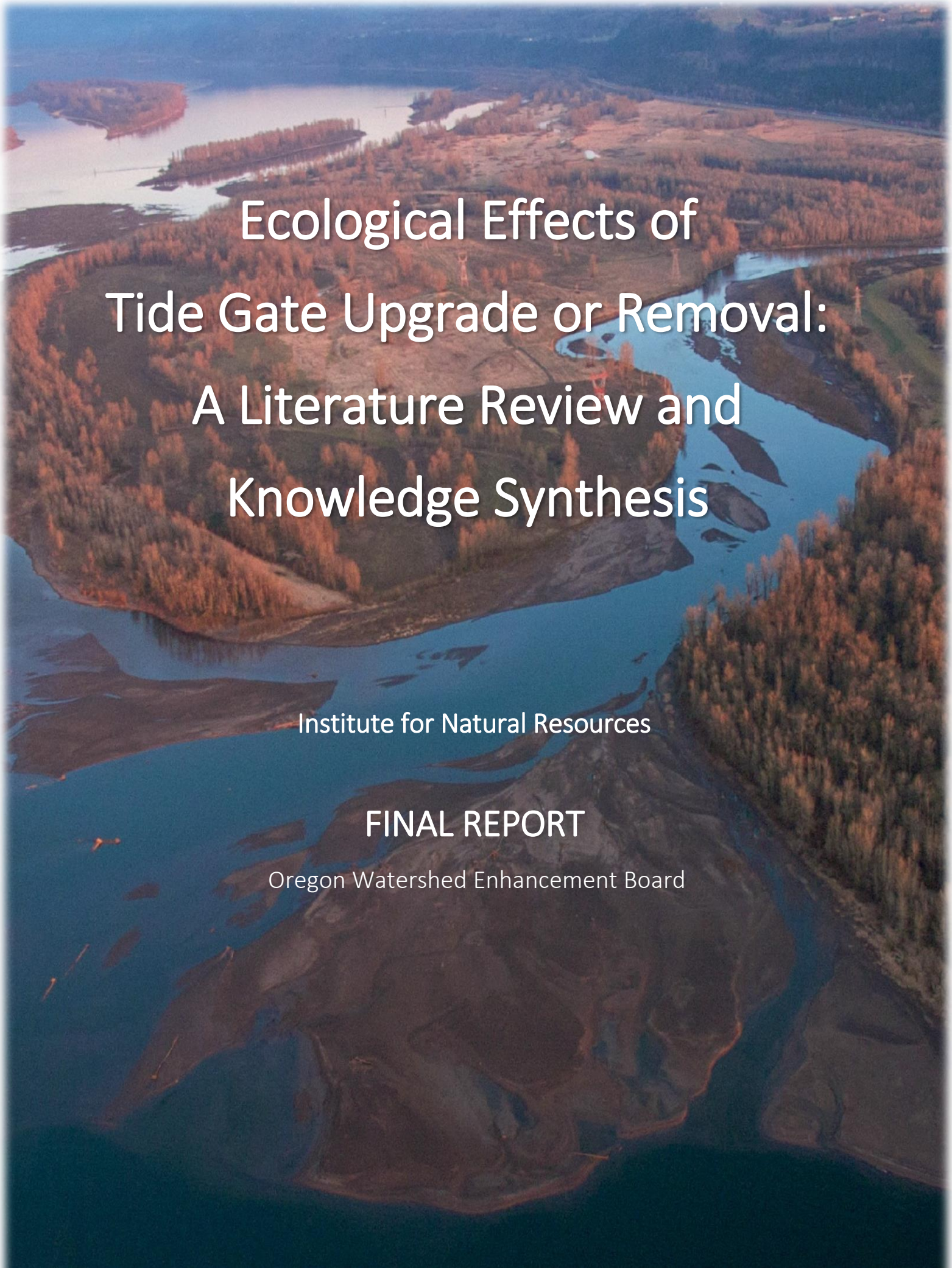

Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis

Institute for Natural Resources

FINAL REPORT

Oregon Watershed Enhancement Board

Ecological Effects of Tide Gate Upgrade or Removal: A Literature Review and Knowledge Synthesis

Final Report

February 2018

Submitted to Oregon Watershed Enhancement Board (OWEB) in fulfillment of grant #217-8500-14090.

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Disclaimer

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The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the material presented. This report does not constitute a standard, specification, or regulation.

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Abbreviations and Acronyms

3FI	Farms, Fish and Floods Initiative
BSDD	Beaver Slough Drainage District
CCMP	Comprehensive Conservation and Management Plan
CDFW	California Department of Fish and Wildlife
CLT	Columbia Land Trust
CoosWA	Coos Watershed Association
CoqWA	Coquille Watershed Association
CPUE	Catch per unit effort
DLCD	Department of Land Conservation and Development
DO	Dissolved oxygen
DSL	Department of State Lands
EMP	Estuary Management Plan
ESA	Endangered Species Act
ESRP	Estuary and Salmon Restoration Program
ESU	Evolutionarily Significant Unit
FEMA	Federal Emergency Management Agency
FWP	Fish and Wildlife Program
GIS	Geographic Information System
HCRCD	Humboldt County Resource Conservation District
HUC	Hydrologic Unit Code
IAE	Institute of Applied Ecology
IMW	Intensively Monitored Watershed
JBHNWR	Julia Butler Hansen National Wildlife Refuge
LCM	Life-cycle Monitoring Project
LCRE	Lower Columbia River Estuary
MLLW	Mean Lower Low Water

MOU	Memorandum of Understanding
MtC	Million Tons of Carbon
MTR	Muted tidal regulator
NAS	National Academy of Sciences
NBA	Net Benefit Analysis
NMDS	Non-metric Multidimensional Scaling
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
NRCS	National Resource Conservation Service
NWR	National Wildlife Refuge
ODA	Oregon Department of Agriculture
ODFW	Oregon Department of Fish and Wildlife
ODOT	Oregon Department of Transportation
OSU	Oregon State University
OTIA	Oregon Transportation Investment Act
OWEB	Oregon Watershed Enhancement Board
OWRI	Oregon Watershed Restoration Inventory
PCFWWRA	Pacific Coast Fish, Wildlife & Wetlands Restoration Association
PIT	Passive Integrated Transponder
PNNL	Pacific Northwest National Laboratories
PNW	Pacific Northwest
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
RGP	Regional General Permit
RM	River Mile
SDHM	Skagit Delta Hydrodynamic Model
SEE	Stream-estuary ecotone
SFC-LPA	Southern Flow Corridor-Landowner Preferred Alternative

SLS	Sustainable Lands Strategy
SRT	Self-regulating tide gate
SRSC	Skagit River System Cooperative
TFI	Tidegates and Fish Initiative
TNC	The Nature Conservancy
TG	Tide Gate
TGID	Tide Gate and Infrastructure Discussion
USACE	United States Army Corps of Engineers
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
WDFW	Washington Department of Fish and Wildlife
WSE	Water Surface Elevation

Executive Summary

This document reports on findings, conclusions and recommendations derived from scientific literature and knowledge regarding the effectiveness of tide gate removal or upgrade in improving conditions for Oregon's native migratory fish species, particularly salmonids, and other plant and animal species that utilize estuarine ecosystems. The project was commissioned by the Oregon Watershed Enhancement Board (OWEB) to foster better understanding of the effectiveness of their past investments in estuary habitat restoration involving tide gates, and to aid in targeting future investments. This will be especially important because many less-complicated projects (e.g. those on public land, smaller, single-action projects, those with consensus on land use) have already been completed, and restoration efforts are becoming increasingly complex and resource intensive. Additionally, restoration actions and benefits can vary considerably according to local conditions. Thus, key questions going forward involve project prioritization and design to achieve maximum return on investments in an environment where demand for projects exceeds available resources. Users of this information may include applicants submitting tide gate and estuary restoration proposals to OWEB, reviewers of these proposals, other OWEB staff, and the OWEB Board of Directors.

The project is premised on the assumption that the ecological effects of existing tide gates are understood well enough to make estuary restoration involving removal or upgrades of aging tide gates generally worthwhile in terms of improved fish passage and estuarine habitat conditions. However, the data on tide gate restoration (removal or upgrade) was not cohesively synthesized. To address this information gap we focused our work around the following four tasks.

Task 1: A review of literature pertaining to tide gate removals and upgrades;

Task 2: Summary and review of completed, primarily OWEB-funded tide gate removal and/or upgrade projects and associated effectiveness monitoring;

Task 3: Summary and review of completed tide gate removal and/or upgrade projects and associated effectiveness monitoring not funded primarily by OWEB; and

Task 4: Summary and synthesis, including findings and recommendations.

We used a multi-faceted approach to knowledge synthesis, including review of relevant scientific literature, OWEB and non-OWEB agency reports on tide gate projects, and inquiries to state and federal agency staff working on estuary restoration in the Pacific Northwest region. The work was completed by a team based at Oregon State University. The report is organized into seven chapters, described below, with significant findings and recommendations at the conclusion of this Executive Summary.

Chapter 1: Introduction provides an overview of tide gates and tide gate hydraulics to help understand their effects. Various types of tide gates are described, including modifications intended to reduce adverse effects on fish passage and water quality. Because tide gate operations are controlled by tidal cycles, we are using an example from the upgraded Willanch Creek tide gates in the Coos Bay estuary to explain how tidal hydraulics govern the timing of gate openings and closing, the degree of opening, and resulting water velocities. The chapter concludes with a discussion of recent OWEB investments in tide gate removals and upgrades, and the desire to have a review of literature and knowledge to lay the

foundation for future programs. Throughout our investigations, we were asked to identify data gaps and areas for future study, as well as major uncertainties or topics of concern that should be considered in grant application reviews for tide gate removal and upgrade projects.

Chapter 2: Methods describes the process we used to conduct the literature search and our examination of completed restoration projects and monitoring. This review focused on four questions:

1. Does tide gate *upgrade* affect salmonid abundance, distribution, growth, survival or habitat availability in the Pacific Northwest (PNW)?
2. Does tide gate *removal* affect salmonid abundance, distribution, growth, survival or habitat availability in the PNW?
3. Does tide gate *upgrade* affect water temperature, salinity, dissolved oxygen and tidal exchange in the PNW?
4. Does tide gate *removal* affect water temperature, salinity, dissolved oxygen and tidal exchange in the PNW?

To conduct our search for relevant literature we utilized systematic review methods (which enhance objectivity and transparency) in conjunction with traditional literature searches. Systematic searches were conducted using Google Scholar and Web of Science. About 350 search results from twelve individual searches were assessed in this manner, producing an initial list of approximately 65 pieces of provisionally included literature, with an additional 15 found through other means. These 80 articles were evaluated and categorized in an Excel spreadsheet, with 32 ultimately considered pertinent for the literature review (although others were used for the ecological context discussion).

OWEB provided project completion and post-implementation reports for restoration and monitoring projects for which they were the primary funder (Task 2). Identifying and accurately describing primarily non-OWEB tide gate projects (Task 3) was not straightforward, due the complex, multi-phase nature of estuary restoration; diversity in participants, funders and project goals; and associated inconsistencies and gaps in project naming, reporting, and monitoring. We identified some primarily non-OWEB projects during systematic searching, and additional projects using variants of project and location names, publication lists, keyword searches within synthesis documents, bibliographies, and queries to estuary restoration entities. We faced similar issues in identifying primarily non-OWEB monitoring efforts. Monitoring was sometimes linked with a particular tide gate removal or upgrade, but was usually focused on watershed-level restoration with multiple components. This limited our ability to distinguish results associated with tide gates from broader watershed-level findings. We included projects from British Columbia, Canada to Humboldt Bay in northern California. Some were well documented while others were not, so the level of detail provided for each project varies.

Our searches to identify and review primarily non-OWEB tide gate projects were extensive but not exhaustive. A “deeper dive” into projects already identified would likely reveal additional information.

Chapter 3: Ecological Context of Tide Gates in Streams and Estuaries examines the effects of existing tide gates, salmon life history diversity, and the importance of coastal marsh habitats for juvenile salmonids. We began with the assumption that ecological effects of tide gates were well understood and accepted. During our investigation we found additional evidence of effects resulting from existing tide gates. We also found new information on early migrating estuary-rearing coho salmon life histories contributing to

the spawning population and highlighting the importance of estuarine habitats to a broader range of juvenile salmonids than previously recognized. We include this information as context for our discussion of tide gate removals and upgrades, and as evidence for the value of such projects.

Chapter 4: Effects of Tide Gate Upgrades and Removal on Aquatic Organisms and Estuarine Environments is a review of findings on this subject reported in the scientific literature (i.e., peer-reviewed journal articles and graduate student theses) and various project reports identified via literature searching. Our review was focused on the Pacific Northwest but included studies from other regions. Documentation and availability of monitoring data—even in cases where we found evidence that monitoring was done—varied significantly from project to project, and by region. Where monitoring data were available, interpretation and synthesis were often insufficient to allow for robust conclusions. Summaries and findings are drawn from peer-reviewed literature and M.S. theses where available, but are also informed by a significant amount of information from non-peer reviewed agency reports and monitoring data. Very few studies only examined the effects of tide gate upgrades or removal independently of other restoration actions. Thus, for most studies we could not distinguish the confounding effects of different actions. As a result, we were not able to answer the guiding questions separately. Instead, we identified two main themes related to tide gate upgrades and removals- 1) effects on salmonids and other aquatic organisms and, 2) effects on water quality- that we used to organize our synthesis of 32 publications. Only a few of these publications were directly relevant to addressing the four guiding questions. The rest provided valuable information to better understand the general context of how and why tide gate upgrade and removal projects benefit salmonids and other aquatic organisms as well as their estuarine habitats. Individual summaries of these publications are included in Appendix A.

Chapter 5: Regional Project Summaries complements the literature review by showing the extent and diversity of estuarine restoration projects in Oregon, Washington, and northern California, extracting information from the detailed project descriptions found in Appendix B (primarily OWEB-funded) and Appendix C (primarily non-OWEB funded). Forty-seven restoration projects in five different regions are highlighted, including 14 in Oregon where OWEB was the primary funder (and another eight primarily funded by others). These projects highlight the diversity of tide gate related estuarine restoration, ranging from single tributary stream tide gates to complex projects involving multiple tide gates, levee setbacks, habitat restoration, and infrastructure improvement. Chapter 5 also discusses monitoring efforts that evaluate these projects. This monitoring includes implementation (whether the project was implemented according to designs), effectiveness (whether the project was likely to meet its goals), and validation (how do these projects fit into the larger status and trend, and salmon life cycles). Thirteen OWEB-funded monitoring projects are discussed, along with an additional 21 funded by others.

Chapter 6: Thinking Systematically about Tide Gates synthesizes the work described in Chapters 3, 4, and 5 into a framework that can be used for program development. We identify four types of project goals (developing estuarine rearing habitat, improving fish passage, providing flood control, and protecting infrastructure) that typically guide tide gate related restoration projects. We also identify three general tide gate geographies (river/stream mouths, tributary mouths, and field drains) and discuss their features as they relate to restoration opportunities. Through our analysis of projects in the previous chapter, four common types of tide gate related restoration projects were distinguished (complete tidal reconnection, partial tidal reconnection, tide gate upgrades for fish passage, and tide gate upgrades to improve rearing habitat). Chapter 6 also provides a number of “lessons learned” by restoration practitioners related to

fish ecology, project implementation, and monitoring. The final section discusses regional frameworks for collaboration, project prioritization, and reducing regulatory uncertainty. Washington's extensive experience in restoring its estuaries offers potential models, Oregon's land use planning for estuary management provides a framework to develop a coast-wide programmatic strategy, and there are recent examples of cooperation and collaboration that could provide a structure.

Chapter 7: Findings and Recommendations concludes the report. "Findings" are used to identify key insights of the review team, organized into five themes: physical and ecological effects of tide gates; project scoping, prioritization, and planning; project implementation and effectiveness; future monitoring and information needs; and potential components of a Phase II follow-on project. Each of the findings provides some elaboration, as well as recommendations that OWEB can consider as they move forward with program development.

A subset of the findings and recommendations from Chapter 7, representing the key findings, are summarized below, divided into five categories.

Physical and ecological effects of tide gates

Finding 1: Limited or nonexistent connectivity significantly affects fish community composition and water quality.

Recommendation: The science is clear that for salmonid fish habitat and passage, the absence of tide gates is preferred, if possible. However, this does not take into consideration current land uses and other factors associated with the use of tide gates. Improved tide gates and their active management have the potential to ameliorate many adverse impacts to fish passage and water quality, especially when seasonal passage needs and habitat utilization are incorporated.

Finding 2: Life-history diversity of juvenile coho salmon is greater than previously realized.

Recommendation: The clear implication of this body of literature is that, besides Chinook salmon, coastal populations of coho salmon will benefit significantly from increased connectivity and fish passage opportunities in the freshwater/estuarine ecotones of rivers and this should be incorporated into tide gate design, installation, upgrades or removal projects.

Recommendation: Additional research into juvenile coho salmon rearing life histories and their habitat use would benefit practitioners if targeted to potential restoration strategies and project site selection and implementation.

Finding 3: Estuary rearing provides increased growth opportunities for juvenile coho salmon.

Recommendation: Plan restoration actions with the expectation that all beneficial ecological effects, such as increased prey productivity creating improved foraging opportunities for juvenile salmon, may not occur for several years after project completion.

Project scoping, prioritization, and planning

Finding 4: Oregon's Statewide Land Use planning framework includes detailed requirements for the planning and management of Oregon's estuaries that need to be recognized in project scoping, design, and implementation.

Recommendation: Social, political, and administrative considerations significantly affect the potential types, places, and methods for tide gate related restoration in Oregon's estuaries. Local conservation organizations should work with local county planners in developing future program strategies. The collaborative process for revising the Coos Bay Estuary Management Plan by Coos County and the Partnership for Coastal Watersheds (South Slough National Estuarine Research Reserve and Coos Watershed Association) can serve as a model and pilot for revising other coastal estuary management plans.

Recommendation: OWEB should work with the Oregon Department of Land Conservation and Development to identify processes that facilitate incorporation of restoration considerations associated with both tide gate upgrades and removals as estuary management plans are revised.

Finding 5: Estuary restoration projects increasingly have multiple goals providing joint benefits.

Recommendation: Recognize that projects that can demonstrate some combination of water quality, fish recovery, agricultural conservation, flood protection, climate change resilience, and/or recreation benefits are more likely to be locally acceptable and fundable, but are also more complex and require coordinated project management.

Finding 6: Oregon lacks a comprehensive framework for estuary restoration.

Recommendation: Develop a comprehensive approach to estuary restoration in Oregon that acknowledges diverse stakeholder goals and benefits, while articulating a common vision for human uses of estuaries, floodplains, and coastal wetlands.

Finding 7: Estuary restoration projects increasingly include acquisition of the lands to be restored, a trend that is likely to continue.

Recommendation: Consider working with stakeholders to develop a more integrated approach for identifying lands that are suitable for acquisition as part of a comprehensive estuarine restoration strategy.

Finding 8: Oregon has a system of watershed councils and soil and water conservation districts that work to coordinate and support local restoration efforts.

Recommendation: Continue to build and maintain capacity in Oregon's coastal watershed councils and districts for partnership building, promoting social learning regarding the multiple benefits of estuary restoration, generating support and helping to coordinate locally-acceptable restoration projects.

Finding 9: Mitigation and environmental damage funds are underutilized for estuary restoration in Oregon.

Recommendation: Explore options for applying mitigation to tide gate removal, upgrade and other estuary restoration actions. This may involve administrative rule-making (or statutory changes) to better coordinate mitigation and restoration.

Finding 10: Benefits and effects of tide gates are related to their geographic location: stream/river mouth and tributaries allow tide gate upgrades to meet multiple goals.

Recommendation: To maximize benefits for salmonids (and potentially other benefits such as flood mitigation) prioritize projects where the tide gate(s) are located at stream/river mouths, or tributary creeks.

Recommendation: When considering projects where the tide gate is a located at a field drain, ensure that suitable rearing or off-channel refuge habitat is available, or restored or created as a project component.

Finding 11: A recently recognized ecosystem service of coastal wetlands is their extraordinary capacity to capture and sequester atmospheric carbon (known as "blue carbon").

Recommendation: Continue investments in monitoring of blue carbon dynamics, and methods to quantify potential carbon benefits of coastal wetland restoration. Explore the potential for investment in tidal wetland restoration efforts by considering the interplay of such efforts with carbon sequestration.

Project implementation and effectiveness

Finding 12: The best restoration results have been reported for large scale and comprehensive restoration projects, and not solely tide gate upgrades.

Recommendation: Whenever possible favor comprehensive restoration projects that aim at reestablishing connectivity and ecosystem level processes over those that focus on changing one single factor (e.g., number of fish that pass, water quality above tide gates, etc.).

Finding 13: Upgrading a tide gate is only the first step in the process of improving ecological conditions and fish migration corridors.

Recommendation: To fully realize the potential benefits of restoration involving tide gates, post restoration management plans should explicitly provide for active and adaptive management of the gates in order to incorporate knowledge gained from research and monitoring, and to account for unforeseen effects or outcomes.

Recommendation: Recognize that to optimize tide gate design and management for fish requires a balancing of: 1) gate opening time and width, 2) culvert width, 3) invert elevation, and 4) upstream pool depth at high tide.

Recommendation: Tide gates should be managed seasonally to ensure that fish passage requirements, water temperatures and dissolved oxygen are suitable for juvenile salmonids when they are present in the system. Additionally, any maintenance that requires a tide gate to be closed should be conducted when salmonids are not present.

Future monitoring

Finding 14: The information base on the effects of tide gate upgrades is very limited. Project practitioners lack support to publish monitoring results in peer-reviewed journals.

Recommendation: Provide funding support, incentives, and technical assistance to allow entities conducting monitoring of OWEB estuary restoration projects to develop publications of their findings for submission to peer-reviewed journals.

Recommendation: Continue and expand partnering with research universities to recruit graduate students to test hypotheses regarding tide gates, conduct in-depth monitoring, and publish results.

Finding 15: Long-term monitoring is critical, but this is resource and time-intensive and support for it is usually limited. There is no comprehensive estuary restoration project monitoring strategy.

Recommendation: Develop a more integrated and cohesive monitoring strategy for OWEB estuary restoration projects, starting with rigorous analysis of what questions the monitoring should be designed to inform or answer. Explicitly consider how monitoring results would be used to inform adaptive management of tide gates. To the extent possible, institutionalize and standardize existing OWEB monitoring protocols, so existing data can be compared to new data.

Recommendation: Review monitoring protocols used by other programs in the PNW (e.g. the Columbia Estuary Ecosystem Restoration Program) to inform development of a more standardized and cohesive approach for monitoring OWEB-funded estuary projects.

Recommendation: Carefully consider which projects to monitor, who will be using the resulting knowledge, and how it will be used. Focus tightly on a carefully selected subset of potential sites or projects to track through time, i.e., 10-20 years.

Phase II project opportunities

Finding 16: There is considerable potential for additional qualitative learning and quantitative data synthesis regarding the effectiveness of estuary restoration actions that involve tide gates in Washington and northern California.

Recommendation: Develop a scope of work to continue knowledge synthesis and development of tools to support restoration and infrastructure modernization in Oregon's estuaries. Potential components include gathering and analyzing additional documentation and data sets, developing a monitoring framework, reviewing and synthesizing frameworks for collaborative restoration, and exploring the potential for development and application of a coast wide approach to hydrodynamic modeling to support project prioritization and alternatives analysis.

Finding 17: There is a lack of clear guidance or reports on the likely costs and benefits of various types of tide gate and estuary restoration projects.

Recommendation: Work with the INR review team and others to further develop this concept for use in a programmatic strategy and to support restoration grant reviews.

Conclusion

We believe there is an opportunity to expand and utilize the data sources and leads identified in this project for use in more robust analyses and syntheses, and generate new knowledge regarding the effectiveness of tide gate upgrades or removal. The information and recommendations contained in this report, coupled with additional efforts in the same vein, could foster a more holistic and integrated approach to estuary restoration projects in Oregon that involve tide gates.

Chapter 1 Introduction

Many coastal wetlands in Oregon and along the rest of the Pacific coast have dikes and tide gates that protect lands from flooding and allow for agriculture and other types of land use. Estuarine wetlands close to seaports and urban centers have been particularly vulnerable to conversion. An estimated 25-90% of coastal estuary habitat and nearly 40% of freshwater wetland was lost in Oregon and the Pacific Northwest in the past 150 years and much of this loss was facilitated by anthropogenic activities (dikes, levees, and tide gates) (Diefenderfer et al. 2013, Simenstad et al. 1982, SOER Science Panel 2000). For example, 75% of the shallow water habitat in the Lower Columbia River estuary has been lost since 1925 (Bottom 2011). However, restoration of even 3% of the potentially recoverable area would lead to noticeable increases in the availability of salmonid nursery habitats despite the fact that levels of prey density and plant biomass at restored sites are only 50% and 75% of levels at reference sites, (Diefenderfer et al. 2016).

Tide gates are doors or flaps mounted on the downstream ends of culverts or concrete boxes in dikes and levees or under roads that allow upstream waters to drain while preventing inflows from tidal surges or flood events. Historically, most tide gates were top-hinged and constructed of steel or wood (Figure 1-1). These gates open when hydrologic head on the upstream side is higher than on the downstream side, resulting in high velocity outflow and a default closed position (Figure 1-1). The changes in river-estuary and river-floodplain connectivity that tide gates cause have a range of undesirable physical, chemical, and biological side effects. The ecological effects of the earliest tide gate designs (top-hinged flap doors) are relatively well documented: limited or non-existent tidal inundation (salt or fresh), blocked or delayed fish passage, degraded water quality (e.g., temperature, dissolved oxygen, salinity), and invasion of upland plant communities in what used to be salt marshes. Since the early 2000s, the ecological and geomorphological consequences of regulating estuarine wetlands with top-hinged tide gates have received increased attention and research. This has been driven primarily by concerns over the direct and indirect effects of tide gates on species that utilize estuaries (e.g., salmonids and their habitats) but also on sediment transport, land subsidence, and estuarine water quality.

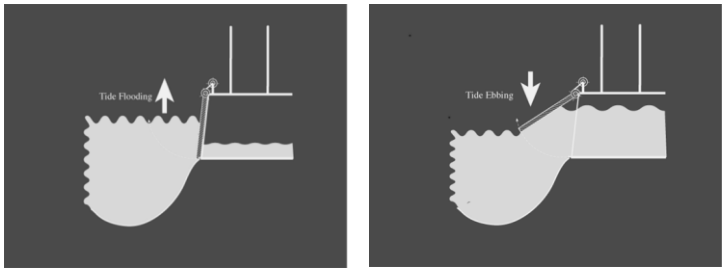

Figure 1-1. Top-hinge tide gate in the default closed position at left; the water elevation is higher downstream forcing the gate closed. At right the water elevation is higher upstream forcing the gate open.

The objectives of estuarine restoration projects often include upgrading existing tide gates with 'fish-friendlier' gates or removal of tide gates entirely in an attempt to restore more natural conditions. Although some restoration projects simply upgrade or remove the tide gate or gates, an increasing proportion also include other restoration actions such as dike removal, breaching, or setback, tidal

channel reconstruction, off-channel habitat construction or reconnection, large wood placements and vegetation plantings. Moreover, current State of Oregon fish passage regulations provide operational criteria for new tide gates and tide gate upgrades, whether as a part of restoration or maintenance activities. Newer 'fish friendlier' gates are usually side-hinged and constructed of aluminum or other lightweight materials, require less hydraulic head to open, and, when sized appropriately, result in lower outflow velocities and longer opening times (Figure 1-2).

Additionally, tide gates may also be fitted with mechanisms that increase the open time and allow greater upstream inflows and improved fish passage opportunities. Early 'fish friendlier' designs included buoyancy compensation (floats) to hold the doors open for extended periods (Figure 1-3).

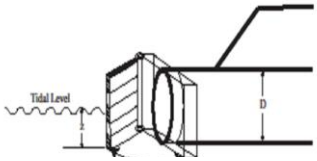

Figure 1-2. Side-hinge tide gate on culvert of diameter D. The tide gate remains open for a portion of the tidal influx when the water elevation downstream is above the bottom of the culvert.

Figure 1-3. Self-regulating tide gate (SRT, top), which is default open. Top-hinge tide gate with mitigator device (bottom), which is open for a portion of the incoming tide.

One example is the self-regulating tide gate (SRT), which has elevated door buoyancy and a set of counterbalancing arms with floats atop the gate (Figure 1-3 top). The buoyant door floats on the incoming tide and remains open until the water elevation reaches the floats, which closes the door. These upgrades cause the door to be open most of the time. Another example is a mitigator device attached to the tide gate door with a cam hinge that holds the tide gate open during end of the outgoing tide and the beginning of the incoming tide (Figure 1-3 bottom). The door closes when the water level reaches the

floats, causing the hinge to rotate and releasing the cam. A more recent design, called a muted tidal regulator (MTR; Figure 1-4), holds the gate open allowing flood tides to enter until the water level upstream reaches a preset surface elevation. This is the only gate control that is dependent on the water level upstream of the tide gate. Some systems have multiple gate types in a single structure. To help illustrate tide gate hydrology and hydraulics we describe below one such system, Willanch Creek in Coos Bay, Oregon, which has a side-hinged gate with a MTR and a top-hinged gate side-by-side.

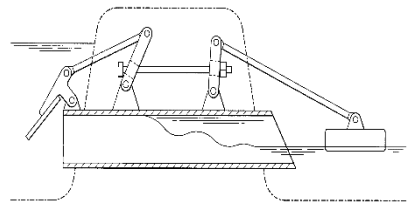

Figure 1-4. Muted tidal regulator (MTR). The tide gate on the estuary side (left) is controlled by the float in the upstream pool (right). Source: U.S. Patent Office, Patent # US6988853 B1.

Tidal hydrology and tide gate hydraulics

Tide gates operate solely on the hydraulic head difference between water on the estuary side of the gate (downstream) compared to the pool reservoir (upstream). In general, when the water surface elevation of the estuary is lower than the water surface elevation of the pool reservoir, gates will open and remain open (to varying degrees) until both elevations are equivalent. The period of time that the gate is open is dependent upon the effective size of the opening (amount opened and opening dimension), and the amount of time that it takes for the tidal elevation to match the pool elevation. Figure 1-6 shows four tidal cycles over two days at the tide gates at the mouth of Willanch Creek in the Coos Bay estuary. Willanch Creek has two tide gates at its mouth: one top-hinged, and one side-hinged with a MTR that holds the gate open during flood tides until a trigger elevation (in the figure, about 3 feet) is reached in the reservoir pool.

The left axis denotes water surface elevation (WSE), and water velocity; the right axis shows the gate

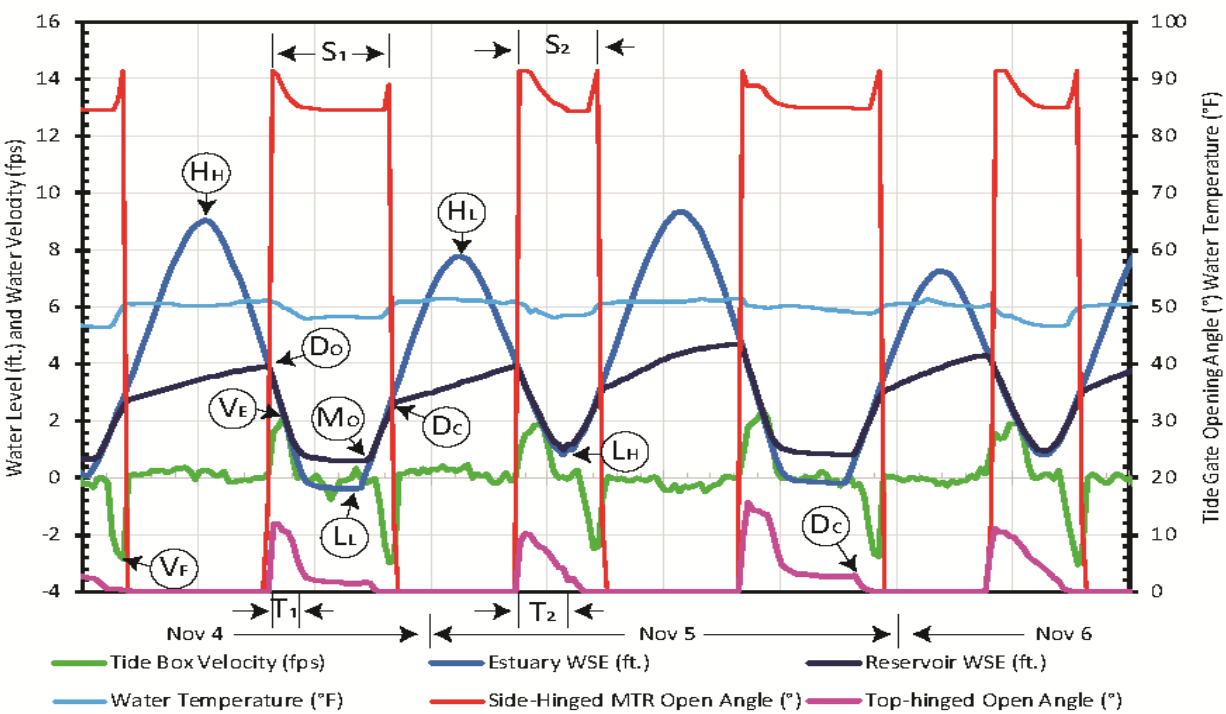

Figure 1-5. Tide gate opening times, opening angles, water level, velocity, and temperature over four tidal cycles at Willanch Creek, Coos Bay Estuary, OR. Source: Coos Watershed Association http://www.cooswatershed.org/wp-content/uploads/2017/01/WillanchTG_Graph.jpeg.

opening angle and water temperature. The horizontal axis represents time, with grid lines every six hours. Labels are placed as space is available, but the patterns are consistent across the tide cycles. The dark blue line is the estuary tidal WSE; the middle blue line is the reservoir pool WSE. The red line shows the opening angle for the side-hinged gate with MTR; the purple line represents the opening angle for the top-hinged gate. The green line denotes the average water velocity through the side-hinged gate opening, with positive values representing outflows into the estuary during ebb tides, and negative values representing flows of estuarine water entering the pool reservoir when the side-hinged gate is held open by the MTR. The lightest blue line is the water temperature inside the tide gate box.

Tidal cycles (driven by the phase of the moon) have a semi-diurnal (twice daily), 13-hour cycle; and within a daily cycle there is a higher-high (H_H) and a lower-high (H_L), as well as a lower low (L_L) and higher-low (L_H). The reservoir pool (middle blue line) drains when the tide gate is open, and refills with fresh water from upstream (and estuarine water when the MTR holds the gate open). The tide gates open (D_O) when the receding tidal elevation matches the reservoir WSE, and they stay open until the rising tide matches the reservoir elevation (D_C, on the top-hinged gate). An MTR holds the door open (M_O) during flood tides for an additional period until the reservoir water surface elevation matches a pre-determined trigger elevation (D_C, on the side-hinged gate) set to avoid unintended flooding.

Fish passage is affected by three, inter-related, factors: (1) the area of the gate that is open (as measured by door angle); (2) the water velocity distributions within the opening; and (3) the amount of time that the gate is open (S_n for the side-hinged door, and T_n for the top-hinged door). The "force" that is driving all three factors is the volume of water stored in the reservoir pool. Door opening periods are a function of how much water can physically pass through the effective opening (opening areas × opening angles) and how fast the water exits (its velocity); and inflows during emptying will extend the opening period. Rainfall patterns change the reservoir elevation: e.g., there is one foot higher pool WSE as a result of rainfall on November 5th.

Thus, there is a trade-off among the size of the openings, water velocities, and opening periods given the volume of water in the reservoir pool. The balancing act is to keep water velocities within the range that the species of interest can handle well by adjusting the opening size: too large an opening will drain the upstream reservoir quickly, while too small an opening take longer to drain but will result in higher water velocities inside the culvert. In general, the gate angle should be open as close as possible to 80° to reduce vortices which are a passage impediment for some fish. The MTR, and other devices that allow estuarine water to enter the reservoir during flood tides, refill the pool faster—and during periods of summer low flows they may allow the gates to open during the higher of the low tides—while providing additional passage during tidal flows into the reservoir until the MTR's pool elevation trigger is activated.

Figure 1-5 shows that the side-hinged gate opens wider (between 80°and 90°) compared to the top-hinged gate (a maximum of about 15°), and stays open approximately 1.5 hours longer per tide cycle due to the MTR. The side-hinged gate is also open longer (S_n) during low-low tides (L_L) compared to high-low tides (L_H) because of the longer period before the tide begins rising again. In the L_L tides, the reservoir pool elevation may be controlled by the invert (bottom of the door, about 1.0 foot), although this doesn't affect the opening period because the rising tide still has to catch up to the invert before the door closes in the absence of an MTR. Velocities during the opening cycle show a distinctive pattern of a maximum outflow velocity of about 2 feet per second (fps) early in the opening sequence when both the top-hinged and side-hinged doors are near to their maximum opening angle and the reservoir pool is completely

filled. Once the reservoir volume is sufficiently lowered the top-hinged almost close and velocities recede to about 0.5 fps during the majority of the opening period. When the tide changes, the inflow (flood) velocities are higher because the effective opening area is less, which in turn is because the top-hinged gate is completely closed. Maximum inflow velocities top out at about 3 fps. While this is considered outside the optimal for coho salmon (*Oncorhynchus kisutch*) juvenile passage velocity of 2 fps, these periods represent less than 0.25 hours during any given tide cycle and happen just as the MTR is closing (D_C). The daily period of opening in the Willanch side-hinged MTR gate is approximately 50% during this season and tidal cycle; this meets current ODFW fish passage criteria. Patterns change by tidal cycle, and seasonal inflows.

Purpose and organization of this report

Since 2007, OWEB has directly funded 12 tide gate upgrade or removal restoration projects totaling $6,948,539, and one pre-restoration grant of $33,960 for infrastructure demolition. Of these 12 restoration projects, two are in progress and ten have been completed. OWEB has also funded 10 tide gate removal or upgrade effectiveness monitoring grants totaling $1,181,442. Of the effectiveness monitoring projects, three are in progress, and seven have been completed. Prior to 2006, there were twelve completed restoration projects with a tide gate upgrade/removal component and three completed monitoring projects. Information on restoration projects prior to 2006 was limited and was not included in this report. However, documentation from the three pre-2006 monitoring projects, totaling $221,243, was available and was included.

Despite the most recent efforts to advance the science and understanding of low-impact tide gates and to focus on estuary restoration, the ecological effects of removing or upgrading tide gates have not been well studied and existing data have not been cohesively summarized. With over $4.5 million already invested and significant future investments foreseen, OWEB sought an up-to-date review and synthesis of knowledge regarding the ecological benefits resulting from tide gate upgrade and removal projects in order to inform future grant applicants, grant review team members, and OWEB Board members. This information will aid in the development and evaluation of grant applications and ultimately help guide decisions about which restoration projects the agency should fund.

This project seeks to synthesize available scientific knowledge in a systematic manner to inform OWEB and other authorities on the effects of past tide gate mitigation and restoration projects on salmonids, other animals and plants that utilize wetland habitats, and estuarine water quality. To this end we have divided our report into several distinct but related sections.

The methods are detailed in Chapter 2, where we describe the process of searching, identifying, reviewing, and synthesizing literature related to tide gate removal or upgrade projects. We document the search and review process as related to four separate tasks that fulfill specific requests from OWEB. The academic literature review includes the discovery, filter, and analysis of references and the summary and synthesis of their findings. Those papers that are categorized for inclusion in the literature review are covered in chapters 3 and 4 and detailed in Appendix A.

The academic review of the literature, which focused on OWEB's questions, is presented in Chapter 4. It is preceded by a short section, Chapter 3, which opens with a summary of the review by Giannico and Souder (2005) on the ecological effects of tide gates and then synthesizes more recent papers detailing additional knowledge regarding these effects. Chapter 3 also reviews recent studies on coho salmon early

nomadic life history and the importance of estuarine habitat connectivity to salmonids during their juvenile phase.

Chapter 5 fulfills the tasks of identifying and describing tide gate restoration and monitoring projects funded either by OWEB or by other organizations. While not exhaustively listing projects in the entire Pacific Northwest, we highlight regional 'hotspots' of estuary restoration that include tide gate mitigation projects and describe the history of projects in these particular estuaries in detail. Additionally, we summarize the results and findings for each primarily OWEB funded project, and a selection of primarily non-OWEB funded projects. References describing these projects are detailed in Appendix B (primarily OWEB-funded) and Appendix C (primarily non-OWEB-funded).

In the first section of Chapter 6, we identify differences in restoration approach based on goals, geography, and tide gate project type. The chapter includes a systematic overview of tide gate projects that includes project goals, possible restoration actions, and the expected effects of tide gate removal or upgrade in each scenario. We examine the monitoring and evaluation of tide gate restoration projects and how these tasks might differ based on whether the project was intended to improve estuarine rearing habitat, fish passage, flood control, or infrastructure protection. The next section discusses findings and "lessons learned", gleaned mostly from primarily OWEB funded project reports, but also from some primarily non-OWEB funded projects including logistical recommendations for future projects.

The last section of Chapter 6 is an exploration of approaches and systems for coordinating estuary restoration in the context of multiple stakeholder, multiple goal projects. We discuss regional frameworks for collaboration and highlight examples that could inform efforts in Oregon to increase communication and cooperation among involved parties. Additionally, we suggest ways to prioritize tide gate projects and reduce regulatory uncertainty for landowners involved in restoration projects.

We summarize our findings, draw conclusions, and present recommendations to address data gaps and future next steps in Chapter 7. This section is intended to draw together the large amount of information presented in the rest of the report and to provide concise conclusions. We also present suggestions for the conditions under which certain project types may be most beneficial and the types of monitoring that best support adaptive management and inform future tide gate restoration projects.

As a brief aside on terminology, when an existing tide gate is modified or removed and a new gate (or updated component of the gate) is installed in its place, it is usually referred to in the literature as a tide gate *replacement*. In this report, we generally refer to either instance as a tide gate *upgrade* under the assumption that the new tide gate or tide gate component represents some type of improvement. However, when a project name or document title uses the term *replacement*, we cite it as such. For the literature search, we mainly used search strings including the term *replacement*. Test searches conducted using the term tide gate *upgrade* were unproductive.

Chapter 2 Methods

In the fall of 2016 OWEB provided a grant to Oregon State University (OSU) to conduct a review and synthesis project focused on the ecological effects of tide gate removal or upgrade. The team completing this work included personnel affiliated with the OSU College of Forestry, OSU Department of Fisheries and Wildlife and OSU Institute for Natural Resources. Work products were divided into four tasks:

- Task 1: Academic literature review
- Task 2: Summary and review of completed, primarily OWEB-funded tide gate removal and/or upgrade projects and effectiveness monitoring projects
- Task 3: Summary and review of completed tide gate removal and/or upgrade projects and effectiveness monitoring projects not funded primarily by OWEB
- Task 4: Summary and synthesis

Task 1: Academic literature review

To complete our search for relevant literature we utilized systematic review methods in conjunction with traditional literature searches. Systematic review is a process originally developed in the late 1980s to enhance objectivity and rigor in the synthesis of scientific studies in clinical medicine but is increasingly being adapted for use in other disciplines, including ecology and environmental management (Pullin and Stewart 2006, Burnett, Giannico and Behan 2006, Doerr et al. 2015). Systematic review generally refers to a focused literature analysis and summary that addresses a specific science question or a small set of related questions, using explicitly-defined methods to search, screen, and synthesize relevant scientific papers and reports. A key step in the process is the pre-work or consultation with end users of the information to specify and refine the question(s) the review will focus on. Transparency is enhanced by use of an explicit review *protocol,* which presents the review's background and purpose, the science questions it will address, details of the literature search strategy, and the criteria for defining which studies are relevant and will be included.

