mulch is an interim option for dense seedling infestations. It will not kill the mature plant roots, but it slows growth and seed dispersal.

Herbicide. Some herbicide options exist. Of the 19 formulations of 17 herbicide active ingredients permitted for use in aquatic habitats (Ecology 2019), glyphosate, imazapyr, and triclopyr may be used on purple loosestrife. All the aspects of herbicide application in or near aquatic habitats in Washington State apply (see Potential Actions under Brazilian elodea).

Biological Control. A few biological control options also exist. One should be aware that biological control can take up to 6 years to have a significant impact (King County NWCP 2011). Purple loosestrife densities can be reduced, but some plants will invariably remain when using biological controls. As a consequence, biological controls should only be used on large infestations, where immediate eradication is not the focal objective. Two chrysomelid beetle species (*Galerucella calmariensus* and *G. pusilla*), initially released in Washington State in 1992, have been released several times in numerous locations. *Galerucella* defoliate plants, attack the terminal buds, and halt or greatly reduce seed production. Purple loosestrife seedling mortality is high, but these beetles do poorly near saltwater. Another biological control agent, *Hylobius transversovittatus*, is a root-mining weevil that also eats leaves. It eats from leaf margins, working inward. Eggs are laid in the lower 2 to 3 inches of the stem, or sometimes in the soil near the root. Larvae then work their way to the root, where they eat the carbohydrate reserves. *Hylobius* tolerates coastal areas and is better for infestations near saltwater. A fourth biological control, *Nanophyes marmoratus*, is a tiny seed weevil that feeds on unopened flower buds. Flower buds with larval damage typically abort and seed production fails. Adults also feed on developing leaves, which further weakens plants. This seed weevil can also be successful when used in conjunction with *Hylobius*.

C. **Parrotfeather (*Myriophyllum aquaticum*).** Parrotfeather is a submerged aquatic plant that has spikes with feathery leaves in whorls of four to six that can grow up to 1 foot above the water surface, are bright green, and resemble miniature conifers (King County 2018). Submerged leaves are more pliable, similar to leaves of other milfoil species. Native to the Amazon of South America, it has become naturalized globally across diverse freshwater habitats, largely because of its popularity as an ornamental with an aggressive growth habit (King County 2018). At least part of its rapid colonization ability is its vegetative reproduction from stem and rhizome fragments; in the United States, parrotfeather colonies are all female vegetative clones, so at least in this part of its introduced range, it does not reproduce from seed. In Washington State, parrotfeather is classed as a Class B noxious weed.

Parrotfeather grows in relatively shallow water. As a result, it can rapidly choke shallow-water areas, which creates ideal habitat for mosquito rearing, impacts salmon rearing habitat (especially for juvenile coho salmon (*Oncorhynchus kisutch*) in side channels and backwaters), causes problems for diverse forms of water recreation (e.g., boating, swimming, and fishing), and can locally increase flooding (King County 2018).

Potential Actions:

<u>Removal.</u> Once established, parrotfeather is costly and difficult to remove. As with Brazilian elodea, small populations can be carefully pulled or raked, taking care to remove all fragments (King County 2018). To succeed, manual control frequently requires persistence over many years. All manual control sites should be monitored for several years for signs of plants growing from roots, rhizomes, or other plant fragments.

<u>Barriers.</u> Bottom barriers may work to shade out or smother very small infestations if complete coverage is attainable. Watch barrier edges for shoots coming up from rhizomes. The barrier should be kept place for at least 12 months.

<u>Herbicide.</u> Aquatic herbicides may be the most reasonable option to abate parrotfeather if correctly applied, but the applicator must be licensed, have an aquatic endorsement, and have a permit for use in water (see herbicide application details under Potential Actions for Brazilian Elodea). Comparison of subsurface (submerged) and foliar application of nine different active ingredients revealed that foliar application of 2,4-D was the only herbicide and application method that resulted in ≥ 90% biomass reduction of parrotfeather. These

studies showed that regrowth occurred regardless of herbicide or treatment method, indicating multiple applications are necessary to achieve longer-term control (Wersal and Madsen 2010).

D. **Japanese knotweed (*Reynoutria japonica*).**[9] Ranked among the 100 worst invasive species in the world (Lowe et al 2004), in 1995, Japanese knotweed was listed a Class B noxious weed in Washington State. It is a robust, bamboo-like perennial that spreads by long-creeping rhizomes to form dense thickets (King County 2020). Originally imported as an ornamental screen or hedge plant, Japanese knotweed is native to Asia. In North America, this plant has almost no natural enemies and can thrive and spread over a broad range of conditions, but it is prominent along riverbanks, roadsides, and other moist, disturbed areas. Further, Japanese knotweed is often confused with its hybrid, Bohemian knotweed (*Polygonum* x *bohemicum*, also listed as *Polygonum cuspidatum* x *sachalinense*; Zika and Jacobson 2003) and the closely related giant knotweed (*Polygonum sachalinense*); both are also invasive species. However, the relative similarity among the two knotweed taxa to Japanese knotweed, and the fact that no native species in Washington are particularly similar, enables addressing all three collectively. A fourth knotweed species, Himalayan knotweed (*Persicaria wallichii*) is the most distinctive of invasive knotweed; it tends to be shorter, denser, and more clump-forming and has pinker flowers and stems that are not hollow (King County 2019). For details on the subtle differences among the three, see Zika and Jacobson (2003), King County (2019, 2020), and references therein.

   Invasive knotweeds are all perennials that develop large, dense thickets reaching 4 to 15 feet in height with green-reddish canes and branched clusters of small white to pink flowers (King County 2019). Reproduction is primarily vegetative via extensive roots and rhizomes, but the species are notorious for stems that easily fragment and develop into new plants. These plants are particularly aggressive, clogging waterways, eroding banks, and even growing into building foundations. Rapid spring growth and deep, extensive roots enable knotweeds to outcompete other plants, even small trees and shrubs. Invasive knotweeds are also relatively shade tolerant, facilitating their success in Pacific Northwest stream-margin environments.

   Potential Actions: Control of invasive knotweeds is challenging. The key to controlling knotweeds is controlling the rhizomes, because what you see at the surface is only part of the problem (King County NWCP 2015). Rhizomes can spread at least 23 feet (7 meters) from the parent plant and can penetrate more than 7 feet (approximately 2 meters) into the soil. Rhizome and root fragments as small as 0.5 inch (approximately 1 centimeter) can form new plant colonies and spread in contaminated fill. Knotweed canes do die back with the first hard frost, but canes regrow from rhizomes protected from freezing in the soil. Hard frosts may decrease in frequency with climate change, so control may ultimately require

[9] Japanese knotweed is also known by the synonyms *Fallopium japonicum* and *Polygonum cuspidatum*. This latter synonym is sometimes incorrectly applied to giant knotweed.

addressing both rhizomes and canes surviving over longer seasonal intervals. As with other invasive weeds, an IPM approach is recommended (see Potential Actions for Brazilian elodea).

<u>Manual Control.</u> Manual control can be used if easy access to the site exists, patches are reasonably small (50 stems or less), and an intensive control regimen can be sustained. When controlling knotweed manually, Soll (2004a) emphasized the "four Ts": timely, tenacious, tough, and thorough. Cutting, mowing, and pulling stimulates shoot growth and can deplete the roots. The greater the shoot density, the more likely it will be to physically pull out enough shoots to exhaust the rhizomes and roots by depriving them of energy (i.e., removing the shoot). Downsides are that it is often difficult to avoid fragmentation and removing the shoots must be repeated relatively frequently to be effective, hence the time required is costly. For these reasons, manual control at a certain level is often coupled with herbicide application. The bottom line for manual control is that success requires persistence over many years. Sites should be monitored for several years for signs of growth from roots, rhizomes, or other plant fragments.

<u>Barriers.</u> Cutting plants and covering them with a light-proof barrier is moderately effective (King County NWCP 2015). This approach needs constant monitoring and controlling of plants around perimeters and scattered plants that grow through sheet mulch through holes/overlap areas. Monitoring should be done every 2 to 4 weeks, and one needs to stomp down regrowth under covering material and clean off debris.

