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Monitoring Framework to Evaluate Effectiveness of Aquatic and Floodplain Habitat Restoration Activities for Native Fish along the Willamette River, Northwestern Oregon

Open-File Report 2022–1037

U.S. Department of the Interior
U.S. Geological Survey

Cover. Inundation extent of the Harkens Lake site facing northeast along the Willamette River (river mile 153.5), during flood conditions, April 8, 2019. Photograph by River Design Group, Inc.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
hectare (ha)	2.471	acre
	Flow rate	
meter per year (m/yr)	3.281	foot per year (ft/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$°F = (1.8 \times °C) + 32$.

Supplemental Information

Concentrations of dissolved oxygen in water are given in milligrams per liter (mg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

7dADMax	7-day moving average of daily maximum
AHWG	Anchor Habitat Working Group
AEP	annual exceedance probability
AIS	aquatic invasive plant species
BPA	Bonneville Power Administration
BSWCD	Benton Soil and Water Conservation District
CPUE	catch per unit effort
DEM	digital elevation model
DO	dissolved oxygen
eDNA	environmental deoxyribonucleic acid
ESA	Endangered Species Act
FPKM	floodplain kilometer
GIS	geographic information system
MMT	Meyer Memorial Trust
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OWEB	Oregon Watershed Enhancement Board
PIT	Passive Integrated Transponder
PSU	Portland State University
UAS	unoccupied aerial systems
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
EPA	U.S. Environmental Protection Agency
WFIP	Willamette Focused Investment Partnership
WSIP	Willamette Special Investment Program

Monitoring Framework to Evaluate Effectiveness of Aquatic and Floodplain Habitat Restoration Activities for Native Fish along the Willamette River, Northwestern Oregon

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Executive Summary

Chapter A. Background for Willamette River Restoration Effectiveness Monitoring

In collaboration with the Oregon Watershed Enhancement Board (OWEB), Benton Soil and Water Conservation District (BCSWCD), and many organizations engaged in restoration of the Willamette River floodplain, a monitoring framework (this document) was developed to evaluate effectiveness of floodplain restoration activities at increasing and enhancing habitat for native fish in the Willamette River corridor, northwestern Oregon. This monitoring framework describes monitoring indicators, metrics, and approaches for evaluating responses in native fish communities and physical habitat conditions to restoration activities and determining effectiveness of restoration activities at improving habitats for native fish. This document is intended as a resource for restoration program managers, practitioners, scientists, and contractors as they develop detailed annual monitoring plans for data collection and identify the monitoring indicators, metrics, and approaches that are most appropriate for evaluating effectiveness of different restoration activities.

Since 2008, large-scale restoration programs have been implemented along the Willamette River to address historical losses of floodplain habitats caused by dam construction, bank protection, large wood removal, land conversion, and other anthropogenic influences. The overarching funding program supporting most of Willamette River restoration from 2008 to 2023 is the Willamette Mainstem Anchor Habitats Funding Program, which combines several restoration initiatives by three different funders. The OWEB funded the Willamette Special Investment Program (WSIP) from 2008 to 2015, followed by the upper and middle Willamette Mainstem Anchor Habitats restoration initiative (hereinafter, WFIP restoration initiative) from 2016 to 2021. Other contributing partners include Meyer Memorial Trust (MMT), which funds the Willamette River Initiative (extending 2008–21) and Bonneville Power Administration (BPA), which funds the Willamette Habitat Program (extending 2010–23). The WFIP restoration initiative brings together more than 16 organizations to improve floodplain habitats on more than 35,000 hectares upstream from Willamette Falls with the overarching goal to expand and enhance native fish habitats through the following restoration activities implemented along the floodplains and off-channel areas of the Willamette River:

1. Modify floodplain topography and human-made barriers to inundation,
2. Enhance gravel pits,
3. Remove revetments,
4. Construct off-channel features,
5. Increase and enhance floodplain forest vegetation, and
6. Treat aquatic invasive plant species (AIS).

The WFIP Effectiveness Monitoring Program was initiated to inform future refinement of Willamette River restoration program goals and activities and has three goals: (A) evaluate the effectiveness of different restoration activities at increasing and enhancing native fish habitat, (B) improve overall understanding of the physical and ecological responses associated with different restoration activities undertaken by the WFIP, and (C) relate site-scale responses to restoration with broader patterns of fish communities,

[1]U.S. Geological Survey

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hydrogeomorphology, stream temperature, and vegetation across the Willamette River floodplain, so that the relative importance of restoration activities on habitat availability for native fish can be assessed. The focus of the WFIP Effectiveness Monitoring Program on informing future restoration program goals and activities that seek to ‘increase habitat for all native fish’ is distinct from other large-scale monitoring programs in the Pacific Northwest that were developed to systematically address regulatory questions motivated by the Endangered Species Act. The monitoring indicators and approaches of this monitoring framework are grouped into five restoration monitoring categories useful for characterizing ecological and physical habitat responses to restoration activities:

1. Fish
2. Hydrogeomorphology
3. Floodplain forest vegetation
4. Birds
5. Aquatic invasive plant species (AIS)

Chapter B. Monitoring Responses of Fish Communities and Their Food Resources to Willamette River Restoration Activities

Monitoring fish and their food resources can complement physical habitat monitoring and determine whether restoration created conditions that support native fish populations. Although restoration activities are intended to improve habitat for native fish species, the effectiveness of some restoration projects may be reduced if those activities also support non-native fish populations that can compete with or prey upon, native fish. This framework focuses on various indicators to evaluate fish responses to restoration activities.

- **Fish presence** monitoring can be used to assess how various fish species respond to habitat restoration. Presence monitoring can be used to verify if individual fish species are present at a specific location.
- **Fish abundance** estimates are important metrics for restoration monitoring. Increasing abundance could indicate that restoration activities improved conditions whereas decreasing abundance could indicate that restoration activities were harmful.
- **Fish community composition and diversity** evaluates the overall community of fish using restoration sites and directly relates to longstanding goals for Willamette River restoration programs that seek to support the overall community of native fish through habitat restoration.
- **Fish growth** assessments can be used to evaluate how rearing and growth opportunities respond to restoration. This is especially informative for assessing Willamette River restoration activities because many of these programs are implemented to support rearing and growth of native fish.
- **Food resource availability** is an important indicator for evaluating restoration effectiveness, especially because several Willamette River restoration activities are specifically implemented to enhance and expand food resources for native fish.
- **Other monitoring indicators** from hydrogeomorphic, floodplain forest vegetation, and AIS monitoring that reflect the type of restoration activities implemented at a particular site and anticipated changes in physical or ecological responses can complement fish monitoring.

Chapter C. Monitoring Hydrogeomorphic and Water Temperature Responses to Restoration Activities That Directly Modify Hydrogeomorphic Processes

Many Willamette River restoration activities to improve fish habitat consist of alterations to floodplain topography or human-made structures to influence hydrologic, hydraulic, and geomorphic processes (collectively, ‘hydrogeomorphic processes’). Hydrogeomorphic monitoring provides an indication of whether the restoration activities are creating physical conditions and processes that support habitats preferred by native fish throughout the year. This framework focuses on four indicators to evaluate hydrogeomorphic and water temperature responses to restoration activities.

- **Floodplain inundation** (including the inundation extent, water depths, and frequency that specified hydraulic conditions are achieved) provides an indication of the available aquatic habitat at a restoration site.
- **Planimetric changes** in channel features can be monitored to determine if restoration activities are resulting in desired morphological changes (such as lateral migration after revetment modification) or if lateral adjustments in channel features are occurring that are potentially harmful to infrastructure or habitats.

- **Vertical changes** in off-channel and floodplain features (such as scour or aggradation) indicate whether restored channel features are (A) remaining vertically stable, (B) experiencing adjustments that can be problematic for fish passage or restoration project longevity (such as incision that creates conditions conducive to fish stranding), or (C) experiencing beneficial adjustments (such as aggradation of incised channel).

- **Water temperature** can be altered by hydrogeomorphic restoration activities and is a critical indicator for assessing fish growth and survival.

- **Other monitoring indicators** from fish, floodplain forest vegetation, and AIS monitoring can complement hydrogeomorphic monitoring activities. Hydrogeomorphic monitoring can be paired with fish sampling to determine if focal fish communities are using (fish presence) or increasing in abundance at a site and whether they have sufficient food resources to support fish growth and survival and other restoration program goals. Fish monitoring (especially fish presence) can be applied at nearly all restoration sites and more intensive fish monitoring can be used where justified. Floodplain forest and AIS monitoring can occur at sites where floodplain forest vegetation was planted after hydrogeomorphic restoration activities were completed or where AIS control activities also occur.

Chapter D. Monitoring Vegetation Responses and Floodplain Inundation at Floodplain Forest Vegetation Restoration Sites

Increasing and enhancing native floodplain forests has been a widespread and central restoration activity in the Willamette River floodplain. Although there are many ecological benefits associated with diverse and expansive floodplain forests, effectiveness monitoring to understand fish habitat benefits of floodplain forest planting can focus on evaluating near-term (within 3–5 years after planting) benefits for fish habitats used in the late autumn, winter, and spring high streamflow period when newly planted areas are inundated, and fish can access those areas. Floodplain forest monitoring activities can focus on characterizing changes in canopy cover that result from tree planting and the frequency that newly planted sites are inundated. This framework focuses on two indicators to evaluate floodplain forest vegetation responses to restoration activities and inundation at floodplain forest restoration sites.

- **Canopy cover** can indicate (A) hydraulic roughness that can slow overbank water velocities, (B) physical cover for fish to hide, hunt, and forage, and (C) food resources provided by newly planted floodplain forest vegetation.

- **Floodplain forest inundation** can indicate the frequency that native fish can access and use floodplain forests habitats during high streamflows.

- **Other monitoring indicators** that can complement canopy cover and floodplain forest inundation monitoring to assess the effectiveness of floodplain forest restoration at increasing fish habitats include monitoring of fish, water temperature, and avian communities. Fish monitoring can focus on fish presence to characterize the types of fish using floodplain forest restoration sites when they are inundated, fish growth to assess how these sites may benefit juveniles that rear in flooded forests and food resource availability. Water temperature monitoring is useful for assessing fish behavior, growth, and survival in flooded forest sites. Avian indicators can be used to describe the overall community composition and structure of floodplain forest sites.

Chapter E. Monitoring Avian Responses to Floodplain Forest Vegetation Restoration Activities

Floodplain forest restoration activities are widely implemented along the Willamette River with a recognition that increasing the diversity and structural complexity of floodplain vegetation enhances habitat used by native fish, birds, and other wildlife. Avian indicators can be used to evaluate floodplain vegetation communities and the broader ecological benefits of forest restoration. Because the composition of avian communities reflects the structure and condition of floodplain vegetation, monitoring birds in Willamette Valley floodplain habitats allows inferences about the current status and future trajectory of these habitats and provides an objective measure of restoration success for entire floodplain ecosystems. For example, restoration of native floodplain forest is expected to benefit floodplain-associated songbird species by increasing nesting, resting, and foraging habitat. Additionally, while many traditional approaches for monitoring vegetation can be expensive, time-consuming, and yield uncertain results, avian monitoring can provide practical indicators of the effectiveness of floodplain forest restoration activities. Birds are excellent indicators of a naturally functioning floodplain ecosystem, and monitoring provides practical information about the effectiveness of floodplain forest restoration activities for improving the conditions for a wide variety of floodplain-dependent species, including native fish. Three avian monitoring indicators to evaluate floodplain forest vegetation restoration activities are included in this framework.

- **Abundance of floodplain focal species,** or the number of individuals of selected avian species, indicates the integrity of the ecosystem through the presence of critical floodplain habitat elements (for example, canopy trees, dense shrubs, and snags) and availability of quality habitat at appropriate spatial scales.

- **Species richness** (number of species) of floodplain avian communities indicates the structural complexity of vegetation and diversity of food and cover resources available at a site.

- **Productivity** (proportion of young captured) **and survival** (proportion of banded birds that are subsequently recaptured) are demographic parameters that provide information on population change and can help link population change to environmental changes resulting from restoration activities. Monitoring the demographic parameters of selected focal species is useful for evaluating the effectiveness of vegetation restoration activities at broad geographic scales, across one or more restoration sites.

- **Other monitoring indicators** from other disciplines (fish, hydrogeomorphology, floodplain vegetation) can be combined with data for avian monitoring indicators to facilitate interpretations of links between near- and long-term avian and vegetation responses with changing fish habitat conditions.

Chapter F. Monitoring Aquatic Vegetation, Dissolved Oxygen, and Substrate Responses to Aquatic Invasive Plant Species Treatment Activities

Willamette River restoration activities include treatment of (control measures to kill or remove) aquatic invasive plants species (AIS) in off-channel waterbodies like side channels and alcoves to improve water quality and physical habitat conditions for native fish. Native and non-native aquatic plants growing in off-channel features influence fish habitat. Emergent aquatic invasive plant species (AIS), such as water primroses (*Ludwigia hexapetala*), form dense mats that cover many off-channel features of the Willamette River and potentially contribute to harmful water-quality conditions for native fish and elevated rates of sedimentation in waterbodies that are hypothesized to result from dense aquatic vegetation. Four monitoring indicators to evaluate the effectiveness of AIS treatments are included in this framework.

- **Emergent and floating leaf plant cover** of AIS changes can be monitored to evaluate the reduction in AIS present above the water surfaces from mechanical and chemical treatments.

- **Plant community composition** is an important monitoring indicator as increased native plant diversity increases habitat and food resources for native fish. AIS often displace native species and produce monocultures, lowering species richness and diversity, while subsequently reducing diversity and density of native fish and invertebrates.

- **Dissolved oxygen** (DO) is necessary for native fish and very low DO concentrations often found in aquatic plant beds can be lethal, so monitoring DO conditions would indicate whether site conditions are suitable for native fish.

- **Substrate characteristics** can be monitored to determine if treatment of AIS result in reductions to the rates of organic and inorganic sediments accumulation.

- **Other monitoring indicators** can supplement the AIS monitoring, especially fish monitoring indicators and water temperature monitoring. Fish monitoring can focus on indicators such as fish presence, abundance, and fish community composition to assess seasonal patterns in use at AIS treatment sites as well as the relative abundance of native and non-native fish species. Water temperature monitoring in summer and early autumn months is useful for determining whether thermal conditions at AIS treatments sites are supportive, harmful, or lethal for various native fish species.

Chapter G. Conclusions for the Willamette River Restoration Effectiveness Monitoring Framework

This monitoring framework provides a common science foundation to support collaborative decision making on future interdisciplinary effectiveness monitoring activities for Willamette River restoration programs. As part of this monitoring framework, linkages among restoration goals, activities, and outcomes for native fish habitat were clarified to facilitate monitoring decisions and prioritize monitoring activities. Once monitoring priorities are identified, monitoring partners can select monitoring indicators and approaches from the monitoring framework that best reflect key questions, the types restoration activities implemented, site conditions, available funding and other factors when developing annual monitoring plans. To evaluate restoration effectiveness, monitoring data must be evaluated according to monitoring metrics and thresholds that permit direct comparison between habitat conditions at the restoration site and restoration program goals; this framework provides examples of monitoring metrics and thresholds for evaluating monitoring data, recognizing that the precise evaluation criteria for a particular site or program will need to be tailored to meet program questions and available resources. Although this framework was developed to support evaluation and adaptive refinement of large-scale floodplain restoration activities implemented under the Willamette Focused Investment Partnership restoration initiative, it is also useful for other large alluvial rivers where restoration activities are implemented on floodplains and off-channel areas to improve fish habitats.

Even when monitoring data are strategically collected according to a robust monitoring framework and monitoring plan and subsequently evaluated using metrics that reflect thresholds for fish habitat, determining restoration effectiveness is challenging due to multiple factors that influence floodplain conditions and habitat availability. To aid in evaluating the importance of restoration projects relative to broader patterns of fish communities and habitat availability, site-scale conditions can be compared with reach or river-scale conditions. Monitoring based on this framework, combined with information necessary to place site-level findings within the broader context of river-scale streamflow, water temperature, and habitat conditions, will form an important science foundation to address uncertainties and inform future restoration activities.