Review questions

Early in the process, the OSU project team worked with OWEB staff to discuss and refine OWEB's information needs and formulate specific scientific questions regarding the ecological effects of tide gate upgrade or removal to focus the literature search process. Among the final four questions, two address effects on salmonids, and the other two address effects on water quality parameters. In both cases, a distinction was made between effects of *upgrading* existing tide gates with newer ones designed and installed in order to reduce ecological impacts, and *removing* tide gates entirely. These questions helped the project team target the literature search and organize results. The review questions were:

1. Does tide gate *upgrade* affect salmonid abundance, distribution, growth, survival or habitat availability in the Pacific Northwest (PNW)?
2. Does tide gate *removal* affect salmonid abundance, distribution, growth, survival or habitat availability in the PNW?
3. Does tide gate *upgrade* affect water temperature, salinity, dissolved oxygen and tidal exchange in the PNW?

4. Does tide gate *removal* affect water temperature, salinity, dissolved oxygen and tidal exchange in the PNW?

OWEB staff also requested that the project team address two additional questions to help guide future investments in estuary restoration:

- What are the known data gaps or areas of future study for tide gate upgrade projects?
- What are the major uncertainties or topics of concern that are important to keep in mind when reviewing tide gate upgrade and removal grant applications?

Literature search

Systematic searches were conducted using Google Scholar and Web of Science. The first 50 search results were saved. If the search produced fewer than 50 results, all were saved. Each saved result was then analyzed for relevance by scanning the abstract and introduction, and searching keywords within each document. If relevant content was found, the reference was entered into an Excel spreadsheet, along with text clips of the relevant content. About 350 search results from twelve individual searches were assessed in this manner, producing an initial list of approximately 65 pieces of provisionally included literature. Initial results of systematic searches are shown in Table 2-1.

Table 2-1. Systematic search results.

Search Engine	Search String	Hits saved	Provisionally included[2]
Google Scholar	tide gate removal coho	48[1]	13
Google Scholar	tide gate removal salmon	50	12
Google Scholar	tide gate replacement coho	50	15
Google Scholar	tide gate replacement salmon	50	17
Google Scholar	"tide gate replacement" coho (SINCE 2010)	16	7
Google Scholar	"tide gate replacement" salmon (SINCE 2010)	15	6
Google Scholar	tide gate upgrade salmon	50	3
Google Scholar	flood gate replacement salmon	49[1]	13
Web of Science	floodgate removal	5	0
Web of Science	floodgate replacement	3	0
Web of Science	tide gate removal	6	3
Web of Science	tide gate removal salmon	4	2

[1]The first 50 hits for each search were saved. If the search returned fewer than 50 hits, all were saved. Some searches returned web link scraps that were not saved.
[2]These results include about 25 duplicates.

The primary criterion for determining the relevance of each reference found during searching was that the document had to address the ecological effects of actively *removing* or *upgrading* a tide gate or gates, as opposed to simply discussing the effects of tide gates already in place. For the purposes of this review, we assumed that existing scientific evidence and consensus regarding deleterious ecological effects of tide gates (see Giannico and Souder 2005) is sufficient to support efforts to modify or remove them. Our focus was on the effectiveness of actions taken to reduce these impacts, not the effects of tide gates themselves. However, more recent studies have increased our understanding of tide gate effects and provide additional context for discussion of upgrade and removal. Accordingly, in addition to literature on tide gate removal and upgrade, we also catalogued recent work on the ecological effects of tide gates (particularly on salmonids and their use of estuary habitats) to the extent that we came across such

literature in our searches. In Chapter 3, this more recent literature is integrated with previous findings in a summary of current knowledge on the ecological effects of tide gates.

Coarse filtering of systematic search results indicated that highly relevant, peer-reviewed literature focused specifically on the effects of tide gate removal or upgrade was very limited. Thus, we turned to non-systematic (traditional) methods to augment the search. In addition to supplementary iterative searching of closely related terms (not documented due to time constraints and high numbers of duplicate hits) we searched literature and publication sections of websites for government agencies and non-governmental organizations involved in estuary and salmonid restoration. We also conducted targeted searches using the names of specific rivers, estuaries and project names, and queried researchers, subject matter experts and estuary restoration practitioners. These methods supplemented our initial body of literature with 15 additional references.

Our focus was on projects in the Pacific Northwest. But given the paucity of peer-reviewed research and findings focused directly on tide gates, we also included relevant literature from other parts of the world, including the U.S. Atlantic Coast, United Kingdom, New Zealand and Australia.

We caution that tide gate removals and upgrades are usually part of larger projects with multiple estuary restoration actions, and that assessment of project effectiveness is usually not focused on tide gates specifically. When tide gates are removed as part of dike removal and setback projects, documentation of these projects often refers only to the dikes and not the tide gates in them. Tide gate and similar terms may not appear as keywords (or even be used) in project reports, even though tide gate removal or upgrade work was done. Lack of inclusion of tide gate or similar terms in project documentation hindered our ability to find potentially relevant documents.

Task 2: Summary and review of completed OWEB-funded tide gate projects

Project completion and post-implementation reports for removal and upgrade projects, and project completion, interim and final reports for monitoring projects, were provided by OWEB for our review. In the course of our literature searches, we identified a few additional projects with significant OWEB contribution. These projects are included in this report. For removal, upgrade, and monitoring projects OWEB was interested in specific information regarding project location, funding and project cost, Oregon Watershed Restoration Inventory (OWRI) metrics, project partners, who performed the work, project summary and findings, changes from proposed, and lessons learned. For monitoring projects, OWEB was additionally interested in the study design, parameters monitored, monitoring focus (tide gate, water quality, biological), biological species monitored, if applicable; and, whether the project examined the larger system, upstream effects, or environment. We included summaries of results by project or estuary following the project descriptions in Chapter 5. Additionally, we present a set of “lessons learned” from primarily OWEB, and primarily non-OWEB funded projects in Chapter 6. Finally, we compiled the information for each project, grouped the projects by estuary, and present them in full in Appendix B.

Task 3: Summary and review of completed tide gate projects not primarily OWEB-funded

Our initial list of primarily non-OWEB funded tide gate projects was compiled from documentation (mostly non-peer reviewed reports) found during the systematic literature search (Task 1). Additional projects were identified by searching different variants of project and location names, keyword searches

within synthesis documents, bibliographies, and queries to entities involved with estuary restoration along with searches of their websites and publication lists.

Identifying non-OWEB projects was not a straightforward process. Reasons for this include: the long-term and often disjointed nature of fish passage and estuary restoration efforts; the diverse range of participating entities; and associated inconsistencies in funding methods, reporting standards, and commitments to monitoring. These factors complicated our ability to define what constitutes a discrete tide gate "project". In some cases restoration components were all part of an integrated project. In other cases the work was funded and completed in discrete phases. Often, several entities worked on components of the same restoration effort, over periods of years or decades, spanning multiple funding cycles. In such cases, information in early planning documents was not always consistent with what was actually implemented years later. Improving access and habitat for salmonids were often primary project goals. But in other cases, these goals were ancillary to flood protection, or upgrading deteriorating dikes or transportation infrastructure. Fairly often, reports on the same overall effort referred to it by different names, e.g., according to particular grants or phases of work in a longer-term effort, or smaller geographic zones within the larger project area.

We faced similar issues in identifying primarily non-OWEB funded tide gate monitoring efforts, finding reports, and summarizing their results. Sometimes, monitoring was closely linked with, and limited to, a particular tide gate removal or upgrade effort. But more often, monitoring was focused at watershed-level restoration that included several individual components or phases, not all of which involved tide gates. This can complicate or preclude the ability to distinguish results associated with tide gate work from broader watershed-level findings. It is also standard practice for monitoring entities or teams to submit annual reports which are often not cumulative and may only contain raw data. Also (likely due to unreliable support) monitoring teams may not submit final synthesis reports that discuss effectiveness or interpret the monitoring data in a larger context. In other cases, more than one entity conducted monitoring, with varying degrees of coordination. It was often not clear whether pre-project baseline monitoring was available, and project reports sometimes contradicted each other on this. Like many funding entities, OWEB sometimes funds part of a larger project in cooperation with other agencies, in multiple project phases, with different entities submitting reports on different phases or aspects of the project to different funders. Thus, it was sometimes challenging to clearly differentiate between tide gate upgrade and monitoring aspects of projects or between OWEB and non-OWEB funded projects.

Owing to these inconsistencies, primarily non-OWEB funded tide gate projects are defined in this report either by particular streams or watersheds in which they occurred, or by the larger restoration efforts of which they were part, whichever made the most sense in each case. We included work done in estuaries from British Columbia, Canada to the Humboldt Bay region in northern California. Some projects were well documented while others were not, so the level of detail provided for each project varies considerably. We tried to identify and document details of any monitoring that occurred for each project, but monitoring efforts are rarely delineated as separate projects. It should also be noted that a comprehensive search for monitoring data for each individual project was beyond the scope of this review.

To streamline comparison with OWEB-funded projects, the information on primarily non-OWEB-funded projects was summarized similarly to the OWEB projects described in the section above. We compiled the information for each project and summarized them by region and estuary, and described representative

projects in Chapter 5. We include "lessons learned" from selected primarily non-OWEB funded projects in Chapter 6, and summarize all such projects that we identified in Appendix C.

Task 4: Summary and synthesis report

As context for the main review in Chapter 4, we provide a summary in Chapter 3 of known ecological effects of tide gates that were presented over a decade ago by Giannico and Souder (2005) and a synthesis of more recently published work on this topic. Chapter 3 also includes a summary of information that illustrates increased awareness and understanding of the importance of estuaries as nursery grounds for species and life-history stages of salmonids that were not considered to be estuarine dwellers until recently.

Chapter 4 is framed by the four questions that guided the systematic literature search, and synthesizes our current understanding of the ecological effects of upgrading or removing tide gates on juvenile salmonids and water quality. We summarize each paper or project and present the results individually, indicating whether they were published as peer-reviewed articles, graduate student theses, or as agency reports. We conclude Chapter 4 by highlighting the most relevant findings of all the literature we reviewed. Information in Chapters 3 and 4 is based on the references included for review in Appendix A.

In the first section of Chapter 6, we address the request for key considerations when prioritizing tide gate projects and uncertainties associated with tide gate upgrade or removal projects. First, we present a systematic framework to categorize tide gates and associated projects by project outcome goals, and tide gate geography or location within the estuary. As mentioned briefly under tasks 2 and 3, Chapter 6 also includes a summary of findings from primarily OWEB and primarily non-OWEB funded projects. We also list "lessons learned", logistical considerations and advice for future project planning, permitting, and implementation, gleaned mostly from primarily OWEB funded projects, but also from some primarily non-OWEB funded projects.

Chapter 6 concludes with a discussion of regional initiatives on estuary restoration planning and execution as examples of programs designed to facilitate coordination and cooperation in larger, more complex projects with multiple partners and goals. These approaches derive their strength and durability from the inclusiveness and compromise inherent in their design. They bring together groups that often are at odds and provide a framework within which they identify common goals and coordinate restoration actions that provide benefits to each party with acceptable costs for all involved.

Chapter 3 Ecological Context of Tide Gates in Streams and Estuaries

This section is intended to lay the groundwork and provide context for the literature review, which follows in Chapter 4. We begin by summarizing Giannico and Souders' (2005) report on the ecological effects of tide gates, including regulatory velocity limitations for various species and life stages. We follow that with a discussion of more recent findings on tide gate effects on fish passage and associated species assemblages. Because coho salmon (*Oncorhynchus kisutch*) are the focal species for most restoration efforts on the Oregon coast, we examine recent research reporting the existence and population contributions of early emigrating, estuary rearing life-history strategies. Then, we review results from life cycle monitoring conducted by ODFW and the Coos Watershed Association to compare productivity among coastal streams, including two that are tide gated at their mouths. Finally, we present recent research that highlights our improved understanding of the importance of estuarine habitat to juvenile salmonids regardless of the life stage or size at migration.

Review of Giannico and Souder (2005)

The ecological effects of tide gates are relatively well understood. In their 2005 synthesis report, Giannico and Souder explained the design and operation of traditional tide gates, described different types of "fish friendlier" tide gates and modifications (reviewed in Chapter 1), and evaluated their impact on water quality, connectivity and fish passage. At the time of their report, the majority of tide gates in the Pacific Northwest were top-hinged with wood or cast-iron doors. These gates are strong and low-maintenance; however, they open only briefly during ebb tide when the hydraulic head upstream is sufficiently high to push the gate open. This leads to high velocity outflows that impede fish passage, thus limiting connectivity between the estuary and upstream areas. Although tide gates and associated structures are often leaky, if working properly most allow very little brackish water inflows by design, creating a sharp contrast between the estuary and the stream system behind the gate.

Tide gates impose a passage restriction through high water velocities and restricted opening periods. The fish not only have to pass through the tide gate but also traverse the associated structure, often a culvert. Fish can only pass a tide gate when it is opened sufficiently wide, the tide gate and its culvert are not completely submerged, there are limited to no water surface elevation discontinuities between the waterway and the tide gate structure, and water velocity through it is low enough to allow for fish sustained swimming. The National Marine Fishery Service (NMFS) does not have published tide gate criteria; however, reports from both NMFS (2011) and the Washington Department of Fish and Wildlife (WDFW 2003) provide general water velocity criteria for fish passage through culverts of different lengths (see Table 3-1). By contrast, the Oregon Department of Fish and Wildlife (ODFW) does not have velocity limitations by culvert length as part of the Administrative Rules of Oregon governing fish passage, but the water velocity criterion in Oregon is 2.0 fps for juveniles of all fish species.

Moreover, tide gate function can be constrained if not properly monitored and maintained because debris may clog the culvert and/or wedge in the door. The new gates and add-ons described in Chapter 1 attempt to enhance fish passage by increasing opening angles and times, and decreasing water velocities through the opening. Additionally, they are meant to provide upstream inundation to increase

connectivity between habitats and foster estuarine plant community production. At the time of their synthesis, Giannico and Souder (2005) noted the lack of empirical evidence comparing the ecological effects of the new tide gates and modifying devices with those of traditional tide gates. In the case of muted tidal regulators, the devices had not existed long enough for any data to be included in their report.

Table 3-1. Maximum velocity of water moving through culverts for passage of salmonids by species, life-stage, and culvert length.

Culvert Length (ft)	Maximum Average Velocity (fps)			
	Adult Chinook, Coho, Sockeye, and Steelhead	Adult Chum and Pink Salmon	Juvenile salmon fry, >60mm (all species)	Juvenile salmon fingerlings, <60mm (all species)
<60	6.0	5.0	1.3	1.0
60-100	5.0	4.0	1.3	1.0
100-200	4.0	3.0	1.3	1.0
>200	3.0	2.0	1.3	1.0

Sources: NMFS 2011 and WDFW 2003.

Tide gates affect upstream water quality and habitat. Because tide gates prevent tidal flows moving upstream, the water in the reservoir behind the gates typically has lower dissolved oxygen, higher temperature, and lower salinity and pH. If no mixing of fresh and brackish waters occurs in these areas, the resulting abrupt change in water quality (especially temperature and salinity) is stressful for fish and other organisms that migrate up- and/or downstream through tide gates. For salmonids, abrupt salinity changes may even cause osmotic shock that can result in juvenile mortality and delayed adult migration. Changes in the water quality of coastal marshlands also leads to changes in plant community. Coastal estuaries that have dikes and tide gates lose their estuarine plant communities when brackish inundation is cut off. Subsequently freshwater aquatic plants or upland species take over, depending on the amount of freshwater influx. These changes in water quality and plant community can make the habitat unsuitable for anadromous or estuarine fish species (Roman et al. 1984, Roman et al. 1995).

Recent studies on fish passage and water quality related to the presence of tide gates

Since 2006, additional studies have added to our understanding of the effects of tide gates on fish passage and water quality in three areas: the effect of high water levels in the receiving stream; the effect of low freshwater inflows on tide gate operations; and the effect of low tides creating perched passage conditions. First, high water levels in the receiving stream can create conditions where gates will not open due to the lack of head difference between the reservoir water level and the receiving water body. This is the case in the lower Fraser River outside Vancouver, BC where gates do not open for long periods during the spring to early summer due to snow melt driven freshets, and pumps are used to drain water behind

the gates (Gordon et al. 2015). This situation is unique to large river systems; however, on the Oregon coast, freshets are more likely to occur in the winter, and high water levels causing this condition would exist for days compared to weeks at a time as in the lower Fraser River (Siefert and Moore 2017).

Second, as discussed in Chapter 1, during periods of low flows into the reservoir from contributing streams, the high-low tides are not low enough for tide gates to open during some tidal cycles because inflows are insufficient to create a positive head difference. Guimond (2010) found this to be the case in Dyke Slough, a tributary to the Courtenay River estuary, on Vancouver Island, BC where during October low flows the tide gates opened twice daily 58% of the time, and only once daily the rest of the days. Low flows also contribute to higher water temperatures, resulting in lower dissolved oxygen (DO) saturation (Guimond2010). However, even with these conditions, Guimond (2010) found coho salmon fry on both sides of the tide gate, although passage conditions hindered the ability of coho juveniles to pass upstream to better overwintering habitat.

A third passage constraint exists when the water level downstream is below the bottom elevation (invert) of the tide gate—which then becomes perched—hindering upstream fish passage for adults and possibly precluding it for juveniles. Poirer et al. (2009) estimated that tide gates at South Deer Creek in the lower Columbia River estuary were perched 46% of the time during adult salmon migration (October through January) and 5% of the time during juvenile salmon migration (March through mid-June). Chinook juveniles (98.6% of the catch) were found on both sides of the South Deer Creek tide gates, although during the April, 2009 sampling 70% were outside the gate, while in June the proportions were 42% found inside and 58% outside (Poirer et al. 2009). Coho juveniles collected in South Deer Creek were of two age classes, and adult coho are known to have spawned in two tributaries, Tide and Merrill Creeks. Poirer et al. (2009) conclude that even with the perching, the top-hinged cast iron tide gates allowed Chinook salmon (*Oncorhynchus tshawytscha*) access to juvenile rearing habitat, and coho (as well as steelhead, *Oncorhynchus mykiss*, and brook lamprey, *Lampetra richardsoni*) access for spawning.

Seasonal opening periods at tide gates affect water quality in their reservoir and upstream. Retaining water in the reservoir pool generally leads to higher water temperatures, as noted in Guillermo and Souder (2005), although this was not found by Siefert and Moore (2017) in the lower Fraser River. Both Poirer et al. (2009) in South Deer Creek in the lower Columbia River, and Guilmond (2010) at Dyke Slough in the Courtenay River, found elevated water temperatures upstream from tide gates, but this was not consistent at all sites. Dyke Slough was often warmer than some sites upstream, leading Guilmond (2010) to hypothesize that groundwater inflows may have contributed to cooler temperatures at some upstream sites. Tide gates on tributaries to the lower Fraser River that do not open have low DO above the gates (Gordon et al. 2015), and those that open less have lower DO than those that open more frequently (Siefert and Moore 2017). Guilmond (2010) found that average DO saturation was highest in the estuary, steadily decreasing going upstream (with the exception of Site 5 at the mouth of a tributary); but that maximum and minimum saturation levels occurred in the reservoir pool, likely reflecting diurnal photosynthesis patterns.

When fish movement is blocked or hindered fish community composition can differ significantly on both sides of tide gates on a seasonal basis, a phenomenon that was documented by Scott et al. (2016) in the lower Fraser River, BC. Similar studies have compared community composition before and after restoration instead of above and below the tide gate. In Crescent Harbor Salt Marsh, WA Beamer et al. (2016a) found only stickleback above the tide gate prior to its removal, but collected 10-16 species in the

years after removal. Prior to restoration at the Kandoll Farm site in the Grays River, WA, only banded killifish were collected, but after installation of culverts to reconnect the slough 9 species were collected (Roegner et al. 2010). Likewise, in the Ni-les'tun Unit of the Bandon NWR species richness increased at specific sampling sites and distribution of species differed after tide gate removal, with coho collected farther upstream and more estuarine species present in creeks (Silver et al. 2015). Species richness also increased in several New Zealand streams above tide gates after the addition of levers to delay closing (Bocker 2015). Finally, fish communities above and below tide gates differ more when the gates open less frequently; in streams where gates rarely open, Seifert and Moore (2017) found that native species richness was ~32% lower above the gates.

The water quality in the reservoir pool and upstream behind tide gates seasonally affects utilization by salmonids. Elevated water temperatures in the reservoir may preclude their use in the summer (Weybright 2011; Guimond 2010). Summer water conditions in the reservoir pool appear attractive to warm water fish species, including exotics (Scott et al. 2015; Siefert and Moore 2017). Fish communities in tide gated systems were found to have higher proportions of non-native species (Seifert and Moore 2017) and the total abundance of non-native fish tended to be higher at gated sites (Scott et al. 2016). While non-native species may make up a high proportion of fish communities where gates are present, they tend to be a relatively minor component in terms of total fish abundance. In the lower Columbia River estuary (LCRE), non-native species comprised 69% and 50%, respectively, of the taxa collected in the tide gated North and South Deer Island sloughs, but native species represented 98% and 85% of the total fish catch (Poirier et al. 2009). It should be noted that in the LCRE sites native fishes were much more numerous than non-native fish but this relationship was driven in large part by the large numbers of threespine sticklebacks (up to 90% of the individuals collected). In the Julia Butler National Wildlife Refuge a broader variety of site types was examined and the proportion of non-native species was negatively correlated with connectivity. Thus the proportion of non-native species was only 12% in ungated reference sites, 37% in upgraded side-hinge gated sites, 44% in newly-connected side-hinge gated sites and 60% in the unconnected control sites (Appendix C, C11) (Johnson et al. 2011).

Coho salmon early life histories

The conventional wisdom was that coho salmon reared in their natal upstream reaches, then moved rapidly as smolts downstream and through the estuary to the ocean, and any juvenile coho found downstream were competitively excluded from preferable habitats and less likely to survive (Sandercock 1991). Only recently was it recognized that early migrating juvenile coho salmon may rear in the estuary during their first summer of life, survive, and even return to spawn as jacks or fully grown adults (Tschaplinski 1988, Miller and Sadro 2003). Koski (2009) described a nomadic life-history variant in coho salmon that enters the estuary as subyearlings and moves back upstream to overwinter in freshwater before emigrating as regular smolts the following spring. Several recent studies have confirmed the existence of this and other early estuarine rearing life histories in the Coos Bay estuary (Weybright and Giannico 2017, Nordholm 2014, Bass 2010, Miller and Sadro 2003,); Salmon River estuary (Jones et al. 2014); Humboldt Bay, CA (Regenack et al. 2015, Wallace et al. 2015); Grays River estuary, WA (Craig et al 2014); and Courtney River estuary, BC (Guimond 2010).

Studies funded by OWEB in Coos Bay, OR using Passive Integrated Transponder (PIT)-tagged subyearling and yearling coho salmon showed that they returned upstream to freshwater habitat as overwintering yearlings and as mature spawners in streams with and without tide gates (Bass 2010, Nordholm 2014).

Otolith analysis of these coho salmon returning as adults showed that this system supports at least three subyearling estuary-rearing life-history variants and one stream-rearing type (Nordholm 2014). All life-history types were represented in the adult spawning population of the tide gated Palouse Creek, and the early estuary rearing life histories made up 31-42% of the spawning runs (Nordholm 2014). Weybright and Giannico (2017) found that during summer the upper portions of Palouse Creek were occupied primarily by sedentary juvenile coho salmon that either did not move far from their natal reach or moved early after emerging from the gravel and settled in a nearby reach. By contrast the lowermost reaches, particularly the one associated with the long reservoir formed above the tide gates, attracted highly mobile individuals that were detected moving among reaches several times. In winter, the highly mobile strategy seemed to be adopted by a higher proportion of individuals throughout the watershed. The sedentary individuals had higher apparent survival rates during winter than mobile fish but the opposite was true in the lower reaches. The authors surmised that a mobile strategy appeared to grant greater survival benefits to fish in glide-like habitat units that were influenced by tidal cycles.

Studies in other estuaries flesh out the picture of estuary rearing coho salmon life histories. Juvenile salmonids do not migrate linearly downstream through the estuary and into the ocean; many individuals may also migrate in and out of estuarine habitats and return to freshwater after spending some time in the estuary. In the Salmon River estuary, OR three of the four coho salmon rearing patterns include estuary rearing phases and individuals that reared in the estuary comprised 20-35% of the returning spawners (Jones et al. 2014). Similar to the Coos Bay tributaries, juvenile coho salmon in Humboldt Bay, CA were also found to be more mobile in winter than in spring and summer (Wallace et al. 2015). Juvenile coho salmon in Humboldt County creeks, CA and the Grays River estuary, WA migrate in distinct pulses as subyearlings and smolts (Craig et al. 2014, Rebenack et al. 2015, Wallace et al. 2015). The juveniles rearing in the stream-estuary ecotone were observed to be larger than those rearing upstream (Craig et al. 2014, Wallace et al. 2015) and early migrating subyearlings were reported to have higher growth rates than stream residents, late migrating subyearlings, and yearlings in the Grays River estuary (Craig et al. 2014). Estuarine rearing subyearling coho salmon were found to have similar condition factors to those rearing above tide gates (Guimond 2010) and to grow faster than freshwater rearing coho and estuarine rearing Chinook (Tryon 2011) in the Courtenay Estuary, BC.

These coho salmon early life-history variants are more reliant on estuarine habitats, particularly tidal marshes and sloughs, than previously realized. Survival rates of the subyearling estuarine rearing life history types probably differs among years with changing ocean and stream conditions (i.e., drought). These life history variants are hypothesized to serve as a “bet hedging” strategy that supports coastal populations in years of poor stream conditions. In the face of rising sea levels, this life history may represent a key to the future viability of coho salmon stocks in coastal watersheds (Nordholm 2014). By altering estuarine rearing subyearling coho salmon behaviors to a greater extent than other life history types, traditional tide gates may reduce the potential productivity boost and resilience that this type may contribute to its populations (Bass 2010). Less studied is the variability in coho salmon spawning run timing, but there may also be variants that are affected by the presence of tide gates restricting their adult movements into and out of the estuary-freshwater ecotone (Quinn et al 2016).

Coho survival in tide gated streams

The ODFW operates a system of seven “Salmonid Life Cycle Monitoring” (LCM) sites along the Oregon coast as part of the Oregon Plan to: 1) estimate abundance of adult salmonids and downstream migrating

juvenile salmonids, 2) estimate marine and freshwater survival rates for coho salmon and 3) evaluate effects of habitat modification on the abundance of juvenile salmonids. However, none of the seven sites is on a tide gated stream. In an effort to better understand freshwater and marine survival of coho salmon in tide gated streams, the Coos Watershed Association in cooperation with ODFW and OSU established two additional life cycle monitoring sites on Palouse and Larson, with funding provided by OWEB. Over the last decade, the Coos LCM program has characterized coho salmon life-history strategies in these tide gated systems (and supported the completion of four M.S. theses), and provided freshwater and marine survival estimates comparable to the sites operated by ODFW. Detailed descriptions of the OWEB-funded projects are included in the monitoring section of Chapter 5. Below, we will focus on the coho survival estimates.

Survival rate estimates are based on data from LCM (juvenile and adult abundances) and individually PIT-tagged fish. The approach from 2004 - 2014 mirrored the ODFW LCM protocols (Suring et al. 2015), but once PIT-tagged fish started returning to their natal streams, tag detections at fixed antennas at the tide gates and upstream provided improved precision (CoosWA 2015). The pattern of apparent freshwater survival closely tracked survival at other LCM sites along the coast; Figure 3-1a shows these estimates for Palouse and Larson Creeks (tide gated) compared to the two nearest ODFW sites, the West Fork Smith River (WF Smith River) in the Umpqua River estuary and Winchester Creek in the Coos Bay estuary. The pattern of apparent freshwater survival closely mirrors that of the WF Smith River, with Palouse Creek (red line) generally matching or exceeding the Smith River site (purple line), and Larson Creek (blue line) usually somewhat lower. The much smaller, and closer to the ocean, Winchester Creek (green line) displays a different pattern from the other three sites, as well as from the other seven ODFW sites (Suring et al. 2015). The apparent freshwater survival rate for juvenile coho salmon in Palouse Creek peaked in 2010, similarly to other sites, but the magnitude of the peak was nearly double what was reported by ODFW for the WF Smith River site (Figure 3-1a). The apparent freshwater survival rate for juvenile coho salmon in Larson Creek also peaked in 2010; however, the degree of variation reported by ODFW for the WF Smith River in other years was not seen at Larson Creek (Figure 3-1a, blue line) (CoosWA 2015).

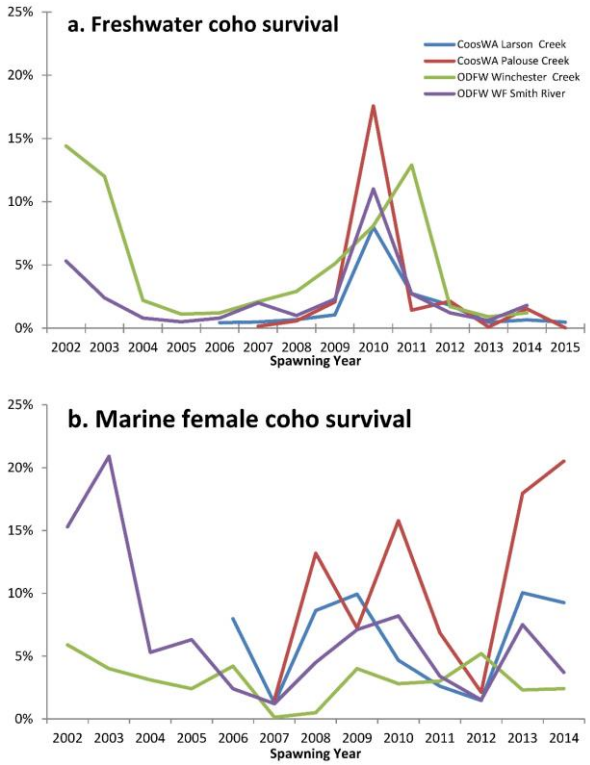

Figure 3-1. Apparent freshwater (top) and marine survival (bottom) for coho salmon in tide gated streams (Palouse and Larson) compared to two non-tide gated streams (WF Smith R. and Winchester Cr.) (CoosWA 2015)

Overall, Palouse Creek apparent marine survival rates are also variable in comparison to other regional LCM sites, generally tracking the WF Smith River but peaking at much higher rates (Figure 3-1b). Apparent marine survival for coho

salmon in Palouse Creek (Figure 3-1b, red line) is highly variable by brood year, with increasing peaks of 13% (2008), 15% (2010) and 18% (2013) interspaced with years of survival below 7% (2007, 2009, 2011 and 2012). Return years 2013 and 2014 showed an apparent marine survival above 12%. In the case of Larson Creek, coho salmon apparent marine survival rates (Figure 3-1b, blue line) ranged between 1% and 10% at approximately 2-year intervals, generally tracking the trend at ODFW WF Smith River LCM site (Figure 3-1b, purple line). (CoosWA 2015).

The Coos LCM data shows that the two tide gated streams follow many of the patterns seen in non-tide gated streams on the Oregon coast, with survival estimates that mirror those sites. While research in these streams has identified passage impediments (Bass 2010), Nordholm (2014) estimated that estuarine life histories comprised 30% of returns in Larson Creek, and 42% in Palouse Creek. It is possible that such contribution of estuary rearing fish to the overall coho salmon production of these streams is constrained not only by the passage restrictions introduced by tide gates, but also by the high summer water temperatures above the tide gates that result from both water impoundment (Weybright and Giannico 2017) and inadequate streamside management practices (CoosWA 2014). On-going LCM studies at the Willanch Creek tide gate in the Coos estuary is likely to provide additional insight as that location has a muted tidal regulator (MTR) and larger estuarine and freshwater wetlands compared to Palouse and Larson Creeks.

Salmonid estuarine habitat preferences

The importance of estuary habitats to migrating juvenile salmonids has become increasingly apparent in recent decades. Subyearling salmon migrants use estuarine habitats differently than smolts. Estuarine habitat use by the two principal species on the Oregon coast, coho salmon and Chinook salmon, are described below.

Coho salmon

Coho salmon utilize distinct habitats within the estuary and their preferences differ by life stage. Subyearling estuarine migrants have been reported to have longer residency times than coho salmon yearlings and Chinook salmon (Tryon 2011). With regards to their diets, the preferred freshwater prey of both subyearling and yearling individuals are aquatic insects (e.g., Chironomidae, Ephemeroptera, Plecoptera and Trichoptera) and, to a much lesser degree, terrestrial insects. Once in the estuary, the diet of subyearling individuals is closer in composition to the freshwater diet because it includes high proportions of aquatic and terrestrial insects, while yearling smolts rely more heavily on crustaceans (e.g., Amphipoda, Cumacea and Isopoda) (Tryon 2011, Mackereth 2016). Coho salmon juveniles in the Courtenay River estuary mainly utilize areas with cover that provide refuge from predators, prefer zones near sources of freshwater input, such as off channel habitats, and demonstrate relatively high site fidelity (Tryon 2011). In the Grays River estuary, WA subyearling coho salmon reared in restored emergent marsh and natural forested wetland habitats in addition to freshwater areas; those rearing in restored emergent marsh habitats had the highest growth rates (Craig et al. 2014). Different life histories may be expressed more fully within the estuary. Coho salmon fry and parr migrants utilized different estuarine habitats in the Grays River estuary with fry relying more on forested marshes and parr preferring restored emergent wetlands (Craig et al. 2014).

Chinook salmon

Estuary habitats are also important for juvenile Chinook salmon. Chinook subyearlings were mainly collected in areas with freshwater influence and complex cover such as woody debris or large rocks in the Courtenay River estuary (Tryon 2011). Chinook benefit from velocity refuges and utilize deep water habitat as such, especially when it is contiguous with intertidal marsh habitats (Tryon 2011). Subyearling Chinook in the estuary ate mainly insects, even when they were not a large proportion of the available prey (Tryon 2011). Recent studies in the Columbia River estuary have shown that 30-55% of juvenile Chinook reside in the lower estuary for more than a month and that they actively forage during this time (Bottom et al. 2011). Additionally, upriver stocks from the Deschutes River, Snake River, and mid-upper Columbia River utilize shallow water habitats in the Columbia River estuary (Diefenderfer et al. 2016). This may mean that there is greater life-history diversity than previously realized because upriver stocks were thought to remain in deeper water and migrate quickly to the ocean. In a separate study, otolith growth data showed evidence of four to five distinct growth pattern trends (life-history strategies) for juvenile Chinook salmon in the Columbia River estuary (Goertler 2014).

Summary

Tide gates affect fish passage, presence, and abundance. Passage is restricted by the presence of a gate (a physical barrier), how long it is open, and outflow velocities. Species presence and abundance may be lower as a direct result of passage impediments. Water quality characteristics such as dissolved oxygen and salinity are generally lower above gates, which may limit fish use of reservoir pools above tide gates during certain seasons, and the abrupt change from freshwater to brackish water they cause may have deleterious effects on juvenile salmonids. At some locations, gates may be perched during some tidal cycles or blocked by extremely high tides or seasonal flows. In an attempt to address these issues several modifications and new tide gates have been designed. These include passage orifices, levers, floats, mitigators, self-regulating tide gates and muted tidal regulators.

Coho salmon early life history diversity and movement are more complex than historically recognized. Juveniles move within and between stream and estuary environments with fish generally more mobile during winter. Coho salmon juveniles may migrate into the estuary in distinct pulses as subyearlings in spring or fall or as smolts the following spring. Some individuals remain in the estuary until they migrate into the ocean while others move back upstream to overwinter. In general survival is lower in the estuary, but growth rates are higher. Estuary-rearing life history variants may contribute 20-40% of adult spawners.

Estuary habitats are important for juvenile Chinook salmon as well as coho. Coho salmon prefer areas with refuge and freshwater input. Coho fry utilize forested marshes while parr utilize emergent wetlands, including restored marshes. Chinook juveniles prefer areas with complex habitat features (wood, rocks) and use deeper water as velocity refuge especially when it is connected to marsh habitats. There is also evidence for multiple estuary rearing life-history strategies for Chinook.

Chapter 4 Effects of Tide Gate Upgrades and Removal on Aquatic Organisms and Estuarine Environments

In this section we examine how tide gates affect salmonids, water quality and estuarine fish nursery habitats. The following four questions were used to guide our literature review and synthesis:

1. Does tide gate *upgrade* affect salmonid abundance, distribution, growth, survival or habitat availability in the Pacific Northwest (PNW)?
2. Does tide gate *removal* affect salmonid abundance, distribution, growth, survival or habitat availability in the PNW?
3. Does tide gate *upgrade* affect water temperature, salinity, dissolved oxygen and tidal exchange in the PNW?
4. Does tide gate *removal* affect water temperature, salinity, dissolved oxygen and tidal exchange in the PNW?

However, given the complexity of most estuarine restoration projects and the manner in which their effects were monitored and reported it is not possible to address each one of these questions separately. Therefore, we will review each project, highlight its main findings, draw parallels among projects where applicable and, finally, discuss the current state of knowledge on the effects of tide gate removal or upgrade.

Below we summarize the results of 32 publications that report on the effects of tide gate removal or upgrades, in many cases as part of larger restoration projects, on both salmonids and the quality of tidal marsh habitats. These publications include peer-reviewed journal articles (9), graduate theses (5), and project completion or monitoring reports by agencies, NGOs or consulting firms (18). Peer-reviewed journal articles undergo a more thorough independent review, MS theses are reviewed by faculty from the students' various committees (advisory and examination committees) and agency or NGO reports are typically just reviewed internally. Study designs and statistical analysis are anticipated to be better in peer-reviewed articles and student theses, but we have done no independent verification for the results reported here. Beyond some comments in the text, the references section of the report indicates whether a publication was peer-reviewed, an M.S. thesis or a report. Their individual summaries are included in Appendix A. There are many interim project progress reports that are inconclusive by themselves; therefore, the entire series plus the final report need to be considered to understand the effectiveness of the restoration projects they monitored. Only a small subset of these publications were directly relevant to addressing the four guiding questions, the rest of the publications help better understand how tide gate upgrade and removal projects may benefit salmonids and fish estuarine habitats.

Effects of tide gate upgrade or removal on salmonids and other aquatic organisms

Bass' (2010) MS thesis, which was largely supported with OWEB funding, was the only study we could find from the Pacific Northwest region that focused on the effects of two different types of tide gates on fish movement in two paired streams (Palouse and Larson Creeks), and included a non-gated creek (Winchester) as a reference site. These small lowland systems that drain in Coos Bay, OR support coho salmon populations with high preponderance (31% to 42%) of a subyearling estuarine migrant life history (Nordholm 2014), which means that tide gates in this kind of coastal basins not only impact out-migrating smolts but also estuarine rearing subyearling individuals. The Palouse Creek tide gates were old top-hinged wooden doors, whereas in Larson Creek the old top-hinged doors had been replaced by side-hinged aluminum doors by the time this study took place. The expectation was that this gate upgrade in Larson Creek would allow for improved fish passage compared to the previous top-hinged door. Unfortunately, Bass (2010) could not collect data prior to the replacement of the old Larson gates, and, therefore, a before/after gate replacement comparison was not done. Instead, Bass (2010) ended up contrasting the fish passage performance of two different types of tide gate in two adjacent streams. Hence, his results were not only influenced by tide gate design or operation but also by the locations of the gates, their different installation in relation to their channels, and the condition of their dikes. In Palouse Creek there was significant leakage in the dike walls underneath the gates to the point that a large lens of salt water formed in the upstream reservoir. However, independently of design and location, Bass (2010) found that the tide gates in his study restricted the free movement of subyearling and smolt coho salmon compared to the daily movement (in both upstream and downstream directions) fish exhibited in the non-gated channel of Winchester Creek.

According to Bass (2010), coho salmon of both age classes showed preference for a specific range of door angles and tailwater depths. In the case of subyearling coho salmon, he observed that their upstream movement through the Palouse top-hinged gates was limited to narrow windows of time during each open cycle because the small fish preferred a range of door angles that only were available for short periods. In contrast, the Larson Creek side-hinged gates seemed to offer better upstream movement opportunities to subyearling coho, which were observed passing during the entire open gate period regardless of door angle. The smolt data show that they preferred passing downstream at greater than average door angles and with high water columns in the culverts (tailwater depths) at both the top-hinged (above 20° angles and 0.3 m in tailwater depth) and the side-hinged (above 40° angles and 1.6 m in tailwater depth) tide gates. However, they did not show any particular angle or water depth preferences when moving upstream. It is possible that the local and abrupt acceleration of flow caused by narrow door angles induced avoidance reactions by fish as was reported by Kemp et al. (2008) and Enders et al. (2009). Considering those facts, Bass (2010) concluded that side-hinged gates were likely to induce passage avoidance only during a small fraction of their open period because their doors tend to remain open at very wide angles. With regards to the avoidance of shallow culvert tailwaters that fish displayed, a solution to this problem would be to ensure that tide gate culverts are installed with low invert elevations so that water column depth is as high as possible. In summary, the side-hinged gates at Larson Creek are likely to be more permeable to juvenile coho salmon passage than its old top-hinged gates may have been; however, both types of gates seem to interfere with the frequent daily movements that Bass observed in fish in the non-gated reference channel. In addition, the above mentioned intrusion of salt

water had some important unexpected consequences on the migration of fish, which are discussed below in the subsection on tide gate effects on environmental factors.

In the Skagit River, WA, significant monitoring effort has been devoted to several projects, primarily Fisher Slough and Crescent Harbor Salt Marsh, both in the delta of the river. Like in most other projects for which reports exist, the work carried out in Fisher Slough included a number of restoration actions such as dike setback (to increase tidal habitat area), ditch realignment and excavation of new tidal channels, tide gate upgrade with newer gate designs (expected to be more permeable to fish movement) or complete tide gate removal (Beamer et al. 2016b, Greene et al. 2016, Henderson et al. 2016). As in several other reports, the monitoring of multiple restoration interventions that were carried out either simultaneously or within a relatively short period of time (2-4 years, which represent a short window of time when trying to detect demographic and environmental responses to restoration actions) make it almost impossible to single out the effects of tide gate upgrade or removal from the rest of the habitat restoration work carried out in this river delta.