<u>Herbicide.</u> Herbicidal control of knotweeds is under the same constraints of other aquatic invasive plants if the application is over water (see Potential Actions under Brazilian elodea). If application is terrestrial (or the aquatic footprint has retreated seasonally), conditions are somewhat less restrictive (see the Ecology Permit for details; Ecology 2019). For overwater applications, the allowable herbicide suite is similar to that used for purple loosestrife (see Potential Actions under purple loosestrife) except that aminopyralid is added to the mix. It needs to be emphasized that the four allowable herbicides are not completely effective, and some combination of herbicides and non-herbicidal methods will typically be needed for adequate control. One of the most effective herbicide methods is hollow-stem injection, but application takes time where stems are numerous; alternative herbicide applications are less effective (King County NWCP 2015). Eradication of knotweed with a single herbicide application is rare. Typically, it takes several treatments over 4 to 6 years to get an infestation under control, and vigilant monitoring is crucial to success.

<u>Biological Control.</u> Historically, no biological controls were known for knotweeds (King County NWCP 2015). However, relatively recently, a potential biological control, the psyllid (jumping plant louse), *Aphalara itadori*, has emerged as a possibility (Grevstad et al. 2013; Clements et al. 2016). On May 28, 2019, the Animal and Plant Health Inspection Service (APHIS) released its Environmental Assessment (EA) of the Hokkaido and Kyushu biotypes of the *Aphalara itadori* as potential biological controls (84 Federal Register 24463). These

biotypes, known for their high host specificity due to their intimate relationship with these knotweeds, are expected to reduce the severity of infestations of Japanese, giant, and Bohemian knotweeds. Public review of the EA has been completed and a decision for their potential use is anticipated.

E. **Smooth cordgrass (*Spartina alterniflora*).**[10] Smooth cordgrass is a perennial rhizomatous grass native to the Atlantic and Gulf coasts of North America (Wang et al. 2006). Smooth cordgrass has spread worldwide; it was accidentally introduced on the West Coast of the United States in the 1800s and has since spread as far north as British Columbia and as far south as California (Frenkle and Kunze 1984; Sayce 1988). Outside its native ecosystems, smooth cordgrass is an aggressive invader that alters ecosystems so significantly that native biodiversity and habitats can be lost (Callaway and Josselyn 1992; Daehler and Strong 1996; Dumbauld et al. 1997). Rapid elongation rates, high leaf area indices, high photosynthetic rates, a long photosynthetic season, and clonal growth make smooth cordgrass an aggressive competitor with native salt marsh plants (Wang et al. 2006). Seed dispersal is also an important mechanism of smooth cordgrass spread (Daehler and Strong 1997).

Smooth cordgrass is one of four invasive cordgrass species that colonized the West Coast, which include English cordgrass (*S. anglica*), dense-flowered cordgrass (*S. densiflora*), and salt meadow cordgrass (*S. patens*; Frenkle and Kunze 1984; Sayce 1988; Daehler and Strong 1996).

Potential Actions: Based on systematic review and meta-analysis, Roberts and Pullin (2006, 2007) extensively reviewed the efficacy of the control methods available for *S. alterniflora*. Within the appendix of their 2006 report, they summarize the individual results of each study and combine these within a meta-analysis to establish the efficacy of control methods and attempt to obtain variables (e.g., inundation time, substrate) that might affect the outcomes of each control method.

<u>Cutting.</u> Cutting alone reduced densities of *S. alterniflora* by 68%, whereas cutting with an herbicide treatment (glyphosate) reduced densities by 91% (Roberts and Pullin 2006). Cutting followed by a glyphosate treatment was the second most effective treatment based on Roberts and Pullin (2007) meta-analysis. When cutting is combined with a smothering element (e.g., industrial black plastic sheeting), this was highly efficient, achieving declines in *S. anglica* averaging 98%. Cutting and smothering was reported as also the only management intervention that caused a decline in dry root weight (Roberts and Pullin 2006).

<u>Mechanical Control</u>. Mechanical control of smooth cordgrass has been extensively studied in Willapa Bay (Patten [unpublished]). Winter tilling produced the most effective control intervention, followed by disking and finally crushing. Crushing effectiveness was affected by the substrate type, with greatest control achieved on sand and soft silt, and least effective

[10] *Spartina alterniflora* is also known by the synonym *Sporobolus alterniflorus*.

on firm silts or those areas with well-established *Spartina* meadows. Overall, crushing was <10% less effective than tilling (Roberts and Pullin 2007). Based on bird usage and sediment softness, tilling seems to restore mudflats back to suitable habitat for foraging shoreline birds (Goss-Custard and Moser 1988). Major disadvantages of tilling are it is a high-cost option for most control programs (largely due to the cost of an amphibious tiller [more than $300,000]), and implementation of the process is slow (approximately 0.25 hectare per hour; Patten [unpublished]).

Grazing. Grazing of *Spartina* by ungulates (e.g., horses, cattle, or deer) has been carried out for decades with little or no apparent effect (Roberts and Pullin 2006).

Herbicide. Herbicide options had fairly high degrees of success. Imazapyr and glyphosate herbicide application were by far the most commonly used. Imazapyr achieved an 85.1% density reduction in smooth cordgrass, whereas glyphosate reduced smooth cordgrass by 57.9%. Adding a surfactant/wetting agent increased the effectiveness of both herbicides by 8% to 12%. Of these two herbicides, imazapyr provides greater control of smooth cordgrass at lower concentrations with a shorter drying time required than glyphosate and was used extensively for the highly effective control efforts in Willapa Bay. Application was conducted, however, over multiple years with extensive effectiveness monitoring.

Biological Control. Biological controls, including insects that suppress growth and substitution of smooth cordgrass with native grasses have had limited success (Grevstad et al. 2003, 2013), but other alternatives have been explored (Li and Zhang 2008). The use of a planthopper, *Prokelisia marginata*, as a control agent is still in its infancy and further trials are required, but information to date shows that it ranks low in effectiveness as a treatment option (Roberts and Pullin 2007).

For a few invasive species, a negative effect on the native biota is not known but is strongly suspected. Verification of the negative effect in the Chehalis Basin system and the degree to which it may be detrimental is needed. These species include the following:

6. **Brook trout (*Salvelinus fontinalis*).** In the Chehalis Basin, brook trout is restricted to a few higher-elevation lakes, ponds, and stream reaches of the upper Humptulips, Satsop, and Wynoochee river systems. This relatively restricted distribution and cool-water requirements are likely to limit brook trout even further with climate change. Nonetheless, brook trout have been successfully introduced to many high-elevation lakes and streams in western North America (Kennedy et al. 2003), and two native species, bull trout (*Salvelinus confluentus*) and the Cascades frog (*Rana cascadae*), are both declining with restricted distributions in the higher-elevation Olympics portion of the Chehalis Basin and may be at risk from brook trout. For the latter, predation would be the likely issue in lakes, whereas for the former, hybridization (Kanda et al. 2002) and predation may be the issue in cold-water streams. Further, Cascades frog in the Olympics is geographically separated from the Cascade Mountains and may be genetically differentiated from those populations. Cascades frog is being considered for listing review in

2021, so if the Olympic population system is differentiated, it will provide a more critical picture for those populations.

Potential Actions: Complete or partial removal of brook trout from different systems have had varying degrees of success. Partial removal of brook trout from Bogart Spring Creek (a medium-sized stream in northwestern California) using electrofishing over 3 years (2007 to 2009) removed tens of thousands of fish at an average removal efficiency of 92% to 97% over the first 2 years with most of the remaining fish removed in the third year (Carmona-Catot et al. 2010). However, lack of a decrease in age 0 brook trout between 2007 and 2008 after removal of more than 4,000 adults in 2007 suggests compensatory reproduction of mature fish that survived and higher survival of age 0 fish. The authors concluded that if the effort had continued and been coupled with screening to keep out immigrating fish, eradication from this creek might have been successful.

Historically, rotenone, a metabolic pathway piscicide that limits oxygen availability, was the only available method for complete removal of fishes from lake or pond systems (Knapp and Matthews 1998), and generally only from smaller systems. Though effective, the predominant disadvantage of this method is that rotenone is also toxic to non-target native species. Hence, it is most useful where only invasive or undesirable fishes are present.