Refining restoration goals and activities as part of an adaptively managed process requires addressing critical uncertainties between restoration goals, restoration activities, and outcomes for habitats used by native fish. The effectiveness of restoration activities at improving fish habitat conditions have uncertainties, reflecting (A) limited scientific knowledge available when restoration program goals and activities were established, (B) complexity of drawing causal linkages between restoration activities and habitat availability on a large, regulated floodplain, and (C) limited resources for the research and monitoring necessary for reducing uncertainties. Although the monitoring activities of this framework will generate important datasets useful for evaluating restoration effectiveness, additional research, syntheses and reporting is ultimately necessary to provide a common science foundation to support adaptively managed restoration programs.

Chapter A. Background for Willamette River Restoration Effectiveness Monitoring

By J. Rose Wallick,[1] Mackenzie K. Keith,[1] Krista L. Jones,[1] Rebecca L. Flitcroft,[2] Tobias J. Kock,[1] Kathleen Guillozet,[3] Joan C. Hagar,[1] Laura A. Brown,[4] and Rich Miller[5]

Introduction

Native fish and wildlife depend on many aquatic and floodplain habitats along the Willamette River corridor (fig. A1). The Willamette River provides critical rearing and migratory habitats for upper Willamette River spring-run Chinook salmon (*Oncorhynchus tshawytscha*) and upper Willamette River winter-run steelhead (*O. mykiss*) (National Marine Fisheries Service [NMFS], 1999a, b; 2008). These anadromous fish species spawn in Willamette River tributaries, their offspring use the main-stem Willamette River for rearing and outmigration to the Pacific Ocean, and then later return upstream through the entire system as adults for spawning. In addition to salmon, diverse array of other native anadromous and resident fish species, such as cutthroat trout (*O. clarkii*), also depend on the availability and connectivity of aquatic and floodplain habitats throughout the year to support their various life stages (Schlosser, 1991; Gregory, Wildman, and others, 2002; Flitcroft and others, 2012; Williams and others, 2022).

Historically, a complex mosaic of aquatic and floodplain habitats along the Willamette River supported a diverse array of native fish and wildlife. Over the last 170 years, that habitat mosaic has been substantially diminished by the construction of flood control dams and bank stabilization structures, conversion of floodplain forests to agriculture and other land uses, and removal of large wood from the river (Sedell and Froggatt, 1984; Hulse and others, 2002; Baker and others, 2004; Wallick and others, 2013; Gregory and others, 2019). Reductions in the number and extent of gravel bars, alcoves, and side channels along the Willamette River have substantially decreased the rearing habitat available for juvenile Chinook salmon and year-round habitats for other native fish (Schroeder and others, 2016; Gregory and others, 2019). Together, these physical habitat and biological alterations have contributed to population declines and listing of upper Willamette River spring-run Chinook salmon and upper Willamette River winter-run steelhead as threatened under the Endangered Species Act (ESA) in 1999 (Public Law 93–205, 87 Stat. 884, as amended). Additionally, the introduction of non-native, invasive species has presented new challenges for native fish communities and their habitats. Predatory, non-native fish such as smallmouth bass (*Micropterus dolomieu)* prey upon and compete with native fish for food and habitat, while invasive, non-native aquatic plants, such as Uruguayan water primrose (*Ludwigia hexapetala*), have altered the biological and physical characteristics of off-channel features, further diminishing habitat suitability for native fish.

Since 2008, several large-scale conservation and restoration initiatives have funded projects to conserve and restore aquatic and floodplain habitats along the Willamette River for native fish including spring-run Chinook salmon, winter-run steelhead (Bonneville Power Administration [BPA], 2016). These restoration programs coincide with a broader suite of actions to improve conditions for Chinook salmon and steelhead that were motivated by the 2008 Biological Opinion (BiOp) for the U.S. Army Corps of Engineers (USACE) Willamette Basin Flood Control Project (NMFS, 2008). The overarching funding program supporting most Willamette River restoration activities from 2008 to 2023 is the Willamette Mainstem Anchor Habitats Funding Program, which combines several restoration initiatives by three different funders. The Oregon Watershed Enhancement Board (OWEB) funded the Willamette Special Investment Program (WSIP) restoration initiative from 2008 to 2015, followed by the upper and middle Willamette Mainstem Anchor Habitats restoration initiative (hereinafter, Willamette Focused Investment Partnership (WFIP) restoration initiative) from 2016 to 2021. Other contributing partners include Meyer Memorial Trust (MMT), which funds the Willamette River Initiative (extending from 2008 to 2021) and the BPA, which funds the Willamette Habitat Program (extending from 2010 to 2023). Together, these groups awarded more than $8.7 million for Willamette River restoration and conservation projects from 2008 to 2015, and more than $14 million dollars have been awarded for projects implemented from 2016 to 2023 (Anchor Habitat Working Group [AHWG], 2015; BPA, 2016). Willamette River restoration projects are implemented by more than 16 organizations (including watershed councils, land trusts, and soil and water conservation districts) who are working to improve floodplain habitats on more than 35,000 hectares upstream from Willamette Falls (fig. A1; AHWG, 2015).

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[5]Portland State University

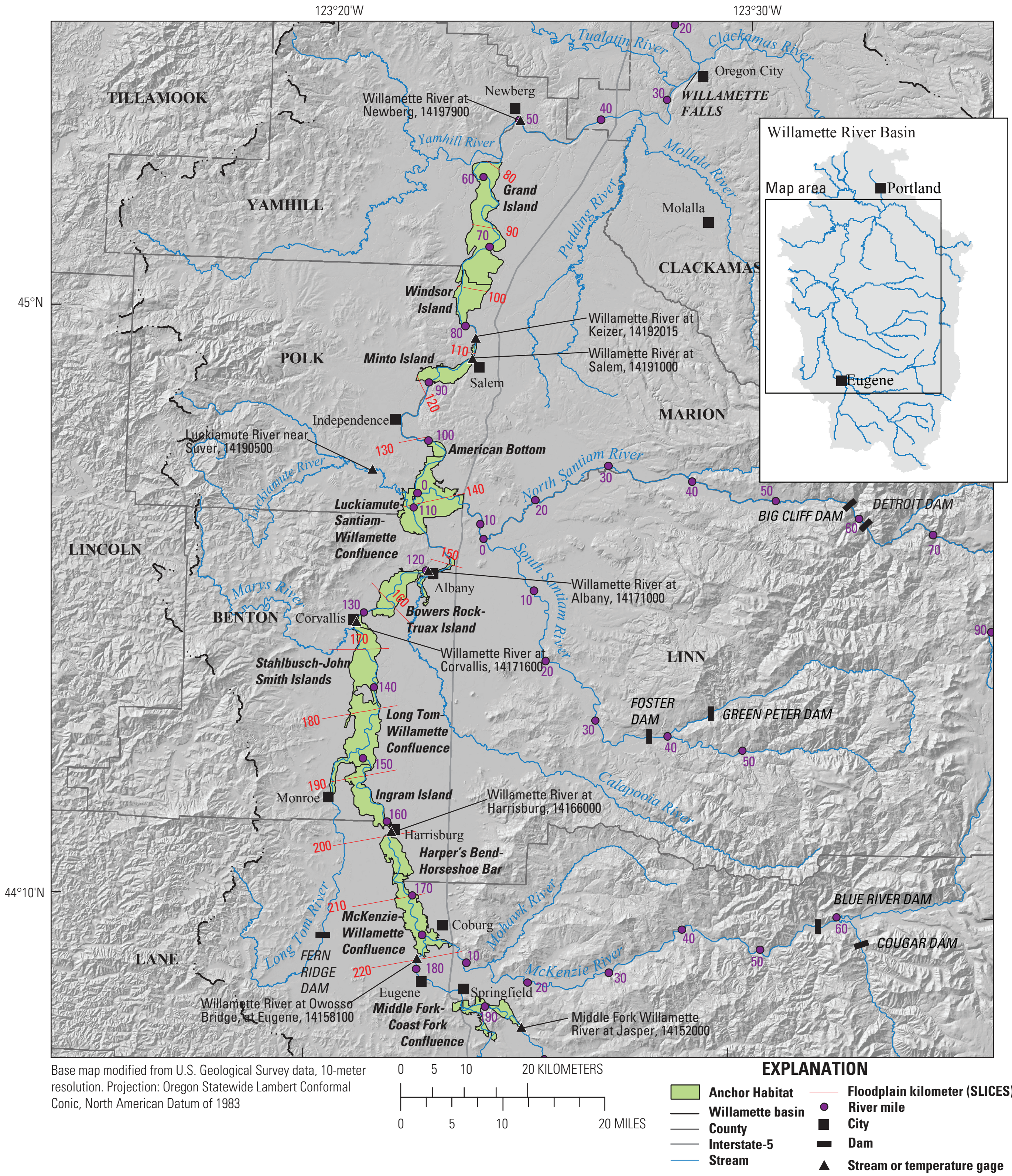

Figure A1. The Willamette Focused Investment Partnership restoration initiative area along the Willamette River between the confluence of the Middle Fork Willamette and Coast Fork Willamette Rivers and Willamette Falls near Oregon City, northwestern Oregon, including restoration areas termed Anchor Habitats (2–8-kilometer-long zones of the Willamette River where restoration activities are prioritized; Anchor Habitat Working Group [AHWG], 2015).

In recognition of the large financial investments made in habitat restoration and the many uncertainties regarding restoration effectiveness along a large, regulated river where fish habitats are influenced by many factors, the WFIP Effectiveness Monitoring Program was initiated to inform future refinement of Willamette River restoration program goals and activities (following the adaptive management framework of Warren and others, 2019). The first step in the WFIP Effectiveness Monitoring Program is the development of an effectiveness monitoring framework that will inform data collection by relating restoration goals with anticipated physical and ecological responses to restoration, and the appropriate methods for monitoring those responses (for example, Roni and others, 2005; Prach and others, 2019). Such frameworks provide a suite of common monitoring indicators, approaches, and metrics that monitoring programs can use when developing more detailed monitoring plans to guide site-specific data collection (Higgins and others, 2011).

To date, effectiveness monitoring programs have been developed for other large-scale habitat restoration efforts in the United States, such as for the Chesapeake Bay (for example, Palmer and others, 2011), tributaries in the Columbia River Basin (for example, Roni and others, 2014; Hillman and others, 2016), the Columbia River estuary (Johnson and others, 2014), and Puget Sound (Fore and others, 2014). These programs provide valuable insights and examples for developing the WFIP Effectiveness Monitoring Program, but they are not directly transferable to the large, streamflow-regulated, gravel-bed Willamette River, its aquatic and floodplain habitats, and types of restoration activities implemented in the system. Another unique aspect of the WFIP Effectiveness Monitoring Program is that it focuses on determining whether restoration activities have led to increased habitat for ‘all native fish,’ whereas other monitoring programs are focused on specific fish species such as those that are ESA-listed.

Habitat restoration funded by the WSIP and WFIP restoration initiatives occurs within floodplain and off-channel areas of the Willamette River, which poses many challenges for assessing restoration effectiveness at sites located along a large, regulated river. Although Willamette River restoration sites are large (tens to hundreds of hectares), they comprise a small portion of the river corridor, and there is considerable diversity in their seasonally varying habitat conditions and fish communities. Also, many monitoring activities developed for small streams are either not suitable or require substantial adaptation to implement affordably along the Willamette River floodplains and off-channel sites, which can encompass wide, deep waterbodies (such as former gravel pits or large side channels). Additionally, the goals and resources for Willamette River effectiveness monitoring programs are modest compared with other large-scale restoration programs in the Columbia River Basin. Hence, a monitoring framework that reflects the unique conditions of the Willamette River floodplain and the goals and resources of the WFIP restoration initiative is needed.

Purpose and Scope

The purpose of this monitoring framework is to inform data collection for the WFIP Effectiveness Monitoring Program. The monitoring framework describes monitoring indicators, metrics, and approaches for evaluating responses in Willamette River fish communities and physical habitat conditions to restoration activities and determining effectiveness of those activities at improving habitats for native fish. Monitoring activities in this framework focus on data collection that can occur within 1–5 years following restoration project implementation but recognize that many of the restoration benefits may not be realized for decades. Monitoring partners will use the framework when planning annual monitoring activities and will select from the framework a limited set of monitoring indicators and approaches that best reflect the types of restoration activities implemented, site conditions, available funding, and other factors. As such, this monitoring framework provides a common science foundation to support ongoing, collaborative decision making on future monitoring activities for the WFIP Effectiveness Monitoring Program.

The monitoring framework was developed specifically for restoration activities supported by the WFIP restoration initiative along the Willamette River between Willamette Falls and the Middle Fork Willamette River (northwestern Oregon; fig. A1); although, this framework can also inform effectiveness monitoring efforts for other restoration programs on the Willamette River or other large, regulated rivers where similar types of restoration activities are implemented to improve fish habitat. This framework recognizes future monitoring activities, especially those for different restoration programs with goals distinct from the WFIP, will depend on the specific questions being asked by restoration program managers and practitioners, the resources available to answer those questions, and other factors; hence, the monitoring metrics and approaches used to quantify indicators are provided as examples that can be refined to fit program needs.

This report synthesizes three key elements necessary for planning effectiveness monitoring activities: (A) Willamette River floodplain conditions where restoration and monitoring occur (this chapter, appendix 1), (B) summary of goals and activities of Willamette River restoration programs (this chapter, appendixes 1 and 2), and (C) description of monitoring indicators and approaches for evaluating whether restoration activities are meeting program goals (chaps. B–F; appendixes 3 and 4). Effectiveness monitoring is summarized in five sections reflecting the distinct monitoring activities necessary for evaluating different ecological and physical responses to restoration (fig. A2):

1. Responses of fish communities and their food resources to Willamette River restoration activities (chap. B),

2. Hydrogeomorphic and water temperature responses to restoration activities that directly modify hydrogeomorphic processes (chap. C),

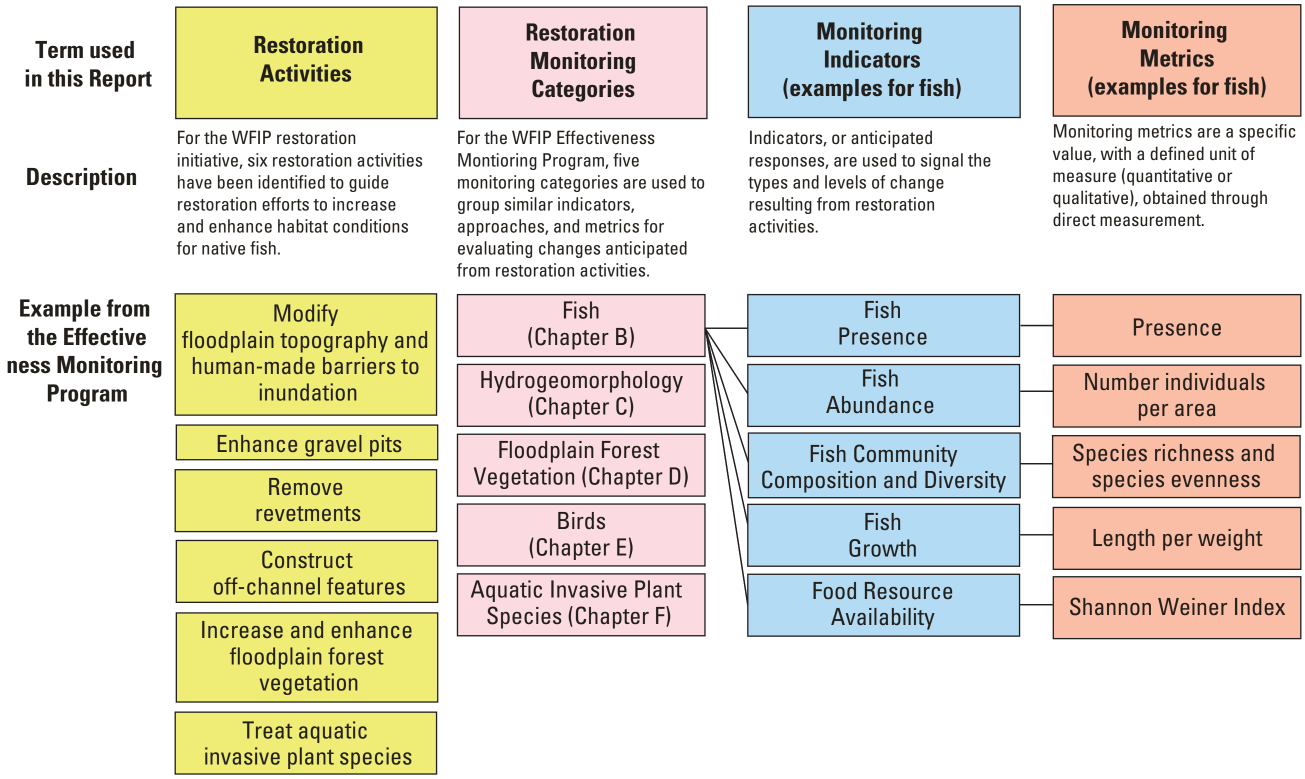

Figure A2. Linkages between six Willamette Focused Investment Partnership (WFIP) restoration activities to monitoring categories outlined for this Monitoring Framework. Examples of indicators and metrics are shown for the fish monitoring category. Restoration activities modified from the eight WFIP 'Strategic Actions,' Anchor Habitat Working Group (AHWG), 2015; Oregon Watershed Enhancement Board (OWEB), 2019.