The Fisher Slough restoration project involved the replacement in 2009 of 3 paired side-hinged wooden doors with 3 aluminum side-hinged Nehalem Marine muted tidal gates (MTRs) that were installed on an existing concrete headwall under the Pioneer Highway crossing. In addition, two small openings on the headwall below the gates were covered with flap gates, one of which opened with tidal flow and the other with an adjustable arm that allowed for greater management flexibility (Beamer et al. 2014; Henderson et al. 2016). The new system was designed and operated to maximize tidal exchange and improve juvenile Chinook salmon spring migration. Although it was difficult to identify the effects of individual restoration actions on fish, the time lag that existed between tide gate upgrade (2009) and dike setback (2011) in this particular project suggests that the upgrade of tide gates alone did not translate into increased fish rearing densities but mainly improved tidal exchange (Henderson et al. 2016). However, once combined with the setting back and breaching of dikes (which increased the inundated tidal area from 9.8 to 55.7 acres) the benefits of the improved connectivity began to show (Beamer et al. 2014, Beamer et al. 2016b). This was further enhanced in 2015 when the tide gate doors were cable opened at the start of the spring fish migration period. The improved connectivity in Fisher Slough was associated with similar tidal amplitude on both sides of the gates and higher non-ebb passage opportunities for fry-sized Chinook salmon, which increased juvenile abundance above the tide gates. In fact, with the exception of the year 2010, juvenile Chinook densities were not significantly different between habitats upstream and downstream of the tide gates (Henderson et al. 2016), which shows that the combination of new tide gates and tide gate management, along with dike setbacks and other restoration actions improved the access of young fish to upstream rearing habitats. Dike setback, in particular, which involves the construction of new dikes behind existing ones and removal of the old ones to increase the total area of estuarine marshlands, was reported to have a positive effect on juvenile Chinook salmon mean fork length during spring (Beamer et al. 2016b). The fish community in Fisher Slough was best described in the interim report by Beamer et al. (2013), which confirmed the presence of a total of 19 species of fish above the tide gates with approximately 40% of the catch made of juvenile salmonids. Among salmonids, coho salmon (67%) and Chinook salmon (27%) were the dominant species with pink salmon (*O. gorbuscha*), steelhead (*O. mykiss*), chum salmon, and cutthroat trout (*O. clarkia*) making up the rest. Non-salmonid fishes included threespine stickleback, peamouth chub, prickly and Pacific staghorn sculpin (*Leptocottus armatus*), large scale sucker, (*Catostomus macrocheilus*), redside shiner (*Richardsonius balteatus*), starry flounder (*Platichthys stellatus*), pumpkinseed (*Lepomis gibbosus*),

bluegill (*Lepomis macrochirus*), bass (juveniles not identified to species) and Pacific lamprey (*Entosphenus tridentatus*).

Fisher Slough, along with two other sloughs in the Skagit River delta, was also the subject of another study comparing the effects of newly installed fish-friendly tide gates. This work was conducted by Greene et al. (2012) and assessed the effects of replacing: a) 3 passive side-hinged tide gates for 3 side-hinged MTRs, equipped with small submerged pet doors, in Fisher Slough; b) three top-hinged gates for a Golden Harvest 850-R "self-restrained" side hinged door, and 3 passively opening top-hinged gates in McElroy Slough; and c) a top-hinged gate for a 48" side-hinged Nehalem Marine mitigator gate in South Fornsby Slough. This temporally extensive study also included un-gated reference sites. As in other cases, these authors observed that the performance of the tide gates varied widely and was affected not only by their design, but by their installation and operation too. For estuarine-rearing fish species in general and juvenile Chinook salmon in particular, muted gates had a slightly smaller negative impact on upstream habitat use than top-hinged gates but still represented important barriers to fish movement when compared to natural reference sites. This was associated with the amount of time gates were opened, because muted gates remained open twice as long as top-hinged gates but still restricted channel connectivity when compared to ungated reference sites. The authors observed that for other salmonid species with limited use of estuarine habitats the muted gates did not seem to have the same impact than on Chinook because their passage restriction on one-way migrants seems minimal. Water elevation was lower above both types of gates than in the reference sites, and water quality varied broadly by site but also over time. The densities of estuarine rearing fish species were at least one order of magnitude higher at reference sites than where gates were present, and juvenile Chinook densities were at least 4 times greater at reference sites than at sites with muted gates or top-hinged gates (which did not differ). Stickleback was the only fish species that showed an increased density in response to the presence of either tide gate type. In the same report, Greene et al. (2012) included the results of a second study, with a spatially extensive design, which looked at the performance of a wide range of muted gates (i.e., side- or top-hinged, with or without pet doors) in comparison to different top-hinged gates in five different systems across Washington and Oregon: Samish and Padilla Bay, Swinomish Channel, the Skagit River delta, the Chehalis River and Young's Bay. They concluded that in general muted gates reduced connectivity by 50% relative to reference sites and that this change affected assemblages of estuarine fish. It is worth noting that they found that top-hinged gates reduced connectivity by 75% compared to reference sites and, therefore, suggested that muted gates may represent a possible "middle ground" between protecting adjacent land use and benefitting estuarine rearing species. Nevertheless, they made clear that the poor connectivity caused by muted gate placements represent a significant negative impact for estuarine-dependent aquatic species. A less technical version of this report was produced in 2013 by Lyons and Ramsey on behalf of the WA Estuary and Salmon Restoration Program (ESRP).

Johnson et al. (2008) examined the response of salmonids on Tenasillahe and Welch Islands, in the Columbia River, to channel improvements and the upgrade of three top-hinged, steel tide gates with side-hinged gates made of aluminum. The new gates were equipped with manually controlled pet doors that were not opened during the duration of the study. Unfortunately, comparisons with reference sloughs in this study were not conclusive regarding the effects of the gates on fish abundance. However, 13 fish species (including Chinook and coho salmon) were observed in the gated channels and the diversity of native fish species was higher in the reference ungated sites. As a continuation of the restoration work in these islands, in 2009 two dead-end sloughs in the Julia Butler Hansen National Wildlife Refuge (JBHNWR)

were reconnected to the Columbia River using culverts and Golden Harvest side-hinged self-restrained tide gates. The most recent report on the channel connectivity conditions in this system was written by Johnson et al. in 2013. In Chapter 3 of that report the authors indicated that juvenile salmon (mainly Chinook and coho, but also chum and cutthroat trout) had increased their access to sloughs after the installation of SRTs at the JBHNWR. Whereas under pre-restoration conditions (2007) juvenile salmonids were only found in the reference sloughs, by 2012 they were caught in all reaches of all reference, gated, and control sloughs in the Refuge. By contrast, the side-hinged gates did not seem to improve fish passage or water quality at Tenasillahe Island at all (Johnson et al. 2013).

In the case of the Columbia Estuary Ecosystem Restoration Program (CEERP), the synthesis of reports that was carried out by Diefenderfer et al. (2013) was eventually published in a peer-reviewed journal (Diefenderfer et al. 2016). The earlier report presents data in greater detail but the 2016 journal article includes more robust analyses. The general findings revealed weak, albeit positive, habitat and fish responses to the multiple restoration actions performed (which included dike breaching, wetland restoration, channel excavation and grading). Accessibility of juvenile salmon to reconnected wetlands was positively related to the degree to which natural hydrologic function was restored. The authors of this review considered that 'restored' areas were trending towards reference site values in terms of both fish response and water-related metrics. However, this did not seem to hold true in relation to the effects of upgraded tide gates in small sloughs. It is important to take into consideration that sites in this study were sampled only once and the resulting data quantity was somewhat limited, which did not allow for strong conclusions.

Beyond the Pacific Northwest region we only found four studies that examined the response of fish to tide gate upgrades or changes in their operation. Two peer-reviewed journal articles were authored by the same research team, Wright et al. (2014) and Wright et al. (2016) of the U.K. In their earlier publication, Wright et al. (2014) focused on downstream migrating juvenile sea trout, *Salmo trutta*, in the River Meon through four top-hinged, counterbalanced tide gates. Sea trout are the anadromous variety of brown trout and have a life history that resembles that of Atlantic salmon, with repeat spawning in adults and smoltification and sea bound migration normally occurring in 2- to 3-year old individuals (see IUCN Red List of Threatened Species: http://www.iucnredlist.org/details/19861/0). In this study, trout had acoustic tags implanted in them and receivers installed by the tide gates detected their presence. On the second year of the study, a 300-mm diameter orifice was drilled in two of the gates to allow fish passage even when the gates were closed. The researchers found that downstream passage efficiency at the gates was very high (95.8% and 100% in years 1 and 2 respectively), but the gates delayed passage time and the orifices did not reduce such a delay. The main factor in delaying trout downstream migration was the proportion of time during which the gates were closed. Most fish showed a tendency to pass at night. By contrast, the focus of Wright et al. (2016) shifted from juvenile downstream passage in the Meon River to upstream migration of adult S*almo trutta* through three top-hinged tide gates in the Stiffkey River, U.K. One of the tide gates (#1) in this study was retrofitted with an orifice and a float controlled, bottom-hinged pet door (referred to by authors as small flap gate) and was also counterbalanced to increase its opening time and width. This study found that sea trout migration speed in tide gated reaches was, on average, 6 times slower than in reaches without tide gates, and time to pass was inversely correlated with water temperature and stream discharge (i.e., the higher the temperature and discharge values the shorter the time it took for fish to pass). The orifice made in one of the gates neither improved attraction and passage efficiency nor decreased delay because no fish used the opening

when the gate was closed. Flood or ebb tide stage did not seem to influence trout passage, but most adult fish also moved at night. Individual trout made a median of 8 approaches to the gates before passing, and once they passed none returned downstream during the period of the study. Wright et al. (2016) also reported that smaller opening angles in gates were associated with protracted trout passage times.

The other two studies outside the USA are from New Zealand and Australia. The former is a M.S. thesis by Bocker (2015). The 'fish-friendly' alterations to existing tide gates examined in this study consisted on the installation of large levers to delay the closing time of gates, thus increasing the time available for tidal flushing. According to Bocker (2015) the degree to which this type of lever delayed the closing time of a gate could be altered by changing the length of cable and weights applied to the lever. This retrofit seems to be relatively easy to install for a low cost at existing tide gates and, according to Bocker's study, it actually extended tide gate open time from 1.5 to 8 additional hours (depending on site conditions and freshwater discharge levels). In examining the response of the fish community to this kind of tide gate upgrade, Bocker (2015) found not only that the total number of fish species collected upstream of the gates was higher after the levers were installed but also that fish abundance increased. By contrast, such changes in fish species richness and fish numbers were not observed in control sites where gates had not been retrofitted with levers. Despite clear differences in fish community composition between this New Zealand study and the Pacific Northwest region of the USA, it is worth highlighting that these particular gate upgrades reduced water velocities to the point of allowing weak swimming fish species to pass. In Oregon, the weak swimmers that might benefit from such gate upgrades would include several species of sculpin (e.g., *Enophris bison, Scorpaenichthys marmoratus, Leptocottus armatus and Hemilepidotus hemilepidotus*), smelt (*Spirinchus thaleichthys, Hypomesus pretiosus and Allosmerus elongatus*) and stickleback (*Gasterosteus aculeatus*).

The Australian study was carried out by Boys et al. (2012). The upgrades described in this journal article included the addition of small pet doors to some tide gates and the winching of others in open position for extended periods of time. These alterations to either the structure or operation of tide gates in three coastal creeks increased tidal flushing significantly. The response of the aquatic community to these changes was reportedly fast with fish community composition shifting above the gates to the point of resembling fish communities at various reference sites without gates. These changes were clearly due to a larger number of marine and estuarine species of fish and crustaceans moving upstream after gates were altered and were observed to continue during the two years of this study.

When it comes to studies on the effects of tide gate removal, we found only one (Beamer et al. 2016a) that looked exclusively at that particular action. The majority of the estuary restoration work for which we found reports involved a wide variety of almost simultaneous projects (such as dike set back or breaching, wetland restoration, channel re-configuration, etc.) that don't allow the identification of changes in fish movement and habitat use that can be exclusively attributed to tide gate removal. These studies, however, offer a wider context that helps understand why the evaluation of tide gates should not be carried out in isolation from their management and maintenance history, the way they were installed, their location in the watershed, their surrounding environment, the configuration and condition of their dikes, the tidal regime they endure and the species of aquatic organisms they may impact.

Beamer et al. (2016a) reported on the restoration work done in the Crescent Harbor Salt Marsh, Whidbey Island, Puget Sound, WA that included a tide gate being replaced by a bridge. This action resulted in

improved tidal flow and fish access to more than 200 acres of the marsh. Prior to restoration only sticklebacks were caught above the tide gate, but afterwards the number of species found in the upper estuarine area increased to 16, including the following salmonids: juvenile Chinook salmon (both wild and hatchery), juvenile coho salmon, pink and chum salmon, yearling sockeye salmon (*O. nerka*), cutthroat trout and even the rare Dolly Varden (*Salvelinus malma*).

An example of a more complex project is the reconnection of tidal freshwater wetlands in Grays River, Lower Columbia Basin, which involved both dike breaching and tide gate removal. Roegner et al. (2010), in one of the few peer-reviewed journal articles published on this topic for the Columbia River estuary, reported that as a result of such estuary restoration work, fish numbers and species richness changed to the point of matching closely those found at reference sites. Life history stages and fork lengths of salmonids that utilized the reconnected wetlands were the same at all sites: chum salmon (*O. keta*) were present as fry, coho salmon as fry, parr, and smolts, while the less abundant Chinook occurred both as fry and parr. Pre-restoration, some of the wetland habitats were almost exclusively occupied by banded killifish (F*undulus diaphanous*), prickly sculpin (*Cottus asper*) and peamouth chub (*Mylocheilus caurinus*); but after the project was completed nine to eleven different species of fish were found in both restored and control sites (although threespine sticklebacks, *Gasterosteus aculeatus*, made 93.6% of the catch, the remaining 6.4% included chum, coho and Chinook salmon).

In a comparative study of two blind tidal channels in the Salmon River estuary, OR, Hering (2010) reported, in his MS thesis, that there were no significant differences in the growth, residence time and movement of age-0 Chinook salmon between restored and the reference sites. The restored channel had been restored to natural tidal inundation in 1996 after being diked and controlled by a tide gate for 35 years. During the study, the highest abundance of juvenile Chinook salmon was recorded in late spring and early summer before temperatures and salinities reached peak levels in both channels. Seven to nine years after dike breaching and tide gate removal the restored marsh habitat seemed to be functionally equivalent to the reference marsh in terms of juvenile Chinook salmon growth, residence time and rearing densities. However, in 2004 fish in the restored channel had a shorter fork length (6.5 mm less in average).

In Bandon's Coquille River estuary, OR, the Ni-les'tun Tidal Wetland Restoration Project included both tide gate and dike removal. The outcomes of that work were monitored over four years after project completion by Brophy et al. (2014) and Brown et al. (2016). OWEB funded this monitoring effort that mainly focused on plant community composition and hydrology. Therefore, these reports barely mention fish community composition, and the main fish monitoring work was carried out by Silver et al. (2015) for the USFWS. Their conclusion is that the restoration project seems to have increased fish access at channel mouth, while benthic community species richness and overall invertebrate abundance increased both in the mid- and upper-sections. The two most abundant fish species were Chinook and staghorn sculpin and their numbers increased after restoration. Catch per unit effort (CPUE) (a commonly used index of fish abundance) increased after restoration for both Chinook and sculpin, but not for other species such as stickleback. Chinook CPUE seemed to be most closely associated with the presence of large wood in the channels. Although there was no noticeable shift in fish species diversity (because the same species were collected pre- and post-restoration) the numbers of estuarine rearing fish, subyearling Chinook, and sea-run cutthroat trout increased post restoration, which made restored and reference marshes look more alike in terms of fish abundance (Silver et al. 2015).

Effects of tide gate upgrade or removal on environmental factors

Bass (2010) reported stark differences in water salinity and temperature between the Palouse Creek top-hinged gates and the Larson Creek side-hinged gates in Coos Bay, OR. Those differences, however, were more directly related to the condition of the dikes than to the gate designs. The top-hinged gates had a leaky dike wall underneath their culverts, while the new side-hinged gates were installed in a well-sealed dike and their doors shut very tightly. As a result of this, water salinity and temperatures in the reservoir above the top-hinged gates tracked much more closely those in the bay side (higher salinity and lower temperatures) than was the case above the better sealed side-hinged gates. In this case, as a result of infrastructure decay the older gates were allowing better tidal flushing than the newly replaced side-hinged doors. These differences seemed to have important effects on the emigration rates of coho salmon smolts in these streams. Bass (2010) found that increased water temperatures in the upstream reservoir were associated with increased likelihood of downstream smolt migration, while increased water salinities were negatively correlated with smolt emigration. This positive association between water temperatures and coho salmon smolt emigration was also reported in other studies (Sandercock 1991). The response of smolts to the different salinity gradients available in the upstream reservoirs of both creeks helps to illustrate the importance of such transition zones to anadromous fish. At the top-hinged gate with a leaky dike that allowed for the creation of an extensive salt water lens in the upstream reservoir, Bass (2010) observed that the migration rate of coho salmon smolts dropped significantly after encountering higher salinity. Such behavior gives fish the time they need to adjust to the osmoregulatory challenges presented by the estuarine waters. An equivalent delay in migration was not observed in the better sealed Larson Creek side-hinged gate site, which had a very small saline signal that fish seemed to ignore. Bass (2010) argued that the abrupt transition into salt water caused by tightly sealed gates, when combined with a likely reduction in opportunities to move back upstream into freshwater, may have potential negative impacts on the performance and survival of coho salmon smolts. Therefore, maintaining a salinity gradient in the reservoir above the tide gates is important to allow smolts more time to acclimate to salt water before migrating into the estuary.

Mackereth (2016) in her MS thesis examined differences in juvenile coho salmon diets between the freshwater and brackish habitats at the mouths of Palouse, Larson and Willanch Creeks, Coos Bay, OR. All three creeks were tide gated at their mouths. The leaky dike associated with the old top-hinged gates of Palouse Creek (described by Bass 2010 above) allowed for the development of a salt water wedge that could extend up to 1.4 km upstream from the gates when river discharge was not too high. The tighter side-hinged gate at Larson Creek had a much shorter (only 0.01 km long) salt lens above the gates; while the Nehalem MTR gate system installed at the mouth of Willanch Creek allowed enough estuarine water intrusion to form a 1 km long salt wedge in the reservoir. This same muted tide gate system allowed for the greatest freshwater discharge of all three study creeks in the estuary and the total elimination of a brackish water lens above the gate during ebb tides. Mackereth (2016) considered that this less constrained tidal exchange in Willanch Creek caused a much higher proportion of freshwater invertebrates to wash into the upper estuary. The greater abundance of freshwater invertebrates near the mouth of Willanch Creek during ebb times may explain the high similarities between the freshwater and estuarine diets of juvenile coho salmon from this creek. This was not observed in the other two creeks that showed much more different fish diets between both habitats, with crustacean prey only present in the diet of fish captured on the bay side of the tide gates.

Gordon et al. (2015) worked on tributaries of the lower Fraser River, BC, like Scott et al. (2016), but they focused their work on water quality problems in 3 gated sites and 3 ungated reference creeks during summer and were able to show the impacts tide gates may have on some key water quality indicators. They found that dissolved oxygen (DO) was lower in gated streams than in reference systems, in turn the concentration of DO was lower above gates (in average 2.47 mg/L and as low as 0.08 mg/L) than below them and significantly lower than the comparable region at reference sites (8.41 mg/L). The hypoxic zone detected above the tide gates extended at least 100 m upstream. These low oxygen levels are likely not only to exclude many organisms from these zones but also act as chemical barriers that prevent connectivity along tide gated channels. Water temperature did not differ between locations or site types, but salinity and conductivity were lower in reference sites and downstream reaches than upstream of gates, which indicated the absence of complete tidal flushing along these channels. In turn, pH was higher in gated streams. This study was followed by the one by Scott et al. (2016) on a slightly higher number of study sites (5 gated and 5 ungated) in tributaries of the lower Fraser River, which also showed no difference in water temperatures between gated and ungated sites and significantly lower DO levels above tide gates than in any of the reference sites, particularly in the summer months.

The M.S. thesis of Ennis (2009) focused on water quality before and after tide gate upgrade in the tidal channels of Tenasillahe and Welch Islands, Lower Columbia River. This study did not detect significant differences on either mean water temperature before and after tide gate upgrade or between control sites and sites above the new tide gates. However, there was a reduction in minimum temperature at all sites after gate upgrade, and the number of days in which water temperature exceeded EPA limits also decreased. The main change caused by tide gate upgrade seemed to be an increase in the frequency, duration and width of tide gate openings during ebb tides. Additional monitoring of these same tidal channels revealed some different results though, with tide gated sloughs having higher water temperatures, lower dissolved oxygen (although in no case below critical levels) and more emergent aquatic vegetation than reference sites (Johnson and Whitesel 2012). Subsequent reports (Johnson et al. 2013) indicated that after the old tide gates were replaced with lighter side-hinged gates water temperatures in the sloughs became similar to reference sites with 7 day-average-maximum temperatures exceeding 18 °C in the same summer months at both site types.

The project reports by Beamer et al. (2013 and 2016b) and Henderson et al. (2016) in Fisher Slough, Skagit River, WA indicate that the entire suite of marsh restoration actions increased tidal amplitude upstream of gates as well as the duration of the inundation periods, made soil accretion more prevalent than erosion in most sampling sites, and augmented total channel length, area, density, and depth. As anticipated, plant communities changed and became dominated by freshwater tidal native species, but these communities remained different from those in reference sites. Although dissolved oxygen stayed above the stress threshold for salmonids most of the year above the tide gates, it dropped below 8 mg/L on hot summer days. Salinity upstream was almost negligible with values of less than 0.1 ppt. Water temperature was always higher upstream but it did not go above 15 – 18 °C at most sites with the exception of late summer when the seven-day-average-daily-maximum water temperatures often exceeded the juvenile Chinook tolerance threshold of 24 °C (Carter 2005).

The dike and tide gate removal work at the Ni-les'tun Tidal Wetland Restoration Project, Bandon, Oregon resulted in the deepening of channels, an increase in fine sediments, a reduction in plant cover, and reduced plant species richness (Brophy et al. 2014). As expected, soils became richer in salt and in % carbon at the restored site. Temperatures (both mean and daily maximum) were lower in upper channel

reaches after restoration, and periods of time with temperatures above 18 °C were reduced. A subsequent report by Brown et al. (2016) presented a clear recovery pattern in wetland functions over time. For example, tidal hydrology (in particular inundation) was restored to the site, and the plant community has been gradually changing to more salt tolerant native species although species richness was still lower at the restoration site than at the reference site. However, the plant community did not seem to be close to a stable state at the time that report was written.

Among predictive models conceived to forecast restoration outcomes, the tool that Boumans et al. (2002) developed is of some relevance to the questions we address here because it looks at management scenarios where full tides are restored to previously restricted areas. They present a computer simulation that examined potential culvert installations and the resulting tidal ranges, water discharges and flood potentials, and applied it to three New England tidal marshes. Field measurements were needed to determine the relationship between water level and volume. These data populated the predictive model, which accurately simulated tidal exchange. The low marsh habitats anticipated as a result of the removal of tide gates were not predicted to develop immediately but only after 5 and 6 years post-restoration. The model predicted different flow responses to restoration for each one of the sloughs, but concluded that in all marsh vegetation would be negatively affected by marsh surface subsidence.

Anisfeld et al. (1999) carried out the only work we found that examined the effects of tide gates on sedimentation rates in salt marshes. Their project focused on 6 marshes in Connecticut along Long Island Sound. The study sites suffered different kinds of flow restriction not only by tide gates but also by extensive diking that restricted water circulation. Treatments included three restricted sites, two reference sites, and one restored site (tide gates removed). The main findings of this study were that vertical accretion rates (i.e., rate of increase in substrate elevation) were higher in restored than in reference sites (although in other aspects restored and reference sites were very similar), and that these rates were the lowest in sites restricted by tide gates. In general, mass accumulation rates were similar among sites but organic material accumulated more slowly at sites with tide gates.

Bocker's (2015) M.S. thesis, mentioned above regarding the effects of retrofitting tide gates to extend their open times, also reported changes in environmental conditions. Although the main focus of this research was on the response of fish and crustaceans, he found that after levers were installed on the tide gates water conductivity, salt water intrusion and DO increased upstream from the gates, while water temperatures did not differ in a consistent manner. In another study from New Zealand, Franklin and Hodges (2015) also examined the effects of manually opening tide gates for extended periods of time. In their case they kept open one out of six top-hinged wooden gates in a small tidal stream and this simple operation change reintroduced tidal inundation and improved habitat characteristics. Both mean daily water temperature and mean maximum temperature decreased at all sites after that single gate was left opened. The response of dissolved oxygen was not as consistent across sites. Prior to gate opening, DO above the gates was relatively low for many species, but after opening one gate, DO increased significantly upstream of two gates and decreased next to two other gates. Macrophyte cover decreased in upstream areas closest to the tide gates but responses were not uniform throughout the study area. The response of fish was subtle; diadromous fish species increased above the gates. The various changes that resulted from maintaining one tide gate open showed that the reintroduction of even limited tidal exchange may reduce the negative impacts of tide gates by restoring hydrological variability, increasing dissolved oxygen, and decreasing water temperatures.

Long-term effects of tide gate removal and dike breaching

Most projects that evaluated the outcome of these restoration actions focused primarily on changes in plant communities and soils. However, a couple of studies (i.e., Gray et al. 2002 and Bottom et al. 2005) also examined the fish and invertebrate responses to the recovery of estuarine wetlands.

Gray et al. (2002) published a peer-reviewed article in which they assessed natural tidal marsh recovery after the removal of dikes in the Salmon River, OR. Their study took advantage of the unique chronological sequence of dike breaching that was carried out in 1978, 1987 and 1996 and provided a unique space-for-time substitution in their study design. The sequence they observed in the restoration response of the three study marshes allowed them to determine a trajectory of recovery over 23 years and to make simultaneous comparisons with a reference site. Their results showed that peaks in Chinook salmon densities were greatest in the reference and the youngest restoration site (1996). This could be due to the fact that the site restored in 1996 had higher densities of chironomids than the other sites. Differences in invertebrate species abundance were reflected in the diet of the juvenile salmon, which consumed primarily insects (mostly chironomids) in the sites restored in 1978 (the oldest) and in 1996 (the youngest), while those occupying the marsh restored in 1987 had a diet that was mainly based on crustaceans (primarily amphipods). In broad terms, the density of important insect prey species was negatively correlated with recovery age of the marsh but for amphipods there was a slight positive trend in density over time. In this study, metrics for capacity, opportunity, and fish performance differed between recovery sites and the reference site even after two decades of restoration work. All in all, there were significant fish and invertebrate responses in the first three years after the breaching of dikes. The long-term benefits of dike removal for the aquatic fauna are likely to be modulated over time by the development of a mosaic of habitats of different quality, at least within the first 20 years of estuarine restoration work.

Another peer-reviewed publication about the recovery trajectory of tidal marshes in the Salmon River estuary, OR, was that by Bottom et al. (2005). In this study the researchers examined variations in juvenile life-history of fall-spawning Chinook salmon for evidence of changes in estuarine habitat use and migration patterns after the removal of dikes in a 145-ha salt marsh. They were able to document three main life-history types: a) early fry dispersal throughout the estuary and into restored tidal channels soon after emergence from gravel, b) Chinook summer parr entering the estuary in June or July after rearing in freshwater for the first few months of life and remaining in the tidal marshes from weeks to several months before migrating to the ocean, and, c) parr migrating to the ocean in the fall after an extended period of rearing in freshwater or the estuary. The stark contrast between the absence of estuary rearing fry prior to the breaching of dikes (no captures during spring and summer samples taken from 1975 to 1977) and the high abundance of fry and parr detected during those same periods in 2000, 2001, and 2002 indicate that wetland restoration increases estuarine wetland rearing opportunities for juvenile Chinook salmon. Despite variation from year to year in the abundance of this particular early estuary rearing strategy, it is clear that wetland recovery creates opportunities for Chinook salmon to express broad natural life-history variation that contributes to improved long term population resilience in an ever-changing environment.

Mitchell (1981) in her M.S. thesis explored the reestablishment of salt marsh plant communities after dike breaching and the removal of one tide gate in the Salmon River estuary, OR. She identified two undisturbed reference sites and sampled vegetation and soil in a permanent plot-permanent transect

system before and for two years after a dike was leveled and tidal creeks reopened. After tidal restoration upland pasture-type species suffered close to 100% mortality. Residual species cover decreased somewhat, salt tolerant colonizing species increased cover to ~20% and bare ground increased from near zero to ~45%. The proportion of biomass represented by residual species increased after dike breaching from about 50% to 80-97% in 1979 and 1980. The percent cover of residual species is related to elevation, distance from a tidal channel, and drainage efficiency because they cannot tolerate flooding. The colonizing species differed with the degree of flooding as well. In areas with the most bare ground plant vigor was the lowest. At the time of that study, future net primary productivity was projected to increase from 800-1200 $g/m^2/yr$ to 1200-1800 $g/m^2/yr$. Soil changes with dike breaching included increase in interstitial soil water salinity from zero to 18-30 ppt. This was the result of more K, Ca, Mg, Na, B and ammonia in soils after breaching, and reduction in nitrates and P. Soil pH increased after restoration from 4.7 to 5.5, a value similar to control marshes. Organic material was high (25-40%) over the site with very little stratification.

Using the baseline data collected by Mitchell in the Salmon River estuary, Frenkel and Morlan (1990) assessed the restoration phase of a 21-ha diked pasture to a naturally functioning salt marsh eleven years after partial dike removal. The early colonizing plant species were mostly annual and their presence was ephemeral, they were subsequently replaced mostly by permanent colonizers. The elevation of the restored area increased 2-7 cm between 1979 and 1988, but one of the control sites also increased in elevation 6-10 cm. Such increases in elevation were more significant in areas with lower initial elevation and greater inundation. Although initially after dike breaching plant biomass decreased as a result of upland species dying back, by eleven years later it had increased to more than double the control sites. Communities showing a stronger increase were dominated by colonizing rather than residual species. Channels with high connectivity and tidal exchange narrowed and deepened over time; whereas those with low connectivity and limited tidal exchange experienced slight down cutting or sedimentation. Soil salinity had increased from zero to 18-30 ppt after dike breaching, but by the time of this study (eleven years after breaching) the salinity was 22-44 ppt with an average of 31 ppt.

Conclusions

We could not find any studies that directly address the four guiding questions of this section. Therefore, the best option is to take into consideration the tide gate effects some researchers have reported and compare them with some of the results of tide gate removal projects. Independently of their design it seems that no tide gate is completely fish friendly, some may be less (side-hinged gates and muted tide gates) of a barrier than others (top-hinged gates) but all have some impact on fish movement (Bass 2010, Johnson et al. 2013, Wright et al. 2014, 2016, Henderson et al. 2016). Side-hinged gates (particularly the SRT type) may open for longer periods than top-hinged gates but they still interfere with normal upstream and downstream daily movements of subyearling salmonids and with the timing of smolt downstream migration (Bass 2010). Even when their original designs are modified to facilitate fish passage, tide gates have been reported to delay both juvenile and adult trout movement significantly (Wright et al. 2014, 2016). Thus, the Nehalem MTRs installed in Fisher Slough, Skagit River Estuary, resulted in juvenile Chinook salmon densities that were an order of magnitude lower than those of reference sites, yet higher than those where top-hinged gates were still in operation. This was the reason why Greene et al. (2012) considered these MTRs a “middle ground” restoration option.

The publications summarized in this section underline that tide gate upgrade or removal projects produce highly variable results and that the final long-term outcomes are determined, in most cases, not just by the type of gate or operation regime but by their location and the characteristics of the channels in which they are installed. Regardless of specific gate design, it is clear that those that remain open the longest and have as wide an opening angle as possible have a significant positive effect on fish passage conditions and opportunities (Boys et al. 2012, Bocker 2015). Similarly, the effects of tide gate upgrade or replacement projects on water quality and habitat are not consistent. Some studies (Franklin and Hodges 2015) reported DO increases and water temperature reductions above gates only in some of their study locations, while others (Boys et al. 2012) were able to detect only pH improvements above tide gates. Many tide gate upgrades (i.e., drilling of small orifices, addition of pet doors, muted tide gates) by themselves do not have remarkable benefits on fish passage (Johnson et al. 2008, Wright et al. 2014 and 2016, Greene et al. 2012, Henderson et al. 2016). However, not all upgrades are equal and some pet door additions have elicited a positive fish and crustacean community response (Boys et al. 2012), while some muted tide gates have facilitated an increase in fish numbers above gates (Johnson et al. 2013).

The majority of the studies we reviewed examined the effects of tide gate upgrade or removal in the context of larger restoration projects which included other actions such as dike set back or complete breaching, ditch realignment, and new tidal channel excavation. In those cases, the responses to such restoration actions were clearer and more consistent than when dealing exclusively with tide gates. In general terms, any work that improves tidal flushing and increases marsh area contributes to making species diversity, fish numbers, fish body sizes and life-history stages similar to those observed in reference sites (Hering 2010, Roegner et al. 2010, Silver et al. 2015, Diefenderfer et al. 2016, Henderson et al. 2016).

Additional information on the effects of tide gate upgrade and removal projects is available in reports produced for management and funding agencies. As a complement to this literature review, in the next chapters we describe tide gate restoration projects along the Pacific coast in Washington, Oregon, and California and examine their influence on fish passage, abundance, water quality, and habitat. Projects are organized by region and whether they were categorized as restoration or monitoring efforts. Additionally, we present monitoring activities generally used to address different project goals and monitoring types. The regional presentation of projects and discussion of monitoring is followed by a systematic, in-depth examination of tide gates and tide gate projects. We summarize tide gate restoration actions by primary project goals and geography within the estuary or watershed. We then present detailed descriptions of several ongoing efforts to coordinate, prioritize, and increase regulatory certainty for tide gate projects. The focus of these frameworks is to increase collaboration among agencies, restoration entities, landowners, and other stakeholders and to improve the likelihood of implementing projects as well as the quality of the completed projects.

Chapter 5 Regional Project Summaries

Introduction

This section compliments the literature review (Section 4 of this report), by showing the vast extent and diversity of estuarine restoration projects that involve either the removal or upgrade of tide gates. The projects presented are not a complete census of projects in Oregon, Washington, and northern California, but rather focus on five geographic areas where there are concentrations of projects (see Figure 5-1), including, from north to south:

Northeastern Puget Sound in Washington state, focusing on the mouth of the Skagit River;

The *lower Columbia River estuary* in Washington and Oregon, including one project at the mouth of the Sandy River (OR) and another draining into Willapa Bay (WA);

The North Coast of Oregon, including Tillamook Bay and the Salmon River estuary;

The South Coast of Oregon including the Coquille River and Coos Bay estuaries; and

Humboldt Bay in northern California, but also including one project on a tributary to the Eel River just to the south.

We identified 29 individual restoration projects that involved tide gates suitable for inclusion in our analysis. These projects span from the earliest estuary restoration in 1978 (in the Salmon River, OR estuary), to some highly complex and extensive current projects (China Camp-Winter Lake in the Coquille, OR estuary and the Southern Flow Corridor in the Tillamook, OR estuary). Many of these projects involved multiple tide gates, including both removal and upgrade, and were components of larger estuarine restoration efforts. In some cases, the primarily non-OWEB funded projects provided mitigation for other estuarine or river impacts such as fill-and-removal, dredging, and/or infrastructure improvements. Maps supplement our project summaries to provide a context for the individual projects.

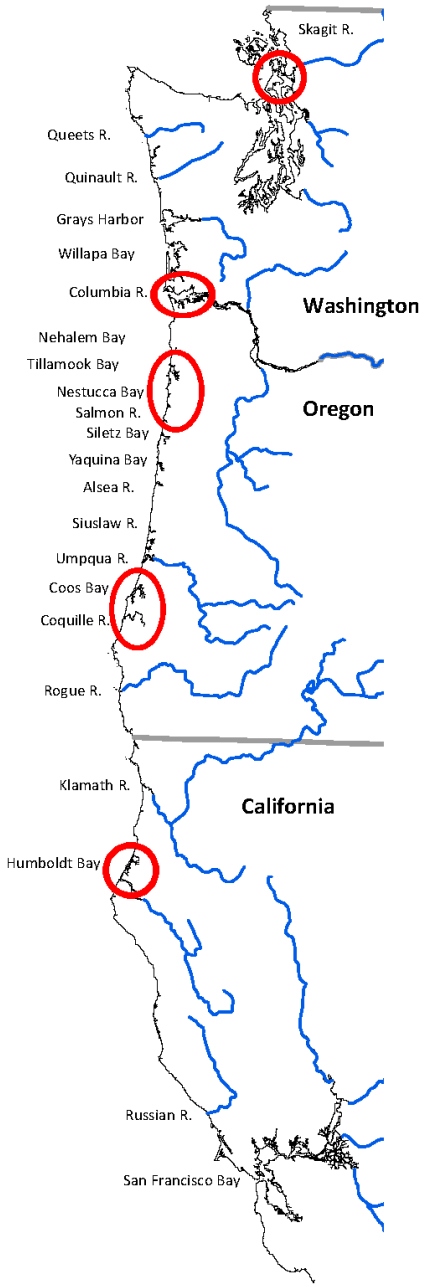

Figure 5-1. Concentrations of tide gate removals and upgrades in the Pacific Northwest.

Relationship to scope of work

This section responds to Tasks 2 and 3 in the scope of work for this project, specifically to identify and provide background information on tide gate related restoration projects and monitoring in the Pacific Northwest. As discussed in Chapter 2, most tide gate related projects have multiple funders, long implementation periods, and produce multiple reports. Additionally, effectiveness monitoring may be tied to a specific restoration project (with or without a unique funding grant), or may be a part of a

Table 5-1. Primarily OWEB-funded tide gate removal and upgrade projects evaluated in this review.

App. Ref.	Project Name	TG Project Type	OWEB Grant #	Primary Goal	TG Geography	Effectiveness Monitoring?
B-1	Willanch Creek Fish Passage and Habitat Improvements	Upgrade	210-2024-7458	Fish Passage	River/Stream Mouth	Yes
B-3	North Slough Restoration Project	Upgrade	212-2022-8872	Fish Passage	River/Stream Mouth	No
B-19	China Camp Creek/Coquille Valley Wetland Conservation and Restoration Project	Upgrade	215-2000-11256 211-115-10755	Estuarine Rearing Habitat	Tributary	Yes
B-21	Ni-les'tun Tidal Marsh Restoration, Bandon Marsh National Wildlife Refuge	Removal	210-2032-7450	Estuarine Rearing Habitat	Drain	Yes
B-28	Thousand Acres Floodplain Restoration Project	Removal	214-3032-10845	Estuarine Rearing Habitat	Drain	No
B-30	Thousand Acres Floodplain Restoration Project, Plant Establishment	Removal	214-3032-11263	Estuary Rearing Habitat	Drain	No
B-34	McDonald Slough	Removal	215-1017-11365	Estuarine Rearing Habitat	Tributary	Yes
B-36	Little Nestucca River Restoration	Removal	207-261	Estuarine Rearing Habitat	Drain	Yes
B-39	Tamara Quays Dike Removal and Fish Passage Culvert	Removal	208-1040, 208-1061-7658	Estuarine Rearing Habitat	Tributary	Yes
B-41	Pixieland Phase 1 – Restoration	Removal	208-1061-8288	Estuarine Rearing Habitat	Drain	Yes
B-45	Pixieland Phase II	Removal	208-1061-8990	Estuarine Rearing Habitat	Drain	Yes
B-48	Waite Ranch Tidal Wetlands Restoration	Removal	212-8004-9544	Estuarine Rearing Habitat	Drain	No
B-50	Kilchis Estuary Preserve Restoration; Kilchis Wetlands Conservation and Restoration Project	Removal	214-1034-10974	Estuarine Rearing Habitat	Tributary	No

broader monitoring program wherein the tide gate specific sampling is conducted.

Specifically, Task 2 requests summaries and reviews of primarily OWEB-funded tide gate removal and upgrade projects (Task 2A), and OWEB-funded tide gate removal and upgrade effectiveness monitoring projects (Task 2B). Table 5-1 provides a list of these projects with references to detailed analyses that respond to the specific requested items for OWEB-funded projects found in Appendix B.

Task 3 requests complimentary summaries and reviews for primarily non-OWEB funded tide gate removal and upgrade projects (Task 3A), and primarily non-OWEB funded tide gate removal and upgrade effectiveness monitoring projects in Oregon, and projects in Puget Sound, the Skagit River system and other areas in the PNW (Task 3B). Table 5-2 summarizes these projects, while Appendix C provides additional detailed information.

Table 5-2. Primarily non-OWEB-funded tide gate projects in Oregon, and projects in Washington and northern California evaluated in this review.

App. Ref.	Project Name	TG Project Type	Primary Funder	Primary Goal*	TG Geography	Effectiveness Monitoring?
Lower Columbia River Region, OR & WA						
C-1	Grays River/Seal Slough, Kandoll Farm (WA)	Removal	BPA	Estuarine Rearing Habitat	Tributary	Yes
C-6	Tenasillahe Island Slough, Julia B. Hansen NWR (WA)	Upgrade	Corps of Engineers	Estuarine Rearing Habitat	Tributary	Yes
C-9	Mainland Unit Restoration, Julia B. Hansen NWR (WA)	Upgrade	Corps of Engineers	Estuarine Rearing Habitat	Tributary	Yes
C-11	Ft. Clatsop South Slough, Columbia River (OR)	Removal	LCREST	Estuarine Rearing Habitat	Tributary	Yes
C-14	South Tongue Point - Liberty Lane OR)	Removal	LCREP	Estuarine Rearing Habitat	Tributary	No
C-17	Wallooskee-Youngs Confluence (OR)	Removal	BPA	Estuarine Rearing Habitat	Field Drain	No
C-20	Chinook River (WA)	Upgrade	WDFW	Estuarine Rearing Habitat	Tributary	Yes
C-23	Greenhead Slough Restoration, Willapa NWR	Removal	SRFB	Fish Passage	Tributary	No
Coastal Oregon						
C-26	Southern Flow Corridor Project, Tillamook Bay	Removal	FEMA, NOAA, OWEB	Flood Control	Tributary	Yes
C-29	Salmon River Estuary	Removal	U.S. Forest Service	Estuarine Rearing Habitat	Drain	Yes
C-32	Phey Lane TG, Siuslaw River	Upgrade	Landowners	Infrastructure Protection	Tributary	Yes
C-34	Kentuck Slough Tide Gate Replacement, Coos Bay	Upgrade	OTIA	Infrastructure Protection	Stream/River Mouth	Yes
C-37	Matson Creek Wetland Preserve	Removal/ Upgrade	USFWS, OWEB	Estuarine Rearing Habitat	Tributary	Yes
C-40	Bandon Marsh	Removal	USFWS	Estuarine Rearing Habitat	Drain	Yes
Puget Sound, WA						
C-42	Crescent Harbor Salt Marsh Restoration Project	Removal	SRFB	Estuarine Rearing Habitat	Drain	Yes
C-46	Fisher Slough Restoration Project	Upgrade	NOAA - ARRA	Estuarine Rearing Habitat	Tributary	Yes
C-51	Wiley Slough Restoration Project, Skagit River Estuary	Removal	SRFB; NRCS; USFWS	Estuarine Rearing Habitat	Drain	Yes

Table 5-2 (con't).