Complete removal from lake systems has had considerable success. In an experimental study conducted in the high Sierra Nevada mountains of California, the presence and absence of the widely introduced salmonids rainbow trout (*Oncorhynchus mykiss*) and brook trout were manipulated to test the hypothesis that their introduction contributed to declines of the mountain yellow-legged frog (*Rana muscosa*; Vredenburg 2004). From 1996 to 2003, the introduced trout were removed from five lakes; 16 nearby lakes were used as controls, eight with introduced trout and eight without. To determine the vulnerable life stage, rainbow trout were placed in cages in three lakes with amphibians. Removal of introduced trout resulted in rapid frog population recovery, and, in the caging experiment, tadpoles were vulnerable to trout predation. The experiments reveal that introduced trout can prey on mountain yellow-legged frog tadpoles effectively, indicating that trout introduction is probably responsible for the decline of this frog and these negative effects are reversible. Removal in this effort was done using 35 hand-deployed gill nets across the five lakes. Knapp and Mathews (1998) demonstrated the utility of gill nets with six bar mesh sizes ranging from 10 to 38 mm in a small (1.6 hectare [approximately 4.0 acre]) alpine lake by removing the resident brook trout population using 14 gill net sets between September 1992 and October 1993; 10 additional sets between July and October 1994 failed to reveal additional brook trout. In mid-August 1994, the California Department of Fish and Game (now the California Department of Fish and Wildlife) stocked fingerling rainbow trout in this same lake. Rainbow trout were first noticed on August 1, 1994, and gill netting began immediately to try to eradicate them. This unanticipated stocking set back efforts to return Maul Lake to its historic fishless condition, but Knapp and Matthews (1998) used this opportunity to determine how quickly a much larger number of trout could be eliminated and whether fingerling trout could be successfully removed with gill nets. Rainbow trout were removed using 15 gill net sets between August 1, 1994 and July 16, 1997. Unlike the brook trout removal, which involved mostly larger fish, a large number of rainbow trout were not removed until the fourth gill set on October 18, 1994, when they had reached a large enough size to become trapped in the smallest bar mesh size, and the last fish were removed on July 16, 1997. The fact that no freshly caught fish were found on July 16, 1997, suggests that rainbow trout may have been successfully eradicated, but gill netting continued over 2 years after 1997 suggested that eradication was in fact complete (Knapp 2020). The most important factor complicating removal is the presence of inlet and outflow streams, which must be evaluated for their seasonal connectivity to make appropriate decisions on the best removal approach (Knapp 2020). Gill-netting is somewhat more costly than rotenone application (Knapp and Matthews 1998), but it avoids mortality to non-target fish species and non-fish species. Where native fish are present, how removal proceeds will have to be evaluated. Kamoroff and Goldberg (2018) demonstrated that eDNA is emerging as an important tool to evaluate removal with some confidence.

Few high-elevation lakes exist in the Chehalis Basin, and the majority of these occur in the Olympics. The current understanding of their fish species composition, if any, is incomplete. However, the lakes are relatively small, and this may lend them to gill net removal if brook trout are present. Besides brook trout presence, one would have to determine whether native fishes occupy these lakes, and if so, what the control options are. The Vredenburg (2004) removal experiments in the Sierra Nevada suggest that Cascade frogs are likely to respond to trout removal. Brook trout are also known to exist in a few of the higher elevation streams (Lestelle 2020). Streams would likely have to be electrofished to remove brook trout, but the effort would have to be pre-sampled to understand their distribution, and how to direct a control or eradication plan, which is highly stream-size dependent (Knapp 2020).

7. **Reed canarygrass (*Phalaris arundinacea*).** Reed canarygrass, prominent among invasive plants in North America, poses a significant problem in Washington State because an ideal temperature regime maximizes its growth potential and precipitation levels enable its exploitation of habitat well into apparent uplands despite it being typically regarded as a wetland species (Hayes et al. 2013). Listed as Class C[11] noxious weed in Washington state, reed canarygrass is an extremely widespread species found on every major landmass except Antarctica and Greenland (Whatcom Weeds 2020). It is a major threat to wetlands because it outcompetes most other native species and can develops monocultural stands resistant to change (WSNWCB 2020c). Reed canarygrass possesses distinctive life history characteristics that make its eradication extraordinarily difficult and its control onerous (Hayes et al. 2013). These life history characteristics are as follows: 1) a perennial life cycle; 2) dense rhizome mat development; 3) frost tolerance that allows early seasonal emergence; 4) condition-responsive

[11] Class C noxious weeds are those weed species that are already widespread in Washington state (WSNWCB 2020b).

above- versus below-ground growth; 5) staggered bud dormancy; 6) inundation-responsive growth; 7) anoxia-tolerant rhizomes; 8) rapid seed germination on exposed substrates that have been recently inundated; 9) high levels of seed production; and 10) development-linked alkaloid production (Hayes et al. 2013; Whatcom Weeds 2020). Reed canarygrass, which spreads easily by creeping rhizomes, vegetative fragments, or seeds, can alter local hydrology by promoting silt deposition in its dense rhizome thatch, which impedes water flow. Silt deposition, especially that which is nutrient rich, will facilitate reed canarygrass invasion of herbaceous meadows, particularly ones that are sedge-dominated (Werner and Zedler 2002; Maurer et al. 2003). In environments like the Chehalis Basin floodplain, cattle grazing facilitates such nutrient enrichment, so reed canarygrass predominance in much of the Chehalis Basin floodplain is not surprising. Alkaloids in reed canarygrass make the species less palatable to grazers as seasonal growth advances (Marten et al. 1976). As a consequence, once established, grazers may drive the system toward greater reed canarygrass dominance.

Potential Actions: A plethora of methods have been applied to control and attempt to locally eradicate reed canarygrass (see Hayes et al. 2013 for a review). Most methods have only had modest success. Selected herbicide treatments involving glyphosate or imazapyr, solarization using a smothering plastic barrier, and flaming may be the most promising, but all have some issues (Hayes et al. 2013). At the landscape scales at which reed canarygrass control may be desired, development of resistance to herbicides may present an issue. This could be addressed by alternation of herbicides, but a broader IPM approach may be needed. Solarization will work if the season with an elevated temperature is adequate; currently, this presents a problem in the near-coastal Pacific Northwest, but the warming climate could diminish this problem. Flaming could work if application under low fire risk conditions can be successful; the increasing fire risk created by warming (and drying) climate change trends will likely limit this kind of application, which human population growth will tend to limit as well. Experimental evaluation of alternative reed canarygrass control methods for Chehalis Basin-specific conditions needs some attention. Additionally, reed canarygrass is currently dominant along wetland margins in floodplain off-channel habitats in the Chehalis Basin. Aquatic vegetation was shown to attenuate the negative effect of centrarchids on amphibians (Holgerson et al. 2019), so if control of reed canarygrass is desired, one will have to understand how those control efforts may affect amphibians and perhaps other native aquatic species in the system. No biological control options are currently known for reed canarygrass.

8. **Himalayan blackberry (*Rubus armeniacus*).** Similar to reed canarygrass, Himalayan blackberry has been listed as Class C noxious weed, in this case since 2009 (WSNWCB 2020d). It is a notorious invasive species globally that has costs millions of dollars for both its control and negative impacts. In western Washington state, Himalayan blackberry does particularly well because of soil moisture levels, so it can occur both along the margins of aquatic habitats and well into habitats typically regarded as uplands where soil moisture is adequate. Contrary to its standard English name, Himalayan blackberry is a native to western Europe (Soll 2004b). First

introduced to North America around 1885 as a cultivated crop, Himalayan blackberry became naturalized along the West Coast by 1945. Himalayan blackberry is a rambling evergreen, perennial, woody shrub with stout stems that has stiff hooked thorns. Its stems, often called canes, can reach up to 40 feet (approximately 12 meters) in length and may root at their tips if they touch the ground (WSNWCB 2020d). The typical growth form is dense thickets, impassable to humans and many larger animals, that sprawl over the surrounding vegetation. This species spreads rapidly, and the thicket growth form and numerous layered dark leaves shade out native plants and limit habitat quality for wildlife and livestock. The berries are an attractive food source to many animals (including humans), which facilitates the rapid dispersal of Himalayan blackberry across many landscapes. Himalayan blackberry may grow in wetlands, but this habitat is marginal for the species (Soll 2004b). Himalayan blackberry appears to invade wetlands by tip rooting of canes; the roots do not seem to be able to survive in anaerobic soils (most wetland soils are anaerobic) without the supporting canes. Ecologically, Himalayan blackberry is a poor functional replacement for a diverse native forest understory, meadow, or riparian floodplain. For example, in southwestern British Columbia, forest understory with Himalayan blackberry had significantly lower bird species diversity than forest understory lacking Himalayan blackberry (Astley 2010).