3. Floodplain vegetation and inundation responses to floodplain forest restoration activities (chap. D),
4. Responses of avian communities to floodplain forest vegetation activities (chap. E), and
5. Aquatic vegetation, dissolved oxygen, and substrate responses to restoration activities that treat aquatic invasive plants (chap. F).

Monitoring native fish communities and their food resources is needed to evaluate whether restoration activities are effective at supporting restoration goals for sustaining and enhancing seasonally important habitats for native fish (AHWG, 2015). However, monitoring changes in physical habitat conditions (by assessing hydrogeomorphology, floodplain vegetation, aquatic vegetation, and water quality) is more informative of the changes in habitat conditions that are important for fish and may be more logistically feasible than fish monitoring. Monitoring avian communities supplements floodplain vegetation monitoring to efficiently assess the composition of floodplain plant communities and illustrate restoration effectiveness at improving habitat conditions for wildlife other than fish.

Willamette River Restoration Program Area

The Willamette River drains 28,800 square kilometers (km^2) in northwestern Oregon before joining the Columbia River near Portland, Oregon (north of map area shown in fig. A1). The main-stem Willamette River flows northward 300 kilometers (km) from the confluence of the Middle Fork Willamette and Coast Fork Willamette Rivers near Eugene, Oregon. Major tributaries draining the Cascade Range, including the McKenzie (3,450 km^2), Santiam (4,660 km^2), and Clackamas Rivers (2,450 km^2), contribute to Willamette River streamflow. More than two-thirds of Oregon's human population lives in the Willamette River Basin, and the Basin includes the three largest cities in the State (Portland, Salem, and Eugene; fig. A1). This monitoring framework focuses on the Willamette River floodplain and active channel areas encompassed by the WFIP restoration initiative upstream from Willamette Falls near Oregon City, Oregon (fig. A1).

Streamflow, Stream Temperature, and Dissolved Oxygen of the Willamette River Main-Stem and Off-Channel Areas

The Willamette Valley has a Mediterranean climate (Beck and others, 2018) with cool, wet winters and warm, dry summers. The valley floor receives 1,000 millimeters per year (mm/yr) of precipitation, primarily as rainfall during the winter (Oregon State University, 2013). Peak streamflows typically occur in winter months and are regulated by 13 dams (owned by the USACE and fully operational by 1970; table A1) located in tributary basins (7 dams shown in fig. A1). Streamflows are measured throughout the Willamette River Basin at numerous gages; nine active U.S. Geological Survey (USGS) gages along the Willamette, Middle Fork Willamette, and Luckiamute Rivers are located within the WFIP restoration initiative area (fig. A1; table A1).

During winter months, peak streamflows are captured in USACE flood-control reservoirs to minimize flood risk to downstream communities, and reservoirs are evacuated between storms to accommodate future high-streamflow events. In spring, reservoirs begin filling to provide water to use in summer low-streamflow months. From April 1 to October 31, streamflows in the Willamette River are managed to meet or exceed minimum streamflows established for ESA-listed spring-run Chinook salmon and winter-run steelhead (termed ‘main-stem flow objectives’ by NMFS, 2008; table A2). The main-stem flow objectives for maximum evacuation releases (table A2) are locally referred to as ‘bankfull flows’ but were developed based on flood damage criteria and do not reflect geomorphic definition of a ‘bankfull’ (Leopold and others, 1964; Andrews, 1983, 1984). In most years, Willamette River streamflows in April through May exceeded bankfull main-stem flow objectives at Albany and Salem (fig. A3) due to streamflows that enter the Willamette River from unregulated tributaries. By June in most years, tributary inputs are minimal as spring snowmelt and spring storms diminish and streamflows in the Willamette River primarily reflect upstream releases of stored water from USACE dams (fig. A3). In the period following the implementation of the main-stem flow objectives (water years 2009–19), median daily streamflows at the Albany and Salem gages for January, February, and March were about three times greater than low streamflow for July, August, and September for the same period (table A2).

In addition to main-stem flow objectives, several streamflow reference conditions are useful for characterizing and anticipating high flood streamflows at floodplain restoration sites and have been defined for multiple sites along the Willamette River (table A2). For example, the National Weather Service (NWS) categorizes flood severity into different levels (action, minor flood, moderate flood, and major flood) according to factors such as inundation extent, likelihood for public evacuation, and property damage stages (NWS, 2019; table A2). Peak streamflows are useful references, especially the recent flood of 2019 that affected many of floodplain restoration sites along the Willamette River. The largest floods of the post-dam era have occurred in 1972, 1996–97, 2012, and 2019 (USGS, 2020). Additionally, the statistical frequency of peak streamflow events since the Willamette River has been fully regulated by upstream dams (beginning in 1970) also are useful references for floodplain restoration sites. The 50-percent annual exceedance probability event (AEP, sometimes referred to as the 2-year recurrence interval [RI]; table A2) is a commonly used reference for flooding in the Willamette River. For comparison at Salem, the NWS defines a major flood as 202,000 cubic feet per second (ft^3/s), the greatest peak streamflow on record during 1996–97 flood event was 244,000 ft^3/s (approximately 1-percent AEP for the post-dam era), the peak discharge in water year 2012 was 170,000 ft^3/s (approximately 10 percent AEP for the post-dam era), and the 50-percent AEP flood for the post-dam era is 105,000 ft^3/s (Adam Stonewall, U.S. Geological Survey, written commun., June 26, 2019; table A2).

Stream temperatures in the Willamette River also vary seasonally and longitudinally, responding to seasonal and spatial variation in the heat budget, including climatic controls, streamflow volume, reservoir releases, and other factors that influence the local heat budget (Poole and Berman, 2001; Caissie, 2006). With some interannual variation, stream temperatures tend to be coolest in the beginning of January and warmest in late July or early August. In general, the river tends to warm downstream during spring and summer (fig. A4) with exposure to surface heating, although the export of heat stored in the surface water of upstream reservoirs complicates this dynamic.

In contrast with conditions in the main channel of the Willamette River, which tends to be isothermal locally and to warm downstream, water temperatures in off-channel features are spatially and temporally variable (Gregory and others, 2019; Smith and others, 2020). Where isolated from an upstream connection with the main stem, off-channel features may thermally stratify and can be warmer or cooler than the main stem or be laterally variable. Water-temperature variation in off-channel features reflects many factors including hydraulic connectivity with main channel, subsurface inputs from hyporheic or groundwater sources, shading from trees or dense aquatic vegetation, width to depth ratios, or other factors (Smith and others, 2020; Stratton Garvin and others, 2022). For example, vegetative cover blocks solar radiation, a large component of the heat budget, from reaching and heating the water. As a result, well-shaded channel segments tend to be cooler than reaches exposed to full sun (Johnson, 2004; Wondzell and others, 2019). Because the Willamette River main channel and many of its side channels are wide and well mixed (Gombert, 2018), shade is likely to be more effective in off-channel areas where streamflow is not well mixed and shade (from aquatic vegetation or trees) effectively blocks a substantial portion of the water body.

Table A1. Streamflow and stream temperature gages along the Willamette, Middle Fork Willamette, and Luckiamute Rivers, northwestern Oregon, that can be used to evaluate conditions within the Willamette Focused Investment Partnership restoration initiative area (U.S. Geological Survey [USGS], 2020).

[Location of WFIP restoration initiative area is shown in figure A1. Only currently (2020) active U.S. Geological Survey gages are listed. Historical data may be available. Parameters in addition to discharge and temperature also may be available for some gages. Parameters measured: Q, discharge; T, temperature. Parameters in addition to streamflow (Q) and temperature (T) could be measured at sites but are not listed here. FPKM: floodplain kilometer from SLICES database. Latitude/longitude: reference datum is the North American Datum of 1927 for all gage locations except for 14158100 and 14171600, which are referenced to the North American Datum of 1983. Date fully regulated: date is the year in which streamflow was fully regulated by upstream flood control damns. Abbreviations: NA, not applicable]

Gage number	Gage name	Parameters measured	Status	River mile	FPKM	Latitude	Longitude	Drainage area, in square kilometers	Discharge begin date	Temperature begin date	Date fully regulated
14152000	Middle Fork Willamette River at Jasper	Q, T	Active	195	NA	43°59'54"	122°54'17"	3,470	Sept. 1, 1905	Oct. 5, 2000	1967
14158100	Willamette River at Owosso Bridge, at Eugene	T	Active	178.8	219.7	44°05'30"	123°06'58"	5,310	NA	Nov. 9, 2010	1967
14166000	Willamette River at Harrisburg	Q, T	Active	161	199.3	44°16'14"	123°10'21"	8,860	Oct. 1, 1944	Oct. 4, 2000	1970
14171600	Willamette River at Corvallis	Q	Active	131.4	165.6	44°33'58.9"	123°15'24.5"	11,400	Oct. 1, 2009	NA	1970
14174000	Willamette River at Albany	Q, T	Active	119.4	151.8	44°38'20"	123°06'20"	12,500	Nov. 1, 1892	Aug. 10, 2001	1970
14190500	Luckiamute River near Suver	Q	Active	13.4	NA	44°47'00"	123°14'00"	620	Aug. 1, 1905	NA	1970
14191000	Willamette River at Salem	Q	Active	84.1	110.8	44°56'40"	123°02'30"	18,900	Oct. 1, 1909	NA	1970
14192015	Willamette River at Keizer	T	Active	82	107.5	44°58'26"	123°02'10"	18,900	NA	Oct. 25, 2000	1970
14197900	Willamette River at Newberg	Q, T	Active	50	72	45°17'05"	122°57'37"	21,600	Oct. 1, 2001	Oct. 18, 2001	1970

Table A2. Summary of streamflow and stream temperature conditions at gages along the Willamette, Middle Fork Willamette, and Luckiamute Rivers, northwestern Oregon, water years 2009–19 (U.S. Geological Survey [USGS], 2020).

[Reference conditions for regulated period: Calculated by Adam Stonewall, U.S. Geological Survey; based on post-regulation data (1970 for the Willamette River, and 1967 for the Middle Fork Willamette River through water year 2018). Minimum main-stem flow objective: minimum instantaneous streamflow specified in the Biological Opinion (BiOp) for Salem and Albany varies during spring and summer; only the minimum value (and associated time period) is reported here; see table 2-4 in National Marine Fisheries Service (NMFS), 2008, for seasonally varying minimum streamflows. Bankfull main-stem flow objective: From table 2-4 in BiOp (NMFS, 2008). Major flood defined by National Weather Service: major flood defined in terms of inundation extent and likelihood for substantial public evaluation National Weather Service [NWS], 2019). NWS flood stage levels available at https://water.weather.gov/. Total number of days that the 7-day mean of the daily maximum exceeds 20 °C and equals or exceeds 24 °C: Oregon Department of Environmental Quality 18 °C water temperature criteria; ≥25 °C for juvenile spring-run Chinook salmon mortality for data summarized from Brett and others (1982), McCullough (1999), Marine and Cech, (2004), and Perry and others (2015), see table A3. Abbreviations: NA, not applicable; °C, degrees Celsius; ft^3/s, cubic feet per second]

Gage number	Gage name	Reference conditions for regulated period				Streamflow and stream temperature summary metrics for water years 2009–19						
		Main-stem flow objective (ft^3/s)		Major flood defined by National Weather Service	50-percent annual exceedance probability for fully regulated period	Number of days exceeding 2-year recurrence interval for regulated period	Peak streamflow (ft^3/s)		Median daily mean streamflow for low-flow months (July, Aug., Sept.; ft^3/s)	Median streamflow for high-flow months (Jan., Feb., Mar.; ft^3/s)	Total number of days that the 7-day mean of the daily maximum water temperature	
		Minimum	Bankfull				Discharge (ft^3/s)	Date			Exceeds 20 °C	Equals or exceeds 24 °C
14152000	Middle Fork Willamette River at Jasper	NA	20,000	NA	17,310	31	24,400	Apr. 12, 2019	2,405	3,350	141	0
14158100	Willamette River at Owosso Bridge, at Eugene	NA	NA	94,300	NA	NA	NA	NA	NA	NA	165	0
14166000	Willamette River at Harrisburg	NA	42,000	100,000	55,040	13	78,500	Apr. 9, 2019	5,050	11,800	171	0
14171600	Willamette River at Corvallis	NA	NA	132,000	NA	NA	99,000	Apr. 10, 2019	5,270	14,200	NA	NA
14174000	Willamette River at Albany	4,500	70,000	153,000	64,430	17	99,200	Apr. 10, 2019	5,325	15,700	469	0
14190500	Luckiamute River near Suver	NA	NA	NA	NA	NA	31,100	Jan. 19, 2012	44	1,170	NA	NA
14191000	Willamette River at Salem	6,000	90,000	202,000	104,900	26	170,000	Jan. 20, 2012	7,790	26,800	NA	NA
14192015	Willamette River at Keizer	NA	NA	NA	NA	NA	NA	NA	NA	NA	671	52
14197900	Willamette River at Newberg	NA	NA	NA	NA	NA	175,000	Jan. 22, 2012	7,750	32,000	687	55