App. Ref.	Project Name	TG Project Type	Primary Funder	Primary Goal*	TG Geography	Effectiveness Monitoring?
C-55	Fornsby Creek/ Smokehouse Tidelands	Upgrade	SRFB	Estuarine Rearing Habitat	Tributary	Yes
C-59	Fir Island Farms Estuary Restoration Project	Upgrade	PSARP	Estuarine Rearing Habitat	Drain	No
C-62	Deepwater Slough	Removal		Estuary Rearing Habitat	Drain	No
C-64	McElroy Slough Estuary Restoration Project	Upgrade	SRFB	Fish Passage	Tributary	Yes
C-68	Shoal Bay Tide Gate Removal, Lopez Island	Removal	SRFB, NFWF	Estuary Rearing Habitat	Tributary	No
C-71	Port Stanley Lagoon Tide Gate Retrofit, Lopez Island	Upgrade	USFWS, WDFW	Estuary Rearing Habitat	Drain	No
C-73	Maxwelton Creek Tide Gate Retrofit, Whidbey Island	Upgrade	NFWF	Fish passage	Tributary	Yes
C-76	Schneider Creek Floodgate Retrofit, Nooksak River	Upgrade	NFWF	Fish passage	Tributary	No
C-78	Qwuloolt Ecosystem Restoration Project	Removal	Corps of Engineers	Estuarine Rearing Habitat	Tributary	Yes
Humboldt Bay Region, CA						
C-83	Rocky Gulch Habitat Restoration Project	Upgrade	Corps of Engineers	Fish Passage	Tributary	Yes
C-86	CDFW Natural Stocks Assessment (Humboldt Bay)	Upgrade	California DFW	Estuarine Rearing Habitat	Tributary	Yes
C-88	Salmon Creek Restoration Project	Upgrade	USFWS	Estuarine Rearing Habitat	Tributary	Yes
C-92	Martin Slough Restoration Project	Upgrade	California DWR	Fish Passage	Tributary	Yes
C-96	McDaniel Slough (Janes Creek) Tidal Restoration	Removal	CA Coastal Conservancy	Estuarine Rearing Habitat	Tributary	No
C-100	Arcata Baylands/Lower Jacoby Creek Enhancement Project (Gannon Slough)	Upgrade	USFWS Coastal Wetlands	Estuarine Rearing Habitat	Tributary	Yes
C-102	Wood Creek Tidal Marsh Enhancement	Removal	USFWS	Estuarine Rearing Habitat	Tributary	Yes
C-106	Salt River Restoration, lower Eel River Watershed	Removal	NRCS	Estuarine Rearing Habitat	Tributary	Yes

*Note: Project scope varies greatly, from removing or replacing a tide gate to projects with multiple habitat improvement components spanning many years and multiple funding cycles from different funders. Therefore, goals and objectives are usually documented for the whole project and for restoration work in addition to tide gate removal or upgrade.

Project Descriptions by Estuary

This sub-section will discuss projects that involve tide gate removals and/or upgrades, highlighting projects that are part of a larger restoration program, strategy, or approach. We will focus on placing the projects in a regional context using the five regions discussed in the introduction to this section and shown in Figure 5-1. Individual maps for each region will be provided to show the geographic relationships among individual projects. These descriptions will briefly summarize the more detailed project descriptions found in Appendix B (OWEB funded) and Appendix C (non-OWEB funded). These

descriptions focus on the restoration; monitoring and evaluation are covered in the following section. The coverage will begin with the Puget Sound region of Washington state, and proceed southward to the Humboldt Bay region in California.

Northeastern Puget Sound

Most tide gate projects that we identified in Washington are located near the mouth of the Skagit River (Figure 5-2). The Skagit River basin is located in northwest Washington and extends into BC, Canada. With headwaters in the high Cascades, the Skagit contributes twenty percent of all freshwater entering Puget

Sound. It has the largest delta and estuary system in Puget Sound, larger than the fifteen other major Puget Sound estuaries combined. The Skagit River floodplain, with its rich mixture of estuarine and intertidal habitats and also some of the best agricultural land in the world, is a major ecological and economic asset to Washington. The area is critical to maintaining native fish and wildlife populations. The

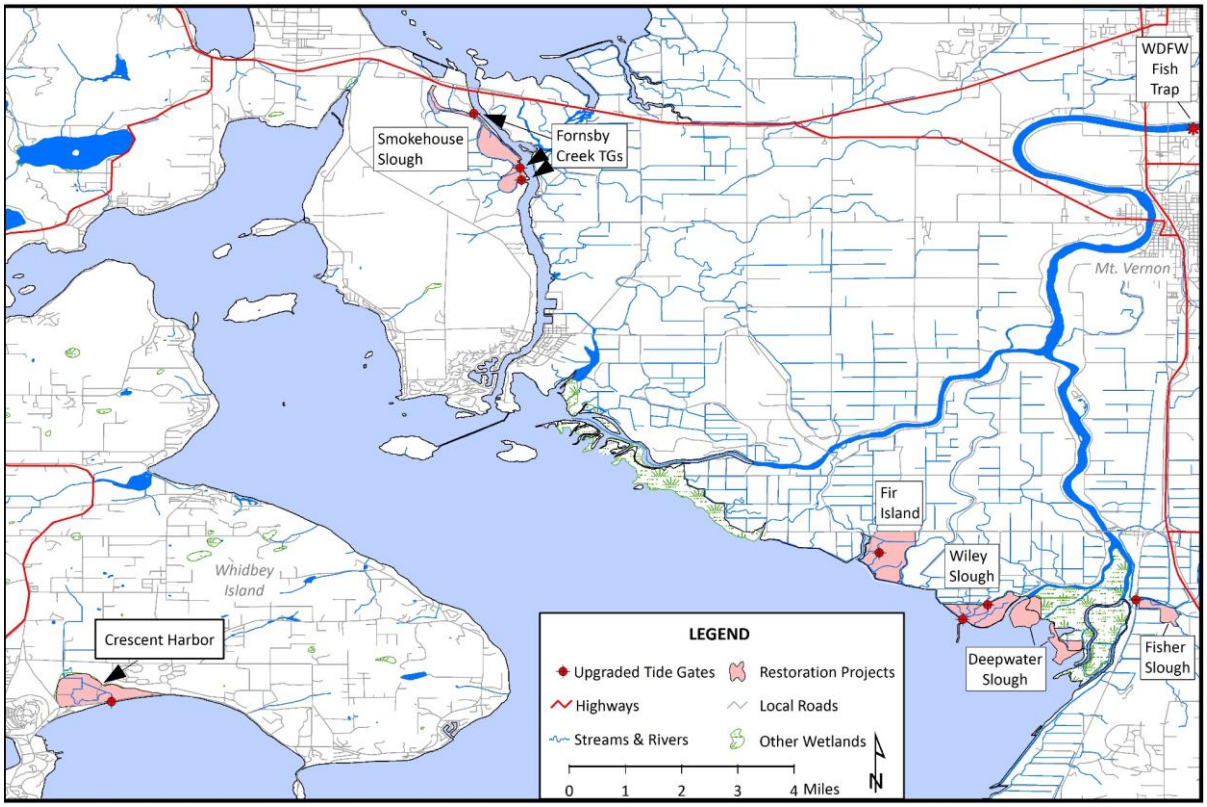

Figure 5-2. Tide gate related projects in northeastern Puget Sound, WA (except Lopez Island and Qwuloolt).

river supports all five salmon species, including the most abundant Chinook run in Puget Sound, and the largest bull trout population in western Washington, as well as steelhead and 17 other fish species.

Logging and construction of levees, dikes and tide gates in the Skagit River basin since the 1850s converted forest and wetlands to farmland, industrial, and urban/suburban residential development. About 120,000 people currently reside in the basin. Rapid population increases are projected. Human

development has significantly impacted the basin's hydrology and geomorphology, which in turn has degraded or eliminated habitat for salmonids historically reliant on Skagit basin tributaries. Low-lying farms, urban infrastructure, and other lands in the floodplain are vulnerable to river flooding and sea level rise. Though not as large as the Skagit, the Snohomish River floodplain has seen a similar trajectory of population growth and development, conversion of tidal lowlands, and subsequent impacts to estuary habitats and salmonid populations.

Most salmonid restoration work in the Puget Sound region is guided by the Puget Sound Chinook Recovery Plan (Plan), developed by local watershed groups in consultation with NOAA National Marine Fisheries Service and finalized in 2007. In 2008 the Puget Sound Partnership became the regional salmon recovery organization, focusing on developing financing plans, and monitoring and adaptive management components for implementation. Annually, groups representing the 15 watershed areas in the Plan develop 4-year work program updates to describe the watershed's accomplishments during the previous year, identify the current status of recovery actions, and to propose future actions and any changes in recovery strategies in the next 4 years necessary to implement the Plan. The Plan includes separate chapters for each watershed, including the Skagit.

Estuary restoration projects in the Skagit basin and elsewhere in Washington are often complex, landscape-scale efforts involving years of planning, land acquisitions, and multiple goals, partners and phases. In addition to federal funding from the US Army Corps of Engineers, NOAA Fisheries, and USFWS, significant funding for estuary restoration is provided via the Washington Recreation and Conservation Office Estuary and Salmon Restoration Program (ESRP), and also the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). Many projects are identified, designed and implemented in coordination with the Skagit River System Cooperative (SRSC), including several that involved upgrading or removal of tide gates.

Fisher Slough Restoration Project. Located in the south fork Skagit River tidal delta near the town of Conway, WA, the Fisher Slough Restoration Project was a collaborative effort to reconnect natural freshwater tidal hydrology to approximately 50 acres of currently diked floodplain; restore historical tidal marsh vegetation communities; provide juvenile Chinook rearing habitat, remove fish passage barriers and improve fish passage to several miles of tributary spawning areas, increase watershed connectivity for coho and chum salmon and other native fish species, and improve floodwater and sediment storage conditions for the tributary levee system. Restoration of the Fisher Slough site was a priority in the Skagit Chinook Recovery Plan to help recover 6 populations of wild Chinook in the Skagit River and their natal estuary. The project broke a long-standing deadlock between agriculture and conservation interests over estuary restoration, restored critical Chinook rearing habitat, and improved fish access to the 22 square mile Carpenter Creek Watershed. Fisher Slough has been monitored extensively and is among the most well-documented projects we examined. In addition to findings summarized below, Fisher Slough monitoring results are also discussed in Chapter 4.

In 2009, NOAA awarded $5.7 million of Recovery Act funding to TNC to restore the Fisher Slough marsh site. Total project cost was $8 million. Construction began in fall 2009, when 3 antiquated, wooden paired tide gates were replaced with aluminum SRTs to improve salmon access to Fisher Slough. The new tide gates are managed by season: fall/winter flood control, spring salmon migration, summer irrigation. The seven-year project was completed in October 2011, with dike setback that increased marsh area from 9.8 to 55.7 acres. Additionally, Big and Little Fisher creeks were rerouted and tidal channels were excavated.

Long-term benefits include reduced risk of structural failure, road damage, and lost farming opportunities caused by flooding, as well as lower maintenance and operation costs. There were also human and social capital gains: conservation organizations, engineering and construction companies, tribes, and drainage and diking districts gained experience in tackling complex problems and finding win-win solutions. Long-standing social barriers and conflicts were overcome, leading to greatly improved relationships and potential for future collaborations.

Across the entire Skagit Basin, projects using dike setback, dike breach, or fill removal had juvenile Chinook densities within the restored area consistent with densities in nearby reference sites. Projects using SRT had much lower juvenile Chinook densities than nearby reference sites. SRTs were better for juvenile Chinook salmon than the traditional top-hinge flapgate they often replace (by ~2X), but SRTs averaged an order of magnitude lower in juvenile Chinook density compared to nearby reference sites. But the combination project at Fisher Slough (dike setback w/tide gate upgrade) performed better. Monitoring detected a 10X increase in habitat use by juvenile Chinook in Fisher Slough upstream of the tide gate, consistent with habitat use observed at other Skagit tidal delta reference sites. This increase was predominantly associated with the dike setback and current operation of the tide gate to allow fish passage during both slack and flood stages of the tide cycle.

The Fisher Slough Restoration Project is widely considered a success with salmonids benefiting more from restoration than expected (Greene et al. 2016). In addition to improvement in fish habitat and estuary ecological conditions, Fisher Slough is notable for having an extensive assessment of socio-economic outcomes from the project, e.g. an expected $7-$21 million in savings from reduced flooding (Weinerman et al. 2012). Other examples in the Skagit watershed include the Wiley Slough Restoration Project, Fornsby Creek/Smokehouse Tidelands Project and the McElroy Slough Estuary Restoration Project.

The state of Washington and federal agencies have made significant investments in pre- and post-project monitoring to assess the effectiveness of estuary restoration in the state, including some studies focused specifically on tide gates. A synthesis by Greene et al. (2012) focused on tide gates by comparing three site types: SRTs, flap gates, and unimpeded reference sites. The study compared ten SRT sites located from the Columbia River estuary north to Samish Bay in northern Puget Sound, five traditional flap gate sites, and five unimpeded reference sites. It also assessed changes in upstream cumulative densities of Chinook salmon across the rearing season, relative to downstream values, before and after SRTs were installed. Greene et al. (2012) and the companion report Lyons and Ramsey (2013, which incorporated manager feedback) constitute some of the most relevant and applicable information that we found regarding the effectiveness of tide gate upgrade and replacement.

Another study that looked closely at tide gate upgrade effectiveness (Beamer et al. 2016b) came out of the large Fisher Slough project. After tide gate upgrade and before dike setback the Fisher Slough sites did not follow the pattern of higher Chinook salmon abundance with increased connectivity seen at long term monitoring sites in the Skagit River delta. However, after dike set back the Fisher Slough sites demonstrated this positive relationship. In a summary of 2009-2015 monitoring data on juvenile Chinook salmon use of restored habitat at Fisher Slough, Beamer et al. (2017) found that the total number of hours of tide gate opening during the non-ebb period 15 days prior to each sampling event better explained variability in the number of juvenile Chinook salmon upstream of the tide gate than the other tide gate operation metrics calculated over 1 and 5 days prior to each sampling event. Specifically, the

longer the duration that the gate was open to fish passage during the non-ebb period over the 15 days prior to each sampling event, the more juvenile Chinook were found upstream of the tide gate.

Qwuloolt Ecosystem Restoration Project, Snohomish Estuary. Though not as large as the Skagit, the Snohomish River floodplain has seen a similar trajectory of population growth and development, conversion of tidal lowlands, and subsequent impacts to estuary habitats and salmonid populations. The Snohomish River drains 1,856 square miles of the western Cascades and is the second largest river draining to Puget Sound. The river supports significant runs of coho, Chinook, chum, and pink salmon, and steelhead, cutthroat and bull trout. The Qwuloolt Estuary lies in the Snohomish River floodplain about 3 miles upstream from the Snohomish outlet to Puget Sound. Historically, the area was tidal emergent marsh and forest scrub-shrub wetland, interlaced by tidal channels and streams. In the early 1900s a levee was constructed on Ebey Slough and tide gates were installed at the mouth of Allen and Jones Creeks to convert the land to agriculture, preventing tidal access and destroying the estuary's marsh habitats. As a result, salmon and other estuarine-dependent species were unable to use the highly-productive environment. Prior to restoration the area was fallow agricultural land covered by invasive reed canary grass, thistle, and blackberries.

The Qwuloolt Estuary Restoration Project in the lower Snohomish River is the largest estuary restoration project in that region with planning and implementation spanning almost 20 years. The Qwuloolt project area is about 360 acres of former estuarine wetland. Restoration of the site is intended, in part, to help compensate the public for injuries to natural resources as a result of the Tulalip Landfill, a Superfund site. Restoration planning began in 1997. Since 2006, project partners worked to refine the preferred alternative to enhance ecological and biological objectives and to reduce overall project impacts and costs. Final designs were completed in 2012 through collaboration between the US Army Corps of Engineers (USACE), the Tulalip Tribes, and ESA-Adolfson.

The USACE and Tulalip Tribes signed an agreement in 2012. The Corps awarded a $3.73 million, two-phase construction contract to Sealaska, of Auburn, WA. Phase I involved stream channel and upland re-contouring, wave attenuation berm construction, and native vegetation restoration. Over 1.5 miles of lower Allen and Jones Creeks were restored to natural alignment. Interior site work included filling of relict agricultural drainage ditches and excavating channels to facilitate natural tidal function. A new outlet channel connecting Jones Creek with the inboard side of the Ebey Slough levee was completed in August 2013. Construction of wave attenuation berms spanned 2012-2015. Most (7.5 acres) native vegetation planting along the eastern and northern edges of project area was completed in 2012. Three stormwater filtration ponds were constructed west of the setback levee to improve the quality of stormwater runoff from the nearby industrial park. In October 2015, three tide gates were decommissioned and sealed at the SW end of Jones Creek, assisting in the final step of restoring natural hydrology to the site.

The most important phase involved the hydrologic reconnection (return of tidal inundation) of the Qwuloolt site. Construction of a 4,000' setback levee on the western edge of the project area, to protect Brashler Industrial Park, the Marysville Wastewater Treatment Plant and residents surrounding the area, was completed in 2015. Once the western setback levee was completed, 1,400' of the Ebey Slough levee was lowered and then a 270-foot breach was excavated in it to allow tidal inundation. Estuarine water circulation has provided for natural hydrologic processes that sustain salmon and wildlife, as well as facilitate the transport and deposition of sediment and seeds for successional native plant restoration.

Monitoring targeted primarily at Chinook salmon was conducted before and after the dike breach, 2013-2016. Following the breach, scientists will monitor changes including elevation, sediment dynamics, water temperature and salinity, nutrient and food availability, fish population and diversity, and wildlife abundance and diversity. There appears to be system-wide monitoring of fish and water quality for the Snohomish Estuary, with a particular focus on understanding the effects of restoration at Qwuloolt. Pre-project monitoring was initiated in 2010, and continued through at least 2016 (one year post-project). As of Sept 2017, a post-project synthesis of results was not available.

Carbon sequestration benefits of estuary restoration: Snohomish Estuary case study. A recently recognized ecosystem service of coastal wetlands is their extraordinary capacity to capture and sequester atmospheric carbon. When coastal wetlands are drained and converted to terrestrial land uses, carbon is rapidly released back to the atmosphere as CO_2. Restoring coastal wetlands stops the drainage-induced releases of carbon and reactivates carbon sequestration (Crooks et al. 2014). Restore America's Estuaries (RAE) developed a widely applicable tidal wetland restoration greenhouse gas offset methodology, which was approved by the voluntary greenhouse gas program Verified Carbon Standard (VCS) in 2015 (Restore America's Estuaries 2014). This process provides a means for coastal managers to initiate tidal wetland restoration projects for greenhouse gas credits. Thus wetland restoration could provide co-benefits in the form of coastal protection, improvements to fisheries, and climate mitigation and adaptation.

In a discussion focused on NOAA investigation of these issues, Sutton-Grier and Moore (2016) summarize an assessment of carbon fluxes over multiple decades for historic drained and future restoring wetlands in the Snohomish Estuary. Completed in 2013 and one of the first studies of its kind, the work demonstrated the carbon sequestration benefits of landscape-scale wetland habitat restoration. The Snohomish Estuary was chosen because it includes wetland habitats ranging from seasonal floodplains, open mudflats, and tidal forests, to salt marshes. The site was also ideal because of its significant restoration potential with several completed, planned or proposed projects (including the Qwuloolt Estuary Restoration Project), and also a sizable body of local data on land-use history, sea-level rise projections, and information on completed projects. (Crooks et al. 2014).

Crooks et al. (2014) found that Snohomish Estuary wetlands have great potential for restoration and carbon accumulation, and that these benefits would be resilient to sea level rise. Much of the currently drained wetlands lie at an elevation suitable for emergent marsh colonization should the wetlands become tidally reconnected and slopes in the upper estuary are gradual, offering potential for wetland migration with sea level rise. Over the long-term (beyond 20 years) carbon sequestration benefits and net greenhouse gas removals will result from restoring tidal marshes.

Specifically, Crooks et al. (2014) found that existing planned wetland restoration activities in the Snohomish Estuary will sequester 0.32 million tons of carbon (MtC) within soils as they rebuild to mature marshes. With sea level rise of 1 m, a further 0.37 MtC or total of 0.7 MtC will be sequestered within these wetland soils as they accrete. The study also found that if all potential restoration projects in the Snohomish Estuary are completed, an estimated 1.2 MtC will be sequestered in soils alone, as marshes rebuild, and a total of 2.4 MtC will be sequestered with sea level rise of 1 m. This calculation was conservative in that it did not account for accumulation of tidal wetland vegetation biomass and associated carbon, both above and below ground. If some of these areas return to forested tidal wetland, biomass carbon accumulation could easily equal soil carbon sequestration. The resiliency of coastal marshes in the face of climate change has been noted elsewhere (National Research Council 2012).

Lower Columbia River Estuary

The Columbia River estuary, with more than 80,000 acres of surface area in Oregon, is larger than all of the other Oregon estuaries put together. Draining one of the largest river basins in North America (259,000 square miles), the Columbia's estuary is dominated by the river's freshwater inflow. Tidal influence extends 146 miles upstream to Bonneville Dam, but salt water rarely extends above river mile 30. The freshwater nature of this estuary makes it very different from Oregon's smaller estuaries to the south. Of the more than 10,000 acres of Columbia estuary tidal marsh, only a small fraction is salt marsh. The rest are freshwater tidal wetlands. (Oregon Coastal Atlas 2017.)

Prior to Euro-American settlement, the mighty Columbia and its tributaries supported some of the largest runs of salmonids on earth. Today, owing mainly to impacts from numerous dams, extensive agriculture, and other human development along this economically vital river system, these runs are a fraction of what they once were. As a result, twelve distinct populations of Columbia River basin salmon and steelhead are currently listed as endangered under the ESA. This has triggered wide-ranging and intensive salmonid recovery efforts, including projects to improve passage and habitat in the Lower Columbia River Estuary.

Most funding for salmonid habitat restoration in the Columbia River watershed comes from the Bonneville Power Administration (BPA), a federal agency within the U.S. Department of Energy that markets power produced by federally owned hydroelectric projects in the region. The BPA is required by law to finance habitat restoration projects to offset (mitigate) the impact of hydroelectric dams it operates along the Columbia and Snake rivers on 13 ESA-listed species of salmon and steelhead. BPA coordinates with the U.S. Army Corps of Engineers (USACE) and the U.S. Bureau of Reclamation to regulate Columbia River flows and to implement environmental projects identified by the Northwest Power and Conservation Council (NPCC) Fish and Wildlife Program (FWP).

The NPCC and its FWP were authorized by the 1980 Pacific Northwest Electric Power Planning and Conservation Act (Act) to balance environment and energy needs and preserve the benefits of the Columbia River for future generations. Specifically, the Act called for BPA to "protect, mitigate and enhance" fish and wildlife affected by Columbia River basin dams while providing an "adequate, efficient, economical and reliable power supply." The FWP funds about 250 projects per year, most of which are focused on protecting the region's iconic salmon and steelhead populations. With an annual budget of $150-200 million, the FWP is one of the largest long-term ecological restoration programs in the US.

Lower Columbia region projects that involved tide gate upgrade or removal in Oregon include Ft. Clatsop South Slough, South Tongue Point/Liberty Lane, and Wallooskee-Youngs Confluence. The Thousand Acres Floodplain Restoration and Tide Gate Effectiveness Monitoring, Columbia River Tributaries projects included OWEB funding. Projects in Washington include Grays River/Seal Slough (Kandoll Farm Property), two projects in Julia Butler Hansen NWR (Tenasillahe Island Slough and Mainland Unit Restoration) and a project on the Chinook River (Figure 5-3). Several of these projects are discussed in more detail below.

***Thousand Acres Floodplain Restoration*.** The Thousand Acres site in the Columbia River estuary is part of a 1500-acre natural area in the Sandy River Delta. It is one of the largest contiguous undeveloped bottomlands in the Portland area of the Columbia River estuary. However, the site has been significantly altered. The site was historically a dynamic alluvial floodplain with a combination of forests, wetlands, and meadows. By 1948 the historical forest had been cleared, vehicle access installed, and channels

deepened. The natural ponds and marshes were disconnected from the Columbia River by water control devices and the delta bottomland area was grazed for several years. The U.S. Forest Service purchased the property in 1991, completed the Sandy River Delta Plan in 1995, and began wetland restoration at Thousand Acres in 1997.

The Thousand Acres Floodplain Restoration project removed a tide gate and water control structure and, as a result, provided unimpeded access to 28 acres of off-channel marsh habitat. The project also included placing log structures and boulders, recontouring channels, and invasive plant control. An additional 70 acres were revegetated with plantings of native cottonwood, dogwood, willow, and spirea. Large numbers of juvenile salmonids were observed above the former passage barriers each year after project implementation. Plantings were also successful. In 2016 survival ranged from 75% in the two drier zones to 90% in the lower wetland zone.

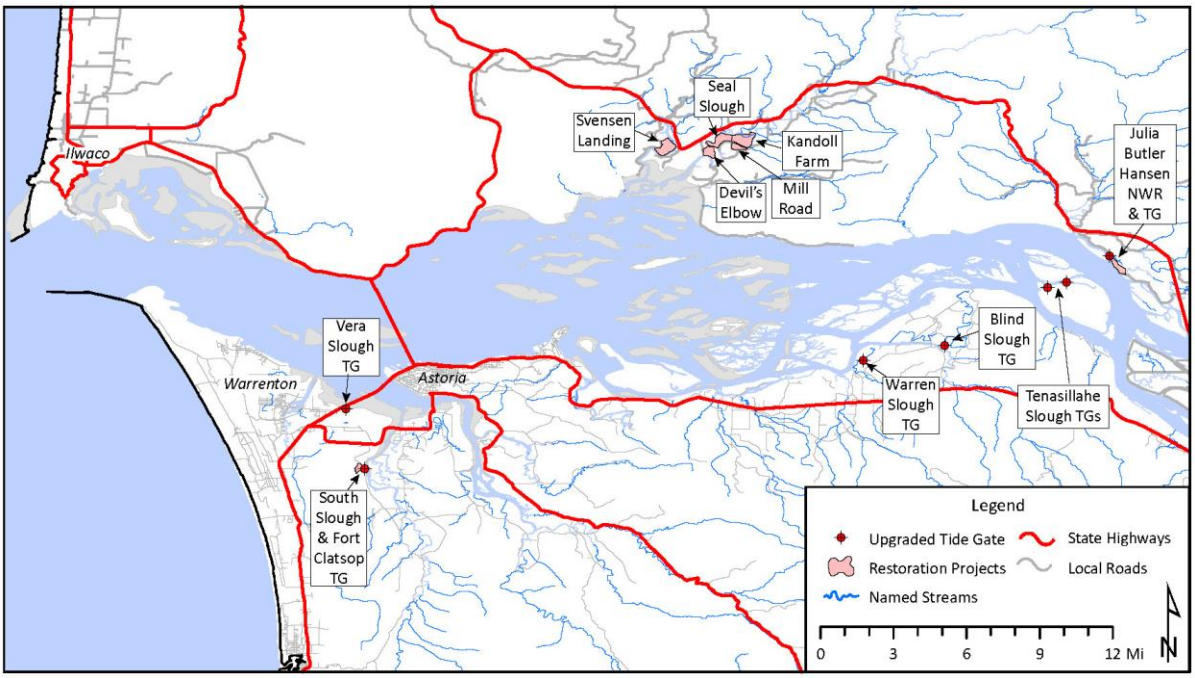

Figure 5-3. Tide gate related projects in the lower Columbia River (except Chinook and Thousand Acres).

Grays Bay-Kandoll Farm Acquisition and Restoration. The Grays Bay-Kandoll Farm Acquisition and Restoration effort in Washington is an extensive, multiphase project involving multiple funding sources and agencies, with an overall goal of protecting 880 acres and actively reconnecting and restoring tidal influence to 163 acres. Projects included tide gate removal or upgrade with large aluminum culverts, levee removal or breaching, drainage ditch filling and tidal channel excavation, and plantings. The Grays River site has been extensively studied, with before and after monitoring data, a comparison "control" site in Seal Slough, and two complementary monitoring efforts.

Restoration at the Kandoll Farm site is part of the Columbia Land Trust (CLT) and other conservation partners' larger Gray's Bay Conservation Effort, which began in 2003. Most of the work has been completed; on-going maintenance and monitoring will continue for many years. The Grays Bay project

has these overall goals: 1) permanently protect 880 acres of habitat, including spruce swamp forested wetlands, inter-tidal floodplain channels and emergent/scrub-shrub wetlands; 2) restore floodplain connectivity to 500 acres of tidal backwater, riparian and wetland forested habitat; 3) restore over 300 acres of potential salmonid rearing habitat; 4) enhance approximately 3 miles of riparian shoreline and; 5) protect 3 bald eagle nests and over 100 acres of potential marbled murrelet nesting habitat.

The Kandoll Farm Property is located 2 miles from the mouth of the Grays River confluence with Grays Bay and the Columbia River. Most of the property is influenced by Seal Slough, a major lower Grays River tributary. In the early 1900s the property was diked, tide gated, and converted to pasture. The property remained in agricultural use until summer 2005. Existing drain ditches have been filled, tide gates have been removed or replaced with large aluminum culverts, and portions of the levees have been removed. The property is now open to free tidal influence.

The focus of the Kandoll Farm project is on estuarine and riparian wetland habitats. Expected results include protection, reconnection, and restoration of 163 acres of riparian floodplain habitat to benefit salmon production in the entire Columbia River basin. The project seeks to provide a rich and productive nursery, rearing and over-wintering habitat, and an anchor point for stabilizing the entire system. Long-term benefits also include increased flood storage capacity, improved sediment dynamics, and improved water quantity and quality conditions for salmonids.

The Kandoll project is a multiphase project involving multiple funding sources. Project phases: 1) Phase 1 acquisition (163 acres) in 2002; 2) Phase 1 additional acquisition (20 acres) in 2003; Phase 1 initial restoration of 163 acres in 2004; and Phase 2 follow up restoration of 163 acres in 2012. [Schwartz et al. 2013.] Phase I restoration (2005) included: 1) replacement of a small tide gate with 2 large 13-foot culverts at the end of Seal Slough; 2) breaching of the Grays River dike in 3 locations; and 3) tree and shrub plantings in locations throughout the site. Phase 2 restoration in 2013 and included channel excavation, along-channel mounding, filling, and dike removal.

Two complementary monitoring programs have been underway since 2005. The Kandoll Farm property was integrated into the Cumulative Effects (CE) study funded by the USACE and implemented by Pacific Northwest National Laboratory (PNNL), which focused on assessing impacts of restoration projects on the overall health of the Columbia River estuary. Project effectiveness monitoring by the Columbia Land Trust (CLT) for the Grays Bay projects is based on the protocols developed by PNNL for their study. PNNL shares data and analysis so that this information can be integrated into CLT's effectiveness monitoring analysis and adaptive management approach.

The Kandoll Farm project and the CE study are described in several large reports that are included in the literature review in Section 4 of this report. Briefly, water surface elevation was similar to reference sites at Kandoll Farm post-restoration. However, for water temperature, sediment accretion, and fish presence data were suggestive but insufficient and for vegetation similarity data were inadequate (Diefenderfer et al. 2016). As part of the CE study the authors determined whether post-restoration conditions were trending toward reference conditions at sites throughout the estuary. While a number of the sites did show positive change, data from the 6 tide gate replacement projects demonstrated no trend (Diefenderfer et al. 2016). However, Roegner et al. (2010) found that after reconnection inundation more closely resembled tidal patterns and fish community composition was more similar to the reference site.

***Wallooskee-Youngs Confluence Restoration Project*.** The Wallooskee-Youngs Confluence Restoration Project is located at the confluence of the Wallooskee and Youngs Rivers in Clatsop County, five miles from the Columbia River near Astoria, OR. The 221-acre project area includes 190 acres of former pastures being returned to wetlands to enhance estuary rearing habitat for juvenile salmon and steelhead, as well as provide habitat for wildlife such as deer, elk, and river otter.

Prior to restoration the wetland was dormant for nearly 120 years, originally diked off from the Youngs and Wallooskee rivers in the early 1900s and utilized as a dairy farm for decades. In 2012, the previous property owner sold the land to Virginia-based environmental resources company Astoria Wetlands LLC. The Cowlitz Indian Tribe partnered with Astoria Wetlands to seek funding from BPA for restoration. At a cost of approximately $10 million, the project is one of the largest BPA has ever funded.

In 2015 crews built five tidal inlets that now run throughout the main site. In late June 2017 the century-old levee was breached in five locations near the base of each tidal channel, two tide gates were removed, and tidewater from Youngs Bay began flooding the land once again. The Crosel Creek tide gate under OR Highway 202 was not modified. Crews built concrete walls along OR 202 to protect portions of the roadway near the restoration site from incoming tides and wave action. The BPA's Allston-Clatsop 230-kilovolt transmission line traverses the middle of the property from Longview, WA to provide power to much of the North Coast. To ensure towers on raised access pads in the restored wetlands can still be serviced, BPA engineered a low-water access road made from boat ramp material (concrete blocks held together by cables). The roadway is built 12-18 inches above the flood plain and designed to withstand daily tidal inundation.

Wetland restoration projects such as Wallooskee-Youngs are critical for fish survival because they provide food and refuge for young salmon and steelhead as they transition to life in the ocean. Scientists estimate as much as 70 to 80 percent of the Lower Columbia River Estuary (LCRE) has been lost to development over the past 150 years, making Wallooskee-Youngs even more valuable. The BPA believes the site could provide some of the best juvenile salmon habitat in the entire LCRE.

Now that five tidal channels are connected to the Youngs and Wallooskee rivers, the site floods twice a day, and the native plant seeds dormant for years will sprout and are expected to overtake the non-native pasture grass. The newly created wetlands will provide valuable off-channel areas for fish transitioning from fresh to saltwater, and habitat for mammals, raptors, waterfowl, shorebirds and amphibians. Next steps include a long-term management plan incorporating public access, such as hunting, a concern raised by residents during project planning.

The site includes 17 acres of upland conservation area outside of the flood plain, which could potentially be used for a youth camp, space for powwows, to grow native plant species used by tribes, or even a potential launching spot for the annual canoe journey by PNW tribes. In 2015, baseline monitoring of channel morphology and carbon stored in coastal wetland soils (blue carbon) was conducted at the Wallooskee-Youngs restoration site and reference sites in the Youngs Bay estuary. This work was conducted by Institute for Applied Ecology, Estuaries Technical Group (ETG) and funded by the Lower Columbia Estuary Partnership (Brophy et al. 2015).

The sediment accretion rate at the high marsh at the Daggett Point reference site was 0.35 cm/yr-1, consistent with preliminary estimates of sediment accretion in other portions of the reference site. Analysis of soil data for other sites is ongoing. Based on LIDAR analysis, channel density was reduced by

approximately 78% at Wallooskee-Youngs following conversion to agriculture. Reference tidal wetlands had many more outlets of first-order channels than previously documented or predicted. Shorter, straighter, and shallower channels dominated the Wallooskee-Youngs restoration site, compared to the deeper, narrower, and more sinuous channels found at the reference sites. Deeper channels transport tidewaters efficiently deep into a site, carrying nutrients that sustain food webs, creating fish habitat, and carrying sediments whose accretion allows tidal wetland elevations to keep up with relative sea-level rise.

Under separate USFWS funding, ETG is also monitoring tidal hydrology (surface water level), surface water salinity, groundwater level, groundwater salinity, and vegetation composition at the Wallooskee-Youngs restoration site and the Daggett Point, Grant Island, and Cooperage Slough reference sites. The resulting data will help advance understanding of the physical drivers behind carbon accumulation rates, complementing the blue carbon study. (Brophy et al. 2015.)

Oregon North Coast Region

For purposes of this report, the North Coast Region encompasses the northern half of the Oregon Coast, south of the Columbia River, and includes several estuaries. (OWEB includes the Columbia in this region; we elected to discuss the Columbia River estuary separately in order to include projects in WA.)

Two estuaries on the North Coast – Nehalem Bay and Tillamook Bay - are relatively large in size with large watersheds. Other estuaries of the north coast – the Necanicum River, Netarts Bay, Sand Lake, Nestucca Bay, and the Salmon River – are small estuaries with relatively small watersheds. Thirteen populations of the Oregon Coast Coho salmon Evolutionarily Significant Unit (ESU), currently listed as threatened under the federal Endangered Species Act (ESA), reside in Oregon's North Coast. **(**National Marine Fisheries Service 2016a.)

In this section, we summarize selected projects that included OWEB support, moving from north to south.

McDonald Slough-Nehalem River. The McDonald Slough Reconnection project, located in the Nehalem Estuary, included OWEB funding. McDonald Slough is one of the largest sloughs in the Nehalem Estuary and drains into the North Fork Nehalem River. Two top-hinge tide gate structures (default closed) disrupted the natural hydrology and nutrient exchange, limited tidal influence in the slough, and impaired access to over 1.5 miles of spawning and rearing habitat for salmonids, including 16 acres of slough habitat. In 2016, the top-hinged gates were replaced by two side-hinged epoxy-coated aluminum gates with muted tidal regulators (MTRs). The new system is default open - the MTRs keep the gates open until the inside inundation level reaches a set height. Large woody debris placements were made in four locations within the slough near the old and new gates and downstream of the new gate. Installation of the new structure has improved access to 1.5 miles of freshwater and forested/shrub and freshwater emergent wetland habitat to benefit coho, Chinook, and steelhead.

Spotlight on the Tillamook Bay Estuary

The Tillamook Bay estuary, a small inlet of the Pacific Ocean, is about 6 miles long and 2 miles wide, on the northwest Oregon coast about 60 miles west of Portland and 45 miles south of Astoria (Figure 5-4). The estuary drains a 597 square mile watershed with five rivers- the Tillamook, Trask, Wilson, Kilchis, and Miami- and some of North America's richest timber and dairy land. In the lower Tillamook Watershed, the Coast Range conifer rainforest transitions to rich alluvial plains used primarily for dairy agriculture. Meandering rivers and networks of small channels once provided plentiful fish habitat, large wood, and

organic matter. Euro-American settlers recognized the area's rich agricultural potential and by the early 1900s had drained most of it with numerous dikes, levees, and ditches. Large forest fires and salvage logging in the 1930s to 1950s caused the loss of native vegetation high in the watershed, and disrupted water infiltration and storage capacity in these steep upland areas. Today about 40 square miles of this converted agricultural lowland adjacent to the estuary supports thousands of dairy cattle, and some 85-90% of the estuary's tidal wetlands have been lost.

Lack of tidal wetland habitats is a primary factor in the decline of Tillamook Bay coho and remains a key impediment to recovery of this species. Habitat loss has also impacted Tillamook Bay's other anadromous fish species, particularly Chinook. Although current coho runs have been drastically reduced (about 2,000 fish in 2012 compared to ~200,000 estimated historic abundance), the estuary is still highly productive for salmonids and also supports significant populations of shellfish and birds. The Oregon Coast Coho Salmon Recovery Plan(National Marine Fisheries Service 2016b), finalized in December 2016, along with the ODFW Oregon Coast Coho Conservation Plan (ODFW 2007), guides conservation and recovery efforts, including estuary habitat restoration.

In 1992 Tillamook Bay became part of the US Environmental Protection Agency's National Estuary Program, a place-based network to protect and restore the ecological integrity of nationally significant estuaries. The Tillamook Bay NEP (TBNEP) developed the 1998 Tillamook Comprehensive Conservation and Management Plan (CCMP) and detailed 63 actions targeted at four priority problems affecting Tillamook Bay and its watershed: water quality, habitat loss and simplification, erosion and sedimentation, and flooding. To address actions in the CCMP focused on estuary habitats and ecological function, the TBNEP established an objective of acquiring and restoring 750 acres of intertidal wetland habitat in Tillamook Bay (Tillamook Estuaries Partnership 2017).

The Kilchis Wetlands Conservation and Restoration Project. One such restoration project in Tillamook Bay estuary was the Kilchis Wetlands Conservation and Restoration Project (Kilchis Project). A primary limiting factor for salmonids in the Kilchis system is availability of off-channel habitat, especially in the salt-freshwater transition zone of the estuary. Remaining wetlands support a wide variety of plants and wildlife, including federally threatened coho, Chinook, chum, steelhead, cutthroat trout, colonial nesting water birds, migrating waterfowl, juvenile marine fishes and resident mammals. The Kilchis Project is a combined dike removal and dike setback project designed to increase protections for existing salmonid core areas and provide off-channel rearing habitat, restore historic tidal marsh and spruce swamp habitat, re-create tidal channels and restore connectivity between tidal sloughs and the Kilchis River. Past restoration has occurred above the project site and complements existing restoration efforts.

The Kilchis Project was made possible by two property acquisitions that are being managed by TNC, which were funded through OWEB's land acquisition grant program and the USFWS's Coastal Wetlands Program, totaling approximately 126 acres. In late 2010/early 2011, TNC purchased a 66-acre diked and drained dairy farm located on the banks of the lower Kilchis River. Completed in 2015, the construction phase of restoration on this parcel removed fill from Stasek Slough, removed the Kilchis River dike, elevated subsided lands, and reconnected the Kilchis River (and tidal exchange) to Stasek Slough. As part of this work, several secondary tide gates were removed, but most were non-functional before activities began. Re-vegetation work funded by OWEB and including planting of 9,750 trees, 37,000 shrubs, and 118,000 willow cuttings, is underway and will continue for several years.

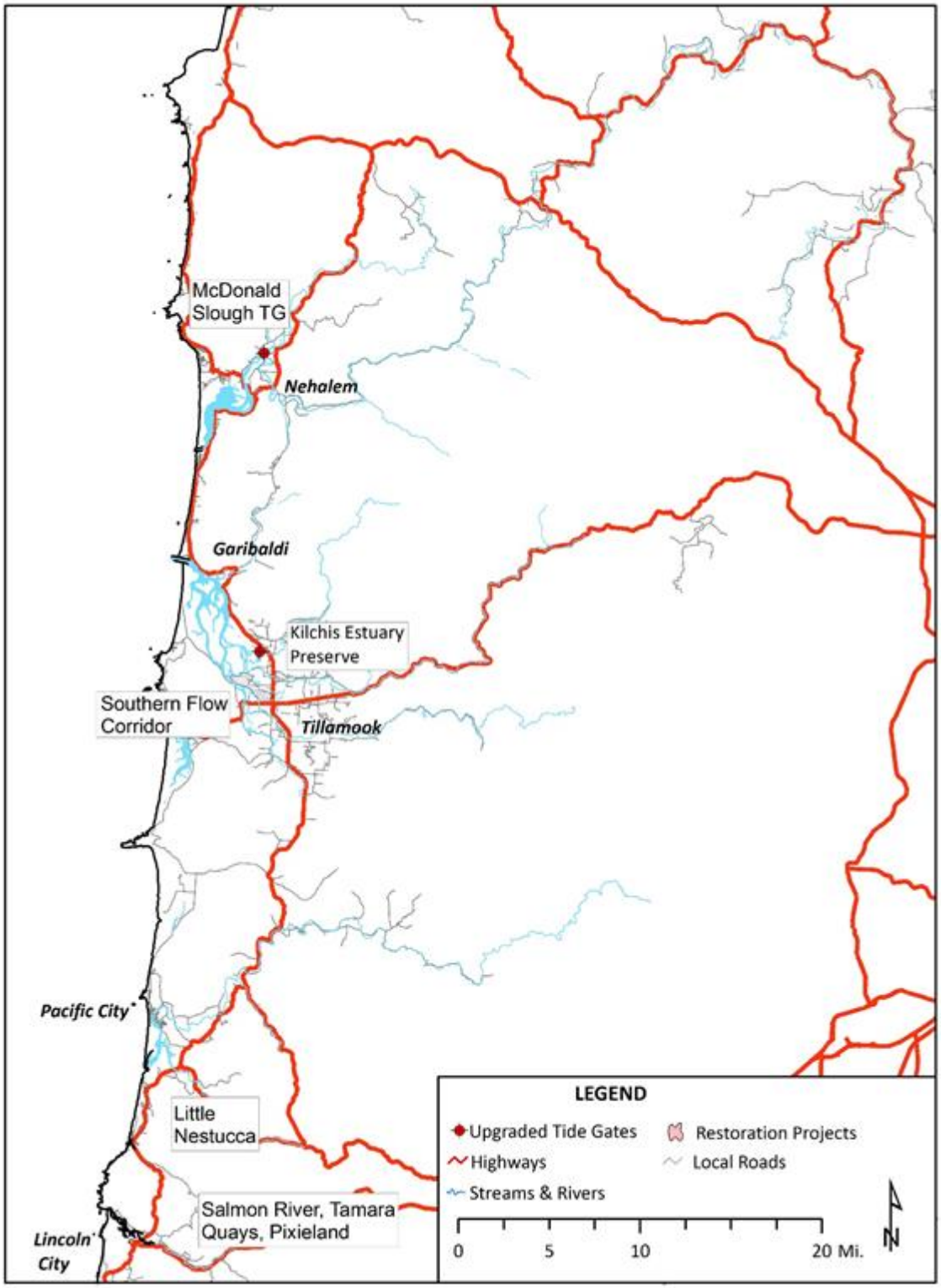

Figure 5-4. Tide gate related projects in the Oregon North Coast region.