Potential Actions: Large stands of Himalayan blackberry are difficult to control due to their impenetrability and multiple rooting and reproductive alternatives, but with proper management, infested areas can be restored to desirable vegetation (Soll 2004b). Control is usually achieved in a two-phased process: removal of aboveground vegetation and killing or removing the root crowns and major side roots (not necessarily in that order). Mechanical removal, whether by hand, machine or burning, is an effective option for removing the above-ground portion. Six primary options exist for long-term (i.e., root) control, listed as follows:

A. Grubbing out root crowns and major roots has proven effective but is expensive.
B. Repeated cutting of aboveground vegetation can also be effective but is expensive and requires treatment over multiple years.
C. Foliar herbicide treatment of re-sprouted canes in the fall after summer clearing has proven effective in some cases.
D. Treating freshly cut stumps with the appropriate concentrated herbicide.
E. Uncut Himalayan blackberry can be effectively treated in late summer or fall with broadcast application of a variety of herbicides including triclopyr (i.e., Garlon 3a and 4) and/or glyphosate (i.e., Round-Up and similar products) or 2-4D combined with triclopyr (i.e., Crossbow). Effective control can be achieved by this method, but the extensive standing dead dry and hard canes then need removal to allow effective restoration.
F. Dense planting of shade-producing vegetation can be a long-term solution, but planted vegetation may need protection from being overtopped by Himalayan blackberry.

Applications proximate to or over water that involve herbicides will require permits and licensing for treatments and need to follow regulations for aquatic habitats (see Potential Actions under Brazilian elodea).

9. **Scotch broom (*Cytisus scoparius*).** Scotch broom, a perennial leguminous shrub native to western and central Europe, was designated as a Class B noxious weed in Washington State in 1988 (WSNWCB 2020e). Introduced as a garden ornamental by early settlers to the Pacific Coast (Parker et al. 1994), Scotch broom displaces native and beneficial plants, causing loss of grassland and open forest (WSNWCB 2020e). It aggressively spreads to form monocultures, replacing desirable forage grasses and young trees. Seeds are toxic to livestock and horses. As of 1994, it had spread across more than a half-million acres of rangeland in California (Parker et al. 1994). Since that time, Scotch broom has moved rapidly into forest lands of western Oregon and Washington, where it interferes with conifer re-establishment on harvested lands.

   Reproduction occurs only through seeds (no vegetative reproduction), but Scotch broom is extremely successful at re-sprouting after cutting (Graves et al. 2010). Full growth may take several years, but seed production starts around age 2. Seed production is extensive and highly variable, ranging from approximately 4,000 to more than 30,000 seeds per plant. As seeds can remain viable in the soil for 30 to 80 years (Bossard and Rejmanek 1994; Graves et al. 2010), the soil seed bed may contain up to 2,000 seeds per square foot. Buried seeds may delay germination, but they can germinate from a depth of up to 2.4 inches (6 centimeters).

   Review of Scotch broom data from around the world revealed that in its introduced range, Scotch broom can be highly fecund and live longer than its native range (Rees and Paynter 1997), implying its ecological release from factors that keep it in check in its native range.

   Rees and Paynter (1997) developed simulation and analytical models to explore the changes in Scotch broom population size. Analysis of the models revealed that sites occupied by Scotch broom are largely determined by the following three parameters: 1) likelihood of disturbance; 2) probability a site become suitable for colonization following plant senescence; and 3) maximum plant longevity. Differences in these three parameters are the likely reason Scotch broom populations are weedier in their invasive species range (where Scotch broom plants can produce several thousand seeds) than in their native range. In its native range, Scotch broom also has a richer specialized invertebrate herbivore fauna than in its invasive range (Memmott et al. 2000).

   Potential Actions:

   <u>Mechanical Control.</u> Small stands of Scotch broom can be controlled through hand removal (Whatcom County [undated]). Plants should be dug or pulled, taking care to remove as much of the root as possible; a Weed Wrench™ is a useful assist. Soil disturbance during removal may cause germination of Scotch broom seeds, so monitoring is important to identify and remove new seedlings that emerge.

   Depending on infestation size, Scotch broom can be sheared to the ground by hand or with a chainsaw, heavy-duty trimmer, or larger machinery (Badgett 2020). Mechanical control requires repeated shearing to kill the plants that re-sprout. Minimizing soil disturbance during shearing episodes is important to minimize seed germination, but similar to hand removal, monitoring is crucial to identify and remove new seedlings that may emerge. Mechanical removal with large tillers and plows is not recommended because it encourages regrowth and colonization via germination as Scotch broom often overtakes areas where soil had been disturbed, as with tilling.

Herbicide. Herbicide options exist. Foliar spray, basal bark treatment, and cutting stems and painting the fresh-cut stems with herbicide can all provide effective control (WSNWCB 2020e). Herbicide options for Scotch broom are more diverse than for aquatic weed species (see Ecology website; options are similar but less restrictive than those outlined for purple loosestrife).

Biological Control. Biological controls exist that have shown success. A seed weevil, *Exapion* (formerly *Apion*) *fuscirostre*, was introduced for Scotch broom control in California in 1964 (Andres et al. 1967). The larvae feed on Scotch broom seeds in its developing pods (WSNWCB 2020e). The adults also feed on flowers and tips of stems, but little damage occurs to those plant parts. Field tests with newly emerged and overwintered adult weevils on the foliage and flowers of diverse legumes including alfalfa, bean, vetch, acacia, and other species of the broom tribe reveal that *E. fuscirostre* does not feed on the economic plant species examined and only slightly on the several woody legumes. A seed-consuming beetle, the Scotch broom bruchid, *Bruchidius villosus*, was first released in the United States in western Oregon in 1998 (Coombs et al. 2008). Similar to *Exapion*, larvae feed on developing seeds and impact its reproduction (Syrett et al. 1999). More than 135 releases of the beetle have been made throughout western Oregon and Washington (Coombs et al. 2008). Nursery sites for the bruchid have been established, and collection for redistribution began in 2003. The initial establishment rate of the bruchid is higher in interior valleys than at cooler sites near the coast and in the lower Cascade Mountains. Seed-pod attack rates varied from 10% to 90% at release sites that were ≥3 years old. Seed destruction within pods varied from 20% to 80% but was highest at older release sites, where *B. villosus* may complement the impact of the widely established *Exapion*. Both the seed weevil and the bruchid should reduce the rate at which broom invades but are unlikely to reduce existing stands (Paynter et al. 1996). At sites where bruchids were established, they made up 37% of the seed-pod beetle population, indicating that they can compete with the weevil and increase their populations (Coombs et al. 2008). What is poorly understood is how both species will operate over longer timelines and at sites with different conditions. Other biological controls agents have been studied for Scotch broom control (Syrett et al. 1999), but effectiveness is not yet well understood.

Other invasive species with serious negative effects on native aquatic species may be identified in the future. As a result, a monitoring instrument will be needed to identify such problem species when they appear and monitor and develop plans to control their spread over time. That instrument, which could be part of the ASRP, should include local, community, state, tribal, and other entities. Ideally, this should represent a linkage of existing entities, one of whose tasks already constitutes monitoring problem invasive species. Such entities have historically been deficient in funding for such work, so dedicated funding for such an effort will be imperative.

The need for an integrated approach using IPM (as discussed previously) to achieve successful control of invasive species cannot be overstated. Development of IPM-guided plans can be taxon-, project-, or region-specific but at their core should have the adaptability and flexibility to incorporate new knowledge and science. Top-down hydrological processes almost invariably facilitate invasive species infestations, likewise top-down application should be a basic consideration on how to apply a control program at a basin or sub-basin level. Furthermore, control options must consider the long time horizon. For example, several control options currently viewed as the best available for many invasive species use an herbicide alternative; if application of a biological control is desired, recognition that an herbicide alternative many limit the biological control agent needs consideration of whether both can be applied in an integrated fashion. Lastly, invasive plant resistance to herbicides was discussed, but the risk is higher for herbicides that have been used on particular species for a long time or over large areas. Herbicide applications to control invasive species should expressly use an IPM tack that avoids or minimizes the development of resistance that could create super weeds that could evade existing control alternatives.