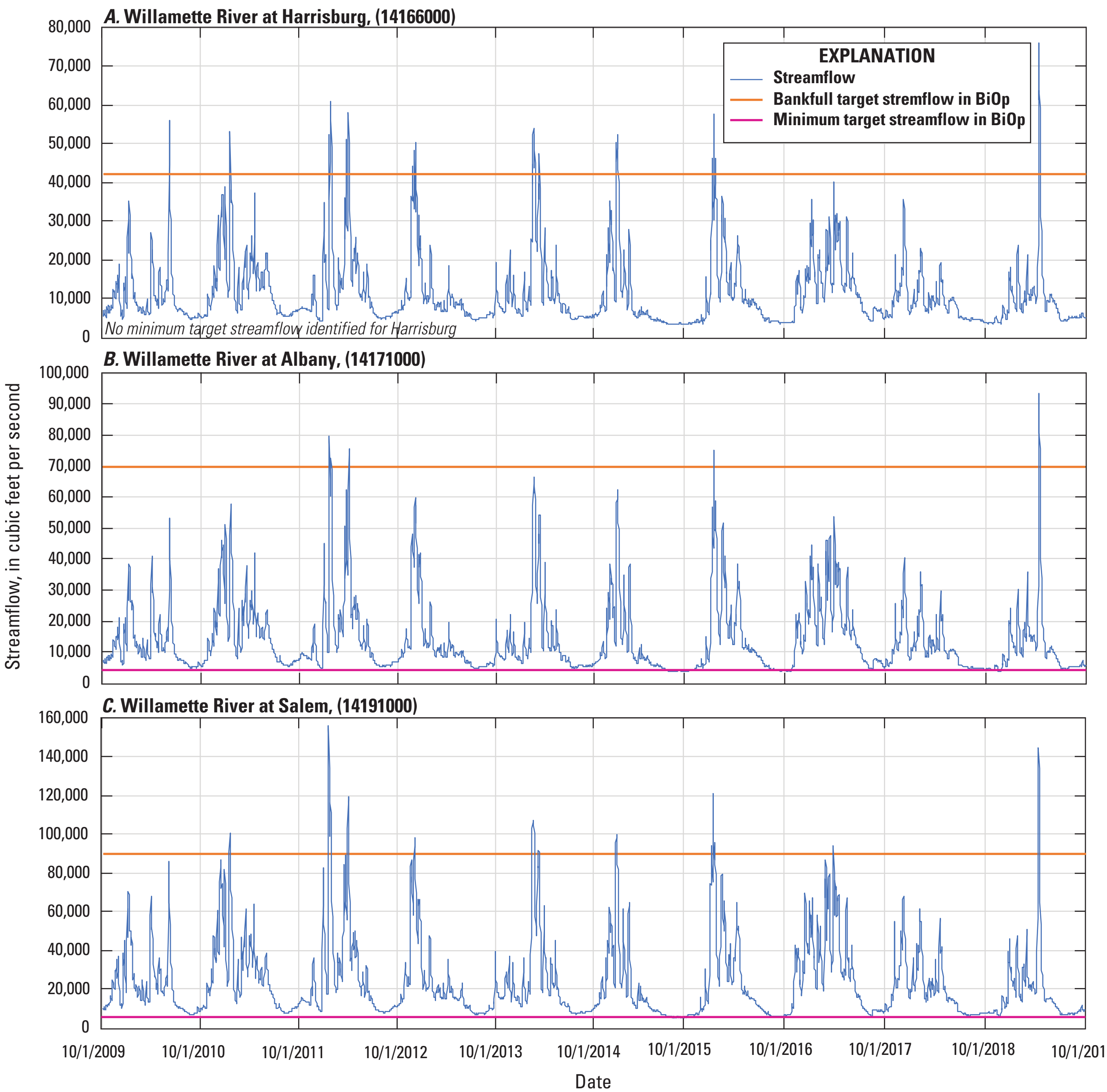

Figure A3. Mean daily streamflows for water years 2010–19 at U.S. Geological Survey gages (USGS, 2020) along the Willamette River at Harrisburg (*A*), Albany (*B*), and Salem (*C*) including bankfull and minimum streamflows listed in the Willamette Valley Project Biological Opinion (BiOp; see table 2-8 of National Marine Fisheries Service [NMFS], 2008).

Dissolved oxygen (DO) is not systematically measured along the Willamette River and its off-channel features but was measured at select sites within the main channel and off-channel features in 2015 and 2016 (Smith and others, 2020). These data showed that the main channel is well mixed with high DO concentrations (often greater than 7 milligrams per liter [mg/L]); in comparison, off-channel areas, especially those with thermal stratification, can have local areas of low DO (hypoxic or anoxic), in deeper areas of the water column (Smith and others, 2020). Overall, DO conditions can be highly variable vertically and spatially in off-channel features depending on many factors such as streamflow, hydraulic connectivity with the main channel, stream temperature, presence of fine sediments, and aquatic vegetation (see chap. F; Smith and others, 2020).

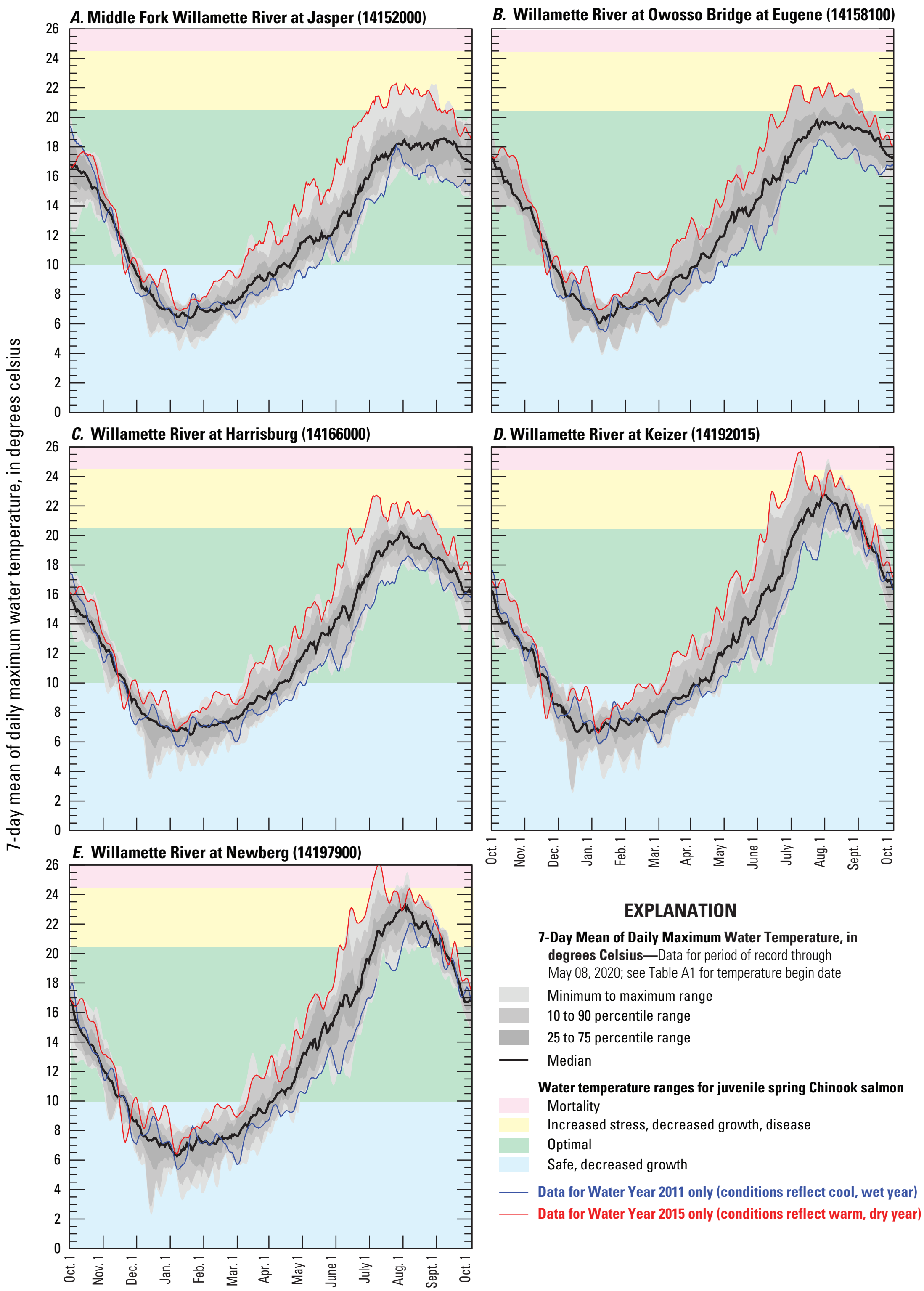

Figure A4. Summary of water temperature conditions for water years 2000–19 at gages along the Middle Fork Willamette and Willamette Rivers at Jasper (*A*), Eugene (*B*), Harrisburg (*C*), Keizer (*D*), and Newberg (*E*), Oregon, including water temperature ranges for juvenile spring-run Chinook salmon rearing conditions (water temperature range information summarized from numerous sources including Brett and others, 1982; McCullough, 1999; Marine and Cech, 2004; and Perry and others, 2015, as summarized in table A3; stream temperature data from U.S. Geological Survey [USGS], 2020). Data are the 7-day mean of daily maximum water temperatures for water years (WY) 2001–20 (partial data for WY 2020) with percentiles, as well as the 7-day mean daily water temperature for representative warm (WY 2015) and cool (WY 2011) years.

Water Temperature and Dissolved Oxygen Considerations for Native Fish

Fish habitat availability is directly influenced by environmental factors such as streamflow, water depth, water velocity, water temperature (temperature; table A3), DO (table A4), and hydraulic connectivity. Individually or in combination, these variables can restrict the survival, health, growth, and distribution of native fish and can be considered limiting factors. Thresholds of thermal conditions and their effect on fish reflect inputs from multiple research studies and are intended to capture anticipated effects across taxa (for example, McCullough, 1999; U.S. Environmental Protection Agency [EPA], 2003). Likewise, DO criteria used for regulatory purposes (table A4; Oregon Department of Environmental Quality [ODEQ], 2019) reflect diverse scientific studies and are intended to capture critical threshold conditions. Water temperature and DO thresholds for native fish are described here to provide useful context when assessing the monitoring data and metrics described later in this report.

Willamette River temperature conditions often exceed thresholds that may be harmful, or in some cases lethal, to native fish (Brett and others, 1982; McCullough, 1999; Marine and Cech, 2004; and Perry and others, 2015 in table A3). The effects of water temperature on fish vary with biotic and abiotic factors, including species, life stage, food resource availability, or magnitude and duration of stressful temperatures. Water temperature thresholds provide a useful framework for considering the effects of Willamette River temperature conditions on native fish. Criteria to support aquatic ecosystems in the State of Oregon are defined based on the 7-day mean (or average) of the daily maximum (7dADMax; ODEQ, 2019) although maximum thermal conditions also may be relevant to consider (EPA, 2003). Water temperature thresholds for spring-run Chinook salmon that rear in the Willamette River (as juveniles) and migrate upstream (as adults) are summarized in table A3. Willamette River temperatures in summer months range from optimal to suboptimal for juvenile spring-run Chinook salmon with frequency and duration of these warm periods increasing downstream (table A2; fig. A4). Over

Table A3. Summary of water temperature thresholds for juvenile and adult spring-run Chinook salmon, Oregon.

[Summarized from numerous sources including Brett and others (1982), McCullough (1999), Marine and Cech (2004), Perry and others (2015), and White and others (2022). Abbreviations: °C, degrees Celsius; ≥, greater than or equal to; <, less than]

Juvenile rearing and growth		Adult migration	
Temperature range (°C)	**Effects on fish**	**Temperature range (°C)**	**Effects on fish**
≥ 24.1	Mortality	≥ 23.1	Mortality
20.1–24.0	Sub-optimal due to increased stress, decreased growth and potential for disease	19.1–23.0	Migration impaired
10.1–20.0	Optimal	12.1–19.0	Optimal
≤10.0	Safe, but decreased growth	≤12.0	Safe, preferred for spawning

Table A4. Dissolved oxygen criteria for cool-, cold-, and warm-water designated waters, Oregon.

[Table modified from Oregon Department of Environmental Quality ([ODEQ], 2019). Abbreviation: mg/L, milligram per liter; –, no data]

General classes of aquatic life	30-day mean minimum (mg/L)	7-day mean minimum (mg/L)	7-day minimum mean (mg/L)	Absolute minimum (mg/L)
Salmonid spawning	–	[1,2]11	–	[2]9.0, [3]8.0
Cold water	[4]8.0	–	6.5	6
Cool water	6.5	–	5	4
Warm water	5.5	–	–	4

[1]When intergravel DO concentrations are 8.0 mg/L or greater, DO concentrations may be as low as 9.0 mg/L, without triggering a violation.

[2]If conditions of barometric pressure, altitude and water temperature preclude achievement of the footnoted criteria, then 95-percent saturation applies.

[3]Intergravel DO criterion, spatial median minimum.

[4]If conditions of barometric pressure, altitude, and water temperature preclude achievement of 8.0 mg/L, then DO may not be less than 90 percent of saturation.

the water years 2009–19 period, the 7dADMax exceeded suboptimal conditions for juvenile Chinook salmon 141 days at Jasper and 687 days at Newberg (table A2). Whereas periods of lethal water temperatures for juvenile spring-run Chinook salmon are rare at sites in the upstream part of the restoration program area (Jasper, Eugene, Harrisburg, Albany), occasional periods of potentially lethal water temperature conditions occur at downstream sites (Keizer and Newberg; table A2; fig. A4). Long sections of the Willamette River between Corvallis and Newberg (fig. A1) that potentially host lethal thermal conditions also lack abundant cold-water refuges (Smith and others, 2020), which can result in stress and mortality of cold-water fish like juvenile spring-run Chinook salmon (fig. A4; table A2).

Different minimum concentrations of DO are required to support aquatic life depending on the type of organism. The State of Oregon has adopted criteria for different minimum DO concentrations for different locations and times of the year to protect cold-, cool-, and warm-water aquatic life (ODEQ, 2019; table A4). Much of the Willamette River is designated as cold-water habitat from May 15 to October 15 with a DO criterion of 8 mg/L. During the rest of the year, the Willamette River is designated for salmon and steelhead spawning use, which warrants a higher DO criterion of 11 mg/L, even though the vast majority of salmon and steelhead spawning occurs in tributaries of the Willamette River, especially those draining the Cascade Range. Within those spawning reaches, DO can be variable, especially immediately downstream from USACE dams (NMFS, 2008), and impacts of DO on spawning success vary with life stage, water temperature and other factors. In general, Chinook salmon juveniles that emerged from eggs that experienced low DO (less than 4.0 mg/L) and moderate to high thermal conditions (greater than 15°C) have greater frequency of deformity and delayed growth to emergence timing than eggs that experience high concentrations of DO (Geist and others, 2006) and similar observations also have been documented in other fish species (Davis, 1975).

Restoration activities seek to address limiting factors through activities such as replacing fish passage structures that hinder access to high-quality habitats or improving poor water-quality conditions. Additionally, other factors such as the presence of non-native fish have been shown to indirectly affect native fish through predation and competition (Henning and others, 2006; Baker, 2008; Matella and Merenlender, 2015).

Geomorphology of the Willamette River Floodplain

The Willamette River and its floodplain have undergone substantial transformations in the last 170 years (Sedell and Froggatt, 1984; Hulse and others, 2002; Wallick and others, 2013; Gregory and others, 2019). Prior to Euro-American settlement, the Willamette River between Eugene and Corvallis was a multi-thread channel evolving by frequent avulsions and rapid meander migration and was flanked by a nearly continuous swath of large expansive gravel bars whereas the Willamette River from Corvallis to Newberg was predominantly a single-thread channel evolving by meander migration, and flanked by intermittent, but still large gravel bars. Maps from the 1850s show that much of the historical floodplain was forested and characterized by diverse stands of vegetation created by annual flooding (Hulse and others, 2002). Plant litter and downed trees in floodplain areas provided the river with large inputs of organic material, and the formerly higher water table sustained thousands of hectares of wetlands and shrub scrub habitats along the river (Sedell and Froggatt, 1984). By the 1970s, however, construction of flood-control dams, wide-spread bank stabilization, large-wood removal, navigation-related modifications, instream-gravel extraction, conversion of floodplain forests to agriculture, and other alterations had changed the streamflow, sediment, and large-wood regimes of the Willamette River. As a consequence of these altered floodplain processes, the Willamette River presently occupies a narrower floodplain corridor, and is more laterally stable, with decreased rates of meander migration and avulsions, and a reduced number and diversity of landform features such as gravel bars, islands, and side channels (Hulse and others, 2002; Wallick and others, 2007).

The restoration activities and monitoring approaches described in this report focus on geomorphic features within the active channel and floodplain areas of the Willamette River (fig. A5). The characteristics and abundance of floodplain and active channel features varies longitudinally along the Willamette River with geologic controls and historical transformations. Between Eugene and Corvallis, the river presently occupies a predominantly single-thread channel with occasional multi-threaded sections that are flanked by low-elevation floodplains rising 1–2 m above the low-streamflow channel and frequent side-channels and gravel bars. In contrast, the Willamette River between Corvallis and Newberg is presently a single-thread, sinuous channel with floodplains rising 2–5 m above the low-streamflow channel and fewer side channels and gravel bars are present (fig. A6; Gregory, Ashkenas, Oetter, Minear, and others, 2002; Wallick and others, 2013). More complete descriptions of Willamette River active channel and floodplain geomorphology are provided in Wallick and others (2013), and key terms are summarized in the appendix 1. Aspects of the Willamette River floodplain and active channel features most relevant to restoration and monitoring activities are described here.