More recently, OWEB, partnered with TNC to acquire an adjacent 60-acre parcel (the Porter property). As

of late 2017, TNC is developing a restoration plan for this parcel and plans to begin planting in early 2018. After restoration is complete about half of the combined 126 acres will be spruce swamp habitat, a quarter will be scrub-shrub habitat, and the remainder mostly emergent high saltmarsh dominated by native sedges. The project incorporates projected climate change impacts by designing the restoration with sea level rise and precipitation changes in mind.

The Kilchis Project has sparked some controversy among the agricultural community and neighboring landowners, over both the conversion of farm land back to tidal influence, and also over changes to the area's hydrology. Major floods in the Tillamook basin in late 2015 altered the river and portions of the project area. Additional hydrodynamic analysis looked at the bathymetry of the constructed tidal channels, the Kilchis River and sloughs and land surfaces that may have been altered by the flooding. Staff at TNC indicated that this extra effort to predict river and tidal flow effects after restoration has been very worthwhile. This information, along with water level monitoring in river and slough habitats, provides data to understand the effects to local hydrology and inform future restoration actions. Even with the extensive public review that accompanies projects of this nature, the history of flooding in the Tillamook area can make restoration projects challenging as long-held beliefs about the causes of flooding, and ways to attenuate it, are slow to change.

When all work is completed the project will effectively double the habitat available to salmon in the Kilchis estuary. Salmon were not known to be using the project area before the restoration took place, but immediately afterwards observers began seeing salmon smolts in the tidal channels which provide refuge during high winter river flows. Fish are not being monitored post-project. Partners in the land acquisitions and restoration actions that comprise the Kilchis Project include the USFWS, OWEB, TNC, Wildlife Conservation Society, ODFW, Wild Salmon Center, National Fish and Wildlife Foundation/OR Governor's Fund, Portland General Electric, Tillamook Estuaries Partnership, Wildlife Conservation Society, National Fish & Wildlife Foundation, and the Northwest Oregon Restoration Partnership.

The Southern Flow Corridor-Landowner Preferred Alternative Project. The recently completed Southern Flow Corridor-Landowner Preferred Alternative Project (SFC-LPA) marks a major milestone toward the goal of restoring 750 acres of intertidal wetland habitat in Tillamook Bay. Developed primarily to reduce flooding, the SFC-LPA also restored over 500 acres of tidal wetland habitats and nearly 14 miles of historical tributaries that serve as important wintering habit for juvenile salmon at the confluence of the Bay's two most productive salmon systems, the Wilson and Trask Rivers.
The SFC-LPA is a complex, long-term, multi-agency project that involved acquisition of large parcels of agricultural land, extensive removal of old levees, dikes, and fill (including 15 tide gates), construction of new setback dikes and tide gates to protect adjacent private lands from tidal inundation, and restoration of areas outside the levees back to tidal marsh. Representing 10% of the watershed's historic tidal acreage and a far greater percentage of "restorable" tidal lands, the project site was an expansive mosaic of tidal wetlands, disconnected freshwater wetlands and drained pasture lands. Now restored to a tidal regime, the resulting habitats (mud flats, aquatic beds, emergent marsh, scrub-shrub wetlands, forested wetlands and sloughs) benefit not only threatened coho, but also chum and Chinook salmon, cutthroat trout and many other species (Oregon Solutions 2017).

Origins of the SFC-LPA date back at least to the early 2000s when Tillamook County, using USFWS grant funding obtained and partially matched by OWEB, purchased 377 acres from three private landowners specifically for estuary and wetland habitat restoration. Restoration efforts stalled after hydraulic

analyses concluded that full restoration of the entire site would result in unacceptable flood levels within the City of Tillamook's Highway 101 business district. After damaging floods in 2006, Oregon Governor Kulongoski invoked the "Oregon Solutions" approach, providing a structure and process for public and private sectors to collaborate on the technically and politically challenging task of balancing flood mitigation with restoration on the acquired lands. Subsequently, a 34-member Project Team and 15-member Design Team of federal, state, and local government agencies as well as community groups, business organizations, and individuals was assembled to forge a path forward (Oregon Solutions 2017).

As a result of evaluating its hydraulic impacts, it was determined that the SFC provided the largest benefits in flood damage reduction, both in terms of flood levels and areas benefited, and also allowed some lands originally slated for acquisition to remain in agricultural land use rather than be converted back to salt marsh. The Design Team prioritized the SFC and initiated discussions with landowners whose properties were to be acquired for the project and also those whose lands were identified as needing dike modification. Based on landowner discussions, the project was slightly modified then modeled to ensure flood level reduction, and renamed the SFC-Landowner Preferred Alternative (LPA).

Significant funding for the SFC-LPA project was available from FEMA through the Port of Tillamook Bay (Table 5-3). Funding for both land acquisition and construction was secured by August 2014. In addition to its significant habitat benefits, the SFC-LPA project was shown to be the most cost-effective flood level reduction measure by creating a flow corridor from Highway 101 out to Tillamook Bay (Oregon Solutions 2017).

Table 5-3. Southern Flow Corridor – Landowner Preferred Alternative Funding Summary.

US Federal Emergency Management Agency	$3,225,000
NOAA	$2,700,000
OWEB	$1,522,144
Oregon State Lottery Bonds	$1,075,000
Oregon Business Development Department	$1,050,974
US Fish and Wildlife Service	$822,618
Loren Parks Foundation	$250,000
Total	$10,645,736

For the project to proceed, Tillamook County acquired an additional 125 acres of private land (primarily with OWEB funding) and also secured 86 acres of permanent floodway easements. Land easements and acquisitions were completed between late 2015 and spring 2016. Baseline monitoring of fish, macroinvertebrates, vegetation, geomorphology and hydrology was funded by NOAA, OWEB and the USFWS and conducted from 2013-2015. The detailed picture of pre-project conditions that resulted (Brown et al. 2016) will be critical in demonstrating progress toward flood attenuation, ecological function and species recovery goals by providing a baseline to compare with post-project data collected from 2017-2020 and beyond.

Engineering designs and all permitting, including an Environmental Impact Statement (EIS) conducted under the auspices of FEMA, were finalized in early 2016. Construction of the SFC-LPA began in May 2016 and was essentially complete by fall of 2017. On-the-ground construction included the removal of levees and associated tide gates and culverts. Over 3.5 miles of ditches were filled and 5.5 miles of new tidal channels constructed. Large wood obtained on site was placed in structures through the floodplain and off-channel areas. Several side channels were reconnected to the mainstem Trask and Wilson Rivers at 18 locations.

The SFC-LPA shows what committed interagency and public-private partners can achieve over the long term. OWEB contributed funds, coordination, and assistance at multiple stages over the nearly 20-year lifespan of the project, and was instrumental in the strategic property acquisitions upon which it hinged. Expected long-term outcomes include reduced flooding in the Highway 101 business corridor and adjacent lands (including measureable reductions in flood elevation and duration), improved freshwater and estuarine water quality, increased tidal wetland habitat complexity and availability, and enhanced ecological function benefitting a range of aquatic, terrestrial, and avian species. The Oregon Department of Fish and Wildlife (ODFW) estimates that wetlands restored by the SFC-LPA will produce 6,000-9,000 adult coho salmon annually and as many as 14,000 with good ocean conditions. The project provides flood reduction benefits to over 3,000 acres of the lower Wilson River floodplain and also the lower Trask and Tillamook River systems, with a projected $9.2 million in avoided flood damages over 50 years. The project also supported an estimated 50 jobs in the area. (McLean 2017.) Over time, restoration to more natural estuarine geomorphology may also help mitigate the effects of climate change and sea-level rise.

Nestucca Bay. Nestucca Bay, at 1,202 acres, is the largest refuge within the Oregon Coastal Refuge Complex. It is located where the Nestucca and Little Nestucca rivers converge. In 2007 an 83-acre tidal marsh restoration project was completed on the Little Nestucca River Unit of the refuge constituting a 30% increase in tidal marsh habitat in the estuary. A 10' breach naturally occurred in 1996 in the 3,450' dike reintroducing limited tidal influence to the site. In 2007, under a $170,696 OWEB grant, two tide gates and parts of the dike were removed, the levee and an old road were breached, ditches were filled and tidal channels were excavated. Nine log weirs and 20 anchored habitat structures were also installed. Access was restored to 2.24 miles of fish habitat.
Wetland use and function were monitored after project implementation as part of the OWEB grant. The project is already benefiting juvenile salmonids, waterfowl and other species. In 2008-2009 the plant community was quite dynamic but on a trajectory toward typical native tidal marsh community. The amount of estuary covered by brackish tolerant plants had increased dramatically post-restoration. Non-native, freshwater wetland, and pasture plant species had decreased significantly. Reed canarygrass was no longer dominant but was still present at the highest elevations. Fish use was significantly different post-restoration. Species composition was more similar to other marshes. Significantly more juvenile salmon were present during key rearing periods. After tide gates were removed the number of tidal migrants and the period of migration increased. Complex habitats with large wood placements had 10x more usage than non-complex habitats. The macroinvertabrate community was transitional; it was not similar to natural or degraded systems.

By 2011-2013 native estuary plants were present over much of site. Most of the rest of the plant species were transitional brackish-tolerant. Tidal channels drained on falling tides and pools had formed around large woody debris placements. Reed canarygrass was still high density at highest elevations. In 2016 there were no changes noted from 2013.

The Salmon River Estuary: Pixieland and Tamary Quays Restoration. The Salmon River Estuary, part of the Cascade Head Scenic Research Area, is located on the central Oregon Coast south of Tillamook Bay and the Nestucca River. This combined protected area originated as Cascade Head Experimental Forest, established in 1934 to represent typical Sitka spruce-western hemlock forests. The Neskowin Crest Research Natural Area was established in 1941 in the northwest corner of the forest. In 1974, Congress established the Cascade Head Scenic Research Area, adding several prairie headlands, the Salmon River estuary- the only estuary on USFS lands in the conterminous United States- and contiguous private lands.

The combined protected area was designated a UNESCO Biosphere Reserve in 1980 and is home to more than 350 wildlife species. Four ESA-listed species use or inhabit the area: spotted owl, marbled murrelet, coho salmon, and Oregon silver spot butterfly.

The Salmon River estuary has been extensively restored in distinct periods of activity over several decades. Between 1954 and1974, most of the estuary was diked and ditched to create pastures. From 1978-1996 land acquisitions and restoration projects restored 339 acres of tidal marsh and three miles of tidal marsh channels. Dikes and tide gates were removed in 1978, 1987 and 1996. The Tamara Quays and Pixieland projects from 2007-2014 both included OWEB funding and were considerably more complex, including marsh restoration and dismantling of a trailer park and an amusement park built directly on tidal marsh land. These projects restored 2.5 miles of stream channel and floodplain, and tidal influence to 108 acres. Restoration also benefited previously restored lands further downstream.

Ellingson and Ellis-Sugai (2014) summarize the history of both sites. The Tamara Quays Project involved removal of a vacant mobile home park dating from 1969, which had problems with its septic and water systems soon after being built. The area was surrounded by dikes. A dam separated the development from the rest of the estuary and a tide gate had been installed on Rowdy Creek. After designation of the Cascade Head Scenic-Research Area in 1974, the USFS obtained rights to purchase land from willing sellers and acquired lots at Tamara Quays as they became available. The entire property was not completely within USFS ownership until 2003. (Ellingson and Ellis-Sugai 2014). Extensive infrastructure and a tide gate were removed, undersized culverts were replaced with a 20' fish passage culvert improving access to 2.25 miles of fish habitat. Ditches were filled, and dikes and fill removed restoring estuarine connection to 4.3 acres. Reed canarygrass sod was removed and covered with landscape cloth. Some large woody debris and log jams were placed. Native tree species were planted on 8.7 acres. To discourage illegal entry by vehicles, gates, logs, and boulders were installed.

The Pixieland amusement park was developed in 1969 on 57 acres near Lincoln City and was bankrupt by 1974. To develop the site, the entire area was surrounded by a dike, which also served as the railroad bed for a small train. Prior to construction, Fraser Creek had been routed into a ditch along Highway 101. Pixieland developers extended the ditch upstream to the crossing under Highway 18. A tide gate was installed at the mouth of the Fraser Creek ditch and surrounded by a massive concrete structure and foundation. Fill was added to the marsh to build on. Interior ponds and ditches were dug as landscaping and water rides. Infrastructure included buildings, roads, parking lots, a sewage treatment plant and a roller coaster ride. An RV park built to the east stayed in business until 1981. (Ellingson and Ellis-Sugai 2014).

In 1981, the USFS purchased the Pixieland and RV park properties as directed by the Cascade Head Scenic-Research Area Act. The buildings were torn down, leaving behind concrete foundations, paved roads, parking lots, ditches, dikes and the tide gate. The only remaining building was a small shed which housed the electric motor and mechanisms for the tide gate. Blackberries, scotch broom and reed canary grass covered the site. On-the-ground restoration began in 2007. The earthwork was completed in 2011.

Today, the restored Salmon River estuary provides a critical juncture between fresh and salt water, supports numerous forms of life, and maintains staging areas for upstream spawning migrations of anadromous fish and rearing areas for juveniles and smolts.

Restoration Phase I involved removing roads and buildings, excavating fill, removing dikes, filling ditches, removing the tide gate, and invasive plant control. These actions restored access to 1 mile of stream habitat and 40 miles of estuarine channel habitat, and restored estuarine connection to 40 acres of estuary. Phase II of the restoration focused on hydrological connectivity. The work involved removal of the remaining infrastructure, including a large dike and a tidegate. Ditches were filled, Fraser Creek was re-meandered, spruce trees were removed and used for wood placements. Native vegetation was planted and managed while invasives were controlled. These restoration actions increased access to 6 miles of fish habitat and 10 acres of estuary.

Ellingson and Ellis-Sugai (2014) provide a detailed but non-technical review and summary of the multiple stages of restoration that have occurred in the Salmon River Estuary. This review, partially funded by OWEB, is notable for its detailed discussion of "lessons learned" regarding the logistical and administrative practicalities of implementing complex projects with multiple partners, and components that must be staged sequentially.

Coos Bay and the Coquille River Estuaries

The Coos Bay and Coquille estuaries are located on the southcentral Oregon coast in Coos County. Of the 22 major estuaries on the Oregon coast, Coos Bay is only one of two (the other is Yaquina Bay) that are designated as "deep draft development" by the Department of Land Conservation and Development (DLCD) for Statewide Planning Goal 16 (estuarine resources) and Goal 17 (coastal shorelands) in its Oregon Coastal Management Program; while the Coquille estuary is among the seven estuaries designated as "shallow draft development," (Cortwright et al 1987). (Oregon land use planning as it relates to estuaries is also discussed in Chapter 6.) The current Coos Bay Estuary Management Plan (CBEMP) was originally approved in 1985, and is presently being updated by the Coos County Planning Department (CWP 2016). The Coquille River Estuary Management Plan (CREMP) was also approved in 1985, but its revision is being deferred as the CBEMP has priority due to information availability and funding.

Both the Coos Bay and Coquille River estuaries are geologically categorized as "drowned river mouth" type (also known as "coastal plain estuaries"), formed when rising sea levels flood existing river valleys. In winter, these estuaries are dominated by freshwater inputs through freshets that bring in large amounts of sediment. In summer, lower freshwater flows allow brackish water to migrate further upstream. The heads of tide are at approximately RM 9, approximately one mile above the confluence of the East and West Forks of the Millicoma River above Allegany, and RM 15 on the South Fork Coos River above Dellwood (DSL 1989). Where streams are tide gated at their mouths, the head of tide historically extended approximately 2 miles upstream from the bay (DSL 1989). The head of tide extends to RM 41 at the confluence of the Middle and South Forks for the Coquille River above the town of Myrtle Point (DSL 1989).

The Coquille River Estuary has lost more marsh habitat than any other estuary in Oregon and there has been a long history of concern about the effects of tide gates on anadromous fish in the Coos and Coquille basins. The "Coos River Basin Fish Management Plan" (ODFW 1990) specifically identified lost habitat and productivity behind tide gates, and called for identification and remediation of those that were defective or non-functional, as did the slightly later one for the Coquille River Basin (ODFW 1992). In addition, the Oregon Department of Agriculture (ODA) SB1010 Management Plan addresses effects of

tide gates on water quality (ODA 2016). Both the Coos Watershed Association (CoosWA) and the Coquille Watershed Association (CoqWA) are active in watershed assessment and action planning.

The CoosWA's Lowland Watershed Assessment and Action Plans (CoosWA 2006) evaluated six sub-basins that drain directly into Coos Bay and have stream/river mouth tide gates. This was followed by their Catching Slough, Daniel's Creek, and Heads of Tide Sub-basin Assessment and Restoration Opportunities report (CoosWA 2008). In 2011, the Isthmus and Coalbank Slough Sub-basin Assessment and Restoration Opportunities (CoosWA 2011) completed the circle of watershed assessments beginning in the north Bay and ending in the south Bay. Another assessment project specifically focused on tidal wetlands and their restoration potential was completed in 2010 using an OWEB technical assistance grant (208-2007) (CoosWA 2010a). Evaluation of tide gates, and prioritization of their removal or upgrade, was a significant component in these assessments and action plans.

The Coquille River Subbasin Plan (2007) was prepared by the Coquille Indian Tribe for NOAA-Fisheries. In 2014, the CoqWA completed its South Fork Coquille Watershed Action Plan based on a contracted report from Inter-Fluve.

Coquille River tide gate inventory. In 2016, the Coquille Watershed Association completed an OWEB and Wild Rivers Coast Alliance funded inventory of tide gates along the lower Coquille River. The resulting data and report will aid in project identification and development, recruitment of project resources, landowner outreach, prioritization and cost analysis, and partner and funder awareness of the importance in improving tide gate functions and the magnitude of potential benefits for both fish and landowner (CoqWA 2016). This approach to tide gate inventories is intended to serve as a model for other areas on the Oregon coast.

Past and on-going restoration efforts. The Coos and Coquille basins have a long history of tide gate removals and upgrades (Figure 5-5). Some of the earliest tide gate upgrades ("pet doors") were installed in the Coquille Valley on Hatchet Slough in 1998 by Paul Heikkila, the local Oregon Sea Grant extension agent, and designed by Jay Charland, an OSU graduate student. The next significant effort in these basins was the installation of side-hinged tide gates on Larson Slough in the Coos in 2001 through a partnership with the Larson Slough Drainage District, Coos County Road Department, and the Oregon Department of Transportation (ODOT). The Larson project also initiated an intensive monitoring program on the effects of tide gates that continues today (CoosWA 2014), with traditional wooden top-hinged doors at Palouse Creek serving as a reference.

As opportunities arose, CoosWA partnered with other drainage districts, ODOT, and the Coos County Road Department to upgrade other river/stream mouth tide gates. The Kentuck Slough tide gates were upgraded in 2007 by Coos County as part of their bridge upgrade project funded by the Oregon Transportation Investment Act (OTIA). A by-pass channel, with tide gates, was installed at Kentuck because two in-water seasons were required for this project. The CoosWA coordinated with Nehalem Marine to size these gates so that they could subsequently upgrade the wooden, top-hinged doors at Willanch Slough in 2010 (CoosWA 2010b). Opportunity arose again when the North Slough Drainage District collaborated to replace their tide gates. All three of these later projects had MTRs, and used existing superstructures. Beyond these four stream/river mouth upgrades, the CoosWA has worked with landowners to upgrade another half dozen tributary and field drain tide gates throughout the estuary, mostly using Nehalem Marine's 'Mitigator' backflow enablers.

The Coos also has a history of tidal reconnections by breeching levees and removing tide gates. The

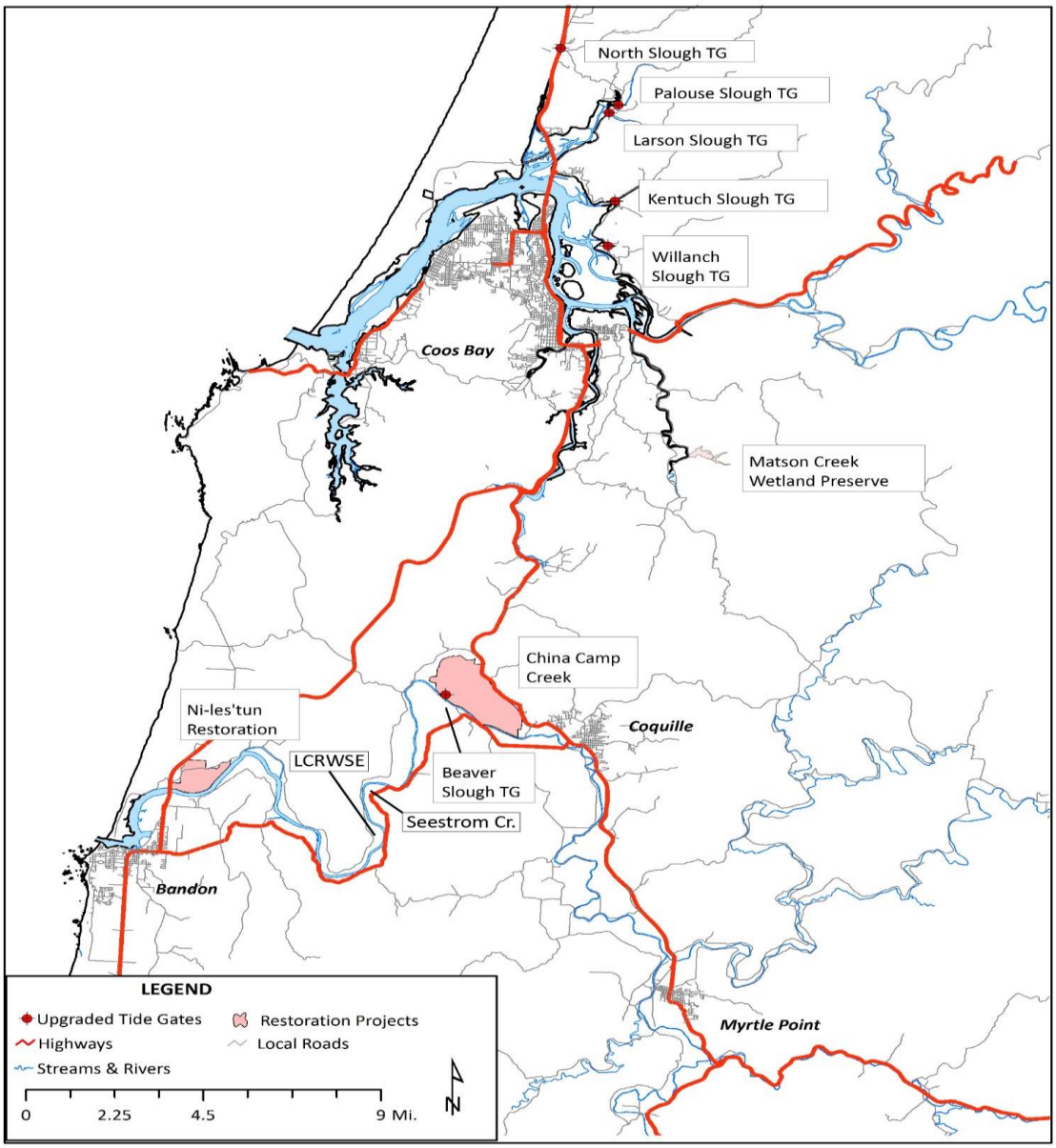

Figure 5-5. Tide gate related projects in Coos Bay-Coquille Oregon region.

earliest examples began in 1993 at the South Slough National Estuarine Research Reserve (SSNERR) with the Winchester Tidelands project that included Kunz (Cornu 2005a), Cox, Dalton and Fredrickson Marshes (Cornu 2005b). Monitoring conducted as part of this project (OWEB 99-372) first identified a coho salmon estuary rearing life history (Miller and Sadro 2003), as well as evaluated potential treatments to resolve marsh subsidence (Cornu and Sadro 2002). Another project, funded with a joint USFWS-OWEB Coastal Wetlands grant to CoosWA allowed the 2000 purchase of the 155 acre Rose Dairy. This property became the Matson Creek Wetland Preserve when title was turned over to The Wetlands Conservancy. The first restoration phase, completed in 2010 re-established tidal reconnection to 75 acres by removing three

tide gates and replacing them with a bridge and a setback levee that contained a 48” diameter tide gate with a mitigator attachment. The second phase, completed in 2015, remeandered upper valley streams, filled ditches, placed large wood, and re-vegetated 24 acres. Both these phases were funded as mitigation by the Coos Bay – North Bend Water Board.

At Willanch Creek two top-hinged tide gates were replaced with a lighter side-hinged gate with a MTR increasing access to 7.24 miles of fish habitat. A 2016 inspection confirmed that the tide gate was performing as expected and the MTR allowed the gate to stay open for longer periods. Log placements were also found to be performing as designed by retaining bedload, providing cover habitat, and creating complex pools. Many of the sites have recruited gravel and additional woody debris. Project sites have not required any maintenance or modification.

In the North Slough restoration a heavy wooden top-hinged gate was replaced with a lightweight gate with MTR improving access to 1.62 miles of fish habitat. Three culverts were upgraded to embedded or flat culverts and 4 cross-drain culverts were installed improving/restoring access to 22 miles of fish habitat.

In Larson Creek, a top-hinge gate was upgraded and the sill lowered 3’ in 2001 to improve fish passage conditions and water drainage between stream and estuarine areas. Part of the Coos Watershed Tide Gate Replacement project, begun in 2004, directly evaluated the effectiveness of the new tide gate. The Larson Creek gate opening time was influenced by tidal fluctuation and streamflow, and thus was seasonally dependent. The duration of gate opening was ~3 hrs in the winter and ~1 hr in summer. Opening frequency and duration were higher during spring tides. During smolt outmigration, March through May, the gate opened once per day during spring tides. In late summer the gate opened once per day regardless of tide cycle because of low inflow, complete drainage, and low sill height.

Recent restoration efforts in the Coquille River estuary have focused on two large projects: (1) the Ni-les’tun Tidal Marsh Restoration at the Bandon Marsh National Wildlife Refuge; and (2) the China Camp Creek/Winter Lake project that includes ODFW’s Coquille Valley Management Area.

Ni-les’tun Tidal Marsh Restoration, Bandon Marsh National Wildlife Refuge. The 582-acre Ni-les’tun Unit of the Bandon Marsh National Wildlife Refuge is located upstream of the 307-acre Bandon Marsh Unit along the Coquille River, east of U.S. Highway 101 in Coos County. Historically tidal wetland, most of the Ni-les’tun Unit was leveed and drained for agriculture in the late 19th or early 20th century. The unit was acquired by the USFWS between 2000 and 2004 to protect and restore intertidal marsh, freshwater marsh, and riparian areas, provide habitats for migratory birds and songbirds, and to restore intertidal marsh habitats for steelhead, cutthroat trout, and chum, Chinook, and coho salmon.
Restoration, managed by Ducks Unlimited and completed in 2011, increased Coquille River estuary tidal marsh habitat by 400 acres. Restoration involved removing levees and three tide gates, disking and filling ditches, constructing sinuous tidal channels, increasing culvert size, reconnecting small coastal streams, large wood placements, native plantings, non-native and invasive vegetation control, and power line relocation. The Ni-les’tun project is described as the largest of its kind in Oregon, with multiple partners. The project had two OWEB Effectiveness Monitoring grants (210-2032 and 212-2068) to evaluate tidal hydrology, re-vegetation success, benthic macroinvertebrates, and marsh surface elevations (see Brophy et al. 2014 and Brown et al. 2016, Appendix A). The USFWS funded pre- and post-project fish monitoring (see Silver et al. 2015, Appendix A). These reports are included in the Literature Review presented in

Chapter 4 of this report. Brief results are provided in the description of monitoring projects later in this section.

China Camp Creek/Coquille Valley Wetland Conservation and Restoration Project (Winter Lake). The second major project in the Coquille, currently under construction, is the combined China Camp Creek/Coquille Valley Wetland Conservation and Restoration project, also known as the Winter Lake Restoration Project. This project involved a partnership among landowners and funders, including ODFW, the Beaver Slough Drainage District (BSDD), the China Camp Gun Club, TNC, the CoqWA and others to upgrade four failing tide gates in order to restore 407 acres of tidal wetlands and open 1,300 acres of pastureland for winter coho rearing habitat. The China Camp Creek project, led by the BSDD, focused on upgrade of the tide gates and associated infrastructure. In the summer of 2017, the four 20-year old, wooden, top-hinged tide gates were upgraded to seven 8' x 10' x 60' concrete box culverts with improved, vertical sluice gates with MTRs. The Coquille Valley Wetland Conservation and Restoration project, led by TNC, will focus on channel reconnection and habitat restoration of the tidal wetland after the tide gate upgrade.

The project has had a challenging history, with dissention from some members of the BSDD, neighboring landowners in Garden Valley, and general opponents of increased conversion of agricultural lands for habitat restoration. Conversely, the project has many supporters in the agricultural and restoration communities due to the strong partnerships that have emerged. Adding to the challenge is the complexity of funding necessary to complete a project of this scale. In order to secure sufficient funds, the project was divided into two distinct phases: 1) the tide gate and associated infrastructure upgrade, and 2) the tidal wetland restoration. Over $8.5 million have been secured to date from a mix of federal, state, and private sources. This includes over $3 million in OWEB grants using State Lottery and USFWS National Coastal Wetland Conservation funds (OWEB projects 215-2000 and 211-115). Project delays due to permitting, weather, site conditions, procession to the final design, and increasing material costs, resulted in an increase to the overall project cost. This necessitated shifting the secured project funds to the tide gate and infrastructure phase of the project and required project partners to seek an additional $1million to complete the restoration work.

The Coquille Watershed Association (CoqWA) has another tide gate related project under construction (CoqWA 2017): the Lower Coquille River Wetland and Stream Enhancement (LCRWSE) project that they characterize as a "mini Winter Lake." This project is upgrading a failing tide gate with a new, side-hinged gate with an MTR, remeandering approximately one mile of stream, and fencing and planting riparian vegetation and shrubs on 5 acres. Just upstream from this site on the south bank of the Mainstem Coquille River is the Seestrom Creek Restoration Project. Currently in 30% design, one tide gate will be removed and a second will be upgraded with a new gate having an MTR to improve access to about 3 miles of stream, improve stream complexity, and restore riparian function.

Humboldt Bay Region

Located on the rugged North Coast of California, Humboldt Bay is a natural bay and a multi-basin, bar-built coastal lagoon and is the largest protected body of water on the West Coast between San Francisco Bay and Puget Sound. Humboldt Bay is about 14 miles long and ranges from ½ mile wide at the entrance to about 4.3 miles wide in the North Bay (Figure 5-6). The surface area of the bay is about 16,000 acres. Historically the bay also had many thousands of acres of coastal marsh, but more than 80% of these habitats have been lost or fragmented by railroad and highway construction, and conversion of tidal

lowlands to agriculture via diking and draining. Each tidal cycle replaces about 40% of Humboldt Bay water although exchange in small channels and sloughs of the bay can take up to three weeks. Freshwater input is relatively small for a bay of this size, so estuary conditions are typically only found

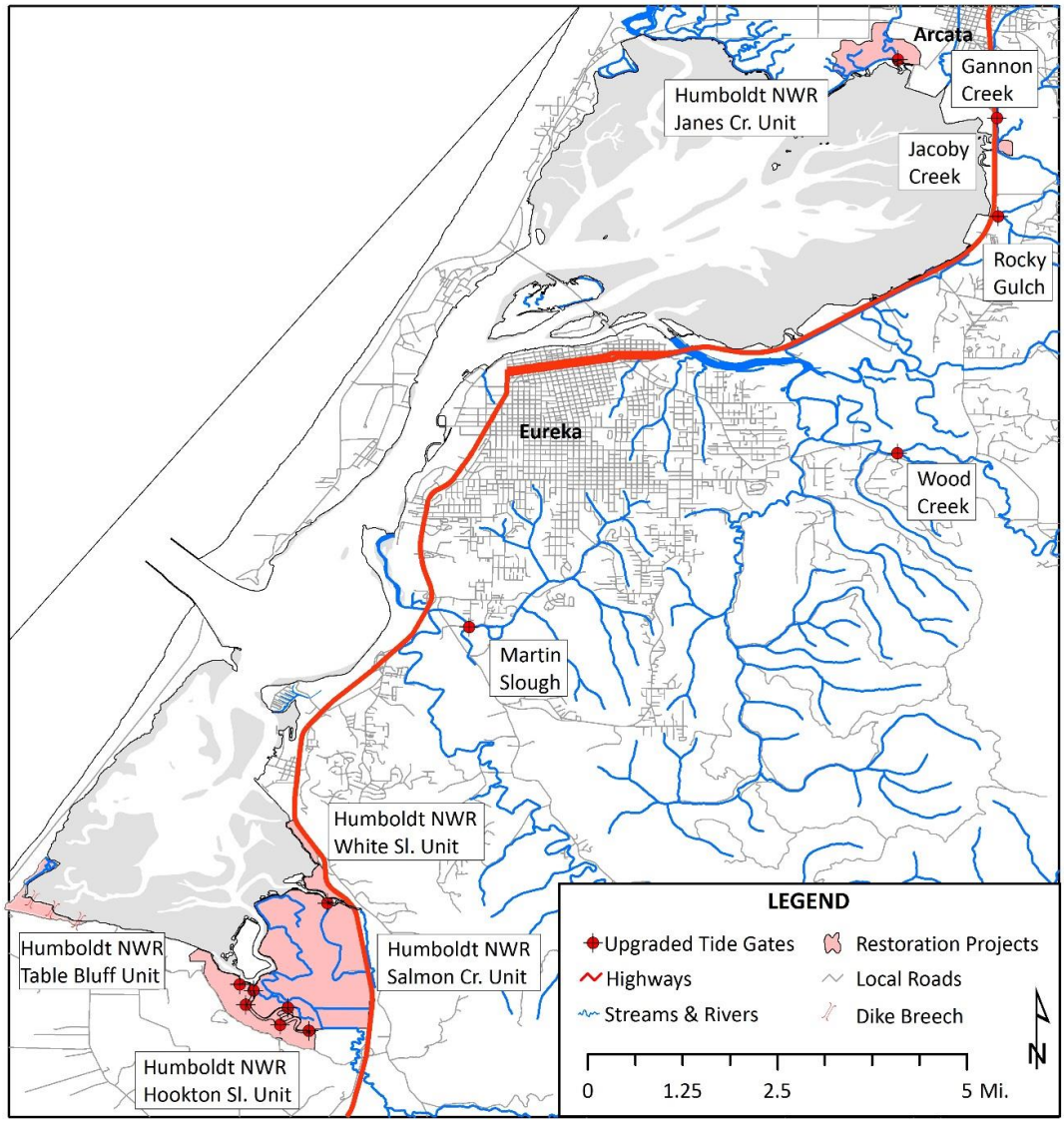

Figure 5-6. Tide gate related projects in the Humboldt Bay, CA region.

within small stream mouths and slough channels.

In the Humboldt Bay Region, populations of Southern Oregon/Northern California Coast ESU coho are listed as threatened under the federal ESA and also the California ESA, and impacts to estuary habitat (e.g. channelization) are a key limiting stressor for these fish. Populations of California Coastal Chinook salmon are listed as threatened under the federal ESA. Populations of steelhead are also threatened. Most fish habitat restoration involving estuaries and tide gates is focused on these species. The tidewater goby is also listed as endangered, and benefits from improvements in estuary habitat.

Estuary restoration projects in the Humboldt Bay Region are similar to those in WA in that they often integrate multiple components, including tide gate upgrades or removal, channel improvements, large wood placements and, notably, a particular focus on creation of off-channel ponds and freshwater rearing areas. State and local governments and many landowners are actively engaged in estuary and salmonid habitat restoration in the Humboldt Bay Region, but there do not appear to be the same type of watershed or regional scale policy frameworks and agreements (e.g. the Tidegate Fish Initiative) for balancing fish habitat, agriculture, and flood control as exist in Washington.

The Coastal Conservancy is a California state agency formed in 1976 that protects and improves natural lands and waterways, helps people enjoy them, and helps sustain local economies along California's coast. The Conservancy has been involved in a number of projects to remove fish barriers and improve estuary habitat in the Humboldt Bay Region. Non-governmental organizations also play a prominent role in estuary restoration in the region. The Northcoast Regional Land Trust works with conservationists, ranchers, farmers, timberland managers, natural resource scientists, environmental advocates, and residents to protect land and help sustain the Humboldt region's family-owned ranches, farms and forests. The Trust does not regularly engage in such work, but has taken advantage of opportunities to match their land conservation work with coastal lowland habitat restoration, with notable projects at Freshwater Farms Reserve and Martin Slough.

California Department of Fish and Wildlife (CDFW) has acquired coastal lowlands suitable for restoration, and CDFW staff have monitored salmonids in Humboldt Bay tributaries for a number of years, both before and after project implementation. Results have added to the knowledge base on estuary habitat use by overwintering juvenile coho and recognition of the importance of this life history variant to overall coho population resilience (Wallace et al. 2015). But CDFW monitoring is rarely directly associated with, or focused on tide gates. Rather, it is focused at the watershed level and restoration efforts as a whole. Results are generally not presented in a way that allows strong conclusions to be drawn regarding the effectiveness of tide gate upgrades or removal. It is possible that more focused analysis or meta-analysis of these data would allow stronger conclusions regarding the effectiveness of tide gate upgrades or removal to be made.

Salmon Creek Restoration. Land acquisitions by Humboldt National Wildlife Refuge and CDFW, and subsequent restoration, have improved conditions for salmonids. One example of a successful restoration project in this region is the work at Salmon Creek, Humboldt Bay's third largest tributary, draining about 12,500 acres and entering the ocean at the extreme southern end of Humboldt Bay via Hookton Slough. Historically, the Salmon Creek delta was a tidal salt marsh with a mosaic of slough channels. The drainage supported significant runs of coho, steelhead, coastal cutthroat, Chinook and pacific lamprey. In the early 1900's the area was converted for grazing by construction of dikes and levees, marsh draining, straightening or relocation of stream channels, and installation of tide gates. Humboldt Bay NWR acquired the ranchlands in 1988 and identified Salmon Creek as needing work to reestablish estuarine and off-channel habitat- sloughs, ponds and oxbows adjacent to the main channel needed by salmonids to transition to saltwater. Compared to pre-1900 conditions, almost all such rearing habitat in lower Salmon Creek had been lost.

In the early 1990's, a small "pet door" was added to a tide gate flap, slightly improving fish passage and allowing minor tidal exchange upstream of the tide gate. In 1993, the refuge dug a new channel and re-established channel sinuosity and complexity. This improved habitat, but further restoration was needed

to increase tidal circulation, and improve hydrology, fish access, and habitat for estuarine dependent species. In the late 1990s the Pacific Coast Fish, Wildlife & Wetlands Restoration Association (PCFWWRA), began looking at ways to decrease erosion in the upper Salmon Creek watershed. The Headwaters Wilderness Preserve was created to manage habitat restoration and conservation, reducing sediment input into lower Salmon Creek, which had been severely impacted by erosion and sediment. In 2001, PCFWWRA submitted a proposal to CDFW to examine existing conditions and identify restoration options and priorities for Salmon Creek. Managers from Humboldt Bay NWR and PCFWWRA established tide gate upgrading as the first priority. During Phase 1 in 2006-2007, the tide gate was upgraded with a pair of side-hinged gates at the mouths of Salmon Creek and adjacent Cattail Creek where they enter Hookton Slough, reducing flow velocities and staying open longer through tide cycles, thus increasing tidal connectivity and influence.

Phase 2 (2010-2011) focused on construction of 4,000' of new tidal slough channel with more capacity and sinuosity, mostly aligned with historic slough channels, but also maintaining connection to the former ditched channel so it could serve as backwater habitat. Four off-channel ponds totaling 2 acres were constructed and a connecting channel between Salmon Creek and Cattail Creek was excavated to provide winter freshwater rearing habitat for salmonids and improve fish movement between the two systems. Over 100 logs and rootwads, and 20 complex wood structures were added to provide cover for fish and add stream hydrology complexity. Also, twelve species of native trees and shrubs were planted adjacent to the channel and ponds. The Phase 2 design process included extensive modeling of both tidal and streamflow conditions using unsteady state hydraulic models, tidal channel geometry relationships, sediment transport analysis, and evaluation of soil properties and salinity data to predict rates of channel adjustment in response to the increased tidal prism.

Generally, stream-estuary ecotone (SEE) habitat restoration (off-channel pond construction; tide gate upgrade) in Salmon Creek appears successful at providing overwinter habitat for juvenile salmonids. Juvenile coho moved into the off-channel ponds in Salmon Creek immediately after they were built. CDFW fish monitoring captured more juvenile coho in the ponds in the first year post-construction (2011-2012) than in the previous 7 pre-project years combined. Monitoring also detected tidewater goby, long-finned smelt, and multiple other estuarine species. Most years, the off-channel ponds were occupied by juvenile salmonids from December-May, but due to high water temperature and salinities and often low DO they were unsuitable for salmonids from June-November. Fish growth could be quite high in the ponds, especially in spring.

McDaniel Slough Wetland Restoration. The 2013 McDaniel Slough Wetland Restoration project created a self-sustaining estuarine tidal marsh system through restoration of natural geomorphic and biologic processes. Actions included removing 4 tide gates, deepening historic slough channels and removing failing or obsolete levees to restore 222 acres of former tidelands and 24.5 acres of freshwater wetlands. Design features included salt marsh, mudflat, tidal channels, brackish and freshwater habitats and uplands. Excavation to create or enhance brackish and freshwater habitats provided the fill for the levees that were constructed to protect adjacent non-project lands.

Historically tidal wetlands, the 280-acre project area was diked and drained for pastureland in the early 1900's. In 1998, the City of Arcata acquired 188 acres of this converted land for the purpose of restoring it to tidal influence. In 2010, CDFW acquired an additional 24 acres and the City acquired another four acres. These acquisitions established habitat connectivity to over 1,300 acres of local-, state-, and federal-

protected lands adjacent to the northern edge of Humboldt Bay including the nearby USFWS Humboldt Bay Wildlife Refuge, Jacoby Creek Land Trust holdings, the City-owned Arcata Baylands and Arcata Marsh and Wildlife Sanctuary, and the CDFW-owned Mad River Slough Wildlife Area.