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Appendix F
Sediment Wedges: A Restoration Opportunity Mimicking a Widespread Process

Accumulation of sediment behind instream wood or boulder structures is a normal stream process. Accumulations behind large in-channel wood structures can create bars (i.e., sediment wedges) variable in length and depth. These wedges contribute ecological services that make aquatic habitat suitable for diverse native aquatic species (Gerhard and Reich 2000). The current lack of large in-channel wood and logjams directly limits the potential to accumulate sediment (Gurnell et al. 2002; Abbe and Montgomery 2003; May and Gresswell 2003) and is widespread throughout the Chehalis Basin (ASRPSC 2019).

Among important ecological services contributed by naturally accumulated sediment wedges is their ability to reduce water temperatures (Bilby 1984). In the Chehalis Basin, this ecological service is highly important because many streams have summer water temperatures higher than optimal for cold-water-adapted species, which has led the Washington Department of Ecology to define many streams in the basin as temperature-limited (Ecology 2019). Recent Ecosystem Diagnosis and Treatment (EDT) and National Oceanic and Atmospheric Administration (NOAA) Northwest Fisheries Science Center salmonid life-cycle model (NOAA model) used in the ASRP incorporated a Chehalis Basin-specific downscaled version of the NorWeST temperature model to identify that current August water temperatures over the stream network are often higher than earlier modeling suggested (Winkowski and Zimmerman 2018). Moreover, cumulative research reveals that without intervention (i.e., the No Action Alternative of the *Aquatic Species Restoration Plan* [ASRP] Phase 1 document [ASRPSC 2019]), water temperatures are likely to increase under climate warming (Wu et al. 2012; Luce et al. 2014). In some parts of the Pacific Northwest, water temperatures have apparently already increased 0.5°C per decade since the 1960s (Bartholow 2004); in recent years, a similar pattern is identifiable in the Chehalis Basin (ASRPSC 2019). Further, changes in water temperature, among basic input variables in the EDT and NOAA models, are primary drivers of projections revealing a high probability of spring-run Chinook salmon (*Oncorhynchus tshawytscha*) functional extinction during the mid- to late century time period (ASRPSC 2019). Frequent mention of temperature in the ASRP Phase I document underscores this point; temperature is first among the seven water quality parameters of primary concern (ASRPSC 2019). Hence, attention to temperature is a pressing issue for restoration of the colder-adapted aquatic fauna in the Chehalis Basin.

The fact that sediment wedges provide other ecological services also needs recognition. These services include locally raising the water table (Loheide and Gorelick 2006; Tague et al. 2008; Hammersmark et al. 2010; Hunt et al. 2018); improving hyporheic flow (Ward et al. 2011); providing bank stability (Bilby 1984); improving other aspects of water quality, including nutrient storage and increased pollutant filtering (Peter et al. 2019); and providing oviposition, rearing, and foraging habitat for native aquatic species (Russell et al. 2004). Improving hyporheic pathways may also benefit the temperature reduction ecological service where such pathways improve connectivity with groundwater resources (Sawyer et al. 2012; Surfleet and Louen 2018).

For these collective reasons, the creation of sediment wedges is seen as an innovative restoration option in the ASRP, and it is currently the focus of an ASRP small project grant. Wedge creation would be keyed by an appropriately designed engineered wood structure. That structure would be pre-filled with an appropriately sized distribution of sediment. Advantages of creating pre-filled sediment wedges include the following:

1. Pre-filling allows any temperature-reduction response to rapidly manifest.
2. Pre-filling allows more rapid development of response of non-temperature ecological services.
3. The method is one of very few that enables an active temperature reduction effort. Passive methods, such a tree planting, have delayed response times.
4. Widespread application is possible (i.e., over a large array of stream sizes). Wedge design flexibility allows full stream-spanning, partial stream spanning, or submerged options, or combinations of these options.
5. Engineering of the structure keying the wedge can be adjusted to ensure longevity (i.e., reducing the likelihood of the structure being blown out by a high-water event of a particular magnitude).
6. Fish passage issues are not a limitation.

These advantages notwithstanding, initial efforts at applying pre-filled sediment wedges need to be experimental because the magnitude of any temperature-reduction and accessory ecological service responses need to be verified for the scale of application (stream size) and engineered keying structure.

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Appendix G
Thermal Refuges

Introduction

Thermal refuges (also called thermal refugia) are either cold- or warm-water areas that allow fish and other organisms to occupy more suitable temperatures when ambient stream temperatures are either too warm or too cold for growth and survival (Torgersen et al. 2012). Scales of thermal refuges range from microhabitats to river basins (Torgersen et al. 2012). This appendix focuses on cold-water refuges, which are important habitat features for salmonids and other aquatic species in river basins with high summer stream temperatures (Berman and Quinn 1991; Torgersen et al. 1999). This appendix considers refuges at two spatial scales: local pockets of cool water within warm reaches (patch-scale) and reaches of cool water within a warm stream network (reach-scale).

Land and river management have reduced availability of thermal refuges in many river basins (Poole and Berman 2001), and identifying where thermal refuges currently exist or where they can be created is an important aspect of restoring aquatic habitats (Torgersen et al. 2012). Because the Chehalis Basin typically has summer temperatures exceeding thermal limits for both adult and juvenile salmonids, protecting and restoring cool-water refugia will likely be an important habitat management strategy for sustaining salmonids and other species in the future. This appendix briefly summarizes the scientific background on thermal refuges, describes the current understanding of thermal refuges in the Chehalis Basin, and discusses potential strategies for addressing thermal refuges in the *Aquatic Species Restoration Plan* (ASRP).

Background

Processes that Create Refuges

Localized pockets of cool water can be created by point sources of water such as tributaries or groundwater seeps, whereas larger reaches of cool water can be created by larger groundwater sources such as in a gaining reach where cool water enters at multiple points (Torgersen et al. 2012; Steel et al. 2017). Localized thermal refuges are also created along a stream network where gravel accumulations occur and the water flowing through these accumulations is cooled, then re-emerges into the surface water. One example of this has been documented in the upper Chehalis Basin in Thrash Creek, where gravel accumulations forced flow through the streambed, resulting in significantly cooled water (approximately 3.9°C cooler) re-emerging downstream into the surface flow (Bilby 1984). At the stream network scale, thermal refuges may also be well-shaded or higher-elevation reaches with cooler temperatures (Waples et al. 2009; Steel et al. 2017).

In larger rivers with complex channel patterns and off-channel habitats, hyporheic exchange through gravel bars and beneath the floodplain can create localized hyporheic seeps that function as cool-water refuges (Fernald et al. 2006; Poole et al. 2008). Natural and analog beaver dams can also increase hyporheic exchange, creating both local temperature refuges and reach-scale reductions in daily maximum stream temperatures (Weber et al. 2017). Hyporheic connectivity can also dampen diurnal variation in side channels and reduce daily maximum temperatures relative to the main channel, whereas groundwater sources can dampen both daily and monthly temperature variations (Steel et al. 2017). Theoretically, hyporheic exchange could also reduce daily mean temperatures in a reach (Arrigoni et al. 2008), although available observations were limited to reduced mean temperatures via hyporheic exchange for beaver dams, and the effect was less than 1°C of cooling in each case (Weber et al. 2017).

At the basin scale, higher-elevation reaches are often cooler because the air temperature is lower and streams may be smaller and more shaded. However, mechanisms that create thermal refuges at the scale of large reaches may also include cool-water inputs from large tributaries or groundwater inputs, topographic shading in canyons, or coastal fog (Fullerton et al. 2015). In the Chehalis Basin, large refuges created by groundwater inputs include portions of the East Fork Satsop River and the South Fork Newaukum River, whereas elevation driven refuges are found primarily in the headwaters of the Humptulips and Wynoochee rivers.

Importance of Refuges to Salmon

While optimal and lethal temperature limits for many species have been identified, this appendix is focused on salmon species, which have upper optimal temperatures of about 16°C for juvenile rearing and 15°C for adult migration (Richter and Kolmes 2005) (Table 1). Lethal temperature limits range from about 24°C to 28°C for juvenile rearing and adult migration (Beechie et al. 2020). However, individual populations may be adapted to higher or lower temperatures depending on local thermal regimes under which each population evolved.