- Geomorphic floodplain—The Willamette River geomorphic floodplain (Wallick and others, 2013) represents the area formed by floodplain processes active over the last 10,000 years and includes areas inundated by large, historical floods prior to dam construction.

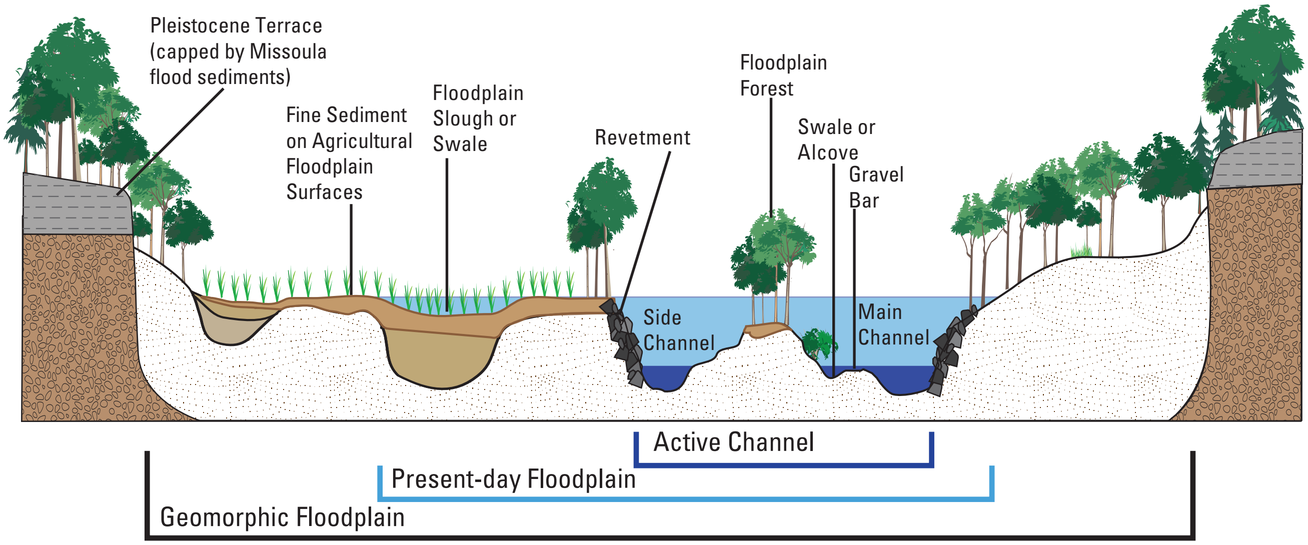

Figure A5. The Willamette River floodplain including surfaces and features targeted for Willamette River restoration activities such as the present-day floodplain and active channel.

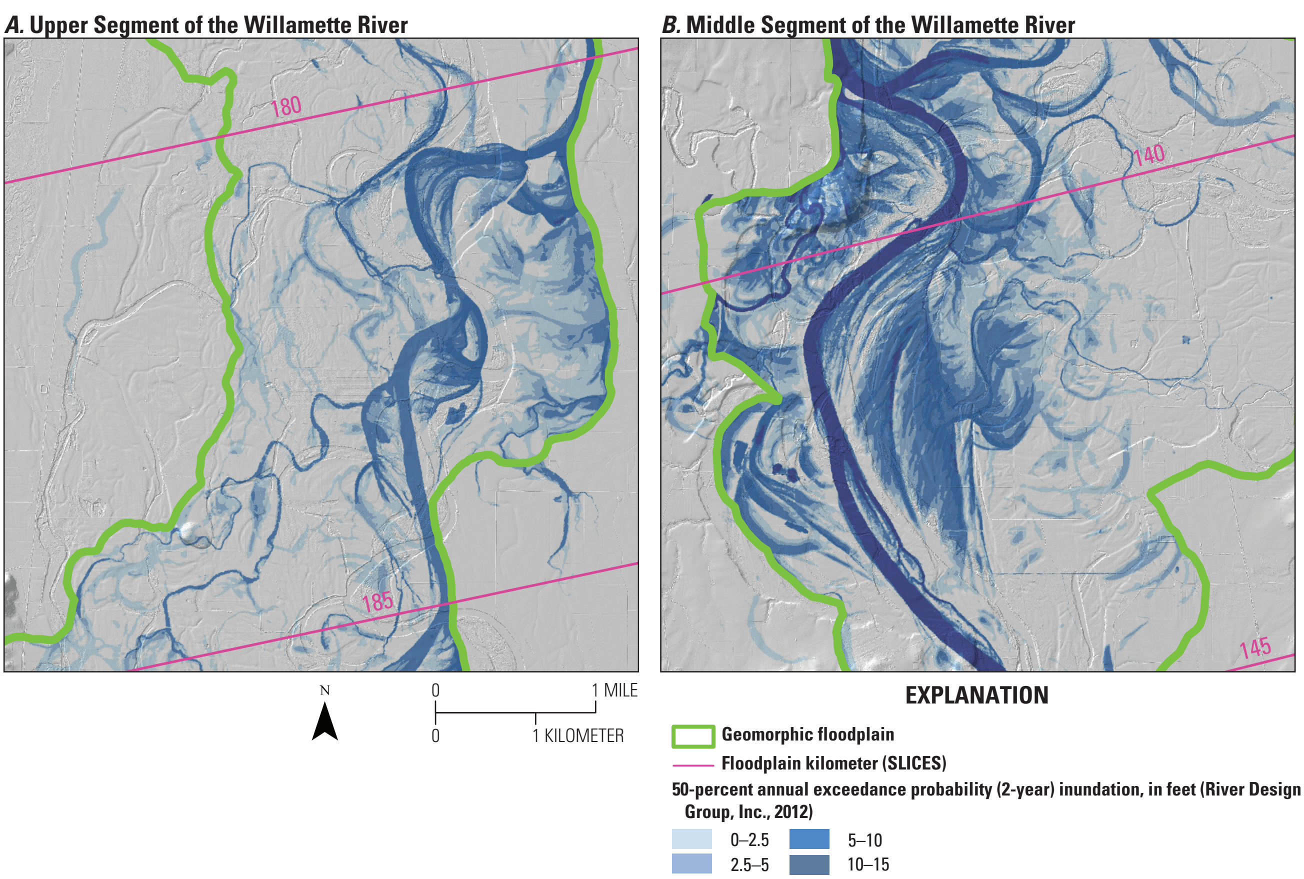

Figure A6. Depth of inundation at the 50-percent annual exceedance probability (2-year) inundation (River Design Group, Inc., 2012) of the upper (*A*) and middle (*B*) segments of the Willamette River displaying differences in floodplain and channel conditions.

- Present-day floodplain—The present-day floodplain represents the portion of the geomorphic floodplain that still evolves by occasional overbank inundation and fine sediment accumulation despite regulation from upstream flood control dams. There is no distinct outer boundary for the present-day floodplain because the extent of inundation varies with streamflow. For this report, the term 'floodplain' is used to describe the present-day floodplain area that floods in the post-dam era, encompassing both the smaller, more frequent high-streamflow events (that may occur several times in typical winter) and larger, less frequently inundated areas that were inundated during floods of 1972, 1996, and 2019 (which are the largest events following dam construction).
- Active channel features (fig. A5)—The active channel of the Willamette River regularly conveys water and bed-material sediment (typically gravel and sand) on annual basis. The active channel is comprised of many features with diverse physical characteristics and ecological roles for aquatic, floodplain, and avian organisms (Landers and others, 2002):
    - Main channel of the Willamette River that conveys the majority of streamflow.
    - Off-channel features, which include the diverse array of side channels, alcoves, sloughs, and swales flanking the main channel. Off-channel features are a focus area for restoration activities because of substantial historical losses (summarized by Wallick and others, 2013; Gregory and others, 2019) and because they are logistically easier to enhance than the main channel of the Willamette River.
    - Gravel bars within or flanking the margins of the main channel and some of the larger and more frequently scoured off-channel features.
- Floodplain features (fig. A5)—Floodplain surfaces along the Willamette River typically are at higher elevations than the adjacent active channel and are covered with finer sediments (sand, silt, and clay) deposited through overbank deposition during high streamflows. The variety of landforms within floodplain surfaces can support refuges during high streamflows and food resources for native fish (Junk and others, 1989; Sommer and others, 2001; Colvin and others, 2009; Bellmore and others, 2013), as well as habitat for red-legged frogs (*Rana aurora*), Oregon chub (*Oregonichthys crameri*), migratory birds, and waterfowl (Gregory and others, 2007):
    - Off-channel features of the floodplain including sloughs, ponds, and swales that are relict features formed by fluvial processes and only hydraulically connected to the main channel during high streamflows as well as floodplain channels and small tributaries that are hydraulically connected to main channel during much of the year.
    - Floodplain landforms, including natural features such as natural levees (relatively high elevation sandy deposits near channel margins), and broad, planar surfaces, as well as human-made features, such as human-made berms and revetment constructed along margins of agricultural fields or other areas to prevent inundation.

Vegetation of the Willamette River Floodplain and Low-Streamflow Channel

Prior to Euro-American settlement of the Willamette Valley, the Willamette River floodplain supported a range of native forest and plant communities, which extended 1–3 km from each side of the river (Towle, 1974; Sedell and Froggatt, 1984; Gregory, Ashkenas, Haggerty, and others, 2002). By the 1930s, much of the historical floodplain and these diverse vegetation communities had been converted to agriculture and other land uses (for example, Gregory, Ashkenas, Haggerty, and others, 2002). Despite these historical transformations, the present-day Willamette River floodplain still retains many of the vegetation classes originally mapped in the 1850 General Land Office surveys, although the dominant type of native vegetation is floodplain forests. Stands of floodplain forest range from young, dense stands of primarily black cottonwood (*Populus trichocarpa)* and willow (*Salix spp*.) shrubs growing on gravel bars to mature, late successional forests of black cottonwood, bigleaf maple (*Acer macrophyllum*), Oregon ash (*Fraxinus latifolia*), and western red cedar (*Thuja plicata*) on floodplains (Gregory, Ashkenas, Haggerty, and others, 2002; Fierke and Kauffman, 2006; Wallick and others, 2013).

The network of side channels and swales bisecting the Willamette River floodplain contribute to spatial diversity in vegetation communities. Agricultural fields frequently alternate with narrow ribbons of forest that flank floodplain channels and are interspersed with wider patches of mature floodplain forests. Hence, the distinction between floodplain forest and riparian forest is often unclear, so the term 'floodplain forest' is used in this report to broadly describe the various spatial areas, successional stages and forest communities of the Willamette River floodplains, following the terminology of Opperman and others (2017, p. 59).

These floodplain forests provide habitats used in different seasons and across different life stages for native and anadromous fish. In summer, low streamflow months, forested areas flanking off-channel features and tributaries can provide shade, cover, and terrestrial food sources to aquatic communities. In high streamflow months of late autumn, winter, and spring, rising river levels incrementally inundate forested bars, then during flooding, agricultural fields, mature forests, and other land uses become inundated, carrying fish and other organisms, nutrients, and sediment onto the Willamette River floodplain (Colvin and others, 2009; Williams and Gregory, 2018).

Native and non-native aquatic plants are present in the active channel and floodplain of the Willamette River. Aquatic plants grow directly in inundated areas of the low-streamflow channel and perennially inundated floodplain features. These plants can be rooted in bottom sediments and grow above the water surface (emergent), rooted and float on the water surface (floating leaf and floating mat), or can be rooted or unrooted below the water surface (submerged; fig. A7). Native aquatic plants common in Willamette River habitats include emergent aquatic plant species Wapato (*Sagittaria latifolia*) and European bur-reed (*Sparganium emersum*), the floating leaf species yellow pond lily (*Nuphar polysepala*), and watershield (*Brasenia schreberi*), and the submerged species Canadian waterweed (*Elodea canadensis*) and Richardson's pondweed (*Potamogeton richardsonii*). The diversity and abundance of these native plants is threatened by excessive growth of non-native, invasive aquatic plants, particularly emergent floating mat species Uruguayan water primrose (*Ludwigia hexapetala*; fig. A8) and floating primrose-willow (*L. peploides*) and the floating leaf species yellow floating heart (*Nymphoides peltata*; fig. A7). Water primroses (*Ludwiga spp.*) arrived in the Willamette River through the aquarium trade as early as the 1940s and have recently expanded to dominate substantial portions of the Willamette River's slow water areas.

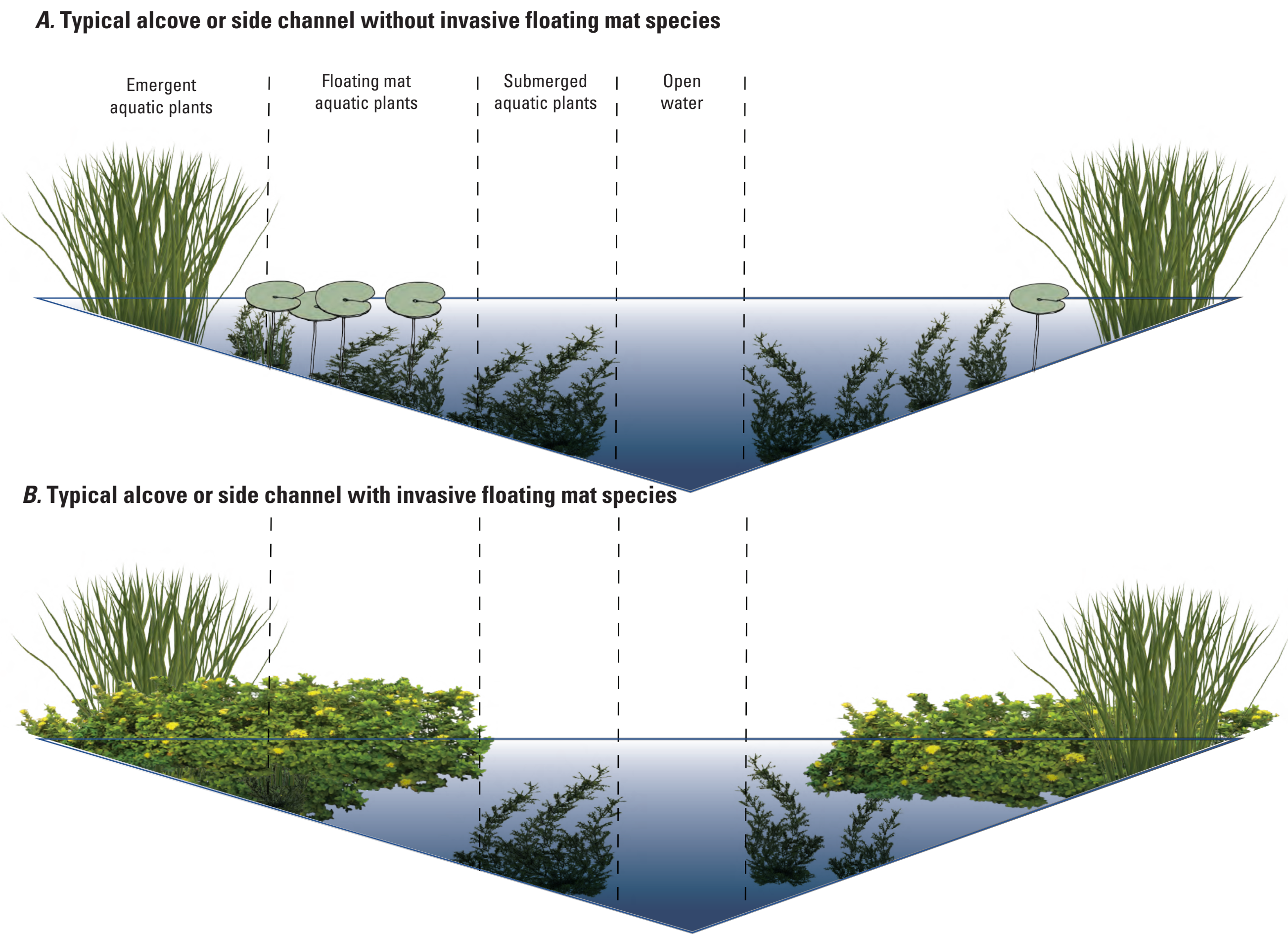

Figure A7. A typical cross section of a Willamette River off-channel area (alcove or side channel) showing a transition with depth from emergent plants, to floating leaf and floating mat plants, to submerged plants, to open water for areas without (*A*) and with (*B*) aquatic invasive plant species (water primrose [*Ludwigia* spp.]).