Hydraulic modeling was used to show that the project, in addition to restoring tidal exchange and fish access, would also help improve flood flows on the creek. Project objectives were to 1) restore a large area of tidal marsh habitat dominated by native vegetation; 2) provide unimpeded access for anadromous fish migration between Humboldt Bay, McDaniel Slough and Janes Creek; 3) create a tidal channel system maximizing estuarine fisheries habitat in large, high-order, sub-tidal channels; 4) provide connectivity of habitats using "eco-levees" with 10-to-1 slopes on the bayward side to create gradation between salt marsh/mudflat habitats and uplands; 5) provide connectivity with existing habitats; 6) alleviate rural and urban flooding due to tide gate restrictions and chronic channel aggradation; and 7) provide opportunities for public access, recreation and education.

The project also has other benefits. Tidal inundation pushing water upstream during winter storms and high tide events has helped kill invasive reed canary grass, which City of Arcata and Coastal Program staff have battled for years. This invasive plant chokes the stream channel, causes poor water quality, impedes flow causing flooding, and overall negatively impacts conditions for fish. The regenerating salt marsh is also expected to provide significant benefits in terms of mitigating the effects of sea level rise. As sea level rise impacts intensify, McDaniel Slough marsh and the new taller and wider internal levees will help buffer Arcata. The salt marsh plain will slowly add elevation as silt is deposited and plants anchor the material in place. Also, salt marshes sequester a tremendous amount of CO_2 over time. Humboldt State University students are calculating the carbon-binding potential for the project.

Over the 13 years it took to complete the project, the main lesson learned was the importance of patience and cooperation among partners and stakeholders. Funders included the California Coastal Conservancy, CDFW, Natural Resources Conservation Service, USFWS, Caltrans, Wildlife Conservation Board, NOAA, Natural Resource Conservation Service, Pacific Coast Joint Venture, Ducks Unlimited, Redwood Community Action Agency, Humboldt Area Foundation, and many local non-profits and businesses.

Eel River Estuary, Salt River Restoration. One of the largest estuary restoration projects in the Humboldt Region is located near the mouth of the Eel River, the third largest watershed entirely within California with one of the largest and most productive estuaries on the West Coast. The Salt River is a tidally influenced slough tributary to the Eel located in Humboldt County. During the mid-Pleistocene, the Eel drained into Humboldt Bay but the river was subsequently diverted by tectonic uplift at the bay's southern end and now drains directly into the Pacific Ocean. Because of its proximity and ecological similarities, the summary of estuary restoration along the Salt River in the Eel River estuary is grouped with other projects in the Humboldt Bay Region.

In the late 1800's the Salt was a functioning river, large enough to accommodate small ocean steamers. At Port Kenyon, the Salt was approximately 200' wide and 15' deep. By 2010 a person could almost jump over it there. Over time fine sediments had eroded from surrounding hills into tributaries then into the Salt River channel. Vegetation colonized the channel; trapping more sediment, blocking fish passage and increasing flooding on surrounding agricultural lands, roads, and residences. Near the Salt River mouth, the 420-acre Riverside Ranch was purchased in 2007 then transferred to the CDFW, which partnered with landowners and other agencies on the Salt River Ecosystem Restoration Project.

The Humboldt County Resource Conservation District (HCRCD) led the project, a multi-year, multi-agency, public-private endeavor that took an ecosystem-scale approach to address sediment, fish passage, flooding, and drainage issues in the Salt River Watershed. Increasingly frequent flooding, reduced drainage capacity, and sediment deposition reduced water quality and the ability of local landowners to utilize their lands for agriculture. The project had four main components: 1) restoration of the Salt River channel and riparian floodplain, 2) tidal marsh restoration at Riverside Ranch, 3) sediment management in the channel and riparian floodplain, and 4) upslope sediment reduction actions. The project affected 46 landowners with a total project cost estimated at $34 million (Estrada 2016).

In 2013, restoration of Riverside Ranch (Phase 1) re-converted 330 acres of pasture back to intertidal wetland habitat by restoring interchange of flow between the Eel River estuary and the lower Salt River. An additional 70 acres will be agriculturally managed to provide short-grass habitat for Aleutian cackling geese and other wetland-associated birds. Three miles of internal slough networks were excavated to create additional habitat for salmonids, tidewater goby, and other fish and provide areas for the natural recruitment of eelgrass. The levee and tide gate at the Salt's confluence with the Eel were removed, two miles of setback berm were constructed to create a boundary between the tidal and agricultural areas, three side-hinged tide gates were installed by Nehalem Marine and a gravel road was built on top of the berm to provide access for monitoring and maintenance. Phase 1 also widened and deepened 2.5 miles of the tidally-influenced portion of the Salt River channel; increasing tidal exchange and greatly improving fish passage and fish habitat in this area. Phase 2 was completed in 2014, with another 1.8 miles of Salt River channel restored. Phases 3 and 4 reconnected Francis and Williams creeks to the Salt River channel, for a total of seven miles of restored channel. All tide gates remaining or installed as part of the restoration are inspected annually and regularly maintained to ensure that they are functioning as designed.

As with projects in OR and WA, restoration in the Salt River involved ongoing, complex, and sometimes contentious relationships with private agricultural landowners, including conflicts over management for Aleutian cackling geese, which at one point threatened to derail the project (Estrada 2016).

The project's California Environmental Quality Act (CEQA) Habitat Mitigation and Monitoring Plan and Adaptive Management Plan require monitoring to assess achievement of project goals. Pre-project monitoring established baseline data and assisted in identifying and protecting resources in the project area. Monitoring during construction helped assure that the work conformed to approved design specifications and protected identified plants and wildlife. Currently under direction of the HCRCD, post-project monitoring is to be conducted for ten years.

By Year 2 post-implementation, native salt marsh plants (mostly perennial pickleweed and saltgrass) had colonized much of the restored tidal area. Between 2013 and 2014 (following excavation activities) percent cover of the rare native eelgrass (*Z. marina*) decreased 81%, but increased by 483% between 2014 and 2015, a substantial recovery in one year. Between 2013 and 2015, *Z. marina* percent cover in the Salt River increased by 11.7%, achieving the project goal one year early. (HCRCD 2016.)

The CDFW, Humboldt State University, and the HCRCD participated in the fish monitoring program. Seventeen fish species were captured during fall and winter sampling in 2014-2015, including the first documentation of longfin smelt in the Salt River. Sampling also confirmed overwintering use by coho salmon, with rapid growth and good condition factors. (Taylor 2015.)

Monitoring and evaluation of tide gate removals and upgrades

Tasks 2B and 3B, respectively, of the Scope of Work request summaries of OWEB funded and non-OWEB funded effectiveness monitoring projects related to the removal or upgrade of tide gates. This sub-section will proceed similarly to the previous one on restoration projects by first laying out the framework for the various types of project-related monitoring, then summarizing these projects and describing monitoring results. Complete descriptions of the projects are in Appendices B and C.

Types of monitoring

While there are many categories and types of monitoring (Roni et al. 2013), the three most commonly used in evaluating projects are:

- Implementation, Construction, or Compliance Monitoring. The basic focus concerns whether the project was implemented according to designs and met all regulatory conditions. This is the most fundamental monitoring, and is usually required by grantors (including OWEB) as a condition for obtaining funds for the project.
- Effectiveness or Performance Monitoring. Considers whether the project had the anticipated, desired effects, i.e., did it produce the benefits expected? Effectiveness monitoring can be used by practitioners as a learning tool, especially if there is a focus on adaptive management whereby individual projects are considered experiments (Walters and Holling 1990) .
- Validation Monitoring. Goes further than effectiveness to evaluate whether the hypothesized causal relationships (e.g. between habitat quality and smolt production) are correct. While this is often characterized as "research," monitoring of this type has been successful in expanding knowledge about variations of coho salmon life histories.

There are numerous variations on these three monitoring types. Both of the latter two usually require a good set of baseline data from which comparisons of project-related effects can be made. In most cases, there will need to be a comparison between the project effects and some reference; both status and trend as well as life cycle monitoring have been used successfully for this purpose (Table 5-4).

Table 5-4. Typical monitoring activities by different category and project goal.

Monitoring Type	*Estuarine Rearing Habitat*	*Fish Passage*	*Flood Control*	*Infrastructure Protection*
a) Compliance / Implementation Has the project been constructed according to specifications?	Amount and quality of resulting habitat. Typically compared to reference sites: • Area of resulting habitat at Mean Higher High Water (MHHW). • Water surface elevation (WSE) at spring tides. • Marsh surface elevation. • Drainage network characteristics.	Gate opening duration and passage conditions determine whether the project complies: • Velocity measurement and distribution through opening. • Duration of gate opening (and opening angle). • Invert and MLLW elevation.	Purpose of these projects is to lower flood levels; were they implemented as designed: • As-built volume for flood storage. • Exiting conditions for stored water (duration, water velocities, etc.).	Flood elevations, whether from tides or freshets, are most important protection criteria: • As-built elevations and locations for features. • Water surface elevation of reservoir pool during king tides and freshets.
b) Effectiveness / Performance Has the project met its goals and objectives?	Were wetland functions improved, especially as they relate to rearing habitat quantity and quality: • Amount of newly accessible habitat; water quality conditions in habitat. • Uplift in HGM wetland functions. • Survival and growth of target fish species using the newly available habitat.	Was the project effective in improving fish passage: • Hydraulic analysis of water velocities; seasonality, and timing of opening periods (tide gate upgrades). • Newly available accessible habitat and its intrinsic potential (IP). • Quality of migratory pathway, including reservoir pool and other wetlands.	Was the project effective in reducing flooding: • Reduction in flood elevations and duration. • Amount of flood damages avoided. • Does the project provide the ancillary benefits expected (i.e., quality and quantity of habitat).	Is the project, with or without tide gates, effective to protect infrastructure: • Modeled damages from various storm scenarios. • Actual experiences with different storm levels. • Resistant/resilient to future climate changes (sea level rise; storm surges).
c) Validation Are assumptions, models, and methods valid?	Does restoring natural hydrologic regimes (or improved ones with TG upgrades) lead to meeting desired reference conditions: • Food web support, i.e., vegetation, macroinvertebrates. • Do HGM function models represent on-site conditions.	Are tide gates the limiting factor for improvements in fish production: • Survival, growth, and recruitment of salmons in the stream-estuary system. • PIT tagging to assess movement within streams and through tide gates.	Are these projects an valid alternative to traditional structural approaches: • Cost:benefit of any mitigation needed for potential flood risk. • Adequacy and appropriateness of hydrodynamic models used for the design.	Are there different approaches to flood protection equally beneficial: • Cost effectiveness of project designs. • Do hydrodynamic models representative actual, post-construction conditions.

In the context of tide gate related restoration projects, Table 5-4 provides some common metrics used to evaluate attainment of project goal(s). These metrics were identified through the project reviews contained in Appendices B and C, and build upon the standard monitoring categories described above. They include physical properties often reflecting tide gate operation (water surface elevations, opening periods, velocity, turbulence), chemical properties (temperature, salinity, dissolved oxygen, etc.), fish responses (survival, abundance, condition, etc.), and other biological parameters (aquatic vegetation, macroinvertebrate food web support, wetland function). While we have not conducted a detailed cost analysis as part of this project, in general, monitoring costs increase exponentially from physical to chemical to fish and other biological parameters.

OWEB funded monitoring and evaluation projects

Since 2004, OWEB has funded 13 effectiveness monitoring grants linked to tide gate removal or upgrade projects (Table 5-5). Four of these grants were directed at two restoration projects involving the removal

Table 5-5. Project effectiveness monitoring funded by OWEB.

App. Ref.	Project Name (OWEB Grant #)	TG Project Type	Implementing Organization	Monitoring				Pub. Ref.[2]
				Physical[3]	Chemical[4]	Salmon[5]	Biological[6]	
B-5	Coos Watershed Tide Gate Replacement Project Effectiveness Monitoring (204-289)	Upgrade	Coos Watershed Association	✓	✓	✓	✓	A-3, A-83
B-7	Coos Watershed Tide Gate Replacement Project Effectiveness Monitoring (206-244)	Upgrade	Coos Watershed Association	✓	✓	✓	✓	A-83
B-9	Coos Watershed Tide Gate Replacement Project Effectiveness Monitoring (207-238)	Upgrade	Coos Watershed Association	✓	✓	✓		A-83
B-11	Coho Life History in Tide Gated Lowland Streams (210-2071)	Upgrade	Coos Watershed Association			✓		A-101
B-13	Coho Life History in Tide Gated Lowland Coastal Streams (212-2044)	Upgrade	Coos Watershed Association	✓	✓	✓	✓	A-101
B-15	Coho Life History in Tide Gated Lowland Coastal Streams 2014-2016 (214-2031)	Upgrade	Coos Watershed Association	✓	✓	✓	✓	A-101
B-17	Coho Life History in Tide Gated Lowland Streams, 2016-2018 (216-2068)	Upgrade	Coos Watershed Association	✓	✓	✓	✓	A-101
B-24	Ni-les'tun Tidal Wetland Restoration Effectiveness Monitoring (210-2032)	Removal	Estuary Technical Group, IAE	✓			✓	A-30, A-33
B-26	Ni-les'tun Tidal Wetland Restoration Effectiveness Monitoring (212-2068-9345)	Removal	Estuary Technical Group, IAE	✓	✓	✓	✓	A-30, A-33
B-32	Tide Gate Effectiveness Monitoring, Columbia River Tributaries (204-277)	Upgrade	Clatsop Coordinating Council	✓	✓	✓		
B-34	McDonald Slough Reconnection Project Effectiveness Monitoring (215-1017-11607)	Upgrade	Lower Nehalem Watershed Council	✓				
B-43	Pixieland Tidal Wetland Restoration, Phase 1 (208-1061-8321)	Removal	Salmon – Drift Creek Watershed Council	✓	✓		✓	A-120
B-47	Pixieland Tidal Wetland Restoration, Phase 2 Effectiveness Monitoring (208-1061-8991)	Removal	Estuary Technical Group, IAE		✓		✓	A-120

1. Restoration and monitoring project descriptions in Appendix B.
2. Publication described in the Appendix A literature review.
3. Includes water and/or marsh surface elevations, water velocity, turbulence, gate-opening angles and periodicity.
4. Temperature, salinity, dissolved oxygen (DO), turbidity, etc.
5. See Appendix reference for specific species of salmon.
6. Other biological monitoring, including other fish species, macroinvertebrates, vegetation, etc.

of tide gates with subsequent full tidal reconnection. These are Ni-les'tun Tidal Wetland Restoration at Bandon Marsh NWR on the Coquille River; and Pixieland Tidal Wetland Restoration on the Salmon River. While Ducks Unlimited was the grantee for the Ni-les'tun project, the monitoring was largely conducted by the Institute of Applied Ecology's (IAE) Estuary Technical Group, and the Confederated Tribe of the Siletz Indians. At Pixieland, monitoring was split with the Salmon – Drift Creek Watershed Council conducting the physical and chemical data collection and the Estuary Studies Group at IAE measuring the vegetation plots. The Ni-les'tun project used a Before-After-Control-Impact (BACI) study design, while the Pixieland project used comparisons with the mainstem Salmon River to evaluate water quality, and applied a Department of State Lands performance criteria protocol for the vegetation analysis. The results of these projects are discussed in detail in Section 4 as their reports were included in the Literature Review. However, a brief summary follows.

Salmon River Estuary: Pixileland Restoration. At Pixieland, monitoring after Phase I and Phase II restoration actions detailed the following changes in the plant community composition and hydrologic function. Native herbaceous species cover increased in all habitats and was higher than that of invasive species in the herbaceous zone but had not yet reached benchmark levels in the shrub zone. The average moisture index meets the benchmark of <3.0. Shrub plot average stem density was 2633/acre, which is greater than the 1600/acre benchmark. In shrub plots invasive shrub and tree species density is 10% or less of total stem density. Total plant cover is progressing toward reference conditions in herbaceous wetlands. There is free tidal exchange and inundation now reflects tidal patterns in the adjacent river. Plant composition was largely unchanged and comprised of native species but there was a decrease in Baltic rush and an increase in tall-fescue, which is non-native. The cover of litter, wood, moss, and open space increased after restoration. Four treatments were tested for reed canarygrass control in the restored marsh area: herbaceous plantings, willow plantings, herbaceous x willow plantings, and landscape fabric. The ratio of native to non-native species, percent cover by native and non-native species, plant species richness, and percent cover and frequency of reed canarygrass did not differ among treatments. Community composition in reed canarygrass experimental plots was different between 2011 and 2013. Although reed canarygrass treatments were ineffective, steep declines in reed canarygrass cover were likely caused by intrusion of brackish (15-20 psu) waters. Failure of willow plantings was likely also caused by the higher than anticipated salinities.

***Ni-les'tun Tidal Marsh Restoration, Bandon Marsh National Wildlife Refuge*.** OWEB-funded effectiveness monitoring at Ni-les'tun compared reference and restoration sites. Results indicated that vegetative cover was moving toward native-dominated tidal marsh communities, and that marsh use by native fish, aquatic invertebrates, and migratory shorebirds and waterfowl increased. Hydrology and channel morphology are trending toward reference conditions. Channels deepened, fine sediment increased, and downcutting began in lower reaches. Full tidal exchange has been restored. By 2015, daily maximum water levels were similar inside and outside and inundation and exchange were restored at even the two highest elevation transects in the restoration site. Groundwater level and amplitude of fluctuation also increased. Surface elevation increases from 2011 to 2015 were similar between marshes. Elevations at specific transects increased an average of 4.9 cm (restored) and 3.6 cm (reference) post-restoration. Vegetation species richness was lower at the restoration site and did not change at the reference site post-restoration. Percent cover (total, native, non-native) did not differ between sites or among years. However, salt-tolerant plants were increasingly present. Native-dominated vegetation communities increased and non-native-dominated communities decreased from 2013 to 2015.

The large changes in specific salt-tolerant early colonizers suggest that the plant community is not yet close to a stable state. However, analysis showed that the restoration plant community was moving toward a low salt marsh community as found at the reference site. Tidal marsh function indicators are approaching or within the range of conditions at reference sites. Soil salinity and % carbon, and channel salinity increased; temperature was more similar to reference. Benthic macroinvertabrate abundance increased and diversity decreased. USFWS funded more extensive pre- and post-project fish monitoring (see Silver et al. 2015, Appendix A), however Brophy et al. 2014 collected some fish data. Fish access to the channels increased from 2% to 27%. Mean peak CPUE in the restoration site was lower than reference pre-removal and higher post-removal for Chinook and staghorn sculpin, and was higher in the restoration site pre- and post-removal for stickleback. Restoration significantly affected sculpin and wood placements significantly affected Chinook and sculpin. Peak migration increased in the 3 restoration subbasins, but not in the reference site. Overall, restoration increased resilience to climate change and the ability to moderate flooding.

The 9 OWEB funded effectiveness monitoring grants that focused on tide gate upgrades can be divided into two categories: (1) those focused on evaluating the effects of the tide gates themselves; and (2) those evaluating larger system responses to improving fish passage. Monitoring at McDonald Slough also focused on the effects of the tide gate upgrade. The remaining seven grants funded monitoring in tributaries to the Coos Bay estuary. Early efforts focused on tide gate effects but later projects focused on fish passage and coho LCM.

Nehalem Estuary: McDonald Slough. In 2015 a 4-year monitoring program began at McDonald Slough in the Nehalem estuary immediately after upgrade with side-hinge MTR gates. Monitoring includes continuous gate angle and water depth measurements. ODFW is contributing to monitoring efforts by performing fish presence/absence surveys and channel morphology measurements in the slough upstream of the gate. Additionally, temperature and salinity are being monitored inside and outside of the slough to evaluate water quality. Results are not yet available; however, some observations have been reported. The MTR tide gates allowed for more tidal flushing resulting in greater dissolved oxygen, decreased water temperatures, and improved water quality in McDonald Slough. The new tide gate system also provided improved fish passage. The large wood placements created complex habitat within the slough and North Fork Nehalem River, providing cover, encouraging pool scour, providing hard surfaces for aquatic invertabrates, and providing additional habitat for other aquatic and terrestrial species.

Coos Bay Estuary: Palouse, Larson, and Willanch Creeks: Effectiveness and Life Cycle Monitoring. In 2004, the CoosWA initiated its tide gate effectiveness monitoring program in collaboration with OSU and ODFW. The earliest projects focused on evaluating the performance of the new Larson Creek side-hinged tide gates in comparison to the traditional wooden top-hinged gates on Palouse Creek. In addition to physical and chemical data, Passive Integrated Transponder (PIT) tags were inserted in coho juveniles and smolts to evaluate their passage through the gates (Bass 2010). Tagged fish were also tracked throughout the freshwater system to better understand their rearing life histories (Weybright and Giannico 2017). As tagged smolts began to return, the project was expanded to use the tagged fish to determine marine and freshwater survival rates (especially for coho jacks), and whether these affected survival and recruitment (Nordholm 2014). Data collected in this effort also allowed for the comparison of lowland, tide gated, streams with seven other locations where ODFW operated salmon life cycle monitoring sites (including Winchester Creek in the South Slough National Estuarine Research Reserve). A summary of results is

presented here. Results from this effectiveness monitoring and LCM are also included in the Literature Review and are discussed in detail in Chapter 4.

In addition to monitoring Larson Creek tide gate function, CoosWA has conducted monitoring of stream conditions immediately upstream of the tide gate and of coho populations in Larson and Palouse creeks. These monitoring efforts were funded by OWEB. CoosWA used PIT technology to tag and remotely track individual fish, which complemented standard ODFW Life Cycle Monitoring (LCM) procedures. For the coho population, spawner estimates varied among years; the range was 341-787 in Larson Creek and 587-1915 in Palouse Creek. Spawner counts in 2001-2004 were similar to historic levels, but decreased in later years. Abundance estimates decreased in ’01-’04 and increased in ’05 and ‘06. Smolt abundance was similar between basins. Fish PIT tagged in tidally influenced areas moved extensively while those tagged in riverine reaches were mostly sedentary. Mobile juveniles' growth rates were more variable than those of sedentary juveniles. Growth rates for both groups decreased throughout the season.

Freshwater and marine survival rates were similar in the Larson and Palouse Creek basins. However, estimates differed between the two approaches. Freshwater survival estimated from life-cycle monitoring data was <3% for all brood years except '07 and marine survival was <2% in '04 and >6% for '07 and '08 for both creeks. Based on PIT data freshwater survival was ~30% in Palouse Creek and 20% and 9% in Larson Creek. Marine survival was 5% in Palouse Creek in '05. The proportion of the run returning as jacks was <2% for all years in both streams. For habitat, the most limiting factor for the coho population in Palouse Creek is summer rearing area, which is influenced by temperature. In Larson Creek, winter rearing area is most limiting. Temperature increased downstream in both creeks and limited salmon use of lower stream reaches, especially in Palouse, which was above 70°F July and August. No juvenile coho were found in either tide gate pool in summer but some moved back into the Palouse Creek pool after temperatures decreased. After the Larson tide gate upgrade salinity was higher and velocity lower than pre-restoration. Prior to upgrade, patchy eel grass beds and algae were present. After upgrade there were rushes and grasses with small algae patches along the margins. Habitat in the two basins was comparable but capacity was higher in Palouse Creek.

Coho Life History Project. The system-wide approach to monitoring in the Coos was continued as CoosWA’s Coho Life History in Tide Gated Lowland Streams project. This life cycle monitoring (LCM) project advanced a long-term monitoring study initiated in 2004 to explicitly examine and describe variations in juvenile coho life histories, including the nomad strategy, and their contribution to adult spawning populations, and evaluate over-winter rearing strategies in relation to temporal and spatial habitat use. Data collected added to the time series described above. OWEB funded four 2-year phases of this project, beginning every two years from 2010 to 2016. Evidence from this project and across the range of coho strongly indicates that connectivity in diverse and dynamic tidal habitats provides alternative rearing pathways critical for the sustainability and recovery of Oregon Coastal (OC) coho stocks. This project reestablished innovative PIT tag mark recapture techniques to monitor coho movements and migrations. Temporal and spatial components of over-winter rearing strategies, in relation to habitat use and project effectiveness monitoring, is the focus in these paired study streams. In 2014-2016, monitoring was shifted to Willanch Creek from Larson Creek. Juvenile coho diet analyses were conducted to determine relationships to seasonal and diurnal variations in environmental factors in order to assess proximal causes of habitat productivity. Diet analyses showed seasonal and diurnal variation in foraging strategies between early migrating sub-yearlings and yearling smolts across their range in estuarine habitats- fundamental mechanisms that promote increased juvenile coho growth and

survival in the estuarine ecotone. In conjunction with prior and current data, results highlight the critical importance of these diverse habitats for recovering viable OC coho populations.

Adult spawner estimates vary up and down, a few years in each direction following the same pattern as other Coos Life Cyle Monitoring (LCM) sites, especially Smith River. Spawner abundance was highest in 2007 and about average in 2008. Smolt abundance increased 2004 to 2009 and was lowest in 2010. Peak spawner counts in Palouse Creek were related to favorable ocean conditions in the north Pacific from the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO).

Freshwater survival was variable, but was generally <5%. For both Palouse and Larson creeks freshwater survival closely tracked the survival at other LCM sites. Marine survival for Palouse was variable with some years below 7% and others 13-18%. Larson marine survival was 1-10% and within the range of other Coos watershed LCM sites. The pattern of survival was similar to that of the Smith River LCM site. Monitoring was shifted to Willanch Creek from Larson Creek in 2014. The Willanch data set did not include all sample years, but tracked other Coos River systems at lower levels. However, some differences were apparent. For example, fry and smolt estimates for Palouse Creek were lower in 2016 than 2015, while those for Willanch Creek were higher in 2016 than 2015. PIT-tag data were not yet available to estimate survival for Willanch Creek. The detection array was anticipated to by operational for the spring 2017 juvenile migration.

Fork length distribution provided evidence for two age classes. Fish size distribution was similar in freshwater and brackish habitats. In summer ~3/4 of the fish were sedentary and in winter ~3/4 were mobile. In summer, mobile fish were mainly in the lower two reaches. In winter mobile fish were distributed throughout the stream. Fish sedentary in summer or winter had higher winter survival. However, in reaches 2 and 3 no sedentary fish survived. Survival was higher for larger fish and for fish farther upstream. Growth rate was influenced by water temperature, coho density and habitat complexity. Total growth in the estuary was higher for estuary-rearing fish and for those with longer estuary residence. Juveniles in lower reaches before their first October were considered early migrants and in 2007 early migrants had the highest percent return. High levels of interrelatedness were found in Larson, precluding analysis of genetic differences in residents and early migrants or nomads. Juveniles residing in the stream-estuary ecotone exist in stressful conditions but they have increased growth rates relative to upstream rearing fish. Juvenile coho diet analyses revealed seasonal and diurnal variation in foraging strategies between early migrating sub-yearlings and yearling smolts across their range in estuarine habitats. These results may reveal mechanisms influencing estuary growth and survival for juvenile coho.

Non-OWEB funded monitoring and evaluation projects

Based on our extensive review of non-OWEB funded tide gate restoration projects, we identified 20 (Table 5-6) that had monitoring data, either as part of project-effectiveness monitoring, or as part of a larger program-effectiveness effort. Although OWEB did fund some of the monitoring listed in this table in Oregon we found documentation that other organizations funded EM and produced separate reports. Therefore, we have identified these as non-OWEB funded projects. Similar to our discussion in the restoration project sub-section, these projects are organized into four regions, extending from Puget Sound in Washington to Humboldt Bay in California. These discussions will be relatively brief because their results are included in Chapter 4.

Table 5-6. Non-OWEB funded tide gate related effectiveness monitoring projects.

App. Ref.	Project Name	TG Project Type	Implementing Organization	Monitoring				Pub. Ref.[2]
				Physical[3]	Chemical[4]	Salmon[5]	Biological[6]	
Lower Columbia River Region, OR & WA								
C-1	Grays River/Seal Slough/Kandoll Farm (WA)	Removal	Columbia Land Trust		✓	✓	✓	A-38, A-89
C-6	Tenasillahe Island Slough, Julia Butler Hansen NWR (OR)	Upgrade	U.S. Fish & Wildlife Service		✓	✓		A-41, A-71
C-9	Mainland Unit Restoration, Julia B. Hansen NWR (WA)	Upgrade	U.S. Fish & Wildlife Service			✓		A-66
C-11	Ft. Clatsop South Slough (OR)	Removal	LCREST		✓	✓		
C-23	Greenhead Slough Restoration, Willapa NWR (WA)	Removal	U.S. Fish & Wildlife Service			✓		
Coastal Oregon								
C-28	Southern Flow Corridor Project – Wilson River							
C-31	Salmon River Estuary Restoration	Removal	Multiple			✓	✓	A-19, A-45, A-51, A-63, A-73, A-80
C-34	Phey Lane Tide Gate Replacement	Upgrade	ODFW	✓		✓		
C-36	Kentuck Slough Tide Gate Replacement	Upgrade	Nehalem Marine	✓	✓			
C-39	Matson Creek Wetland Preserve	Removal, Upgrade	The Wetlands Conservancy				✓	
C-42	Bandon Marsh Restoration Monitoring	Removal	USFWS		✓	✓	✓	A-30, A-33, A-95
Puget Sound, WA								
C-44	Crescent Harbor Salt Marsh Restoration Project, Skagit River Estuary	Removal	Skagit River System Cooperative		✓	✓	✓	A-12
C-48	Fisher Slough Restoration	Upgrade	Skagit River System Cooperative	✓		✓		A-5, A-8, A-14, A-54, A-56, A-61
C-53	Wiley Slough Restoration Project		Skagit River System Cooperative	✓	✓	✓		A-10
C-80	Qwuloolt Estuary, Snohomish River	Removal	NOAA - NW Fisheries Science Center	✓	✓	✓	✓	
Humbolt Bay Region, CA								
C-85	Rocky Gulch Habitat Restoration Project	Upgrade	California F&W			✓		A-99
C-88	Natural Stocks Assessment Project	Multiple	California F&W					A-99
C-90	Salmon Creek Restoration Project	Upgrade	California F&W			✓		
C-94	Martin Slough Restoration Project	Upgrade	California F&W			✓		A-99
C-98	McDaniel Slough Tidal Restoration	Removal	California F&W			✓		
C-104	Wood Creek Tidal Marsh Enhancement Project, Freshwater Farms Reserve	Removal	California F&W			✓		A-99

1. Restoration and monitoring project descriptions in Appendix C.
2. Publication described in the Appendix A literature review.
3. Includes water and/or marsh surface elevations, water velocity, turbulence, gate-opening angles and periodicity.
4. Temperature, salinity, dissolved oxygen (d.o.), turbidity, etc.
5. See Appendix C reference for the specific species of salmon.
6. Other biological monitoring, including other fish species, benthic macroinvertebrates, vegetation, birds, etc.

Puget Sound Region. Significant monitoring on effects of tide gate removal and upgrades in the Puget Sound region has occurred, largely through funding provided as mitigation for hydropower projects on

the Skagit River as a result of the Skagit Fisheries Settlement Agreement of 1991 (revised in 2011) obtained as part of Federal Energy Regulatory Commission relicensing (Project No. 553) for Seattle City Light's Skagit Project that involves three dams producing about 690 megawatts of power.[1] Mitigation funds have provided restoration and research support to the Skagit River System Cooperative, as well as NOAA's Northwest Fisheries Science Center and the USGS Western Fisheries Research Center, both in Seattle, WA.

The Skagit River System Cooperative (SRSC) provides natural resource management services for the Sauk-Suiattle Indian Tribe and the Swinomish Indian Tribal Community (www.skagitcoop.org). Their Research Department, one of five program areas, works both locally and regionally for salmon recovery by improving knowledge about habitat use by juvenile Chinook salmon, fish response to recovery efforts (including habitat restoration), and linkages between habitat conditions, landscape processes, and land uses. The SRSC has field crews that collect fish distribution data as well as physical, chemical, and vegetation information. A particular focus is the role of estuaries for the recovery of wild Skagit Chinook runs (ESA-listed), especially small pocket estuaries along the Whidbey Island shoreline (Beamer et al. 2005). The SRSC has been particularly effective in linking estuary restoration with effectiveness monitoring, with significant long-term monitoring of the Fisher Slough tide gate upgrade project. Technical memorandum and progress reports are readily available through the Research Department's website; however, these have not been converted into peer-reviewed journal publications.

The Skagit is also an Intensively Monitored Watershed (IMW), a program coordinated by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) to test the effectiveness of stream restoration programs.[2] The Skagit is one of sixteen IMWs extending from Prince of Wales Island in British Columbia, east to the Lemhi in Montana, and as far south as the Ten Mile and Pudding Rivers in California. The Skagit is the only one investigating estuarine restoration. The advantage of the IMWs is that they provide significant resources for sample design and data management best practices.

Lower Columbia River Region. Monitoring in the lower Columbia River region is similar to northeast Puget Sound in that most of the restoration projects are funded as mitigation for Corps of Engineers, channel dredging, and Bonneville Power Administration's (BPA) responsibilities under the Northwest Power Act to mitigate hydropower generation impacts and meet ESA obligations.[3] The Pacific Northwest National Laboratory (PNNL) has taken the lead in coordinating monitoring in the lower Columbia through the Columbia Estuary Ecosystem Restoration Program (CEERP) that has focused on seven lines of evidence (Diefenderfer et al., 2013, 2016): spatial and temporal synergies, cumulative net ecosystem improvement, estuary-wide meta-analysis, offsite benefits to juvenile salmon, landscape condition evaluation, and evidence-based scoring. Many local groups in the lower Columbia River are monitoring their restoration projects using protocols developed by PNNL, which has allowed for meta-data analysis spanning multiple sites, multiple years, and comparison with other published literature (Diefenderfer et al. 2016). These results are included in the Literature Review in Chapter 4.

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[1] https://www.seattle.gov/light/skagit/docs/FisheriesSettlementAgreement1991andAppendices.pdf. https://www.seattle.gov/light/skagit/docs/Modified%20Skagit%20FSA_January%202011final_withAppendix_with%20Signatures.pdf.
[2] https://www.pnamp.org/project/3133.
[3] https://www.bpa.gov/efw/Analysis/NEPADocuments/Pages/EstuaryRestorationProgram.aspx.

Coastal Oregon. Monitoring conducted on non-OWEB funded tide gate related restoration projects on the Oregon coast has been less coordinated than the efforts in the Skagit delta and lower Columbia River. There are five areas that have projects with monitoring (Table 5-5): (1) the Salmon River estuary projects located on lands managed by the U.S. Forest Service; (2) the Phey Lane tide gate upgrade in the Siuslaw estuary; (3) the Kentuck Slough tide gate upgrades in the Coos Bay estuary; (4) Matson Creek Wetland Preserve; and (5) the Bandon Marsh NWR tidal marsh reconnection, discussed above as part of the Ni-les'tun Tidal Wetland Restoration monitoring program. Of the five areas, the Salmon River restoration program has the longest history and richest set of publications (Frenkel and Morlan 1990; Bottom et al. 2005; Jones et al. 2014). These papers and others focused on this region are included in Chapter 4 as part of our Literature Review. Flitcroft et al. (2016) provide an overview of the restoration and monitoring that has been conducted at the Salmon River.

Phey Lane and Kentuck represent two efforts to evaluate tide gate upgrades, and both have muted tidal regulators. Phey Lane monitoring was conducted by ODFW to better understand fish passage at a new muted tidal regulated tide gates. Data from this project has not been reported or published. The Kentuck tide gate monitoring was initiated and funded by Leo Kuntz of Nehalem Marine in order to demonstrate the utility of MTRs. The monitoring equipment consisted of real-time tide gate opening angle loggers, water surface elevation transducers, and water temperatures inside and outside the tide gates. Data sets were archived, but no reports have yet been produced. After a couple of years, this equipment was donated by Nehalem Marine to the CoosWA for deployment at the Willanch Tide Gate where it is presently installed in conjunction with acoustic Doppler current profiler and PIT tag antennas as part of CoosWA's Life Cycle Monitoring project.[4]

Both the Matson Creek Wetland Preserve and Bandon Marsh NWR (Ni-les'tun) projects involve tide gate removals, although there is a tide gate attached to a setback levee at Matson Creek. Monitoring in the tidally reconnected areas of Matson Creek was conducted to meet DSL and ODFW mitigation requirements on the part of the Coos Bay – North Bend Water Board; only vegetation monitoring at permanent plots was conducted. Fish monitoring at Bandon Marsh was conducted by USFWS staff as part of the larger effort described in the OWEB-funded monitoring section and is included in the Literature Review in Chapter 4.

Humboldt Bay Region. Monitoring in Humboldt Bay, CA is significant because it is an integrated, long-term program focusing on the effects of restoration projects on coho salmon (Wallace et al. 2015). Sampling began in 2003 and continues today. The focus of the sampling was on coho use of the stream estuary ecotone (SEE). Similar to the monitoring of the Coos Watershed Association, fish seining, rotary screw traps, and PIT tagging were used to sample coho and determine their movement patterns.
One publication in the California Fish and Game journal (Wallace et al. 2015) has resulted from the data collection, with many other annual progress reports. Tide gates were mentioned in the abstract and very briefly in the discussion but this study was not set up to evaluate effects, did not alter any stream reaches or impediments in any way, and did not discuss the habitat conditions that were most beneficial to juvenile salmon. However, it does provide additional evidence for fish moving into the lower stream reaches and mildly brackish habitats as both subyearlings and yearlings. Additionally, three of the upgraded tide gate locations—Wood Creek, Martin Slough, and Rocky Gulch (see Figure 5-7)—were extensively sampled. These three sites correspond to our Stream/River Mouth tide gate geography, and

[4] http://www.cooswatershed.org/wp-content/uploads/2017/01/WillanchTG_Graph.jpeg.

would be comparable to some of the Coos Watershed Association's monitoring. It is possible, that the Humboldt data could be re-analyzed to provide more tide gate specific findings.

Chapter 6 Thinking Systematically about Tide Gates

Ecological and geomorphological considerations

The large number of projects identified in Tables 5-1 and 5-2 provide the raw material to generalize tide gate related projects into a set of categories based on their goals and geography. Some of the results of this classification can be seen in the "Project Type" and "TG Geography" columns. This sub-section will provide a background on the development of these categories, and provide a framework to find commonalities among different projects. Additionally, it will include a discussion of findings from OWEB and non-OWEB projects along with a list of recommendations and advice for planning and carrying out tide gate restoration projects.

Project goal(s)

Our literature review (Section 4), examination of restoration projects, and our experiences with tide gates led us to develop two matrices to help organize our thinking about tide gates and their effects. The first matrix, Table 6-1, highlights four goals that drive most tide gate related projects:

- Developing estuary rearing habitat, typically for salmonids but with benefits to other species;
- Improving fish passage between brackish and freshwater, particularly for juveniles and smolts;
- Providing flood control by affording storage capacity during high flows; and
- Protecting infrastructure, the original purpose for installation of almost all tide gates.

While there is often a primary goal that provides the original impetus for a project, many—if not most—projects encompass more than this goal in practice to build support and acquire needed funding. For example, a levee setback project that removes a tide gate to improve estuarine rearing habitat may need to install an upgraded gate at an interior location to protect adjacent infrastructure. Multi-goal projects also often respond to the needs of multiple funders and landowners so that each one gains some benefit.

The Table 6-1 matrix also identifies effects related to each goal that might be expected from either removing the tide gate or upgrading it to meet current standards. These generally correspond to the benefits that accrue to the primary project goal, but may also have other effects. Generally, upgrades provide some proportion of habitat benefits achieved through removal, but there are certain instances where upgrades provide benefits that removal cannot. For example, reservoir pools behind tide gates provide freshwater rearing habitat during those seasons when their water quality is suitable; this habitat is lost if the tide gate is removed and tidal exchange of brackish water is restored. Similarly, infrastructure protection benefits can still be achieved if the tide gate is upgraded, but those same benefits are typically lost if the gate is removed. However, these benefits may be transferable: the Southern Flow Corridor project provides infrastructure benefits to upstream areas through re-flooding currently diked properties while also providing estuarine habitat benefits to fish and other aquatic species.

Table 6-1.Categorization of tide gate related estuarine restoration projects.

Project Goals	***Action Descriptions***	***TG Removal Effects***	***TG Upgrade Effects***	***Evaluation Metrics***
a) Estuarine Rearing Habitat	Restoration occurs primarily in diked areas that have tide gates to allow water behind the dikes to drain into the estuary. Restoration actions include: • Dike breeching. • Dike removal. • Levee setback.	Tide gates were usually present in previously diked areas. Removal benefits: • Improved hydrologic connectivity. • Dike breeches may still have high velocities and limited inundation. • Sediment scour (channels) and deposition (marsh surface).	New tide gates usually installed landward of the previous ones to protect property. Benefits include: • Balanced protection and restoration. • Improved connectivity between freshwater and estuarine habitats. • Hydrologic function recovery.	• Quantity of estuarine wetlands newly accessible. • Uplift in HGM wetland functions. • Salmonid abundance and condition (length, weight). • Aquatic food web support.
b) Fish Passage Between Freshwater and the Estuary	Tide gates prevent passage by anadromous fish during closed periods, and may impede passage when open due to high velocities, raised sills, and/or debris. Focus in fish passage is on the stream channel. Typical restoration actions are: • Remove tide gate. • Upgrade tide gate.	Generally, no tide gates are a desirable project outcome. Benefits include: • Allows free passage for all life stages. • Improved sediment transport. • Thorough mixing of fresh and brackish water.	If tide gates are needed, upgrades can provide: • Improved passage for at least some periods. • Reservoir pool that <u>may</u> provide suitable habitat and velocity refuge.* • Mixing zone of fresh and brackish waters.	• Salmonid movement. • Miles of accessible habitat and its intrinsic potential (IP). • Quality of migratory pathway connectivity. • Velocity distribution and timing. • Water quality (temperature, salinity).
c) Flood Control (major events)	Diked and tide gated lowlands prevent flows from spreading onto floodplains, raising water levels during floods and storm surges. Restoration actions: • Levee removal. • Levee setback.	Removal will provide: • Full tidal inundation. • Access to off-channel velocity refuge.* • Improved food web support.	In this case, the tide gates function as "flood gates." Benefits possible include: • Seasonal management, for flood storage (open) or protection (closed). • Provide velocity refuge.*	• Opening duration. • Juvenile survival and growth rates. • Flood elevation reductions. • Uplift in HGM wetland functions.
d) Infrastructure Protection (tides)	The function of tide gates is to protect land and infrastructure from tidal flooding. This need is likely to expand with sea level rise. Typical restoration actions: • Upgrade tide gates. • Raise road and building elevations.	Removal may make it difficult to meet protection goal due to: • Requirement for landowner consent. • High costs for raising infrastructure elevations. • Community assent (i.e., Drainage Districts).	There is a large demand to assist landowners to upgrade their tide gates. Benefits include: • Support working landscapes and provide incentives to cooperate in restoration. • Better drainage due to greater outflow capacity.	• Duration and timing of suitable passage during critical life stages. • Cost-share percent. • Amount and extent of leveraged projects. • Other metrics in the Fish Passage goal above.

* We use the term "refuge" for temporal or spatial protection from disturbance or competition consistent with the nomenclature of Keppel et al. (2012).