Table 1
Optimal and Lethal Temperature Limits for Adult Spring-Run Chinook Salmon Holding and Juvenile Steelhead and Coho and Chinook Salmon Rearing

SPECIES AND LIFE STAGE	UPPER OPTIMAL LIMIT	LETHAL LIMIT
Adult spring-run Chinook salmon holding	15°C	29°C
Juvenile Chinook salmon rearing	16°C	24°C
Juvenile coho salmon rearing	18°C	28°C
Juvenile steelhead rearing	22°C	26°C

Cold-water refuges are important both for avoiding lethal temperatures and regulating metabolism. Where temperatures are high but not lethal, salmon metabolism increases and food consumption must increase to sustain positive growth rates through the summer. However, cool-water refuges may help sustain growth with lower food resources when fish can access cooler water when not feeding. Where temperatures are very cold, fish may increase growth by feeding on high-energy food in cold water and then moving to warmer water to increase efficiency of digestion (Armstrong and Schindler 2013). At the basin scale, maintaining or restoring longitudinal connectivity to cooler upper reaches is also important for supporting species and life history diversity (Waples et al. 2009), and long (2.7 to 13 kilometer) thermal refuges occurring in rivers throughout the west may help salmonids survive warmer summers (Fullerton et al. 2018).

Thermal Refuges in the Chehalis Basin

Both reach-scale and patch-scale thermal refuges currently exist in the Chehalis Basin. For example, observations indicate that groundwater inputs create significant reach-scale cold-water refuges in the upper South Fork Newaukum River at Pigeon Springs and in the upper East Fork Satsop River (ASRPSC 2019). In addition to groundwater inputs, higher-elevation reaches in the West Fork Humptulips, West Fork Satsop, and North Fork Newaukum rivers are generally cooler than lower-elevation reaches (Winkowski et al. 2018) and may also function as reach-scale thermal refuges.

Potential reach-scale thermal refugia have also been documented in the mainstem Chehalis River in two U.S. Geological Survey seepage studies (Ely et al. 2008; Gendaszek 2011). These studies do not document temperature change but identify reaches with significant groundwater inflows that are presumably cooler than surface water. The first study identified gaining and losing reaches in the mainstem Chehalis River from near Elk Creek downstream to the Satsop River. They highlighted significant gaining reaches near Doty, between Stearns Creek and the Newaukum River, near Scatter Creek, and downstream of the Black River (Ely et al. 2008). Much of the mainstem between Oakville and the Satsop River was also mapped as gaining reaches, but the range of seepage estimates for each indicate higher uncertainty for those reaches (i.e., the range of estimates includes zero, suggesting that these reaches might be losing reaches). A second seepage study focused on reaches between the Newaukum River and Oakville (Gendaszek 2011). This study considered uncertainty in seepage estimates and classified most reaches as near neutral (neither gaining nor losing) because of uncertainty in the estimates. Only one reach upstream of Scatter Creek was identified as a gaining reach, although some reaches downstream of the Black River also had relatively high inflows (Gendaszek 2011). Gendaszek (2011) suggested that the difference in discharge at the times of the two surveys (339 cubic feet per second [cfs] in 2007 and 449 cfs in 2010) may account for some of the difference in seepage measurements between years.

Several localized cool-water patches have been identified in the mainstem Chehalis River in various studies. For example, one temperature study from Dell Creek (near Rainbow Falls) to Adna identified several cool-water patches at groundwater seeps or tributary confluences (Vonada 2018). These include cooler patches at the mainstem Chehalis River confluences with the South Fork Chehalis River, Garret Creek, and Bunker Creek, as well as two apparently groundwater-influenced patches just below Nicholson Creek and just upstream of the South Fork Chehalis River (Vonada 2018). The ASRP Phase 1 document also identified cool-water patches at the confluences of the Newaukum and Skookumchuck rivers (ASRPSC 2019).

An aerial forward-looking infrared radar (FLIR) survey of the mainstem Chehalis River was conducted by Watershed Sciences, Inc., over a 4-day period in mid-September 2013, extending from near the confluence of the East and West Forks of the Chehalis River downstream to about the city of Chehalis. Images from this survey identified cool-water patches at most tributary confluences upstream of Pe Ell, as well as cool-water patches at Elk Creek and Stearns Creek, in addition to sites identified in other studies (e.g., the Newaukum River confluence).

Radio telemetry studies of spring-run Chinook salmon movements in 2014 and 2015 found that some reaches of the mainstem Chehalis River contained patches of cooler water near the river bed, most notably between the Newaukum and Skookumchuck rivers, downstream of Mox-Chehalis Creek, and downstream of the South Fork Chehalis River (Liedtke et al. 2016, 2017). There was also a small patch of cooler water near the mouth of the Skookumchuck River (Liedtke et al. 2017). However, most tagged fish appeared to avoid the high temperatures in the mainstem by moving to higher elevation or spring-fed cool-water refuges such as the upper North and South Forks of the Newaukum River (Liedtke et al. 2016).

Strategies for Protecting and Restoring Thermal Refuges

Inventory Existing Refuges

Protecting thermal refuges in the Chehalis Basin will require a comprehensive inventory of where they currently exist. Patch-scale refuges can be identified using FLIR, which maps spatial variation in surface temperatures of the river (Torgersen et al. 2012; Leonetti et al. 2015). FLIR has been used to map temperature variation in the upper mainstem (upstream of the city of Chehalis), but the remainder of the river and warm tributaries (e.g., lower Newaukum or lower South Fork Chehalis rivers) could also be mapped.

Some patch-scale refuges are near the stream bed and will not be identified using FLIR. Subsurface refugia could be identified using paired temperature loggers, one near the surface and one near the stream bed (Liedtke et al. 2016). Liedtke et al. applied this approach at eight sites in the mainstem Chehalis River between the South Fork Chehalis River and Elma and found consistently cooler temperatures near the bed at two of those sites and evidence of near-bed cool water during some portion of the summer at two other sites. Expansion of this approach may identify additional cool-water sources that could be protected. Initially, this effort could focus on known gaining reaches that are most likely to contain near-bed cool-water patches.

Larger reach-scale refuges in tributaries can by identified either by FLIR or temperature loggers. Many of these refuges have been identified, but a comprehensive inventory of unsurveyed areas could be useful for managing temperature refuges in the Chehalis Basin. This inventory could initially target reaches that are known or suspected cool-water areas so that current institutional knowledge is captured and inventory costs can be lower in the near-term.

Actions to Protect or Restore Refuges

Actions to protect thermal refuges include protection of cool groundwater sources and protection of complex floodplain habitat. Cool groundwater sources can be protected by limiting groundwater withdrawals in key areas and protecting forest cover within groundwater watersheds. Complex floodplain habitat can be protected by land acquisition or easements to limit loss of habitat.

Actions to restore thermal refuges may include restoring floodplain connectivity, restoring riparian shade, purchasing water rights to increase stream flow, restoring fish passage to higher elevation or cooler stream reaches, restoring beaver populations, or constructing beaver dam analogs (Katz and Luff 2020). Use of large wood to restore gravel accumulations on the streambed where it has been lost or to create sediment wedges can also create thermal refuges (Appendix F). These actions all have varying effectiveness depending on the physical and ecological setting for the action (Katz and Luff 2020).

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Appendix H
Freshwater Mussels

Status of Freshwater Mussels in the Pacific Northwest and the Chehalis Basin

Freshwater mussels have recently received increased conservation attention due to the valuable ecosystem functions they provide and the increase in monitoring efforts that suggest several species and populations have been declining. The most notable ecosystem function provided by freshwater mussels is water filtration; freshwater mussels can filter between 5 and 30 gallons of water each day. Clean water is especially important to salmonids in the Chehalis Basin. Freshwater mussels also provide other important ecosystem functions, including structure and habitat for other species, a food source for wildlife, and cultural significance to some Northwest tribes.

Blevins et al. (2017) documented declines in freshwater mussels across their geographic range in the western United States and noted that three of the four species and clades found in the western United States are currently imperiled and/or facing increased risk of extinction. Freshwater mussels face numerous threats, including habitat loss and destruction, poor water quality, reduced flows, increased dewatering of stream beds, and declines or loss of their host fish species. One additional threat to freshwater mussels that is often overlooked—and one that is particularly relevant to the Chehalis Basin Aquatic Species Restoration Plan (ASRP)—is the potential for detrimental effects of habitat restoration projects. When large sections of rivers are dewatered for construction activities associated with habitat restoration projects, mussel beds can become dewatered, resulting in high mortality. Furthermore, large woody debris placed into the stream channel on top of mussel beds may also be harmful. The Xerces Society has developed best management practices for freshwater mussels, including guidelines for stream restoration projects (Blevins et al. 2018).