Figure A8. Photograph showing emergent floating mat species Uruguayan water primrose (*Ludwigia hexapetala*) in bloom. Photograph by C. Durbecq, Benton Soil and Water Conservation District, July 7, 2014.

Fish and Wildlife of the Willamette River Floodplain

Native Fish

The Willamette River Basin supports a complex fish community comprised of at least 34 native species (Williams, 2014; Williams and others, 2022). Distributions of native and non-native fish species vary seasonally and within the river network and are shaped by physical factors (such as water temperature, depth, and velocity), biological factors (such as competition with other species, predation, and available food resources), and species-specific traits (such as body morphology, feeding strategy, physical tolerances, and life-stage; Williams, 2014). Fish habitat in the Willamette River can be generally classified according to the geomorphic units of this report: main channel, off-channel areas, and seasonally inundated floodplains (table A5; Williams and others, 2022). Most native fish species, such as largescale sucker (*Catostomus macrocheilus*) and northern pikeminnow (*Ptychocheilus oregonensis*), use both main channel and off-channel features for habitat. A small subset of native species relies on specific habitats; for example, mountain whitefish (*Prosopium williamsoni*) and Paiute sculpin (*Cottus beldingii*) prefer sites with swift water and low amounts of fine sediments and macrophytes (Williams, 2014). Redside shiner (*Richardsonius balteatus*), three-spine stickleback (*Gasterosteus aculeatus*), northern pikeminnow, largescale sucker, reticulate sculpin (*Cottus perplexus*), and speckled dace (*Rhinichthys osculus*) are the most common non-salmonid fish species found in seasonally inundated floodplains (Colvin and others, 2009; Williams, 2014). In these same seasonally inundated floodplains, salmonid species included spring-run Chinook salmon and cutthroat trout (Colvin and others, 2009; Williams, 2014).

Table A5. General habitat types, benefits, and usage for general categories of native fish and examples of limiting factors.

[More detailed information on fish species, distributions, and diets is shown in Williams and others, 2022. Examples of detected native fish species: Summarized from Colvin and others (2009) and Williams (2014)]

Habitat type	Examples of detected native fish species	Limiting factors for native fish in summer and early autumn	Limiting factors for native fish in late autumn, winter, and early spring
Main channel	Spring-run Chinook salmon, steelhead/rainbow trout, cutthroat trout, white sturgeon, largescale suckers, northern pikeminnow, mountain whitefish, redside shiner, sculpins, lampreys, and threespine stickleback	Water temperatures can be suboptimal for cold and cool-water fish for several weeks (or longer) downstream from Albany with short periods of potentially lethal conditions. Non-native predators are most active in warm months particularly in the main channel downstream from Albany.	Swift water velocities and lack of cover can be limiting during moderate to high streamflows. Cool temperatures in winter can be suboptimal for growth conditions for juvenile Chinook salmon and other species.
Off-channel features	Cutthroat trout, largescale suckers, northern pikeminnow, mountain whitefish, redside shiner, sculpins, lampreys, and threespine stickleback	Water temperatures in off-channel features are highly variable. Some alcoves are fed by subsurface flows and cooler than main channel providing suitable conditions for cool and cold-water fish. Other features are much warmer than main channel and may have suboptimal to lethal conditions. Fish access to off-channel features depends on hydraulic connectivity to main channel and streamflows; stranding may be a concern for some features. Dissolved-oxygen concentrations may locally be harmful for native fish. Non-native predators are most active in warm months in the off-channel features particularly downstream from Albany.	The extent and availability of off-channel features vary with streamflow and hydraulic connectivity with main channel. Limiting factors include shallow water depths and swift water velocities that may limit egress and food availability. Cool temperatures can create suboptimal growth conditions for juvenile Chinook salmon and other species.
Seasonally inundated floodplains	Spring-run Chinook salmon, cutthroat trout, redside shiner, threespine stickleback, northern pikeminnow, largescale sucker, reticulate sculpin, speckled dace	Most floodplain areas are not inundated or not hydraulically connected to the main channel in summer months and only provide aquatic habitats to native fish in high streamflow months.	Access to floodplains depends on hydraulic connectivity with main channel and streamflow. Once inundated, factors that affect fish passage (such as water depths, water velocities, and water recession rates) are primary limitations. Cool temperatures can create suboptimal growth conditions for juvenile Chinook salmon and other species.

Current and Former ESA-Listed Fish

Upper Willamette River spring-run Chinook salmon and upper Willamette River winter-run steelhead, both listed as “threatened” under the U.S. Endangered Species Act (ESA; NMFS, 1999a, b), are anadromous fish species that depend on the Willamette River and its tributaries. Adults of both species migrate through the main-stem Willamette River when returning from the ocean to spawn in tributaries. Juvenile steelhead predominantly rear in tributaries before out-migrating to the ocean whereas spring-run Chinook salmon juveniles exhibit numerous rearing strategies including spending substantial time in the main-stem Willamette River (Schroeder and others, 2016). Thus, spring-run Chinook salmon require an array of rearing habitats throughout the year and are distributed along the river corridor where they display diverse life history strategies. Because of this life history diversity, rearing habitats have been identified as to key limitation to spring-run Chinook salmon recovery in the Willamette River (NMFS, 2008; Schroeder and others, 2016). For these reasons, many Willamette River restoration projects have focused on creating or enhancing habitat that can be used by juvenile spring-run Chinook salmon when rearing and migrating in the Willamette River.

In addition to anadromous ESA-listed fish species, the Willamette River also supports other native fish species of concern. Oregon chub, which were formerly an ESA listed species (U.S. Fish and Wildlife Service, 2015), prefer low-velocity habitats with abundant cover (typically provided by aquatic plants) where they can hide from predators (Bangs and others, 2011). Off-channel areas historically used by Oregon chub are abundant along the main-stem Willamette River, but as of 2020, Oregon chub had only been found in one of these sites (Bangs, 2020). Restoration activities that expand and enhance off-channel habitats potentially provide habitat that can be used by Oregon chub as their population increases and they expand their range in the Willamette River (AHWG, 2015).

Non-Native Fish

There are more than 28 non-native fish in the Willamette River that compete with (for habitats and food resources) or prey upon native fish in the basin (Gregory, Wildman, and others, 2002; Williams, 2014, Williams and others, 2022). Restoration monitoring should include considerations for non-native species (in addition to native species) to determine (1) fish community context at the restoration site, (2) if restoration activities have unanticipated consequences of bolstering non-native populations, and (3) if restoration effectiveness is affected by benefits to non-native fish. Non-native fish such as smallmouth bass (*Micropterus dolomeiu)*, largemouth bass (*Micropterus salmoides)*, various crappie (*Pomoxis* spp.), and sunfish (*Lepomis* spp.) species are found in the Willamette River (Williams, 2014) and pose a significant predatory threat to juvenile salmon, steelhead, and other native fish. The proportion of non-native fish species in the Willamette River increases downstream (Gregory, Wildman, and others, 2002), so restoration sites in the upper Willamette River may encounter different levels of competition and predation than restoration sites in the middle or lower Willamette River.

Other Wildlife

In addition to providing critical habitats for native resident fish and ESA-listed anadromous fish, the Willamette River floodplain also provides habitats used by a diverse array of other native wildlife. In recognition of the broader ecosystem benefits assumed to result from floodplain restoration actions, many Willamette River restoration projects consider the benefits for other wildlife, and restoration program plans cite non-fish wildlife as important beneficiaries of floodplain restoration (AHWG, 2015; BPA, 2016). Key organisms identified by the Oregon Conservation Strategy (Oregon Department of Fish and Wildlife [ODFW], 2016) for the Willamette River Ecoregion include reptiles, mussels, birds, amphibians, and mammals, as well as floral species. Western pond turtles (*Actinemys marmorata*), for example, have been observed using ponded floodplain habitats throughout the Willamette River. Mussels, such as the western pearlshell (*Margaritifera falcata*) and western ridged mussel (*Gonidea angulata*) use oxygenated areas with stable substrate (Nedeau and others, 2009) and have been found in alcoves and side channels within the active channel of the Willamette River. Invasive, non-native animals, such as shellfish (New Zealand mud snails [*Potamopyrgus antipodarum*] or Quagga mussels [*Dreissena bugensis*]), also are present throughout the Willamette River and can compete with native species (in this case, native aquatic invertebrates) and disrupt aquatic ecosystems. Several avian species associated with floodplain areas have large abundances along the main-stem Willamette River and tributaries, and others are common (table A6).

Table A6. Floodplain-associated avian species modified from Partners in Flight Conservation Strategy (Altman, 2000; Rockwell and others, 2022) for the main-stem Willamette River and tributaries.

[Floodplain association: highly associated—species reaches greatest abundance in this habitat; associated—species commonly found in floodplain areas. Focal species: species with an "X" are the focus of monitoring as indicators of specific floodplain habitat features (table E1); –, not a species with a focus for floodplain monitoring]

Common name	Species	Floodplain association	Focal species
Red-eyed vireo	*Vireo olivaceus*	Highly associated	–
Red-shouldered hawk	*Buteo lineatus*	Highly associated	–
Spotted sandpiper	*Actitis macularius*	Highly associated	X
Swainson's thrush	*Catharus ustulatus*	Highly associated	X
Willow flycatcher	*Empidonax traillii*	Highly associated	X
Yellow warbler	*Setophaga petechia*	Highly associated	X
Yellow-billed cuckoo	*Coccyzus americanus*	Highly associated	X
Yellow-breasted chat	*Icteria virens*	Highly associated	–
Belted kingfisher	*Megaceryle alcyon*	Highly associated	–
Black phoebe	*Sayornis nigricans*	Highly associated	–
Cedar waxwing	*Bombycilla cedrorum*	Highly associated	–
Common yellowthroat	*Geothlypis trichas*	Highly associated	–
Pacific-slope flycatcher	*Empidonax difficilis*	Highly associated	–
Song sparrow	*Melospiza melodia*	Highly associated	X
Warbling vireo	*Vireo gilvus*	Highly associated	X
Bullock's oriole	*Icterus bullockii*	Associated	X
Cooper's hawk	*Accipiter cooperii*	Associated	–
Downy woodpecker	*Dryobates pubescens*	Associated	X
Tree swallow	*Tachycineta bicolor*	Highly associated	X
Wrentit	*Chamaea fasciata*	Associated	–
Black-capped chickadee	*Poecile atricapillus*	Associated	X
Black-headed grosbeak	*Pheucticus melanocephalus*	Associated	X
Brown creeper	*Certhia americana*	Associated	X
Brown-headed cowbird	*Molothrus ater*	Associated	–
Bushtit	*Psaltriparus minimus*	Associated	–
Purple finch	*Haemorhous purpureus*	Associated	–
Purple martin	*Progne subis*	Associated	–
Rough-winged swallow	*Stelgidopteryx*	Associated	–
Rufous hummingbird	*Selasphorus rufus*	Associated	X
Spotted towhee	*Pipilo maculatus*	Associated	X
Western wood-pewee	*Contopus sordidulus*	Associated	–
Wilson's warbler	*Cardellina pusilla*	Associated	–

Overview of Willamette River Restoration Goals, Activities, and Expected Ecological and Physical Responses

The WFIP restoration initiative identifies the program's restoration goals, objectives, and activities in its Strategic Action Plan (AHWG, 2015; OWEB, 2019). The goal of the initiative is to "sustain and enhance seasonally important resources for native fish" (AHWG, 2015). Linkages among restoration goals, activities, and outcomes is the foundation for this monitoring framework, development of detailed monitoring plans, and future assessment of restoration effectiveness (for example, Roni and others, 2005; Prach and others, 2019). The two objectives for meeting the WFIP restoration initiative goal are to:

1. Enhance quality and extent of habitats used in summer and early autumn months when streamflows are low and warm stream temperatures can be harmful for native fish and

2. Enhance the quality and extent of habitats used in the late autumn, winter, and spring, when streamflows are moderate to high and stream temperatures are cool.

Eight restoration activities to meet the initiative goals and objectives outlined in the WFIP Strategic Action Plan (AHWG, 2015) are simplified into six generalized restoration activities (table A7; appendixes 2 and 4), for the focus of this monitoring framework:

1. Modify floodplain topography and human-made barriers to inundation (fig. A9),

2. Enhance gravel pits (fig. A10),

3. Remove revetments,

4. Construct off-channel features,

5. Increase and enhance floodplain forest vegetation (fig. A11), and

6. Treat aquatic invasive plants species (AIS; fig. A12).

Linkages between restoration goals, objectives, and activities of habitat restoration and hypothesized ecological responses are summarized in table A7 and described more completely in appendixes 2 and 4 based on review of WFIP restoration initiative documents (AHWG, 2015; BPA, 2016; OWEB, 2019) and existing restoration projects. These linkages were illustrated in the WFIP Results Chain or Theory of Change that was developed in 2015 based on current scientific understanding at that time and were intended to be adaptively refined as new science and monitoring results become available (AHWG, 2015; OWEB, 2019). As of 2020, some restoration activities (such as floodplain forest planting, modifying floodplain topography, treating aquatic invasive plant species) have been implemented at numerous sites, while others (such as revetment removal and modification) are planned for several sites, but have only been implemented at a single site.

Table A7. Summary of restoration activities, potential benefits for fish habitat and expected responses in hydrogeomorphic, vegetation, fish and avian communities that can be evaluated with effectiveness monitoring.