Tide gate geography

In addition to the categorization of projects based on their primary goals, where tide gates are located in relationship to the estuary influences their effects. Figure 6-1 shows a schematic of the three potential locations for tide gates. Table 6-2 provides descriptions for the characteristics of these locations, an overview of the effects of tide gate removals or upgrades as affected by their location, and potential metrics to evaluate these effects. The three locational types are:

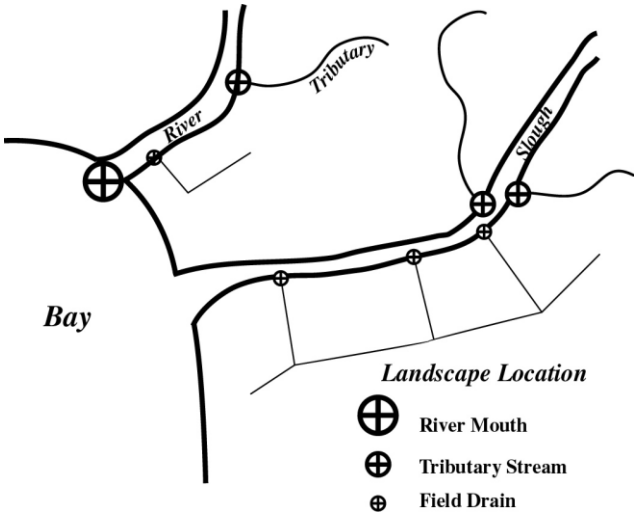

Figure 6-1. Geography of tide gate locations (Giannico and Souder, 2005).

1) At the mouths of rivers or streams that drain 6th or 7th HUC watersheds.

2) At the mouths of tributary streams that either drain directly into an estuary or drain upstream from a river mouth tide gate.

3) Field (or urban) drains that have not historically included streams extending beyond the floodplain.

Stream/river mouth tide gates (also called "tidal barrages") potentially have the largest impact on aquatic life because they are typically located at the mouth of mainstem streams where they enter the estuary (Figure 6-1). This critical location controls fish passage from freshwater to estuarine waters, while diminishing the transitional salinity gradient between freshwater and marine environments. The drainage areas above these tide gates are generally in the 6th HUC (10,000 to 40,000 acres) or 7th HUC (3,000 to 10,000 acres) in extent, also known as 12-digit and 14-digit, respectively, watershed delineations (USGS and NRCS 2013). For traditional, well-functioning tide gates there is an abrupt transition between fresh and brackish waters, particularly in the summer when freshwater inflows behind the tide gate are reduced; with a limited "wedge" of freshwater flowing into the estuary and a limited "wedge" of saltwater flowing upstream into the stream or river when the gate is open. In many cases, these stream-mouth tide gates are located at road or highway crossings, and often have multiple gates within a larger structure. This location means that their removal is often precluded; and their upgrade more difficult and expensive. The existing openings were likely sized based on cost and drainage considerations; and inverts may be elevated in relation to streambed and Mean Lower Low Water (MLLW) elevations. When the existing superstructure is suitable, replacing the existing tide gates with upgraded models is often the most cost-effective approach.

Tributary stream tide gates drain smaller areas, and control shorter distances of stream (Figure 6-1). These tributary streams will extend beyond the floodplain, and may have limited spawning areas for salmonids in their upper reaches, although often they do not. In contrast to the stream/river mouth tide gates, tributary stream tide gates will have few subsidiary tide or flood gates above their installation. These tributary stream tide gates may drain directly into the estuary, or they may drain into the reservoir pools or streams controlled downstream by a stream/river mouth tide gate. These tide gates are smaller (generally in the range of 36" to 60"), usually attached to culverts, and most commonly have only one

tide gate (although multiple gates are possible where smaller culverts are used to reduce fill heights). In the past these gates have been either cast iron, top-hinged designs (Waterman is the most common brand), or have been site-built from steel plate or wood planks (and usually held to piling by chains). Tributary streams controlled by these tide gates historically provided velocity and thermal refuge for juvenile salmon, and connectivity between freshwater rearing habitat and brackish estuarine waters.

The third geographic category of tide gates are those that drain fields or areas converted to commercial or residential use (Figure 6-1). These tide gates may empty into the estuary, but more commonly into either streams controlled by tributary or stream/river mouth tide gates. Drain tide gates are usually located in dikes, which may also serve as roads and driveways. Often, there is additional infrastructure (houses, garages, barns) that these gates protect. Tide gates in these locations range from 12” to 36” in diameter, and are almost always attached to corrugated metal pipes. The ditches leading to these gates are constrained to the floodplain, and provide no potential spawning habitat for salmonids. Areas behind these tide gates are typically protected from flooding by dikes, and generally would have been either estuarine or freshwater wetlands. These areas can provide potential juvenile rearing habitat if conditions are suitable. However, water quality (temperature, DO) is frequently poor for aquatic life, and there may be harmful inputs from adjacent fields and lots such as petroleum products, fertilizers and pesticides.

Table 6-2. Systems perspective on tide gates in their watersheds.

Tide Gate Location	***Description***	***TG Removal Effects***	***TG Upgrade Effects***	***Evaluation Metrics***
a) River/stream Mouth	These tide gates are typically located at the mouth of mainstem streams where they enter the estuary. In many cases, these tide gates are located at road or highway crossings, and often have multiple gates within a larger structure. The salient feature of these tide gates are: 1. They drain 6th or 7th HUC watersheds that have named tributaries upstream. 2. There are subsidiary tide (or flood) gates upstream that control tributary streams and field drains (see below).	Effects of removal will depend upon whether the attachment structure remains or is also removed: • Velocities will likely be reduced, especially if the opening is enlarged. • Fish will be able to freely move with the tides up to the extent of tidal influence or the next barrier. • Full restoration of sediment transport processes in main channel.	Effects will depend on whether the existing structure is suitable for an upgraded tidegate: • Amount of habitat accessed dependent on next upstream barriers (lateral & longitudinal). • Reservoir behind TG may provide (seasonally) freshwater habitat if WQ is suitable. • Partial restoration of sediment transport processes in main channel.	• Hydraulic analysis of water velocities; seasonality, and timing of opening periods (upgrade). • Amount of newly accessible habitat; WQ conditions in habitat. • Whether the existing superstructure is suitable for upgrading; cost of replacement. • Fish passage (PIT tag antennas) • Survival and abundance.
b) Tributary Creek	These streams have comparatively small drainages, often into remnant sloughs that have been tide gated downstream. Tide gates on these streams protect upstream areas from tidal inundation, commonly to create pastureland, but may also contain areas filled for development. These upstream areas historically provided tidal wetlands suitable for estuarine rearing habitat. The distinguishing characteristic of these gates is that there are no (or few) subsidiary gates upstream.	Gains to channel and adjacent floodplains (pastures) will be dependent upon whether: • Tributary empties directly into an estuary; or, • A TG exists between site and estuary. • Whether the floodplain is diked and drains are tide gated.	Similar to removal, whether opening to tidal influence or merely expanding the extent of the reservoir pool. • Improves passage window while protecting areas behind TG. • Potential gains to stream channel habitat and existing wetlands due to muted tidal cycles.	• Limiting factors analysis for potential habitat; i.e., spawning, summer rearing, winter rearing. • Intrinsic Potential (IP) for upstream areas newly opened. • Survival and abundance.
c) Drain	These tide gates can be located in agricultural fields, or in urbanized areas. While some may drain directly into tidal waters, others are placed above River/Stream Mouth and Tributary Creek tide gates to protect adjacent fields. The salient feature is that there may be limited habitat inland from the gate (i.e. the ditch channel) except during flood events, and no salmonid spawning areas.	Dependent upon whether there are intervening TGs between site and estuary: • Tidal reconnection if no downstream barriers; typical in former estuarine fringe wetlands. • Potential expansion of TG reservoir if downstream barrier.	Effects are dependent upon the potential habitat quality upstream of the TG: • Poor quality: outbound passage after floods to prevent stranding. • Good quality: additional habitat, especially refugia during flooding. • Bi-directional passage for all life stages.	• Amount & seasonality of suitable habitat behind existing TG. • Cost:benefit of any mitigation needed for increased flood risk. • Survival and abundance of fish using the flooded fields.

Project types

Our previous work (Giannico and Souder 2005) focused on the performance of tide gates and their installation structures. Our analysis for this report has demonstrated that frequently tide gates are merely one piece of a larger project; and as such, the entire project needs to be assessed rather than just the tide gates. Through evaluating the combination of project goals (primary and secondary), and project geography (stream/river mouth, tributary, or field drain) there are four typical types of tide gate related projects (Figure 6-2):

- Complete tidal reconnection. In this case, any levees in the project area are breeched or completely removed, as are all tide gates. Previously existing, linear drains may be filled, and new meandering channels excavated; the new marsh surface may be raised through fill if it had subsided; and there may be active re-vegetation ranging from wetland species to trees and shrubs. Alternatively, the site may be allowed to recover naturally.

- Partial tidal reconnection. Existing levees are either set back to allow tidal reconnection to a portion of the project area or tide gate management allows improved tidal reconnection to the project area during specific seasons (typically the winter). Generally, protective levees are built to a higher standard as part of the project, and any tide gates are upgraded in size and type (i.e., side-hinged, MTR, etc.) to meet current fish passage requirements. Tide gates may drain portions of the sites, and/or they may provide access to tributary streams used for spawning and rearing habitat.

- Tide gate upgrade for fish passage. This has been the traditional focus for tide gate projects where the gates are located at the mouths of streams/rivers or tributaries. For these projects, the tide-gated stream has fish rearing use extending beyond the floodplain, and may have freshwater spawning habitat for salmonids as well. Where possible, the existing tide gate is simply replaced with a new model meeting current fish passage criteria; alternately, the superstructure may need to be replaced if the gate needs to be enlarged or the invert lowered. The post-project maximum water surface elevation (WSE) often determines the degree to which tidal flows are allowed back into the reservoir pool. There may be habitat improvements upstream from the tide gate installation (i.e., large wood placements, riparian fencing and planting, etc.) as part of a larger project, but the primary focus is on the tide gate(s).

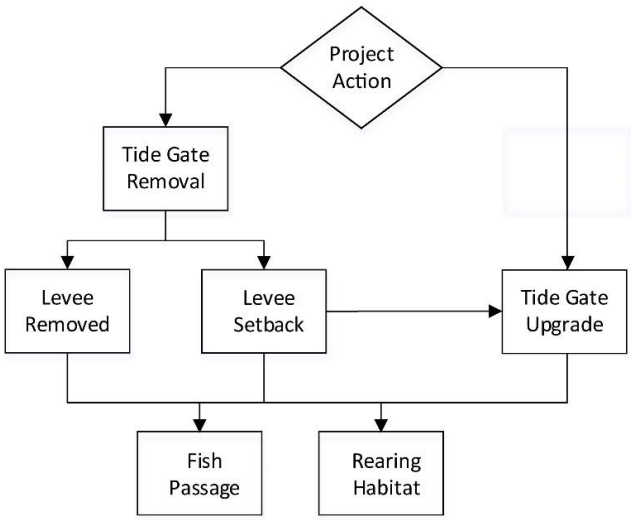

Figure 6-2. Typology of tide gate related projects.

- Tide gate upgrade to provide rearing habitat. These projects focus on lowland areas that potentially provide rearing habitat for salmonid juveniles and smolts. These areas are commonly diked, either by stand-alone levees, or through road and railroad fills. The dikes may protect farm/pasture lands, and/or other infrastructure such as barns, houses, septic fields, etc. The allowable WSE to protect infra-structure is a key design criterion. These dikes remain as the tide gates are upgraded to meet current standards. Bi-directional fish passage may be desired if the area behind the gates is available for rearing habitat; alternately, one-way passage out to the receiving stream may be desired to allow fish to avoid stranding if the habitat is not considered for rearing and the fish have entered through flood flows overtopping the levees.

The primary distinction among the four types is between upgrading a tide gate versus completely removing it. If removed, there are two possibilities: the levee is either breeched or eliminated, or the levee is set back. In the former case, the entire project area is open to tidal reconnection. In the latter case, a portion of the project area is newly open to tides, and the setback levees are commonly reinforced as a part of the project. Levee breeches or removals typically occur in areas where the adjacent properties are either adequately protected by other levees, or where the lands are sufficiently elevated from any tidal effects. When adjacent properties need to be protected, levees can be setback to allow tidal circulation in a portion of the project area. Setback levees, however, commonly still require tide gates to drain areas behind them, and/or control tidal influence on tributary streams. Since these are typically new tide gates, they must meet current fish passage standards as a condition of the construction permits.

Along with the desire by landowners and drainage districts for better performance, tide gates are upgraded usually to meet two goals: (1) to provide improved fish passage; and (2) to provide access to juvenile rearing habitat. Improving fish passage is necessary for both goals, but we distinguish between these two project types depending upon whether the passage is intended to provide access to rearing habitat versus access to spawning grounds. Mixed goals are possible for stream/river mouth and tributary locations where there may be suitable lowland rearing habitat either in the reservoir pool or other nearby wetlands, while there is suitable spawning habitat in the upper stream reaches. By definition, tide gates located on drains only have the potential to provide rearing habitat. The quality of this potential habitat determines the relative value of the project in terms of benefits to fish.

Tide gate upgrade and removal effects summary

We examined a variety of tide gate projects fitting into the categories described above, some of which were funded by OWEB and some of which were funded through other sources. Monitoring data for individual projects was included in Chapter 5. Here we summarize our findings across projects, estuaries, and regions to gain a better understanding of the impacts of tide gate upgrade and removal projects on fish and plant communities, hydrological connectivity, and water quality. We limited the projects to those for which monitoring was completed and results were available. Many studies have sufficient data to conclusively support one or a few findings. By considering them together we are able to provide a more complete representation of tide gate project outcomes and impacts.

Tide gate upgrades. A large review in the LCRE found that for sites with tide gate upgrade only, post-restoration conditions demonstrated no improvement and did not trend toward reference conditions. A large comparative study in the Skagit River estuary found that although salmon abundance at SRT sites

was twice that at traditional tide gate sites, it was still an order of magnitude lower than that at reference sites.

When tide gates are necessary and some upstream flooding can be tolerated, MTRs provide the most connectivity and best passage availability. Preliminary monitoring in the McDonald Slough demonstrated that MTRs increased tidal flushing resulting in increased DO, decreased water temperature, and improved water quality shortly after project completion.

The accessibility of upstream habitats to juvenile salmonids depends on the amount of time the tide gates are open. Tide gate upgrade generally increases the opening time and decreases the outflow velocity. However, this can vary seasonally, depending on the amount of freshwater influx upstream of the gate.

Tide gate removal. Tide gate removal increases habitat available to juvenile salmonids and estuarine species by improving access and increasing the area inundated. After tide gate removal fish community composition becomes more similar to that at reference sites. The abundance of juvenile salmonids and the period of time they utilized the marsh increased after tide gate removal. Fish distribution is also influenced by restoration; estuarine species may move into creeks and juvenile salmonids may move farther upstream.

When juvenile salmonids are present in the system they often begin using newly restored off-channel habitats very shortly after they become available. Fish are often observed using restored areas even when a monitoring program is not in place. Although monitoring generally focuses on water quality and fish usage, many studies note increased presence of aquatic invertebrates, migratory shorebirds, and waterfowl.

Tidal reconnection also supports reestablishment of wetland plant communities where upland species had become dominant or of brackish species where tide gates had created freshwater habitats. Over time salt-tolerant plants become increasingly common. The proportion of the estuary covered by brackish tolerant plants can increase dramatically post-restoration, and the reintroduction of brackish waters, in marsh habitats and in tidal flux upstream, has contributed to reed canary grass control efforts.

However, because the presence of dikes and tide gates often lead to subsidence, the type of marsh (high or low) may differ from that historically present. Plant communities are transitional for several years post-restoration. The amount of open space generally increases post-restoration as well. The proportion of native plant species often increases after tide gate restoration. The plant community in the shrub zone responds more slowly because it is generally out of the inundation zone.

Coupling tide gate upgrade or removal with other restoration actions increases the positive impact of the project. Wood placements increase scour and pool development in tidal channels and provide cover for juvenile salmon and other aquatic and terrestrial species. One study found that juvenile salmon usage of complex habitats was ten times higher than of non-complex habitats.

Restored areas continue to transition after the projects are completed. Hydrologic circulation causes changes in channel morphology through deepening, sedimentation, and down-cutting. Dike setback vastly increases inundation, natural hydrologic circulation, and the amount of available habitat. Restoring marsh habitats is also expected, when designed appropriately, to buffer against seasonal flooding and sea level rise.

For all project types, different parameters respond at different time scales so the duration of monitoring may dictate which parameters demonstrate improvement. Water surface elevation and tidal inundation are generally the first to improve following restoration. Composition of plant and fish communities have longer response times-scales and sediment accretion response time is even longer.

"Lessons Learned" in fish ecology, project planning, implementation, and monitoring

Our reviews in Chapters 3, 4, and 5 identified observations made by practitioners about how to more effectively plan, implement, and monitor tide gate upgrade and restoration projects. Most of these observations came from grant completion reports (especially OWEB-funded projects), and from other agency reports. These are compiled and organized here into four different categories: (a) fish ecology; (b) project planning and permitting; (c) on-the-ground project implementation; and (d) monitoring. For each of the lessons, we've identified a number of observations, pieces of advice, and tips on how best to use the lesson.

Fish ecology considerations. The ecological effects of tide gate upgrades and removals are summarized above and discussed extensively in Chapters 3 and 4. There were two lessons from project practitioners that are pertinent.

Lesson: **A specific habitat quality level or threshold may need to be achieved before fish and invertebrate communities respond as desired.**

Observation. Incrementally staged tide gate management resulted in faunal assemblages becoming more similar to reference sites assemblages only after the final implementation stage was completed. (Boys 2016).

Lesson: **Tide gate upgrades can be especially important for passage of weak swimming species.**

Observation. In the PNW representatives of this group include sculpin species (Scott et al. 2016, Brophy et al. 2014) and in New Zealand several native species are weak swimmers (Bocker et al. 2015).

Project planning and permitting. Reporting documents identified a number of challenges that practitioners faced during the project planning and permitting stage. These can be synthesized into four lessons.

Lesson: **Communication management is time consuming but necessary**. Additionally, coordination between disciplines is very important.

Advice: For partnership agreements it is important to have 1) a chain of command for responsibilities, delineating roles, and 2) an accounting system to share cost estimates clearly organizing and managing multiple fund sources (OWEB grant 208-1040, 208-1061-7658).

Tip: Some activities cannot co-occur and must be timed precisely (eg. site grading and fish evaluation). Likewise, if on-site work is divided among contractors oversight and scheduling are extremely important for keeping the project on its timetable (OWEB grant 208-1061-8288).

Tip: Examine the cost-effectiveness of different grading equipment (OWEB grant 208-1061-8288).

Lesson: **Developing relationships with stakeholders is important to project implementation success.**

Advice: Cooperation with neighboring landowners can be critical to project success, especially when there is controversy among stakeholders about the project because of concerns over hydrologic changes and losing farmland (OWEB grant 214-1034-10974).

Advice: Thank and acknowledge stakeholders, contributors, and partners at celebratory events such as completion parties and site tours to foster relationships and sow goodwill (OWEB grants 208-1040, 208-1061-7658).

Tip: Projects are easier to implement and require less time to completion in areas where stakeholder relationships are aleady developed (Bringing Back the Fish, NSW, Australia).

Lesson: **Being up to date on fish passage design and permitting requirements is critical.**

Advice: Project partners should establish a clear protocol for communicating with permitting agencies and outline expectations (modeling approach, metrics, conditions) at the outset of a project. This should decrease delays associated with requirement clarity and staff turn-over (OWEB grant 215-1017-11365).

Tip: Check for permitting changes prior to application submission. Designs that fit outdated requirements will have to be reworked, causing delays (OWEB 212-2022-8872).

Lesson: **Project implementation will be smoother, monitoring more successful, and goals more readily attainable with careful and detailed planning**. This will lessen the likelihood of scheduling difficulties, project delays, and cost overruns.

Advice: Cost contingencies should be developed to respond to unexpected issues. A strategy should be developed with project funders to fund these contingencies since most grants do not allow for a fixed percentage.

Advice: A high priority should be placed on effective distribution of channels to provide adequate drainage for all areas of the site, limiting potential areas for stranding and mosquito breeding (OWEB grant 210-2032-7450).

Advice: Consider additional costs when planning and budgeting, particularly for organizing, storing, delivering, and distributing plants. Bare root timing is critical because they should not dry out or be exposed to harsh weather (OWEB grant 214-3032-10845).

Tip: Site tours with regulatory agencies and potential contractors prior to creating construction bid packages will help make the work and equipment estimates more accurate (OWEB grant 208-1061-7658).

On the ground project implementation. All the best strategies and plans can be for naught if projects can't be implemented successfully. Three lessons on project implementation stood out in the reports.

Lesson: **Specialized expertise may be required from construction contractors**. There are few contractors experienced in tidal area construction, but these people and groups are very valuable for restoration projects.

Observation: A lack of qualified contractors may limit the number of projects that can be included in large-scale time-sensitive projects (Bringing Back the Fish NSW, Australia).

Advice: Providing flexibility for a good contractor can achieve design goals while saving money and improving production and product (OWEB grant 207-261).

Advice: If possible give preference to competent local contractors. Their intimate knowledge of the project area can result in benefits such as cost savings and positive grass roots public relations (OWEB grant 212-8004-9544).

Tip: When undertaking unfamiliar restoration goals, full time contract inspection during the work will assist in successful completion and limit delays or costly reworking (OWEB grant 207-261).

Tip: All utilities should be moved prior to restoration activity (OWEB grant 207-261).

Tip: Consider enrolling in local programs such as the fire department's 'Burn to Learn' program when structural demolition is necessary (OWEB grant 212-8004-9544).

Lesson: **The success of restoration plantings can be increased by considering contingencies and implementing additional steps prior to placing the roots in the ground.**

Advice: Consider plant species sensitivities and strengths in relation to expected post-restoration conditions to optimize success of plantings. For example, cottonwood appears to be better adapted to harsh conditions than dogwood, and willow plantings can survive in somewhat low water conditions but do not tolerate salinity well (OWEB grant 214-3032-10845).

Tip: Adding a layer of topsoil in newly excavated or graded areas may benefit plantings (OWEB grant 214-3032-11263).

Tip: Apply herbicide to weeds prior to planting, when it can be done with large equipment. Once plantings are done all herbicide must be applied by hand (OWEB grant 214-3032-10845).

Lesson: **Timber companies that are willing to partner to make wood placements upstream may not have experience with such placements in the estuary.**

Advice: Timber companies may be primarily concerned with liability and damage in the event that wood breaks free, which can increase the difficulty of getting ecologically successful placements (OWEB grant 210-2024-7458).

Tip: Organizing a site tour with local timber placement experts and the partnering timber company may be necessary to achieve placements that will create the intended habitat benefit (OWEB grant 210-2024-7458).

Monitoring. Implementing a monitoring program, after the study design has been completed, is often challenging. We identified three lessons from project practitioners that provide useful insight.

Lesson: **Tidal reaches of lowland streams are seasonally dynamic and difficult to sample during the critical overwinter period.**

Advice: A variety of sampling approaches may need to be deployed to sample throughout the year. Sampling techniques such as PIT arrays can 'recapture' individuals without physical sampling during winter (OWEB grant 214-2031).

Tip: All equipment should be securely anchored to withstand high water conditions and deter theft (OWEB grant 212-2044).

Lesson: **Monitoring data is most useful if measurements are taken at appropriate time scales.**

Advice: For tide gate effectiveness or ecological monitoring, sites should be sampled more than once per year and in subsequent years to be able to draw strong conclusions (OWEB grant 210-2032). Longer duration is better for tidal hydrology monitoring. Even year to year differences can obscure long term conditions (Ennis 2009).

Advice: Temporally sensitive metrics should be monitored continuously or at a high frequency (especially for metrics expected to vary with time, such as water temperature and fish density) over relatively long periods to capture important patterns. The use of data loggers can be extremely helpful. (Greene et al. 2012).

Lesson: **Sampling needs to be adjusted to current site conditions at the restoration marsh.**

Advice: Gather elevation data for the site to be restored and design sampling so that these elevations are sampled at the reference and control sites. Pre-restoration reference data will be unusable if it does not correspond properly to the newly restored marsh (Brophy et al. 2014, Brown et al. 2016).

Advice: Marshes that have subsided drastically may need to be restored slowly so as to avoid flooding the area and creating open water habitat instead of marsh habitat.

Regional frameworks for collaboration, project prioritization and reducing regulatory uncertainty

Estuary restoration in Oregon is evolving from mostly smaller scale projects, often focused just on tide gates, to more complex, larger scale projects, usually involving multiple partners and restoration actions, and longer time frames. Projects completed in the 1990s and early 2000s were often smaller in scope (sometimes just involving upgrading of a single tide gate), conducted in a less complex regulatory and political environment, and were thus relatively straightforward to permit and implement. In contrast, restoration opportunities today increasingly involve acquisition of private lands, more diverse partners with a wider array of primary interests, overlapping and sometimes inconsistent layers of federal, state and county regulations, and multiple goals and benefits.

Table 6-3 lists four recently completed projects that involved tide gate upgrade or removal in OWEB's Regions 1 (North Coast) and 2 (South Coast) with information that illustrates the complexity of these projects. The upgrade projects listed included habitat enhancement upstream of the tide gate to benefit fish after passage was improved. These habitat improvement elements are important, but can significantly increase project complexity via the involvement of additional stakeholders, the need to secure additional permits, and resulting increases in time necessary to complete the project. Two of the tide gate removal projects listed were preceded by land acquisitions, which enabled larger scale

ecological benefits. Compared to tide gate upgrade projects, tide gate removal projects typically require significantly more funding and a greater number of permits.

Complex, larger-scale projects also often require significant time to generate stakeholder support prior to project design and implementation. Landowner interest in participating in estuary restoration varies considerably and local resistance to conversion of agricultural land back to tidal wetland is fairly common. In a complex regulatory environment, even landowners who are otherwise amenable to addressing habitat restoration goals may be reticent to enter into dialog to solve problems associated with aging dikes and tide gates on their lands. Further complications include rising storm frequency and intensity in the Pacific Northwest which increase wave heights and extreme wave events that contribute to greater coastal flooding. This adds to the urgency of addressing aging flood protection infrastructure. (Dalton et al. 2017.)

In this landscape, and with a significant backlog of dikes and tide gates in need of repair, Oregon is seeking ways to better prioritize and streamline the process of implementing estuary restoration projects. One potential source of knowledge is the state of Washington which, with its larger population and amount of estuary habitat, has extensive experience in this arena. Oregon is different in some ways, but also has many commonalities with Washington with regard to land use history in estuaries, how this has affected salmon and estuary ecology, and restoration options going forward. In particular, both states face serious and growing problems with deteriorating dike and tide gate infrastructure at a time when sea level rise and increasing storm effects are exacerbating flood damage and risk.

Table 6-3: Complexity of selected OWEB projects involving tide gates[1]

OWEB region	*Tide gate action*	*Project Title*	*OWEB Contri-bution*	*Match $ (in-kind and cash)*	*Number of funders*	*Number of tide gates*	*Primary goal(s)*	*Time: Design to completion*[2]	*Broad outcome*	*Habitat enhance-ment?*	*Land acquis-ition?*	*Number permits required*
1	Removal	Southern Flow Corridor-Landowner Preferred Alternative	$1,522,144	$9,123,592	7	15	Partial tidal reconnection	3 years (2014-2017)	521 acres of estuarine wetland habitat restored	Yes	Yes	8
1	Upgrade	McDonald Slough Reconnection	$295,003	$147,186	9	1	Rearing habitat	2 years (2014-2016)	1.5 miles of habitat made accessible	Yes	No	4
2	Removal	Bandon Marsh NWR Ni-les'tun	$893,365	$1,694,806	3	3	Complete tidal reconnection	7 years (2008-2015)	418 acres of estuarine wetland habitat restored	yes	Yes	8
2	Upgrade	Willanch Creek Fish Passage and Habitat Improvements	$105,504	$56,452	5	2	Fish passage	4 years (2010-2014)	7.24 miles of habitat made accessible	yes	No	3

[1] Table courtesy of OWEB. Information drawn from Oregon Watershed Enhancement Board Grant Management System and Oregon Watershed Restoration Inventory.

[2] May not include all phases of pre-project scoping and planning.

The following section 1) summarizes examples of regional approaches in Washington that emerged from recognition of the need to collaborate to optimize estuary restoration, flood protection, and preservation of working agricultural lands; 2) describes similar efforts that are underway in Oregon; and 3) discusses similarities and differences in these examples, and what might be useful to Oregon.

Regional frameworks in Washington

The Skagit Delta Tidegates and Fish Initiative. Tide gate removal and upgrade work that involves private land in the Skagit region is usually coordinated via the Skagit Delta Tidegates and Fish Initiative (TFI), a collaborative, multi-stakeholder process organized by the Western Washington Agricultural Association, the NOAA National Marine Fisheries Service, U.S. Fish and Wildlife Service, and Washington Department of Fish and Wildlife. The TFI formally commits these parties to a delta-wide landscape approach to address tide gate and flood gate maintenance needs within the Skagit Delta area, in conjunction with estuarine habitat restoration goals for recovery of ESA listed Chinook salmon in the Skagit River system, and with input and support from the U.S. Army Corps of Engineers (USACE), the Washington Department of Ecology, and the Washington Governor's Office of Regulatory Innovation and Assistance (somewhat analogous to the Oregon Governor's Regional Solutions program).

Fish, Farm and Floods Initiative. In addition to better passage and habitat conditions for salmonids, estuary restoration also provides flood protection, as described by the Farms, Fish and Floods Initiative (3FI), a landscape-scale effort in the Skagit Delta based on a Memorandum of Understanding (MOU) between NOAA, Skagit Conservation District, Skagit County, Skagit County Dike and Drainage Partnership, Skagitonians to Preserve Farmland, TNC, Washington Department of Fish and Wildlife (WDFW) and the Western Washington Agricultural Association. The 3FI focuses on advancing mutually beneficial strategies that support the long-term viability of agriculture and salmon while reducing risks of destructive floods and complements the TFI.

The Skagit Delta Hydrodynamic Model Project (SHDM Project) is a key part of 3FI. The SHDM Project is a landscape-scale hydrodynamic modeling and alternatives analysis to help identify and prioritize multiple-interest, mutually beneficial flood risk reduction and estuarine habitat restoration projects to achieve the Skagit Chinook Recovery Plan 2005 goal. Project leads TNC, NOAA, and WDFW work with a larger SHDM team of representatives from the conservation, agriculture, and flood risk reduction interests participating in 3FI. The team identified goals that further these three interests, creating a suite of objectives for providing juvenile Chinook habitat, reducing flood risk and reducing impacts to agriculture. The SDHM assesses projects with hydrodynamic modeling, geographic information system (GIS) analysis, and estimation of potential Chinook salmon benefits through two mathematical models developed by the Skagit Rivers System Cooperative (SRSC).

Rationalizing their initial SHDM results, Whiting et al. (2017) submit that the lack of quantitative information about the effects of proposed land use modifications on coastal hydrodynamic and hydrologic processes is the primary impediment to estuary restoration projects. They argue that quantitative models for estuary environments can minimize uncertainty about restoration goals: the recovery of tidal exchange, supply of sediment and nutrients, off-channel habitat, and establishment of fish migration pathways. The SHDM included a high-resolution circulation and transport model of the Skagit River estuary to assist with nearshore habitat restoration design and analysis. Deliverables from the SHDM project include area of inundation calculations, cumulative frequency plots for water surface

elevation, maps showing the depths of inundation, histograms for water depths within project sites, maps showing the changes in WSE, maps showing the changes in bed shear stress, maps showing the changes in salinity, and plots showing changes in stage and flow.

The SHDM allowed assessment of interactions between different restoration actions and their cumulative effects, and also the effects of restoration in estimated 2080 future conditions. Model output can also aid in engineering design by providing insight into how the hydraulics of the system can be expected to change. The SHDM analysis was fairly broad scale, but sub-models can be created to assess individual projects in greater detail, using outputs from the landscape-wide model for boundary conditions. (Whiting et al. 2017.)

Each project was assessed for the following objectives and indicators to evaluate potential benefits and impacts:

- Increase the area subject to natural tidal and riverine processes in the study area (Fish)
- Minimize impacts to existing habitats subject to tidal and riverine processes (Fish)
- Increase the area of tidal and riverine channels suitable for Chinook fry rearing in the study area (Fish)
- Increase Chinook smolt production (Fish)
- Increase landscape connectivity of the study area (Fish)
- Maintain or improve existing diversity of tidal marsh habitat along the historical elevation gradient (Fish)
- Minimize conversion of agricultural land (Farm)
- Maximize the number of smolts per acre of converted agricultural land (Farm)
- Support tidegate maintenance through TFI Implementation Agreement (Farm)
- Prioritize Public Lands (Farm)
- Avoid conversion of farmland preservation easements (Farm)
- Reduce water surface elevation within the study area (Flood)
- Reduce risk of levee failure by constructing new engineered levees (Flood)
- Avoid creation of new dike infrastructure where none existed previously (Flood)
- Improve agriculture flood drainage (Flood)

The SHDM Project results inform additional alternative analysis in which each individual project will be assessed for restoration objectives and from which indicators will be created to promote long-term viability of Chinook salmon tidal delta habitat and community flood risk reduction in a manner that protects and enhances agriculture and drainage. Details about the ranking of potential projects and judging of the viability of each project will be available from separate publications by TNC, NOAA, and WDFW. (Whiting et al. 2017.)

Floodplains by Design. The public-private Floodplains by Design partnership between TNC, WA Department of Ecology (Ecology), and the Puget Sound Partnership, is based on the premise that science, collaboration, and coordinated investment can bring together historically opposed interests to address fish-farm-flood needs in a comprehensive way. The 2013 WA State Legislature created a new program to

fund such multi-benefit flood hazard reduction projects, implemented via Ecology's Shorelands and Environmental Assistance (SEA) Program. These projects must demonstrate benefits beyond flood hazard reduction, including salmon recovery, habitat restoration, water quality improvement, and channel migration zone protections. Solicitation for 2017-2019 biennium included a new "Small Projects" category that provides up to $500,000 for projects with the same elements as the regular program, but which are less costly and smaller in scale. This allows smaller projects to compete within their own pool, and not compete against larger projects. The final ranked project list put together by Ecology, TNC, and the Puget Sound Partnership supported a $70 million capital budget request by Ecology for the 2017-19 state biennium.

Other Washington Regional Efforts. Another basin-scale effort to integrate fish, farms, and flooding considerations into river floodplain and estuary planning, management and restoration is the Snohomish County Sustainable Lands Strategy (SLS), a multi-stakeholder forum for identifying "net-gains" for simultaneously preserving and enhancing agriculture and salmon habitat. The Snoqualmie Valley Fish Farm Flood Advisory Committee is yet another regional effort focused on similar goals.

U.S. Army Corps of Engineers Regional General Permit. A U.S. Army Corps of Engineers (USACE) regional general permit (RGP) authorizes, on a limited geographic scope, activities that are substantially similar in nature and cause only minimal individual and cumulative impacts on the aquatic environment. Each RGP has specific terms and conditions of which all must be met in order for an applicant to qualify for an RGP. Regional General Permit RGP-8 (U.S. Forest Service Aquatic Restoration Program Within the State of Washington) authorizes eleven restoration activities in U.S. waters designed to maintain, enhance, and restore watershed functions that affect aquatic species, including: 1) fish passage restoration; 2) large wood, boulder, and gravel placement; 3) dam, tide gate, and legacy structure removal; 4) channel reconstruction/relocation; 5) off-and side-channel habitat; 6) streambank restoration, and 7) set-back or removal of existing berms, dikes, and levees.

Regional frameworks in Oregon

Species Recovery and Conservation Strategies for Managing Oregon Coastal Salmonid Populations. Tide gate upgrades and estuary restoration also occur within a framework of state and federal regulations and plans that should support overall program strategies. The ESA Oregon Coast Coho Salmon Recovery Plan (NMFS 2016b) identifies 21 Independent Populations in five geographic strata that have specific recovery goals and criteria. Biological recovery criteria require that most independent populations be sustainable in each stratum, and that all five strata have to be sustainable (NMFS 2016b). The Oregon Department of Fish and Wildlife's Coho Conservation Plan (ODFW 2007) and Coastal Multi-species Conservation and Management Plan (ODFW 2014) provide Oregon's strategies to recover coastal salmon, including coho salmon, Chinook salmon, chum salmon, and steelhead so that in addition to being sustainable, they also support robust fisheries and provide ecological, cultural, and economic benefits for present and future generations (ODFW 2007, 2014). A key goal of the 2014 plan (p. 4) is to "avoid additional ESA listings and ad-hoc species-by-species, basin-by-basin, and year-by-year management" by "supporting prioritized and effective habitat restoration efforts."

The Oregon Conservation Strategy (OCS, ODFW 2016) is an overarching plan to conserve Oregon's fish and wildlife, and their habitats. The OCS identifies priority species, habitats, conservation opportunity areas and key conservation issues. All estuaries on the Oregon coast are designated as conservation

opportunity areas. Among the directives identified here, the OCS provides the best model for how to integrate land use planning processes and estuary restoration, including tide gate upgrades and removals. The OCS includes estuaries as one of eleven "strategy habitats", and coho and chinook salmon as "strategy species". The OCS identifies altered or blocked tidal flow (including diking, ditching, and drainage and tide gates) as a Limiting Factor for estuary habitats. The OCS Recommended Approach for estuaries includes, where appropriate, efforts to restore hydrology to tidal wetlands. Removal and upgrading of tide gates falls into this category.

Currently, fish passage is required at all artificial obstructions, including tide gates, where native migratory fish are or were historically present when a "trigger" event (e.g., abandonment, major replacement, construction) occurs. ODFW maintains detailed fish passage requirements and works with owners and operators of artificial obstructions in several ways to ensure adequate passage of native migratory fish. Addressing fish passage requirements entails the owner/operator obtaining from ODFW: 1) approval for a passage plan when passage will be provided, 2) a waiver from providing passage, or 3) an exemption from providing passage. It is the intent of state fish passage laws (ORS 509.585(1)) that, in most cases, option #1 should be sought and passage should be provided at the artificial obstruction.

Land Use Planning and Management in Oregon Estuaries. Oregon's Statewide Land Use planning framework includes detailed requirements for the planning and management of Oregon's estuaries. Under Statewide Planning Goal 16 (estuarine resources) and Goal 17 (coastal shorelands) in its Oregon Coastal Management Program, the Oregon DLCD has designated each estuary in Oregon into one of four classes (Table 6-3) based on the overall level of development permitted:

- Natural estuaries lack maintained jetties or channels, and are usually little developed for residential, commercial or industrial uses. They may have altered shorelines, but not adjacent to an urban area. Shorelands around natural estuaries are generally used for agriculture, forestry, recreation and other rural uses. Natural estuaries have only natural management units.
- Conservation estuaries also lack maintained jetties or channels, but are within or adjacent to urban areas which have altered shorelines. Conservation estuaries have conservation and natural management units.

Table 6-4. Oregon estuary classification. Estuaries listed north to south.

Estuary	Classification
Columbia River	Deep Draft Development
Necanicum River	Conservation
Nehalem River	Shallow Draft Development
Tillamook Bay	Shallow Draft Development
Netarts Bay	Conservation
Sand Lake	Natural
Nestucca Bay	Conservation
Salmon River	Natural
Siletz Bay	Conservation
Depoe Bay	Shallow Draft Development
Yaquina Bay	Deep Draft Development
Alsea Bay	Conservation
Siuslaw River	Shallow Draft Development
Umpqua River	Shallow Draft Development
Coos Bay	Deep Draft Development
Coquille River	Shallow Draft Development
Sixes River	Natural
Elk River	Natural
Rogue River	Shallow Draft Development
Pistol River	Natural
Winchuck River	Conservation

Source: Oregon Coastal Atlas, 2017.

- Shallow draft development estuaries have maintained jetties, a main channel maintained by dredging at 22 feet or less, and development, conservation and natural management units.
- Deep draft development estuaries have maintained jetties, a main channel maintained by dredging to deeper than 22 feet and development, conservation and natural management units.

Within these classes are designated three different types of management areas, defined by their physical and biological qualities, as well as existing uses and alterations (DLCD 2014):

- Natural management units include sub-tidal, mudflats, and saltmarshes that have been relatively unaltered.
- Conservation management units consist of smaller, less natural habitat areas that may have been altered but contain recreational or commercial potential such as shellfish beds.
- Development management units include areas adjacent to dredged channels that have minimal biological significance.

Goals 16 and 17 are realized through Estuary Management Plans in County Comprehensive Plans (OAR 660-015-0010[1]) which become official ordinances once they are acknowledged by the DLCD and approved by the County Commission (DLCD 2014). For these planning purposes, the area covered by Goal 16 for estuaries extends to the mean higher high water line, including sub-tidal (submerged) and inter-tidal zones, while Goal 17 for shorelands extends into the uplands, and requires designation of sufficient areas to support water-dependent, water-related, and water-oriented uses.

One requirement for an estuary plan is a comprehensive inventory of the estuary, including physical, biological, and socio-economic characteristics (DLCD 2010). The major outcome of the plan is “zoning” of the plan area into management units, divided into two broad categories (aquatic and shoreland) then into the three different management classes (natural, conservation, and development), that are subsequently distinguished between urban and rural; and finally, for the development class, into water-dependent versus non-water-dependent uses.

Administration of estuary plans is done by the relevant cities and counties as part of their overall comprehensive planning responsibilities. Goal 16 also calls for coordinated action by all local, state and federal agencies that regulate or have an interest in Oregon's estuaries, including work on estuary restoration.

Oregon Fish Passage Banking Program. In 2012, with support of ODFW staff, ODOT, Willamette Partnership, and TNC initiated a pilot Fish Passage Banking Program in Oregon’s North Coast. The program’s purpose is to allow ODFW to steer mitigation from multiple fish passage waivers toward fish passage banks - locations where high priority barriers are removed and significant benefits for fish are created- and provide ODFW, waiver applicants, and other stakeholders with a more standardized process to evaluate whether mitigation is appropriate, adequate, and sustainable in meeting salmonid habitat conservation goals. The intention is to provide greater net benefits for native migratory anadromous fish than providing passage at a low priority waiver site, streamline the state’s fish passage waiver process for fish passage banking and make the ODFW approval process more transparent and defensible, and use ODOT resources more efficiently to provide greater benefit to native migratory fish compared to its traditional approach. (ODFW 2015.)

A key feature of the pilot program is a Net Benefit Analysis Tool developed by Willamette Partnership and TNC that combines site and watershed scale information to calculate an index of habitat quality for native migratory fish. This measure is combined with the quantity of newly accessible habitat to calculate the benefits (or credits) generated by a barrier improvement or removal. The first test of this approach was removal of a high priority barrier on a tributary of the Trask River in August 2016 that opened up 23 miles of stream habitat for salmonids. In exchange, ODOT can waive provision of fish passage on state highway culvert repair projects in limited amounts of low quality habitat creating a net benefit for salmon and other fish species (Willamette Partnership 2017). While not targeted at tide gates specifically, the goal of this effort appears similar to Washington's TFI namely to streamline and standardize the process of prioritizing projects to improve fish passage. At the end of the pilot phase (2015-2018) ODFW will evaluate its success and lessons learned, and potentially develop a statewide mitigation banking program for Oregon that could include prioritization of tide gate upgrades or removals.

The Oregon Tide Gate and Infrastructure Discussion (TGID) addresses the growing challenge of aging tide gates and associated infrastructure, and appears similar to regional efforts in Washington, but with a scope that encompasses the entire Oregon coast. The goal of this effort is to support resilient coastal communities by reducing risks from coastal hazards, protecting landscapes that support local economies, and enhancing ecological function of estuarine resources for fish and wildlife. Currently, discussion participants include landowners, ODFW, OWEB, ODA, DSL, ODOT, Regional Solutions, NOAA-Fisheries, National Resource Conservation Service (NRCS), Oregon Cattlemen's Association, Oregon Farm Bureau, Oregon Dairy Farmers, Oregon Water Resources Congress, counties, and conservation organizations (watershed councils, conservation districts, TNC, land trusts, Wild Salmon Center, Tillamook Estuaries Partnership, and The Freshwater Trust). Participants are reaching out to tribes and other interested groups as the project moves forward. (OWEB 2017a, b.)