There are three species of freshwater mussels in the Chehalis Basin: the floater species (*Anodonta* spp.), western ridged mussel (*Gonidea angulata*), and western pearlshell (*Margaritifera falcata*). Declines have been observed in mussel beds in several subwatersheds across the Chehalis Basin, although the extent of those declines is not fully understood at this point. Mageroy et al. (2017) found that the western ridged mussel within the Chehalis Basin represented a genetically distinct population. In 2016, the Xerces Society and the Washington Department of Fish and Wildlife began routine monitoring efforts for all three freshwater mussels in the Chehalis Basin. These efforts have focused on the mainstem Chehalis, East Fork Satsop, Newaukum, and Skookumchuck rivers. The primary objective of these efforts has been to establish baseline data for the Chehalis Basin. The western ridged mussel had been a focal species for these efforts and is also focal species of the ASRP (ASRPSC 2019). Monitoring efforts for the western ridged mussel have shown widespread declines in the mainstem Chehalis River between River Mile (RM) 21 and RM 76 (Blevins et al. 2020). These monitoring efforts have recently expanded their focus to document freshwater mussel distribution and abundance in additional sub-basins, investigate large-scale die-offs in the basin (see the following section, Freshwater Mussel Die-Offs), explore the use of eDNA as a survey tool, and examine the overall condition of freshwater mussels. Additional partners in these monitoring and research efforts include the U.S. Fish and Wildlife Service (USFWS) and the U.S. Geological Survey (USGS).

Freshwater Mussel Die-Offs

Large-scale die-offs of freshwater mussels have been observed in multiple river systems across the Pacific Northwest in recent years, including in the Chehalis Basin. These die-offs include all three species found in the Pacific Northwest. The initial observation in the Chehalis Basin was in 2015 and included tens of thousands of dead individuals. This die-off spanned more than 50 miles in the mainstem Chehalis River. Since the initial observation, additional mortalities have been observed in areas upstream of the initial site. The underlying cause(s) of these die-offs is poorly understood at this point. Preliminary data from a study by the Xerces Society and USGS suggest that there may be a novel virus associated with these die-offs (Blevins et al. 2020).

Western Ridged Mussel Listing Petition

The western ridged mussel is the most imperiled freshwater mussel species in the western United States due to many of the threats described previously (Blevins et al. 2017). The species has been lost from 43% of its historic range, and the southern terminus of its distribution has now shifted 475 miles northward (Blevins et al. 2017). Furthermore, nearly half of the historic sites where western ridged mussels had been recorded did not have western ridged mussels when they were recently re-surveyed (Blevins et al. 2017). At sites where western ridged mussels do still occur, numbers of individuals are only a fraction of what the numbers documented in historical records. In addition to these dramatic declines, the species has also experienced the substantial die-offs described previously in several watersheds, including the Chehalis Basin. Because of these precipitous declines and continued threats to the species persistence, the Xerces Society petitioned USFWS to protect the western ridged mussel under the Endangered Species Act on August 18, 2020 (Blevins et al. 2020).

Data Gaps to Address and Next Steps

Several key data gaps remain for freshwater mussels in the Chehalis Basin. Possible next steps for freshwater mussels in the ASRP process could include the following:

- Continue to provide funding for and collect baseline monitoring data on freshwater mussel distribution and abundance in key areas of the Chehalis Basin.
- Continue to investigate and address (where possible) the causes of freshwater mussel die-offs in the Chehalis Basin.
- Follow best management practices to avoid and minimize effects on mussels for all in-stream habitat restoration projects implemented through the ASRP (Blevins et al. 2018).
- Explore the feasibility of targeted restoration activities to benefit freshwater mussels in the Chehalis Basin.

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Appendix I
Potential Conflicts Between Species

Differing habitat requirements of the multiple focal aquatic species have the potential to result in conflicts in protection or restoration efforts. This appendix describes three obvious conflicts, but there may be conflicts for other species or other conditions, especially for those species where life history knowledge is incomplete or uncertain. The three main potential conflicts are as follows:

1. **Oregon spotted frog (*Rana pretiosa*) and most salmonids.** The post-metamorphic stages of Oregon spotted frog are warm-water adapted and thrive best in habitat where daytime surface water temperatures reach ≥20.0°C (≥68.0°F) during most of their active non-breeding season. This is one reason that all Oregon spotted frog-occupied sites have significant open and exposed habitat consisting primarily of low-emergent marsh, a habitat structure that extends to their oviposition habitat. Indeed, one of the challenges facing Oregon spotted frog habitat is that both succession (of woody vegetation) and reed canarygrass (*Phalaris arundinacea;* which creates monocultures of dense, tall herbaceous emergents) have resulted in significant habitat loss for Oregon spotted frog across its Washington range. This loss is thought to be related to a reduction in grazers, hydrological changes, or an interaction between the two.
   In contrast, most salmonids function best at temperatures <16.0°C (60.8°F), and that is why the Washington Department of Ecology's water temperature criteria pivot around this temperature. As a result, tree planting in riparian and marsh areas has been promoted as one of several restoration options to reduce water temperatures for salmonids. This situation came into direct conflict with Oregon spotted frog habitat in Whatcom County when Oregon spotted frogs were discovered in at least two new sites where riparian planting was proposed and initiated. Hence, restoration actions in marshes and riparian areas that are occupied or potentially occupied by Oregon spotted frogs need evaluation prior to those actions being implemented, and restoration actions may need modification if the frogs are found on the sites.
2. **Western toad (*Anaxyrus boreas*) and some salmonids.** The conflicts for salmonids and Western toad occur where salmonid distribution overlaps toad riverine breeding habitat: medium river habitat (characterized as fifth- to seventh-order reaches based on the National Hydrographic Database). Like the Oregon spotted frog/salmonid conflict, a temperature conflict likely exists, but it manifests in context of shade. Western toads require well-insolated oviposition habitat; that is, they tolerate virtually no shade on oviposition sites. This is evident in that Western toads are not found breeding in small streams that are too shaded; for streams in the Chehalis Basin, this typically happens at stream sizes that fall within the fifth-order range. They also fail to oviposit in streams that are of larger order but happen to be shaded; this was observed near the mouth of Crim Creek, where habitat seemed structurally ideal but was shaded by large red alder (*Alnus rubra*). Though no conflicts with restoration efforts for salmonids that occupy medium river habitat have yet occurred for Western toads, the opportunity exists if riparian plants are designed to shade locations that are or could be Western toad oviposition habitat.
3. **Native salmonids and introduced centrarchid fishes.** Centrarchid basses—most prominently smallmouth bass (*Micropterus dolomieu*) and, where less flowing embayments exist, largemouth

bass (*M. salmoides*)—are known to occur in the mainstem Chehalis River and the lower portions of its larger tributaries. Details of their abundance are lacking, but the mainstem Chehalis River has been known as a bass-fishing stream for several decades, and observations of large groups of basses exiting large wood accumulations during Washington Department of Fish and Wildlife helicopter surveys where rotor wash disturbed the water surface above these accumulations indicates that their numbers are probably significant. Addition of large wood is an important restoration tool, at least in part for cover and refuge for juvenile native salmonids. Because basses are well known as ambush predators from such cover, it would be important to understand whether large wood additions really provide a net benefit for juvenile salmonids or would simply provide feeding stations at which the introduced centrarchid fishes could find shelter. Uncertainty exists about the ultimate outcomes and responses to these restoration actions, so experimental evaluation of such additions would seem important.

Other potential conflicts may exist that either need evaluation to determine their reality or evaluation to determine whether a suitable path to minimize conflicts exists.

Appendix J
External Factors

The success of the Aquatic Species Restoration Plan (ASRP) will be affected by external factors that operate outside the ASRP. This is especially true for anadromous salmonids that spend most of their life in marine waters. The following factors need to be considered during implementation of the ASRP and in evaluating the effectiveness of restoration actions toward achieving the vision of the ASRP.