[Restoration activities and description of restoration activities: adapted from the Strategic Action Plan for the Willamette Focused Investment Partnership (WFIP) restoration initiative; Anchor Habitat Working Group (AHWG), 2015; Oregon Watershed Enhancement Board (OWEB), 2019. Anticipated benefits for native fish habitats: adapted from the WFIP Theory of Change (AHWG, 2015; OWEB, 2019). Hypothesized near-term and long-term responses vary with restoration actions and the hydroclimatic conditions in the ensuing years and is approximate. Abbreviations: >, greater than; WFIP, Willamette Focused Investment Partnership; DO, dissolved oxygen]

Restoration activities	Description of restoration activities	Examples of typical restoration actions	Anticipated benefits for native fish habitats	Hypothesized near-term responses (1–5 years)	Hypothesized long-term responses (>10 years)
Modify floodplain topography and human-made barriers to inundation	Increase native fish access to floodplains by modifying floodplain topography and human-made barriers (such as levees, berms, and culverts) to increase the frequency, extent, and duration of floodplain inundation	Deepen floodplain swales; deepen inlets of side channels; lower natural levees and other topographic highs; lower, notch, or remove levees and berms; remove or modify culverts, road crossings, and other structures that impede inundation and fish passage	Increase slow-water refuge extent, duration, and frequency for native fish in high streamflow months; provide fish access to floodplain areas that may have greater food resources than main channel; increase hydraulic connectivity between off-channel areas and main channel to minimize stranding and improve fish passage	Frequency, extent, and duration of surface-water connection between main channel and floodplain increases enabling fish access to floodplain habitats during moderate to high streamflows	Fish access to floodplain habitats during moderate to high streamflows increases native fish abundance; fine sediment deposition during floods may cause deposition of natural levees or filling of modified topography
Enhance gravel pits	Enhance former gravel pits and alleviate stranding by re-connecting shallow pits, regrading pond boundaries and filling ponds	Connect gravel pit to main channel river; modify pond topography and adjacent levees and berms to improve hydraulic connectivity and alleviate fish stranding	Increase area of slow-water habitats available to fish in high-streamflow months; improve connectivity between ponds and main channel to increase the frequency and duration that fish can access ponds and improve water quality in ponds; improve fish egress from ponds to alleviate stranding	Frequency and duration of surface-water connection between main channel and gravel pit increases; flooding increases transfer of sediment, fish, and other organisms; regrading pond topography facilitates fish egress after floods and vegetation establishment	Increases in flooding and fine sediment deposition may support floodplain formation and vegetation establishment that benefit native fish; channels connecting gravel pits with the river subject to bank |erosion, incision, aggradation, or other morphological adjustments that affect fish access
Remove revetments	Remove revetments and levees in reaches likely to experience channel changes	Revetment removal to expose erodible banks to erosion	Increase bank erosion to promote creation of gravel bars, alcoves, and other features that support channel complexity and habitats used by native fish	Bank erosion and lateral channel shifting and associated changes in channel position and planform (magnitudes dependent on streamflows and other factors)	Increases in landforms such as gravel bars and bathymetric complexity from lateral channel migration and deposition of newly liberated sediment can support diverse array of fish habitats at different streamflows

Table A7. Summary of restoration activities, potential benefits for fish habitat and expected responses in hydrogeomorphic, vegetation, fish and avian communities that can be evaluated with effectiveness monitoring.—Continued

[Restoration activities and description of restoration activities: adapted from the Strategic Action Plan for the Willamette Focused Investment Partnership (WFIP) restoration initiative; Anchor Habitat Working Group (AHWG), 2015; Oregon Watershed Enhancement Board (OWEB), 2019. Anticipated benefits for native fish habitats: adapted from the WFIP Theory of Change (AHWG, 2015; OWEB, 2019). Hypothesized near-term and long-term responses vary with restoration actions and the hydroclimatic conditions in the ensuing years and is approximate. Abbreviations: >, greater than; WFIP, Willamette Focused Investment Partnership; DO, dissolved oxygen]

Restoration activities	Description of restoration activities	Examples of typical restoration actions	Anticipated benefits for native fish habitats	Hypothesized near-term responses (1–5 years)	Hypothesized long-term responses (>10 years)
Construct off-channel features	Construct off-channel features in areas with a high likelihood of hyporheic flow	Construct or deepen side channel through forested bars or low floodplains for specific purpose of collecting hyporheic flows	Increase the area of cool and cold-water habitat for native fish in summer months	Increasing the area and temporal period when an off-channel feature has cooler water temperatures than main channel will provide more summer habitats for cool and cold-water fish	Hyporheic flux and water temperature in restored sites may change; other morphologic adjustments (erosion, deposition) may influence habitat availability and temperature patterns; hyporheic flows also may influence DO
Increase and enhance floodplain forest vegetation	Increase and enhance floodplain plant communities through native vegetation planting and invasive species control	Plant native trees and shrubs in former agricultural fields inundated in winter months and along off-channel areas inundated in summer months; treat invasive plants to facilitate establishment of native plants	Increase hydraulic roughness, cover and food availability in floodplain areas inundated in winter months to enhance and expand slow water refuges; create shade, cover and food resources in off-channel areas inundated in summer months	Newly planted trees and shrubs provide some cover and food resources during moderate- to high-streamflow periods when floodplain surfaces are inundated	Native shrubby and woody vegetation increases, thereby increasing food resources and stem density that creates slow-water refuges for native fish during moderate- to high-streamflows when inundated
Treat aquatic invasive plants species	Control aquatic invasive plant species that degrade water quality and biodiversity	Chemical or mechanical control to remove or kill aquatic invasive plant species	Improve water quality in off-channel features where aquatic invasive plant species create harmful DO conditions; increase open water areas where dense plant beds restrict fish movement	Aquatic invasive plants are reduced or removed from off-channel features resulting in decreased levels of dissolved oxygen from decomposition of vegetation matter	Native fish use of off-channel features increases; streamflows that flush fine sediment out of some off-channel features maintain or increase habitat area; reduced root densities of aquatic invasive plant species trap less sediment leading to reduced regrowth of future infestations

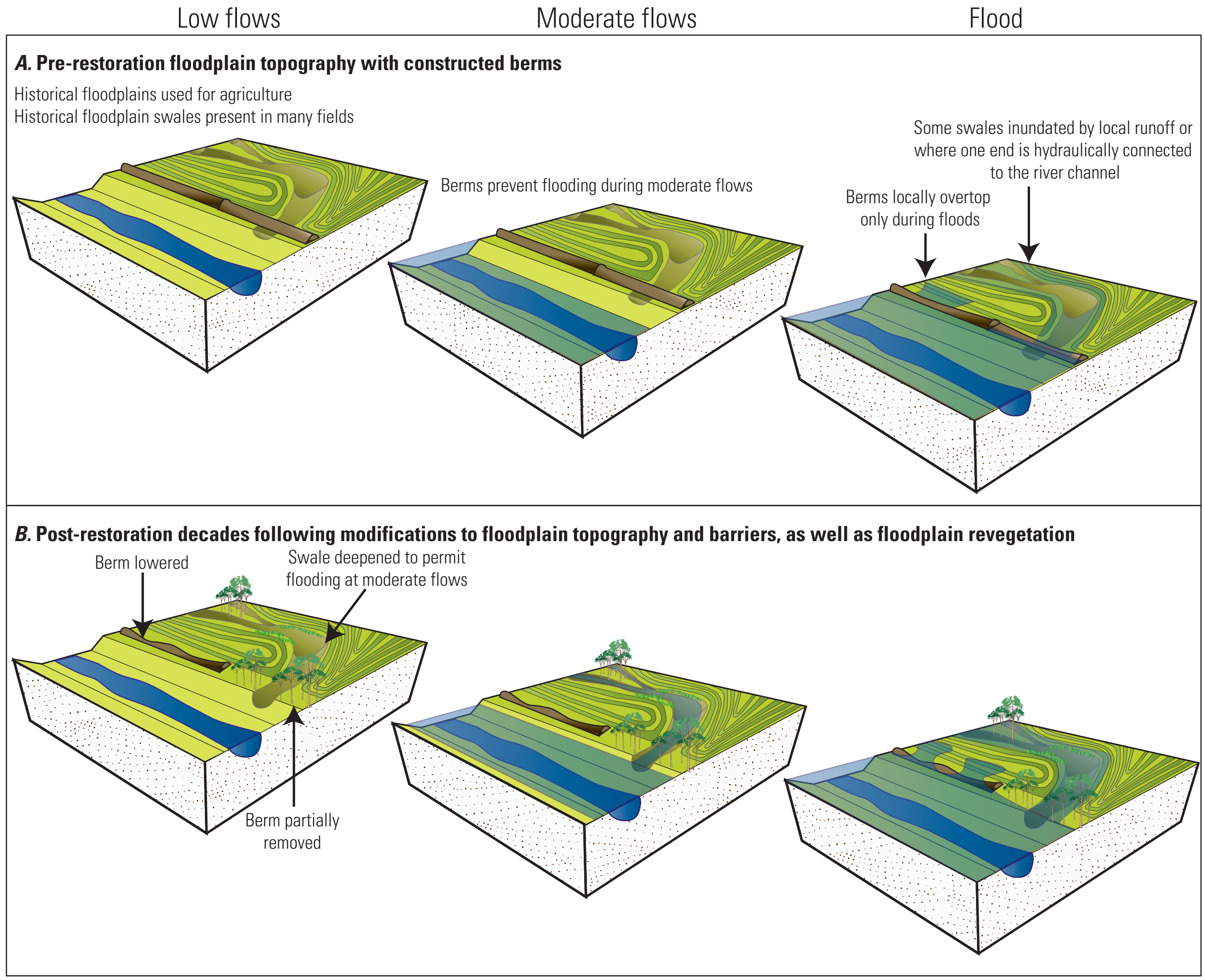

Figure A9. Topographic and human-made barrier modification restoration activities to increase floodplain inundation and fish access. *A*, pre-restoration conditions at low, moderate, and flood streamflows where constructed berms limit flooding of swales carved into floodplain surfaces. *B*, post-restoration floodplain that permit flooding at moderate and flood streamflows, including floodplain revegetation.

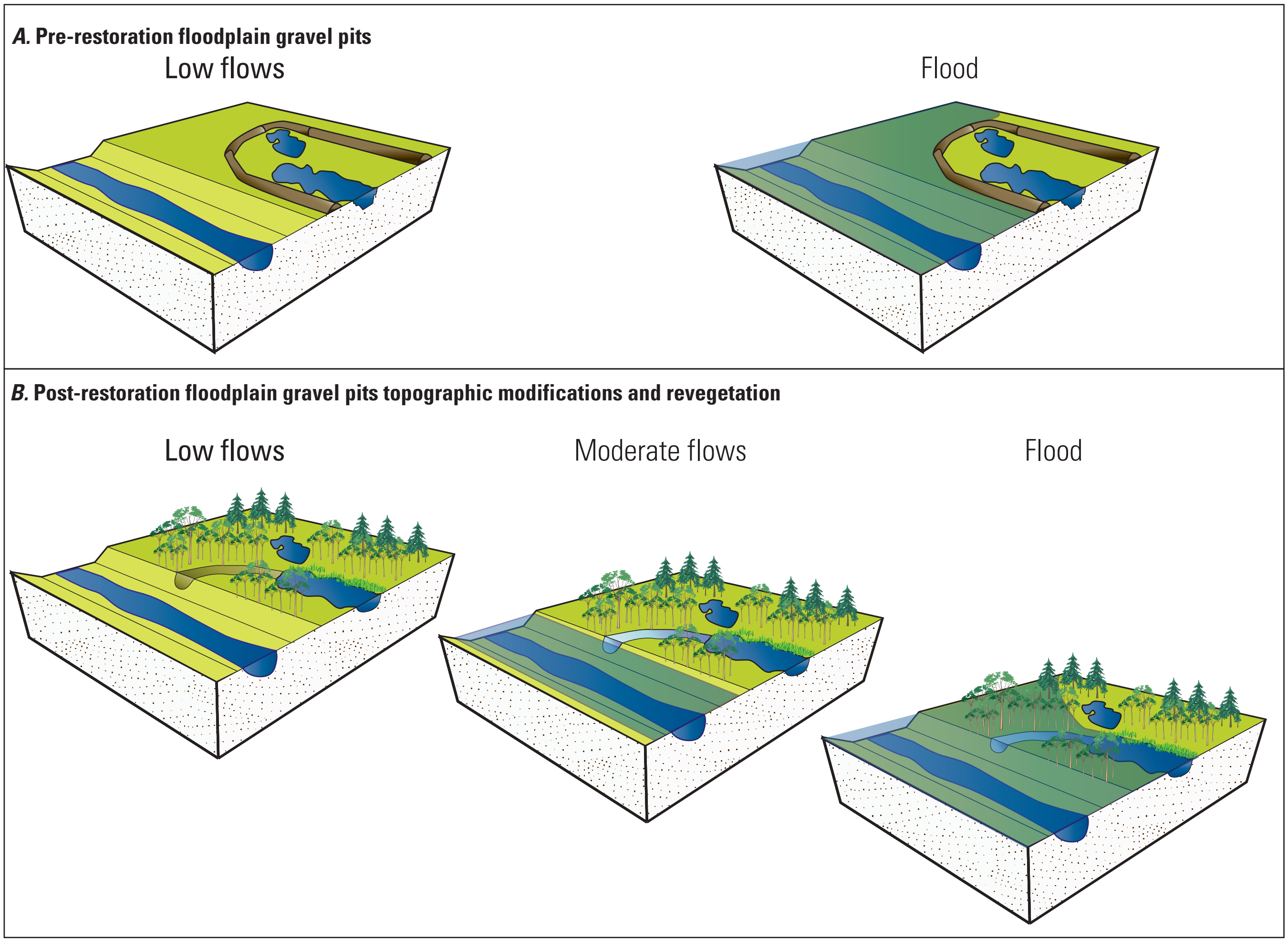

Figure A10. Gravel pit restoration site. *A*, prior to restoration activities, gravel pits are hydraulically disconnected from the river channel at low streamflows, while constructed berms limit inundation during high streamflows. *B*, post-restoration gravel pits illustrating topographic modification to provide gently sloping pond boundaries, channels that connect pits to the river channel at moderate streamflows, and more substantial inundation at flood streamflows, as well as floodplain forest revegetation activities.

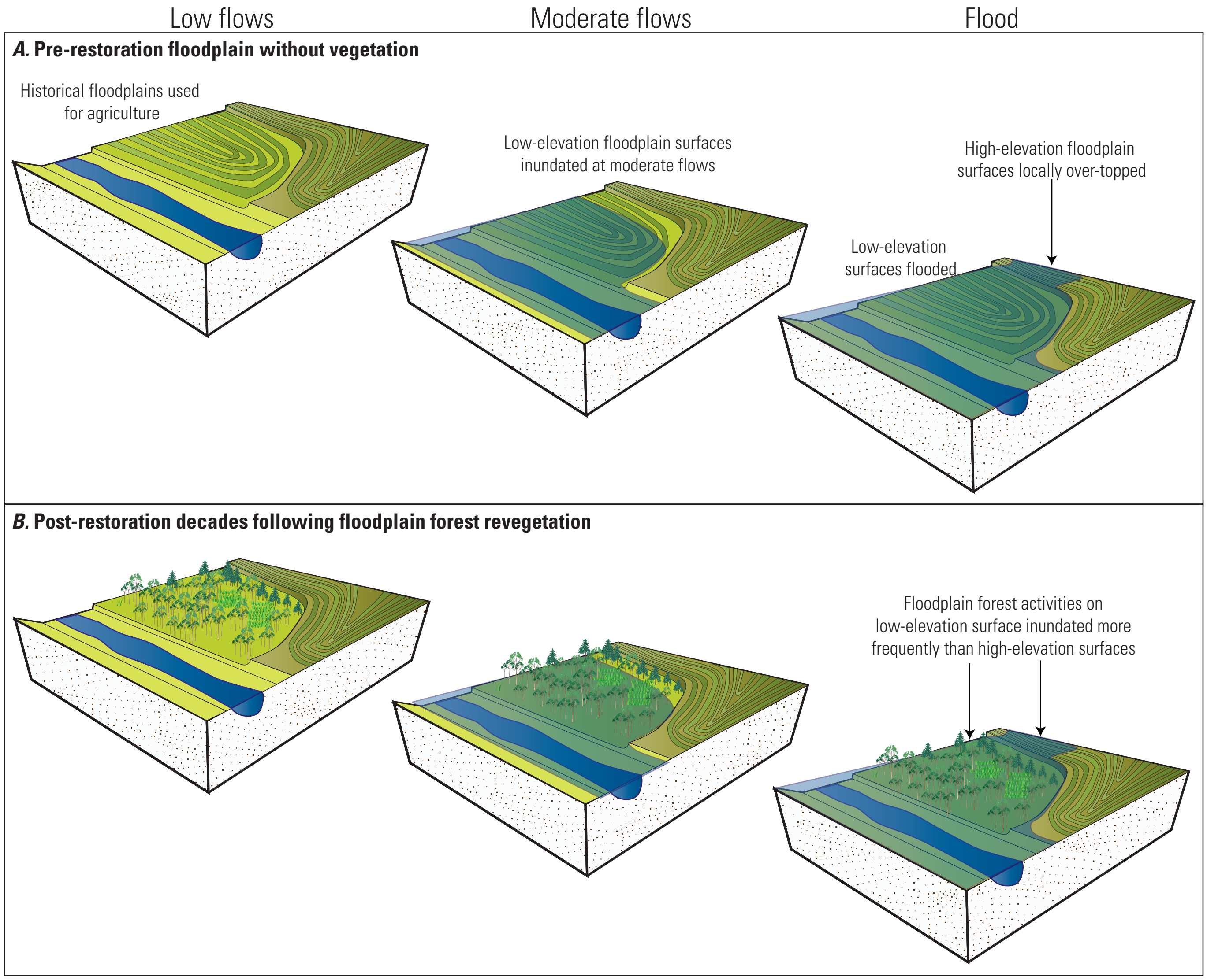

Figure A11. Floodplain forest restoration activities that increase or enhance floodplain vegetation. *A*, pre-restoration along typical floodplain surfaces in agricultural land-use areas with low-elevation field inundated during moderate streamflows and flood events. *B*, post-restoration revegetated floodplain surfaces.