The Oregon TGID has several elements:

- *Local outreach* to engage local landowners, tribes, communities and stakeholder representatives through facilitated meetings in each county to discuss issues surrounding tide gates and infrastructure in coastal communities and sub-committees to inform project actions and build trust between parties.
- A statewide *tide gate inventory* developed from publicly available information (e.g. existing inventories, Google Earth imagery, local knowledge).
- An *interactive decision support tool* that provides a flexible and systematic approach for identifying priority project sites.
- An *engineering toolbox* including permanent engineering design options for tide gate alternatives, and also interim engineering measures that could be approved and implemented to avoid catastrophic failure of existing tide gate infrastructure until more permanent solutions are feasible.
- A *regulatory toolbox* of regulatory assurances for landowners who volunteer for tide gate improvement projects. Explore opportunities to improve consistency among and within agencies to streamline and increase the predictability of regulatory permitting and associated costs.
- *On-the-ground demonstration projects* will help explore, demonstrate, and document the partnerships and new approaches for tide gate projects. Projects will also help identify lessons

learned and considerations for planning and implementing future tide gate repair and replacement.

The Oregon Coast Coho Business Plan. In 2014, OWEB, ODFW, National Marine Fisheries Service, NOAA, the Wild Salmon Center and the National Fish and Wildlife Foundation assembled as the "Coast Coho Partnership". The group is focused on local implementation of federal and state coho conservation and recovery plans in Oregon, with two goals: 1) develop a replicable model to assist local teams in prioritizing habitat protection and restoration actions for coast coho populations; and 2) coordinate funders, and increase funding available for locally-led implementation of completed plans. With OWEB support, in 2015 the Partnership piloted a planning process for the Nehalem, Siuslaw, and Elk River coho populations. The resulting Strategic Action Plans (SAPs) identify highest priority projects which are then incorporated into the Oregon Coast Coho Business Plan. The purpose of the plan is to leverage funding for implementing projects contained in completed SAPs. The plans clearly tie locally led projects to the improvement of several habitat indicators that are essential to coho recovery. The group focuses on development and implementation of SAPs for coho habitat restoration, but also seeks to integrate conservation with local and regional economic development goals by identifying win-win scenarios where protection and restoration of high value habitats also benefits owners and managers of private "working lands." Participation in the program is voluntary. (Oregon Coast Coho Business Plan 2017.)

Facilitating and Streamlining Collaborative Estuary Restoration in Oregon. There are commonalities in the challenges that Oregon and Washington face in attempting to integrate estuary restoration with the maintenance and upgrading of coastal protection infrastructure. The two states have similar estuarine ecosystems and estuary land use histories. Both are actively addressing the need to improve degraded estuarine habitat and passage conditions for salmonids while also providing protection from flooding and storm surges in the face of climate change and sea level rise. Due to its larger population, economy and extent of estuary habitats, Washington may have more extensive capacity and experience to address these challenges. However, OWEB participates in similar large, complex estuary restoration and coastal infrastructure improvement projects here is Oregon, and is seeking ways to ramp up and streamline these efforts via its Tide Gate and Infrastructure Discussion and Oregon Coast Coho Business Plan.

The regional efforts outlined above may provide some useful guidance as Oregon mobilizes to address fish passage and habitat issues, and aging coastal protection infrastructure. Comparing and contrasting the two states indicates that:

- Estuary restoration in Washington is primarily (or at least significantly) driven by mitigation. For example, significant projects have been funded by BPA as part of mitigation for the effects of Columbia River dams. Oregon does not appear to have pursued mitigation funding for estuary restoration to the same extent that Washington has.
- To a greater degree than in Oregon, landowners in Washington participate in regional, collaborative efforts to prioritize and implement multiple goal coastal infrastructure and estuary restoration projects.
- Compared to Washington, Oregon has a more robust system of local watershed councils that could serve as social infrastructure where estuary restoration efforts could be initiated, promoted and coordinated.

- Oregon has a more comprehensive and integrated system for land use planning via its statewide land use planning goals.
- In both states there is a trend toward larger, more integrated projects. During project prioritization and planning, it is more complicated but also more realistic and potentially sustainable to account for the interconnected nature of ecosystems, social systems, and effects of actions.

Insights and lessons from this initial comparative analysis include:

- Projects that can demonstrate multiple benefits (e.g., water quality, fishery recovery, agricultural conservation, recreational benefits, tribal harvest, flood mitigation, climate change resilience, or correction of environmental injustice) usually appeal to a broader range of stakeholders and can draw from a broader range of national and state funding sources than single objective projects.
- Stakeholders in Washington have recognized the value of multiple-stakeholder, multiple-benefit collaborative frameworks (e.g. the TFI) to facilitate estuary restoration efforts such as the Fisher Slough Project. Oregon has successfully completed some similar large scale projects (e.g. the SFC-LPA Project) but lacks an administrative framework such as the TFI for coordinating multiple stakeholders, goals and project components.
- The value of robust hydrodynamic models for project planning and prioritization. The use of such models in both states, but particularly in Washington, is increasing and the models are becoming more sophisticated. These models can help save time and money by facilitating project plans, reduce unforeseen effects beyond project boundaries, and alleviate landowner concerns.
- The importance (and challenges) of strategic land acquisitions to facilitate estuary restoration. Opportunities to acquire "restorable" parcels emerge where deteriorating coastal infrastructure and rising sea levels make farming or other human uses increasingly untenable, but these opportunities often arise in haphazard, unpredictable fashion and accounting for potential ecosystem service values in the purchase of these parcels remains challenging.

Adapting these insights and lessons to socio-economic, political and ecological conditions in Oregon is mostly beyond the scope of this project. However, we believe there is considerable potential for this. Within its forward looking and innovative land use planning framework, existing network of watershed councils and OWEB guidance, Oregon could develop an integrated approach to help identify, prioritize and implement projects designed for multiple objectives. A key part of this approach would be to leverage and expand existing expertise within Oregon universities for hydrodynamic modeling, building on experience gained from efforts in both states. The overall goal would be to attract diverse investments and maximize public values in integrated estuary restoration and coastal protection projects.

Developing a more strategic framework and expanding stakeholders in estuary restoration could both increase potential funding sources and reduce delays in project implementation. OWEB has made good investments and considerable progress to address aging coastal protection infrastructure and its effects on threatened salmonid populations. With continued investments and the TGID, the state is now poised for additional steps toward a more robust and integrated approach to meet these challenges.

Chapter 7 Findings and Recommendations

In this chapter, we present findings garnered from our review of literature pertaining to tide gate upgrading or removal and our review of estuary restoration projects that involved tide gates in Oregon, Washington and California. These findings and recommendations also encompass broader estuary restoration issues with which tide gate work is inextricably linked. For many of the findings, we also submit recommendations intended to help OWEB further their goal of making cost-effective investments in restoring estuaries and flood protection infrastructure along the Oregon coast.

This chapter is organized into four sections: 1) *Physical and Ecological Effects of Tide Gates*; 2) *Project Prioritization, Scoping and Planning*; 3) *Project Implementation and Effectiveness*, and 4); *Future Monitoring*. Within each section, we identify a "finding" that results from the work of this project; some bullet points elaborating on this finding; then, when appropriate, one or more recommendations for OWEB to consider. The sections are not necessarily discrete; several findings and recommendations apply across more than one. We conclude by identifying potential tasks for further work on these issues (Phase II).

Physical and ecological effects of tide gates

A. **Finding: Limited or nonexistent connectivity significantly affects fish community composition and water quality.**

- Fish community composition is influenced by the presence of tide gates and season; non-native species may be more abundant at gated sites, and juvenile salmon abundance higher at ungated sites (Scott et al. 2016). Differences in above and below gate fish communities were greater when the gates opened less frequently (Seifert and Moore 2017).
- Water quality in gated and ungated streams differs; especially for salinity gradients and water temperature. The effects may limit the reservoir pool's habitat quality and rearing capacity, especially during smolt migration and summer (Bass 2010; Gordon et al. 2015; Weybright and Giannico 2017).

  Recommendation: The science is clear that for salmonid fish habitat and passage, the absence of tide gates is preferred, if possible. However, this does not take into consideration current land uses and other factors associated with the use of tide gates. Improved tide gates and their active management have the potential to ameliorate many adverse impacts to fish passage and water quality, especially when seasonal passage needs and habitat utilization are incorporated.

B. **Finding: Life-history diversity of juvenile coho salmon is greater than previously realized.**

- Conventional wisdom held that coho salmon reared in their natal reaches for their first year then migrated rapidly as smolts through the estuary on their way to the ocean; any pre-smolts that moved downstream were considered to be competitively displaced and less successful (Sandercock 1991).

- Although Tschaplinski (1988) was the first one to report estuarine rearing coho salmon fry, the view that these fish could represent an alternative life history began to develop in the early 2000s with the work of Miller and Sadro (2003) in Winchester Creek, Coos estuary. Koski's (2009) study in Duck Creek, Mendenhall estuary, Alaska, added to this knowledge by identifying a nomadic life-history type, which showed seasonal movements between brackish and fresh waters. Juvenile coho salmon nomadic migration expands the available rearing area, food resources, and growth potential and increases overall productivity (Koski 2009).
- More recent studies in Oregon by Jones et al. (2014) in the Salmon River estuary and Nordholm (2014) in Palouse Creek, Coos Bay estuary, identified as many as six distinct coho salmon rearing life histories, including fry migrants, nomads, and parr migrants, as well as stream resident smolts. Both of these studies documented that all life-history types contribute to the spawner population as adults. Four distinct coho juvenile life histories were found in the Grays River estuary, WA (Craig et al. 2014). There may be additional coho salmon juvenile life history diversity yet to be identified: Tryon (2011) found multiple coho salmon age classes rearing for variable amounts of time in the Courtney River estuary, BC and Wallace et al. (2015) found the the same in the Humboldt Bay, CA estuary.
- Diverse life histories, including estuary rearing, provide long-term resiliency to salmon populations under changing ocean and climatic conditions (Craig et al. 2014).

  <u>Recommendation</u>: The clear implication of this body of literature is that, besides Chinook salmon, coastal populations of coho salmon will benefit significantly from increased connectivity and fish passage opportunities in the freshwater/estuarine ecotones of rivers and this should be incorporated into tide gate design, installation, upgrades or removal projects.

  Additional research into juvenile salmonid rearing life histories and their habitat utilization would benefit practitioners if targeted to potential restoration prioritization strategies and project site selection and implementation.

C. Finding: Estuary rearing provides increased growth opportunities for juvenile coho salmon.

- After dike breaching in the Salmon River estuary, juvenile salmon use of estuarine habitats, especially by sub-yearlings, began earlier and lasted longer than prior to the restoration work (Bottom et al. 2005).
- Condition factor of subyearling coho salmon did not differ between those collected above the tide gate and those collected below in Courtenay River estuary (Guimond and Bio 2010). Growth rates were similar between sedentary and mobile juveniles in Palouse Creek, but in the low tidally influenced reaches summer to smolt survival was higher for mobile than for sedentary individuals (Weybright and Giannico 2017). Coho salmon rearing in the stream-estuary ecotone of a Humboldt Bay tributary were larger than those rearing upstream; likewise, those rearing in lower sloughs were larger than those in the upper sloughs (Wallace et al. 2015).
- Chinook and coho salmon subyearlings utilized different habitats in the Courtenay River estuary, B.C., Canada. Chinook salmon preferred upper ecotone habitats near freshwater input, while coho salmon were collected in areas with good refuge and freshwater inflow. Estuary rearing coho salmon grew faster than those in stream habitats, and even faster than

estuary rearing Chinook salmon (Tryon 2011). However, during early restoration foraging opportunities for juvenile salmonids may be modulated by lower quality habitat and prey resources, which can also be affected by connection to upland habitats (Gray et al. 2002).

Recommendation: Plan restoration actions with the expectation that all beneficial ecological effects, such as increased prey productivity creating improved foraging opportunities for juvenile salmon, may not occur for several years after project completion.

D. Finding: No tide gate is entirely fish friendly; they all have some impact on aquatic organism passage.

- Some side-hinged gates (particularly the SRTs type) may open for longer periods than other types of gate designs but they still interfere with normal up and downstream daily movements of subyearling salmonids and with the timing of smolt downstream migration (Bass 2010). Even those gates that are upgraded to facilitate fish passage still delay the movements of both juvenile and adult fish significantly (Wright et al. 2014 and 2016).

  Recommendation: Have realistic expectations on the fish passage effects of tide gate upgrades or complete replacement projects. Take into account that they may have some negative impact on fisheries resources, at least initially. The tide gates that interfere the least with fish migration are those that are removed entirely.

E. Finding: Tide gate upgrade or removal projects produce highly variable results. The design and operation of these structures are important factors, but their location in the channel network and installation are equally important.

- The gates that remain open the longest and widest improve fish passage conditions and opportunities (Boys 2012, Bocker 2015).
- Many tide gate upgrades (i.e., drilling of small orifices, addition of pet doors, SRTs) by themselves do not improve fish passage (Johnson et al. 2008, Wright et al. 2014 and 2016, Greene et al. 2012, Henderson et al. 2016). However, some that had positive effects on fish or crustacean communities may have benefitted as much by their operation or installation as by the upgrades they received (Boys et al. 2012, Johnson et al. 2013).

  Recommendation: Consider that a replacement gate, in some cases, might produce better results if installed elsewhere along a dike or in a different location in a channel. Equally important is the sill elevation of the culvert, its length, width and gradient that may negatively impact the fish permeability of some of the best designed gates. However, a benefit/cost analysis should be considered where the existing superstructure remains functional to ensure that any added benefits from replacing some of its components are commensurate with additional costs.

F. Finding: Although the negative impacts of tide gates on water quality and aquatic habitats have been well documented the upgrade of tide gates or their replacement with newer designs have produced mixed outcomes.

- Some studies (Franklin and Hodges 2015) reported DO increases and water temperature reductions above gates only in some of their study locations, while others (Boys et al. 2012) were able to detect only pH improvements above tide gates.

  Recommendation: Don't expect the simple upgrade of an old tide gate for a new one that remains open longer to solve an entire series of water quality factors. Consider that not all estuarine channels (i.e., streams, marsh channels, ditches, sloughs, etc.) have similar characteristics (e.g., discharge, tidal flushing level, sediment deposition rates, etc.). Therefore, the simple replacement of a door is not going to yield the same results every time.

Project scoping, prioritization, and planning

A. **Finding: Oregon's Statewide Land Use planning framework includes detailed requirements for the planning and management of Oregon's estuaries that need to be recognized in project scoping, design, and implementation.**

- Oregon's land use planning Goal 16 (Estuarine Resources) and Goal 17 (Coastal Shorelands) effectively "zone" estuaries into one of four development classes: (i) natural; (ii) conservation; (iii) shallow draft development; and (iv), deep draft development (DLCD 2014).
- There are three different management areas designated in each of these estuary classes: (i) natural, relatively unaltered areas; (ii) conservation management units, representing less natural areas; and (iii) development management units, which have minimal biological significance (DLCD 2014).
- Detailed allowable uses and activities (including restoration, tide gate replacement, and other infrastructure development) are specified in each Estuary Management Plan that is a component of its County's Land Use Plan. These Estuary Management Plans were approved in the early 1980s, relying on 1970s-era data.

  Recommendation: Social, political, and administrative considerations significantly affect the potential types, places, and methods for tide gate related restoration in Oregon's estuaries. Local conservation organizations should work with local county planners in developing future strategies. The collaborative process leading to the on-going revision of the Coos Bay Estuary Management Plan by Coos County and the Partnership for Coastal Watersheds (South Slough National Estuarine Research Reserve and Coos Watershed Association) can serve as a model and pilot for the revision of other coastal estuary management plans.

  Recommendation: OWEB should work with the Oregon Department of Land Conservation and Development to identify processes that facilitate incorporation of restoration considerations associated with both tide gate upgrades and removals as estuary management plans are revised.

B. **Finding: Tide gate upgrades and estuary restoration also occur within a framework of state and federal regulations and plans that should support overall program strategies.**

- The NFMS Recovery Plan for Oregon Coast Coho Salmon ESU (NMFS 2016b) identifies 21 Independent Populations in five geographic strata that have specific recovery goals and criteria. Biological recovery criteria require that most independent populations be sustainable in each stratum, and that all five strata have to be sustainable (NMFS 2016b).

- The ODFW Coho Conservation Plan (ODFW 2007) and Coastal Multi-species Conservation and Management Plan (ODFW 2014) provide Oregon's strategies to recover coastal salmon, including coho salmon, Chinook salmon, chum salmon, and steelhead so that in addition to being sustainable, they also support robust fisheries and provide ecological, cultural, and economic benefits for present and future generations (ODFW 2007, 2014). A key goal of the 2014 plan is to "avoid additional ESA listings and ad-hoc species-by-species, basin-by-basin, and year-by-year management" by "supporting prioritized and effective habitat restoration efforts." (ODFW 2014, (p. 4.)
- The Oregon Conservation Strategy (ODFW 2016) identifies priority species, habitats, conservation opportunity areas and key conservation issues. All estuaries on the Oregon coast are designated as conservation opportunity areas.

  Recommendation: The Oregon Conservation Strategy provides the best model (of the three identified here) on how to incorporate land use planning processes and restoration.

C. Finding: We identified four general categories of estuary restoration goals among the 45 projects evaluated (Table 6-3).

- *Estuarine rearing habitat* expansion, including increasing the area of suitable habitat for salmonids (and other species), and providing unique conditions (such as high flow refuges).
- *Fish passage improvements* to increase connectivity and facilitate movement between the estuary and freshwater streams for spawning adult salmonids and smolts.
- *Flood damage reduction* by increasing the area available for high flow storage and gradual release downstream. This is usually accomplished by removing or setting back levees. If tide gates are present, they can be managed seasonally open during the winter and closed in the summer.
- *Infrastructure protection* through upgrading tide gates and appurtenant structures to meet current engineering and regulatory standards. This project type is commonly requested by local agencies and landowners due to high costs.

  Recommendation: These restoration categories provide a basis for identifying a continuum of project types and their relative benefits. Some projects might focus solely on one goal, and have neutral or adverse effects on other goals. Other projects may provide joint benefits for multiple goals, with or without adversely affecting other goals. It would be possible to flesh out this continuum using the restoration projects identified in Section 5 as well as other information (i.e., permits, watershed assessments, etc.).

D. Finding: Estuary restoration projects increasingly have multiple goals providing joint benefits.

- Very few projects that we reviewed identified only a single goal, and many of these were older projects.
- Generally, project implementers had multiple funding partners, with each having their own goal for participating. Thus, how a project is framed may be critical to getting it implemented. To fishing and conservation stakeholders, it may be a habitat restoration project; to agricultural interests and local community members it may be a drainage or flood control project (Cereghino 2015, Furlong 2017).

- It is more realistic and potentially sustainable, but also more complicated, to account for the interconnected nature of ecosystems, social systems, and effects of actions.
- Multiple benefit projects are potentially attractive to a wider range of funders and stand a greater chance of garnering local support. Because they are more complex, they may also take longer to plan, permit and implement.

  Recommendation: Recognize that projects that can demonstrate some combination of water quality, fish recovery, agricultural conservation, flood protection, climate change resilience, and/or recreation benefits are more likely to be locally acceptable and fundable, but are also more complex and require coordinated project management.

E. Finding: Oregon lacks a comprehensive framework for estuary restoration.

- For projects in Oregon, outside the BPA's Columbia Estuary Ecosystem Restoration Program, there is a lack of landscape scale restoration/management plans.
- Management plans exist for individual estuaries but these are typically focused on acquisition priorities rather than more holistic plans that combine various project types, landowner incentives, and synergistic benefits. This has led to a lack of coordination among interests, and disjointed restoration projects.

  Recommendation: Develop a comprehensive approach to estuary restoration in Oregon that acknowledges diverse stakeholder goals and benefits, while articulating a common vision for human uses of estuaries, floodplains, and coastal wetlands.

F. Finding: Oregon can learn from Washington's experiences with estuary restoration.

- Compared to Oregon, the state of Washington has a larger population and more estuary habitat but is also very similar with regard to land use history in its estuaries and current estuary management issues.
- Oregon can learn from Washington's extensive experience in this arena, and its landscape-scale, administrative responses to the ecological and sociopolitical challenges of estuary restoration.

  Recommendation: To inform Oregon's Tide Gate Discussion, review regional frameworks being used in Washington (e.g. Tidegate Fish Initiative, Fish, Farms and Floods Initiative, Floodplains by Design) for collaborating on the prioritization, permitting and coordination of estuary restoration projects, including tide gate removal or upgrading. Consider hosting a workshop on this topic, where invited speakers could elaborate on what has worked, what hasn't, and lessons learned.

  Recommendation: Building on knowledge and experience gained from analyzing Washington models, explore the potential for a coast-wide plan for estuary restoration and flood-control structure renovation in Oregon that establishes a framework for prioritizing projects and for coordination on implementing them.

G. Finding: Estuary restoration projects increasingly include acquisition of the lands to be restored, a trend that is likely to continue.

- As discussed in Chapters 5 and 6, land acquisition for estuarine restoration can be complex and controversial. Most "low hanging fruit" - i.e. less complex restoration projects on public lands (e.g. Siletz and Bandon Marsh National Wildlife Refuges) have already been completed.
- Projects that include real property acquisition typically involve private lands that were converted from estuarine wetlands into agricultural fields through extensive diking and draining. Often, acquisition of more than one parcel is necessary for the project to proceed, and these acquisitions occur over several years.
- Nimble and incremental acquisition of historically estuarine parcels of land is usually the crux of large estuary restoration [in Washington] and funders must be willing to accumulate and hold parcels until enough suitable land is acquired that projects can move forward (Cereghino 2015).
- OWEB has been a key player in facilitating land acquisitions along the Oregon Coast that supported major restoration efforts, but current processes are cumbersome and time consuming.

  Recommendation: Consider working with stakeholders to develop a more integrated approach for identifying lands that are suitable for acquisition as part of a comprehensive estuarine restoration strategy.

H. Finding: Current appraisal procedures may undervalue lands suitable for estuarine restoration making acquisition from willing sellers difficult.

- Restoration of diked pasture lands can provide considerable ecosystem service values, while in many cases, due to subsidence and waterlogging, these lands may have lost their productivity for agricultural uses.
- Land acquisitions are subject to laws and regulations (and for land trusts, certification standards) that require adherence to appraisal standards that usually defer to the Federal "Yellow Book" procedures.
- Appraisal procedures are based on their "highest and best use"; however, potential ecosystem services are not incorporated into the appraisals, resulting in purchase offers that are not attractive to landowners.
- Recognition and inclusion of ecosystem service values may allow for compensation levels that provide the necessary incentive for the sale to occur (Cereghino 2015).

  Recommendation: OWEB should work with its partners (NRCS, USFWS, Land Trusts) to determine whether there are appraisal approaches that consider ecosystem service values, and/or ecosystem service payments (i.e., "stacking") to landowners outside the appraisal process.

I. Finding: Oregon has a system of watershed councils and soil and water conservation districts that work to coordinate and support local restoration efforts.

- The capacity of individual councils and districts varies considerably and some could benefit from additional, targeted technical and financial support, based on clearly identified needs.

- There is a range of perspectives within and among councils and districts regarding the value and importance of estuarine restoration, tide gate upgrades, and land acquisitions.
- Cereghino (2015) notes that estuary restoration projects rely on local "estuary groups" to serve as a nexus for community outreach and partnership building, garner and maintain local support, supply project management, and help coordinate work. Oregon watershed councils and districts can serve as local estuarine stewardship groups, and in some cases already do.

  Recommendation: Continue to build and maintain capacity in Oregon's coastal watershed councils and districts for partnership building, promoting social learning regarding the multiple benefits of estuary restoration, generating support and helping to coordinate locally-acceptable restoration projects.

  Recommendation: Continue and expand outreach (and inputs) from the Tide Gate Discussion process to better involve councils and districts so that a consensus approach can be developed for each estuary.

J. Finding: Mitigation and environmental damage funds are underutilized for estuary restoration in Oregon.

- Outside of the Lower Columbia River Estuary, mitigation strategies (and funding) have not been consistently utilized in Oregon to promote targeted estuary restoration to the same extent as in Washington.
- The Wetlands Conservancy (TWC) has used mitigation funds to acquire property in the Yaquina estuary, and to restore properties purchased with Coastal Wetlands grant funds at Matson Creek in the Coos Bay estuary.
- Environmental damage funds from the *New Carissa* oil spill were used to purchase 3,900 acres for $15.5 million to restore marbled murrelet habitat. Another 400 acres of salt marsh at the Bandon Marsh NWR were also restored using this funding source (M/V New Carissa Natural Resource Trustees 2007).
- The Oregon Department of State Lands (DSL) operates a mitigation banking program where small fill-and-removal projects can serve as "payment-in-lieu" instead of conducting mitigation themselves (http://www.oregon.gov/dsl/WW/Pages/Mitigation.aspx). Impact fees are ~$50,000 - $120,000 per acre. Several projects identified in Section 5 (Pixieland, Tamara Quays, Kilchis River) are in the banking program. The DSL has shown interest in working with coastal watershed councils to use these funds for estuarine wetland restoration.
- A fish passage banking program on the North Coast is currently being piloted by ODOT, Willamette Partnership and TNC (http://www.dfw.state.or.us/fish/passage/mitigation.asp); primarily focused on overcoming fish passage barriers. The three pilot projects are in upper watershed areas but the Net Benefit Analysis (NBA) tool developed by the Willamette Partnership is also applicable to lowlands. An earlier version was used by CoosWA to transfer in-stream flow requirements from Pony Creek to Matson Creek Wetland Preserve stream restoration (e.g., channel re-meandering, large wood placement, riparian planting).

  Recommendation: Explore options for applying mitigation to tide gate removal, upgrade and other estuary restoration actions. This may involve administrative rule-making (or statutory changes) to better coordinate mitigation and restoration.

K. Finding: Hydrodynamic modeling is critical to project prioritization, planning and monitoring. There is a lack of bathymetric and other types of data to support construction of hydrodynamic models.

- As estuary restoration projects have become more complex, agencies and planners are increasingly using hydrodynamic modeling to help inform decisions regarding which projects to prioritize and the potential hydrological outcomes of restoration alternatives.
- Evidence suggests that these models are very useful because they address the key information need of forecasting hydrologic outcomes of restoration actions (e.g. how susceptible will my property be to flooding if this dike is set back, and agricultural land converted back to wetland?) Evidence also suggests that such models are becoming more sophisticated.
- Hydrodynamic modeling that is being conducted in a number of Oregon's estuaries by scientists from the University of Oregon (David Sutherland) and Oregon State University (David Hill) can form a foundation for the modeling needed for project prioritization and implementation.

  Recommendation: To accelerate project prioritization and planning, maintain or increase support for hydrodynamic modeling of estuary restoration alternatives and potential outcomes of management actions.

  Recommendation: Explore the potential to apply methods, techniques, or lessons learned from the Farms, Fish and Floods Initiative (3FI) Skagit Delta Hydrodynamic Model Project to estuary restoration project prioritization and planning in Oregon.

  Recommendation: Identify the kinds of raw [GIS, Lidar] data needed to develop hydrodynamic models for estuary restoration, and prioritize location and acquisition of such data. Integrate this into protocols for pre- and post- project monitoring.

  Recommendation: Work with the Oregon research community to develop strategies for acquiring bathymetric and other types of data needed to develop hydrodynamic models for estuary restoration project prioritization and planning.

L. Finding: Benefits and effects of tide gates are related to their geographic location: stream/river mouth and tributaries allow tide gate upgrades to meet multiple goals.

- Based on earlier work (Giannico and Souder 2005), we categorized three different types of locations for tide gates (Figure 5-3):

  - *Stream/river mouth* tide gates are located where drainage from larger watersheds (HUC 6th or 7th field) enters an estuary. These are larger structures, often containing multiple gates, and may be integrated into a road bridge or larger dike system.
  - *Tributary creek* tide gates are located at the mouths of smaller streams, but have spawning and rearing habitat outside the floodplain. These tide gates may be located where the tributary enters the estuary, or may drain into a reservoir pool or stream reach controlled by a stream/river mouth tide gate.
  - *Drains*, whether they control tidal flows into field or other protected areas, empty water only within the floodplain itself, and not into uplands beyond. Drains may

empty directly into the estuary, or into either tributary stream or stream/river mouth reservoirs.

- Stream/river mouth and tributary locations may have suitable lowland rearing habitat either in the reservoir pool or other nearby wetlands, and also suitable spawning habitat in the upper stream reaches.
- In contrast, tide gates located on drains only have the potential to provide rearing habitat. The amount and quality of this potential habitat determines the relative value of the project.

  Recommendation: To maximize benefits for salmonids (and potentially other benefits such as flood mitigation) prioritize projects where the tide gate(s) are located at stream/river mouths, or tributary creeks.

  Recommendation: When considering tide gate projects, ensure that suitable rearing or off-channel refuge habitat is available, or restored or created as a project component.

M. **Finding: A recently recognized ecosystem service of coastal wetlands is their extraordinary capacity to capture and sequester atmospheric carbon.**

- This so-called "blue carbon" is stored in soils of healthy coastal wetlands. Restoring coastal wetlands stops drainage-induced releases of carbon and reactivates carbon sequestration (Crooks et al. 2014).
- Healthy coastal marsh ecosystems are also resilient in the face of climate change, as a result of their ability to accrete sediment at the same rate as sea level rise (National Research Council 2012).
- Greater recognition and understanding of these benefits is focusing interest on the potential for use of carbon sequestered in coastal wetlands as a funding mechanism for estuary restoration (Sutton-Grier and Moore 2016).
- OWEB and other entities are investing in projects to develop a more robust understanding of factors that affect blue carbon dynamics.

  Recommendation: Continue investments in monitoring of blue carbon dynamics, and methods to quantify potential carbon benefits of coastal wetland restoration. Explore the potential for investment in tidal wetland restoration efforts by considering the interplay of such efforts with carbon sequestration.

Project Implementation and Effectiveness

A. **Finding: The best restoration results have been reported for large scale and comprehensive restoration projects and not solely tide gate upgrades.**

- Overall fish and habitat responses to projects that combined a spectrum of restoration actions (i.e., tide gate upgrade or removal, dike setback or breaching, tidal channel creation, and upstream riparian plantings and in-stream complexity enhancements) were consistently stronger and more positive than those of simple and localized enhancement work (Hering 2010, Roegner et al. 2010, Silver et al. 2015, Diefenderfer et al. 2016, Henderson et al. 2016).

Recommendation: Whenever possible favor comprehensive restoration projects that aim at reestablishing connectivity and ecosystem level processes over those that focus on changing one single factor (e.g., number of fish that pass, water quality above tide gates, etc.).

B. Finding: Upgrading a tide gate is only the first step in the process of improving ecological conditions and fish migration corridors.

- Monitoring by OWEB and other agencies indicates that active and informed management of the tide gate is critical to realizing the full potential benefits of the upgrade.
- Also, some landowners may be reluctant to actively manage tide gates, even after cooperating on upgrading. Therefore tide gate improvements often underperform.

  Recommendation: To fully realize the potential benefits of restoration involving tide gates, post restoration management plans should explicitly provide for active and adaptive management of the gates in order to incorporate knowledge gained from research and monitoring, and to account for unforeseen effects or outcomes.

  Recommendation: Recognize that to optimize tide gate design and management for fish requires a balancing of: 1) gate opening time and width, 2) culvert width, 3) invert elevation, and 4) upstream pool depth at high tide (Lyons and Ramsey 2013).

  Recommendation: Tide gates should be managed seasonally to ensure that fish passage requirements, water temperatures and dissolved oxygen are suitable for juvenile salmonids when they are present in the system. Additionally, any maintenance that requires a tide gate to be closed should be conducted when salmonids are not present. (Beamer et al. 2017.)

C. Finding: Some unforeseen outcomes should be expected after implementation of large restoration projects.

- Appropriate attention to the quality and extent of pre-project planning, combined with considerations of the scale of hydrological processes and the possible final outcomes of the cumulative effects of multiple restoration actions will reduce the likelihood of unforeseen outcomes.
- Regular monitoring of upgraded tide gates is critical to help identify and mitigate unforeseen impacts before these impacts accumulate or worsen.
- Each project should have an operations and maintenance plan, with provisions for funding seen and unforeseen needs, in place prior to project completion.

  Recommendation: Sites should be operated to ensure that any adverse effects arising from implementation of the restoration actions are identified and rectified in a timely fashion

  Recommendation: Post-implementation monitoring will provide information on the project's long term outcomes, facilitating an adaptive management approach to subsequent estuarine restoration projects.

Future monitoring and information needs

A. Finding: The information base on the effects of tide gate upgrades is very limited. Project practitioners lack support to publish monitoring results in peer-reviewed journals.

- Despite the increasing number of estuary restoration projects that have been completed, there is still a paucity of reliable information regarding the effectiveness of tide gate upgrades and, to a lesser extent, broader estuary restoration actions such as dike setback.
- This is likely due to a number of factors, including the complexity of these projects and their synergistic and cumulative effects, the extended time that it can take for ecosystem components to recover, but also to insufficient support for the rigorous analysis, synthesis and publication of existing data.
- The low numbers of peer-reviewed publications is due in part to the fact that grant applications generally request funding for only field work, some analysis and a final project report. Thus, local groups or agencies lack the resources to prepare their results for peer-reviewed journals.
- In addition, agencies lack the capacity or cannot afford the time that is required for rigorous peer review processes.

  Recommendation: Provide funding support, incentives, and technical assistance to allow entities conducting monitoring of OWEB estuary restoration projects to develop publications of their findings for submission to peer-reviewed journals.

  Recommendation: Continue and expand partnering with research universities to recruit graduate students to test hypotheses regarding tide gates, conduct in-depth monitoring, and publish results.

B. Finding: Monitoring can be a learning tool for practitioners, and can aid in identifying and improving effectiveness over time, especially when it is part of a feedback loop in an adaptive management approach (Walters and Holling 1990).

- Recognizing this, OWEB has funded both pre- and post-project monitoring for a number of estuary restoration efforts it has been involved with.
- Monitoring is challenging, however, given the complexity of tide gate related restoration projects, the difficulty of prizing out effects of different project components, and the long period often required to detect effects.

C. Finding: Long-term monitoring is critical, but this is resource and time-intensive and support for it is usually limited. There is no comprehensive estuary restoration project monitoring strategy.

- It is preferable to apply monitoring resources on fewer projects, but with more robust protocols (e.g., multiple sites, number of days sampled, sampling for several years). If monitoring resources are spread too thinly, or monitoring is truncated after only a couple of years, the resulting data may not be useful.
- Many monitoring projects that OWEB has supported are well-grounded and executed, but there has not been an integrated and consistent approach among different monitoring entities.

  Recommendation: Develop a more integrated and cohesive monitoring strategy for estuary restoration projects, starting with rigorous analysis of what questions the monitoring should be designed to inform or answer. Explicitly consider how monitoring results would be used to

inform adaptive management of tide gates. To the extent possible, institutionalize and standardize existing monitoring protocols, so existing data can be compared to new data.

Recommendation: Review monitoring protocols used by other programs in the PNW (e.g. the Columbia Estuary Ecosystem Restoration Program) to inform development of a more standardized and cohesive approach for monitoring OWEB-funded estuary projects.

Recommendation: Carefully consider which projects to monitor, who will be using the resulting knowledge, and how it will be used. Focus tightly on a carefully selected subset of potential sites or projects to track through time, i.e. 10-20 years.

D. Finding: Nationally-recognized restoration programs can provide guidance on overcoming challenges involved in monitoring.

- The National Research Council reviewed the effectiveness monitoring program at an early stage in the restoration of the Florida Everglades and provided recommendations to implementers. National Academy of Sciences, Engineering and Medicine (NAS) produce biennial assessments of progress towards meeting restoration goals and knowledge gained in the process.
- The National Academy of Sciences (2017) recently conducted a similar review for the Gulf of Mexico ecological restoration program resulting from the Deepwater Horizon oil spill. In addition to listing 20 reasons why monitoring is challenging and often unsuccessful (NAS 2017, pp. 14-15), they provide six recommendations that are pertinent to improving knowledge about the ecological effects of tide gates (NAS 2017, p. 6):
    1. Identification and prioritization of critical restoration uncertainties where adaptive management can be utilized to improve decision making and reduce risk;
    2. Development of project-level adaptive management plans that formalize the key steps and responsible parties throughout the adaptive management process;
    3. Institutional support for synthesis and evaluation in support of decision making;
    4. Development of a decision-making process in advance for making adjustments to restoration projects;
    5. Clear financial and procedural commitment to adaptive management, which will likely require a dedicated organizational structure and additional planning and monitoring beyond typical restoration projects; and
    6. Coordinated guidance for implementing adaptive management for restoration efforts.

Potential phase II project components

A. Finding: There is considerable potential for additional qualitative learning and quantitative data synthesis regarding the effectiveness of estuary restoration actions that involve tide gates in Washington and northern California.

- Our research revealed that while there are significant efforts and resources being focused on estuary restoration along the west coast, and that these projects often involve tide gates, projects are documented in a mostly haphazard and piecemeal fashion.

- Tide gate removal or upgrades are regularly not mentioned specifically in project reports, even when such work was part of a broader estuary restoration project.
- Further work (i.e., more extensive searching, follow up on projects previously identified, reading all documentation) would likely reveal additional information and projects involving tide gates, and potentially useful lessons learned.
- In our review of restoration projects and monitoring we identified potential datasets that seem particularly relevant to evaluating the effectiveness of tide gate upgrades. These datasets include:
    - Phey Lane (ODFW)
    - Palouse, Larson, and Willanch Creeks (CoosWA)
    - Humboldt Bay (Mike Wallace, Cal. Fish & Game)
    - Lower Columbia (Battle PNNL)
    - Kentuck Slough and MacDonald Slough (Nehalem Marine)
    - Fisher Slough (Skagit River System Cooperative)

- We found evidence of, but did not have the time or resources to track down, additional monitoring data and further searching and targeted outreach would likely identify more such instances.
- Meta-analysis of these data could provide additional, pertinent knowledge particularly about the effects of tide gate upgrades, an area where we found few published results.

Recommendation: Develop a scope of work to continue knowledge synthesis and development of tools to support restoration and infrastructure modernization in Oregon's estuaries. Potential components include gathering and analyzing additional documentation and data sets, developing a monitoring framework, reviewing and synthesizing frameworks for collaborative restoration, and exploring the potential for development and application of a coast wide approach to hydrodynamic modeling to support project prioritization and alternatives analysis.

B. Finding: There is a lack of clear guidance or reports on the likely costs and benefits of various types of tide gate and estuary restoration projects.

- The data and reports collected in this initial effort provide sufficient sources to obtain the raw material to construct these guidelines using standard econometric methods.
- As discussed above, potential project benefits such as ecosystem services (i.e., flood control, blue carbon) could be explicitly factored into project evaluation.
- Having this information available to project developers, grant reviewers, and funders would allow for a more consistent and transparent process.

Recommendation: Work with the INR review team and others to further develop this concept for use in a programmatic strategy and to support restoration grant reviews.

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Chapter 9 Glossary

Alevin. The stage of salmon development after eggs hatch, but the fish remain in redds while their yolk sacs (food supply) remain, usually lasting about 12 weeks depending upon the water temperature.

Delta. An area that forms as stream and river flows reduce their velocity and deposit sediment that they carry from upstream.

Dike. An embankment constructed of earthen or other suitable material to protect land against overflow or to regulate water.

Dike Setback. Construction of a new dike inland of an existing dike prior to removal of the original dike. Purposes of setting a dike back include the restoration of tidal exchange to improve estuary habitat and improve flood control.

Ebb Tide. The outgoing, or receding, tide occurring during the period from high tide to low tide.

Estuary. A semi-enclosed body of water, connected to the ocean, where salt water is measurably diluted with fresh water from the land. A zone of transition between marine-dominated systems of the ocean and the upland river systems, some of the most biologically productive areas on Earth.

Estuarine Habitat. Areas available for salmonid feeding, rearing, and smolting in tidally influenced lower reaches of rivers. These include marshes, sloughs and other backwater areas, tidal swamps, and tide channels.

Flood Tide. The incoming, or rising, tide occurring during the period from low tide to high tide.

Freshet. Flood of a river from heavy rain or melting snow (or both).

Fry. A stage of development in salmon when the fish swim up from the gravel (redds), gulp air to fill their swim bladders, and begin to feed at the water surface.

Higher High Water. The higher of the two daily high tides.

Invert Elevation. The bottom, or sill, elevation of a culvert or concrete box. The invert becomes the lowest elevation that can be drained from upstream.

King Tide. The highest predicted high tide of the year at a coastal location.

Lower Low Water. The lower of the two daily low tides.

Mean Higher High Water (MHHW). The average height of the higher high waters over a 19-year National Tidal Epoch (cycle).

Mean Lower Low Water (MLLW). The average height of the lower low waters over a 19-year National Tidal Epoch (cycle).

Marsh Surface Elevation. The elevation of the mud or sand bottom in a marsh. This elevation determines the likely vegetation that will grow on the site.

Mitigation *(contrast with restoration)*. The restoration, creation, or enhancement of an area to compensate for permitted losses, typically used for wetlands, but also more recently for fish passage. Distinguished from "Restoration" because it is required rather than voluntary.

Muted Tidal Regulator (MTR). A device that holds open the tide gate during a flood tide until a pre-determined elevation in the reservoir pool is reached. Nehalem Marine developed and holds the patent for the MTR.

Neap Tide. Occurs during the first or third quarters of the moon, when the sun and the moon are at right angles to the Earth. Time when the difference between high and low tides is the least.

Parr. The stage of salmon development after fry, but before smolification, identified by the dark vertical marks on their sides that camouflage them from predators.

Reservoir Pool. The area behind a tide gate structure that impounds water during the time that the tide gate is closed. The pool contains freshwater draining from above, leakage through the gates during high tides, and any additional tidal inflow permitted (see MTR).

Restoration *(contrast with mitigation).* The return of an area to a close approximation of its condition prior to disturbance. In the context of this report, restoration refers to voluntary actions to bring about this condition.

Slough. Quiet, backwater part of a bay, part of the estuary, where freshwater flows from creeks and runoff from land mix with salty ocean water transported by the tides.

Smolt. A life stage of anadromous salmon when they adapt to life in saltwater by undergoing behavioral, developmental, and physiological (endocrinological and osmoregulatory) changes that allow them to adjust from living in freshwater to living in saltwater.

Spring Tide. Occurs during the new or full moon when there is the greatest difference between low and high tide levels.

Storm Surge. Abnormal rise of water caused by low pressure weather, above and beyond the normal tides.

Tidal Exchange. The volume of seawater that enters and exits an estuary on each tidal cycle, along with the freshwater input rate.

Tidal Marsh. Wetlands from lower high water (LHW) inland to the line of nonaquatic vegetation.

Wetlands. Land areas where excess water is the dominant factor determining the nature of soil development and the types of plant and animal communities living at the soil surface. Wetland soils retain sufficient moisture to support aquatic or semi-aquatic plant life. In marine and estuarine areas, wetlands are bounded at the lower extreme by extreme low water; in freshwater areas by a depth of six feet. The areas below wetlands are submerged lands.