Hatcheries: Fish hatcheries have been used for more than 100 years to augment salmon populations to support harvest and to mitigate for environmental degradation (Bottom 1997). Hatcheries have also played a conservation role in supporting at-risk species (Anderson et al. 2020; Flagg 2015). Hatcheries in the Chehalis Basin are managed by the Washington Department of Fish and Wildlife (WDFW) or by other parties in cooperation with WDFW (e.g., the Mayr Brothers facility, Wishkah River, or the Chehalis Basin Task Force facility, Satsop Springs, Satsop River). These hatcheries currently release coho (*Oncorhynchus kisutch*) and fall-run Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) that contribute to harvest and annual returns. Hatcheries can have significant negative impacts on wild or naturally spawning fish due to competition, disease, and introgression (the introduction of genes from hatchery-origin to wild-origin fish). Interbreeding of hatchery and natural populations can decrease fitness and survival of natural populations (HSRG 2002). The potential negative impacts of hatchery production on the fitness and productivity of native species in the Chehalis Basin needs further discussion. Because of this, hatcheries are identified as a regional policy issue in need of further consideration (Section V of the Prioritization and Sequencing Plan to Guide Implementation of the ASRP).

Harvest: Harvest of salmon and steelhead from the Chehalis Basin is managed by international, federal, state, and tribal co-managers operating under treaties and federal and state regulations. Providing harvestable salmon populations in the Chehalis Basin to support commercial, sport, and tribal ceremonial and subsistence fisheries is part of the vision of the ASRP. Healthy and productive salmon populations can generally support fisheries with proper harvest management. However, for fish populations with diminished productivity due to habitat degradation, harvest can have a negative effect and contribute to declining abundance and designation of at-risk status. In the Chehalis Basin, coho, fall-run Chinook, and chum salmon populations currently support ocean, estuarine, and freshwater commercial, sport, and tribal fisheries, while steelhead support freshwater tribal and sport fishing. As climate change, land use, and human population increases in the basin impose additional constraints on productivity, the capability of the populations to sustain harvest at current levels will decline unless restoration efforts are able to offset those effects.

Spring-run Chinook salmon is the Chehalis Basin species that is potentially most negatively affected by harvest due to their vulnerability to the kinds of habitat degradation that have occurred over time. While overall harvest rates (ocean and freshwater combined) on Chehalis Basin spring-run Chinook salmon have not been measured, it can reasonably be assumed that ocean harvest rates on Chehalis Basin spring-run Chinook salmon are similar to those for Chehalis Basin fall-run Chinook salmon due to similar spatial distribution along the continental shelf, though perhaps somewhat less due to their earlier migration timing back to Grays Harbor in the final year of life. Diminished productivity of Chehalis Basin spring-run Chinook salmon due to habitat effects makes this population most susceptible to ocean harvest impacts. It bears noting that within-basin harvest rates on spring-run Chinook salmon have been reduced to extremely low levels (less than 5%) in the past several years, though ocean harvest has continued.

Climate change: Climate change is the preeminent global environmental challenge (IPCC 2014). Changing climate conditions are expected to have significant regional impacts (Mote et al. 2014) and specific impacts in the Chehalis Basin (Mauger et al. 2016). There is now substantial evidence that the ultimate cause of climate change is the increase in atmospheric greenhouse gases resulting from human activities (IPCC 2014). In the Chehalis Basin, climate change is expected to shift precipitation patterns and increase air temperature over the next several decades (Mauger et al. 2016) and raise sea levels in Grays Harbor and the lower Chehalis River (Sandell and McAninch 2014). These environmental changes will negatively affect aquatic habitat for native species by increasing the strength and frequency of winter storm events with impacts on flooding and bed scour, increasing summer and fall water temperatures, reducing summer flow and channel width, and moving the tidal surge plain farther upstream. Thus, climate change will further degrade habitat in the Chehalis Basin and reduce the abundance and productivity of most native species (ASRPSC 2019). Elements of the ASRP are designed specifically to address the effects of climate change that restoration must overcome to result in positive change in species abundance and achievement of the ASRP vision.

Land use: Environmental conditions in streams reflect upland processes occurring throughout their watersheds (Hynes 1975). Flow, sediment, chemical, and organic matter inputs to streams are the result of vegetation, geology, and typography of their watersheds and are affected by land use practices. Intensive agriculture, silviculture, and urbanization generally lead to negative changes to aquatic environments and the native fish and wildlife species they support (Allan 2004). The processes creating and maintaining aquatic habitats are fundamentally linked to upland conditions and land use. Land use management should be recognized as an important factor determining the success of the program and is an important component of the overall Chehalis Basin Strategy.

Like much of Southwestern Washington, the predominant land cover in the Chehalis Basin is still forestlands/grasslands/wetlands (80%), followed by developed lands and agriculture; however, most natural plant communities have been highly modified for timber production and other uses. The predominant land cover[1] in the floodplain of the mainstem Chehalis River in 2013 was agriculture (47%), forest canopy (33%), and development (4%). In the upstream (southern) portion of the Chehalis Basin above Pe Ell, the Chehalis River valley is relatively narrow with less natural floodplain area, and land use is predominantly managed timber lands. Forests account for a large percentage of the Chehalis Basin land cover, and much of that is in commercially managed timber (Gustanski et al. 2020). Headwaters and upper portions of many tributaries to the Chehalis River lie in commercially managed forests. The adverse impacts of commercial logging on streams has been well documented (e.g., Chamberlin et al. 1991; Tschaplinski and Pike 2016) and include increased water temperature, stream bank erosion,

[1] The land cover assessment by Pierce et al. (2017) assumed that all vegetation in the floodplain is either agriculture or canopy. The mapping quantified agriculture to include all herbaceous areas and half of the shrub/small tree areas. Canopy included all forested areas and half of the shrub/small tree areas. Development included built areas.

changes to instream wood loading and recruitment potential, and increased sediment transport. A study of logging practices over a 60-year period in Oregon showed that "contemporary logging practices produced persistent, large summer low flow deficits" for 6 to 9 months of each year compared to unlogged reference streams (Segura et al. 2020). The Washington Forest Practices Habitat Conservation Plan sets minimum riparian buffer widths and other considerations for fish-bearing streams (Washington Forest Practices Board 2001), but it provides less protection to non-fish-bearing streams that provide important habitat for stream-associated amphibian species (Bury et al. 1991). Clear-cut harvest of uplands and portions of the riparian management zone in non-fish-bearing streams under current forest practices has negative impacts on some amphibian species, notably coastal tailed frog (*Ascaphus truei*; McIntyre 2021).

Agriculture in the Chehalis Basin constitutes a relatively small portion of the basin (about 5.8%; Gustanski et al. 2020), but it is concentrated in valley bottoms and floodplains of the Chehalis River and many tributaries, as noted previously. In these areas, it can have effects on streams including alterations to stream hydrology due to irrigation withdrawals and draining of wetlands, increased stream temperatures due to removal of riparian vegetation, input of fertilizer and pesticides, loss of wood and other in-stream structure, channel incision, and increased sedimentation (Berg et al. 2003). Water withdrawal for irrigation can reduce summer base flows and may be a concern in some Chehalis River tributaries such as the South Fork Chehalis River.

Urbanization in the Chehalis Basin is relatively limited but is expected to increase with anticipated human population growth in the basin (Gustanski et al. 2020). This growth is expected to result in the expansion of existing urban centers, including Chehalis, Centralia, the Interstate 5 corridor, and areas around Olympia, with more limited urban expansion in the Aberdeen area. Increased human development and urbanization typically affects stream hydrology as a result of groundwater extraction, reduced aquifer recharge, and increased impervious surfaces that increase peak storm flows, reduce wetland and floodplain habitats, increase pollutants, and direct modifications to stream channels in urban environments (Meyer et al. 2005; Walsh et al. 2005). The increase in human population in the basin will likely exacerbate the negative impacts of future climate on aquatic environments and further reduce the beneficial effects of ASRP actions (Hale et al. 2016). Impacts are generally a function of population density as influenced by zoning and land use planning (Section VII of the Prioritization and Sequencing Plan to Guide Implementation of the ASRP).

Environmental variation: The abundance of salmon and steelhead populations varies widely from year to year. This variation reflects variation in precipitation and other factors in freshwater and large-scale changes in the Pacific Ocean (e.g., Pacific Decadal Oscillation, El Nino). Healthy and productive salmon populations can absorb periodic downturns in survival conditions and persist over time (Lawson 1993). However, weaker species such as spring-run Chinook salmon and populations of other species in the Chehalis Basin could decline to unsustainable levels due to this variability, with implications for the long-term persistence of this run of salmon.

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