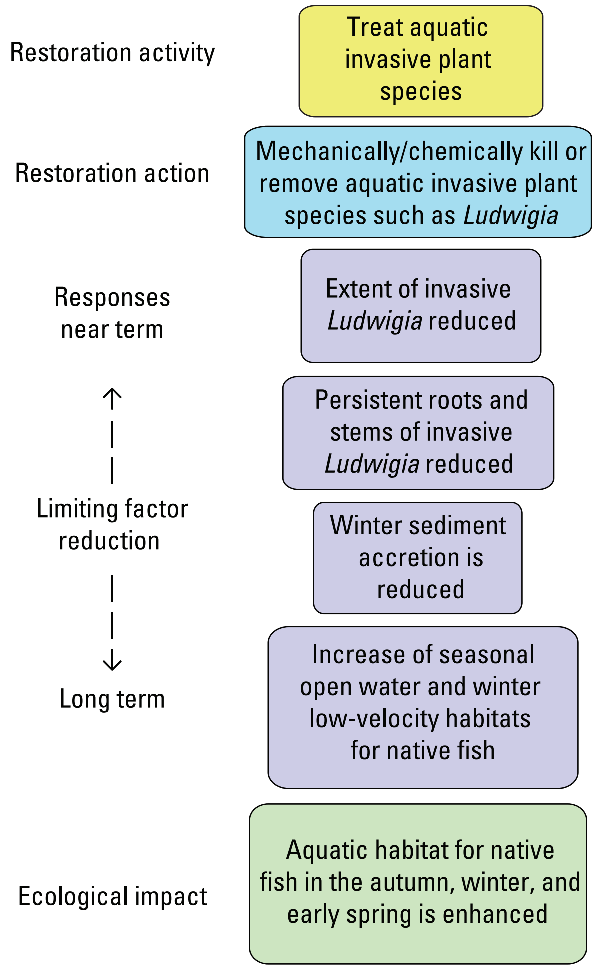

Figure A12. Near- and long-term hypothesized responses to aquatic invasive plant species restoration activities for the Willamette Focused Investment Partnership Effectiveness Monitoring Program, modified from the Willamette Focused Investment Partnership Theory of Change (Anchor Habitat Working Group [AHWG], 2015; Oregon Watershed Enhancement Board [OWEB], 2019; see table A7).

Overview of the Willamette Focused Investment Partnership Effectiveness Monitoring Program

Recognizing the many challenges of restoration, the WFIP restoration initiative was developed in an adaptively managed context, where restoration goals and activities would be implemented based on best available science and effectiveness monitoring would be used to refine goals, restoration activities, and best practices in the future (Warren and others, 2019). The WFIP Effectiveness Monitoring Program has three goals:

1. Evaluate the effectiveness of different restoration activities at increasing and enhancing native fish habitat,
2. Improve overall understanding of the physical and ecological responses associated with different restoration activities undertaken by the WFIP, and
3. Relate site-scale responses to restoration with segment-scale patterns of fish communities, hydrogeomorphology, stream temperature, and vegetation, so that the relative importance of restoration activities on spatial and temporal patterns of habitat availability for native fish can be assessed.

Large-scale restoration programs on the Willamette River consist of multiple projects that typically entail several years of planning, followed by several phases of implementation that can span 5–10 years. Recognizing these timelines and the additional time needed to monitor and evaluate effectiveness, it is not feasible that monitoring findings can support substantial refinement of current program goals and actions. Therefore, the WFIP Effectiveness Monitoring Program aims to evaluate whether restoration actions are meeting current goals, and so that restoration program managers and practitioners can use these findings when refining program goals and activities in the future. Another unique aspect of the WFIP Effectiveness Monitoring Program is to determine whether restoration activities have led to ‘increased habitat for all native fish’ (in reflection of WFIP Restoration goals), which is distinct from other large-scale monitoring programs in the Pacific Northwest that were developed to systematically address ESA-driven regulatory questions (for example, the Integrated Status and Effectiveness Monitoring Program [ISEMP] for the Columbia River Basin).

This monitoring framework outlines indicators, metrics, and approaches for assessing changes within five ecological and physical monitoring categories (fish, hydrogeomorphology, floodplain vegetation, birds, and AIS) following habitat restoration (fig. A2; tables A7 and A8). The approaches described in this monitoring framework are examples to inform future monitoring, recognizing that exact approaches used in future monitoring will need to reflect factors such as site conditions, emerging technologies, and monitoring budgets. These approaches have been proven to be efficient and reliable for measuring changes in physical habitat conditions resulting from restoration in the Willamette River. For most of these monitoring approaches, published protocols already exist, and further evaluations can inform the selection of specific protocols for future effectiveness monitoring. The monitoring activities of this framework occur at several spatial scales including river reaches, restoration sites, monitoring points as described in appendix 3 and illustrated in figure A13. Additional considerations related to monitoring resources, temporal and spatial resolution, field implementation, and evaluation are outlined in appendix 3.

Table A8. Summary of effectiveness monitoring indicators for Willamette River restoration activities for the Willamette Focused Investment Partnership Effectiveness Monitoring Program.

[For all restoration activities, use of different monitoring indicators and approaches will depend on the specific restoration project evaluated and other factors like site conditions and resources available for monitoring. Abbreviations: X, restoration activity and monitoring indicator for effectiveness monitoring; –, no monitoring indicator for the restoration activity]

Restoration activities	Seasonal focus for monitoring	Monitoring indicators for Willamette River restoration activities																	
		Fish					Hydrogeomorphology				Floodplain forest		Birds			Aquatic invasive plant species			
		Fish presence	Fish abundance	Community composition and diversity	Fish growth	Food resource availability and diversity	Floodplain Inundation	Planimetric changes in channel features	Vertical changes in channel and floodplain features	Water temperature	Forest canopy cover	Forest inundation	Species richness of floodplain-associated birds	Abundance of floodplain focal species	Avian productivity and survival	Emergent and floating leaf plant cover	Plant community composition	Dissolved-oxygen concentration	Substrate characteristics
Modify floodplain topography and human-made barriers to inundation	Late autumn, winter, spring	X	–	X	X	X	X	–	X	X	–	–	–	–	–	–	–	–	–
Enhance gravel pits	Summer, autumn, winter, spring	X	X	X	X	–	X	X	X	X	–	–	–	–	–	–	–	–	–
Remove revetments	Summer, autumn, winter, spring	X	–	–	–	–	–	X	–	X	–	–	–	–	–	–	–	–	–
Construct off-channel features	Summer, early autumn	X	X	X	X	–	X	X	X	X	–	–	–	–	–	–	–	–	–
Increase and enhance floodplain forest vegetation	Late autumn, winter, spring	X	–	–	X	X	–	–	–	X	X	X	X	X	X	–	–	–	–
Treat aquatic invasive plant species	Summer, autumn, winter, spring	X	–	–	–	–	–	–	–	X	–	–	–	–	–	X	X	X	X

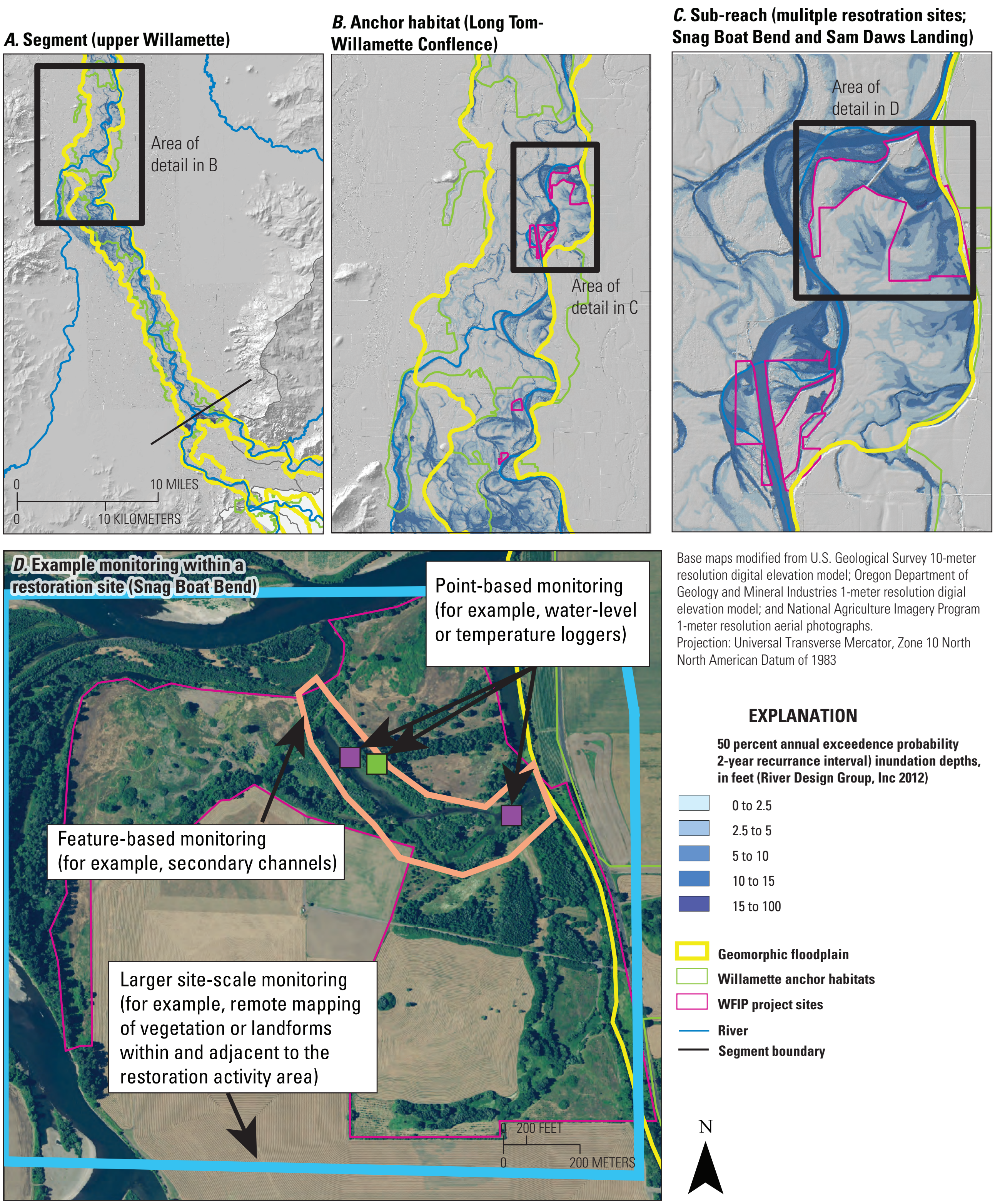

Figure A13. Spatial scales for effectiveness monitoring of restoration activities implemented along the Willamette River. Monitoring and evaluation will vary by restoration activity and monitoring approach. *A*, Segment, example for the upper segment of the Willamette River; *B*, Anchor Habitat, example of the confluence of the Long Tom and Willamette Rivers (Long Tom–Willamette Confluence, fig. A1); *C*, subreach including multiple sites, example near Sam Dawes Landing and Snag Boat Bend; and *D*, restoration site, example at Snag Boat Bend showing example areas where monitoring within and adjacent to a site can be done at the scale of a single point, feature, or throughout the whole site.

Chapter B. Monitoring Responses of Fish Communities and Their Food Resources to Willamette River Restoration Activities

By Rebecca L. Flitcroft,[1] Tobias J. Kock,[2] J. Rose Wallick,[2] and Krista L. Jones[2]

Restoration activities may improve habitats used by native fish in the Willamette River Basin at different times of the year (table B1; fig. B1). Restoration activities that seek to improve fish habitats in low-flow summer months include removing aquatic invasive plant species and constructing off-channel features. In contrast, activities such as increasing and enhancing floodplain forests and modifying floodplain topography are expected to improve aquatic habitats used in the late autumn, winter, and spring when floodplains are likely to be inundated. Monitoring fish and their food resources can complement physical habitat monitoring (chaps. C–F) and confirm whether focal fish species or specific communities of fish species are utilizing sites, hence, helping to determine if restoration created physical conditions supportive of native fish. Further, fish and food resource monitoring can identify if other biological factors are influencing restoration effectiveness, such as the presence of non-native fish that may predate upon or compete with native fish for food and habitats. Monitoring responses of native fish to restoration activities in the Willamette River Basin is complicated by seasonal variability in habitat use, the diversity of aquatic and floodplain habitats that can support distinct fish communities, the presence of non-native fish and the inherent challenge of biological sampling in deep or fast-water environments. However, investments in monitoring fish and their food sources can provide critical information to understand and document the effectiveness of different restoration activities in the Willamette River system for native fish (table B1; fig. B1).

Although many monitoring indicators can be used to assess fish responses to restoration activities, this framework has identified five monitoring indicators for evaluating effectiveness of restoration activities at increasing or enhancing habitats for native fish in the Willamette River: (1) fish presence, (2) fish abundance, (3) fish community composition and diversity, (4) fish growth, and (5) food resource availability (table B1; fig. B1). This chapter describes the use of these indicators, along with example metrics, monitoring approaches, applications, and drawbacks associated with each monitoring indicator. Considerations regarding the spatial and seasonal context of Willamette River restoration and monitoring activities and the expected fish communities for different river sections and seasons also are included to aid in the development of fish sampling plans (see chap. A, section, “Fish and Wildlife of the Willamette River Floodplain”; table A5; Williams and others, 2022). Because all six Willamette River restoration activities described in this report are hypothesized to directly or indirectly improve habitats used by native fish (fig. B1), fish monitoring activities can be implemented to evaluate all six types of restoration activities; however, some monitoring activities are better suited to certain restoration activities than others (tables A7, A8, and B1).

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Table B1. Fish monitoring indicators, metrics, and approaches for selected restoration activities.

[Abbreviations: X, potential fish monitoring approach for effectiveness monitoring; –, not a potential fish monitoring approach for effectiveness monitoring; P, presence; A, absence]

Effectiveness monitoring indicators	Example fish monitoring metrics	Example fish monitoring approaches (additional approaches in text)	Restoration activities					
			Modify floodplain topography and human-made barriers to inundation	Enhance gravel pits	Remove revetments	Construct off-channel features	Increase and enhance floodplain forest vegetation	Treat aquatic invasive plant species
Fish presence	Presence, absence	Presence or absence (P/A)—can be determined using: snorkeling, camera traps, eDNA, electrofishing (boat or backpack), minnow trapping, nets (for example fyke, seine, gill, screw-trap)	X	X	X	X	X	X
Fish abundance	Number individuals/area	May be more rigorous methods and design than P/A. Methods of capture similar to P/A but may include multiple pass sampling method to determine escapement. Catch per unit effort also may be used as a simple assessment of fish abundance.	X	X	X	X	–	X
	Total number of individuals/site		X	X	X	X	–	X
	Ratio of native to non-native fish (relative abundance)		X	X	X	X	–	X
Fish community composition and diversity	Species richness and species evenness (community composition)	Similar to fish abundance. Removal sampling, mark and recapture and snorkel surveys may be used.	X	X	X	X	–	X
	Shannon Weiner Index (for diversity of fish community)		X	X	X	X	–	X
Fish growth	Length/weight, condition factor	Mark and recapture methods using electrofishing, nets, or traps for fish capture may be used, as would representative sample collection pre- and post-restoration.	–	–	–	–	X	X
Food resource availability	Shannon Weiner Index (for diversity of food resources)	Quantification of lotic and lentic food sources and food webs. May include sampling for benthic macroinvertebrates, macroinvertebrate drift, leaf matter, and terrestrial insects. Methods include drift nets, kicknets, and periphyton collection.	X	X	–	–	X	X
	Weight/area		X	X	–	–	X	X

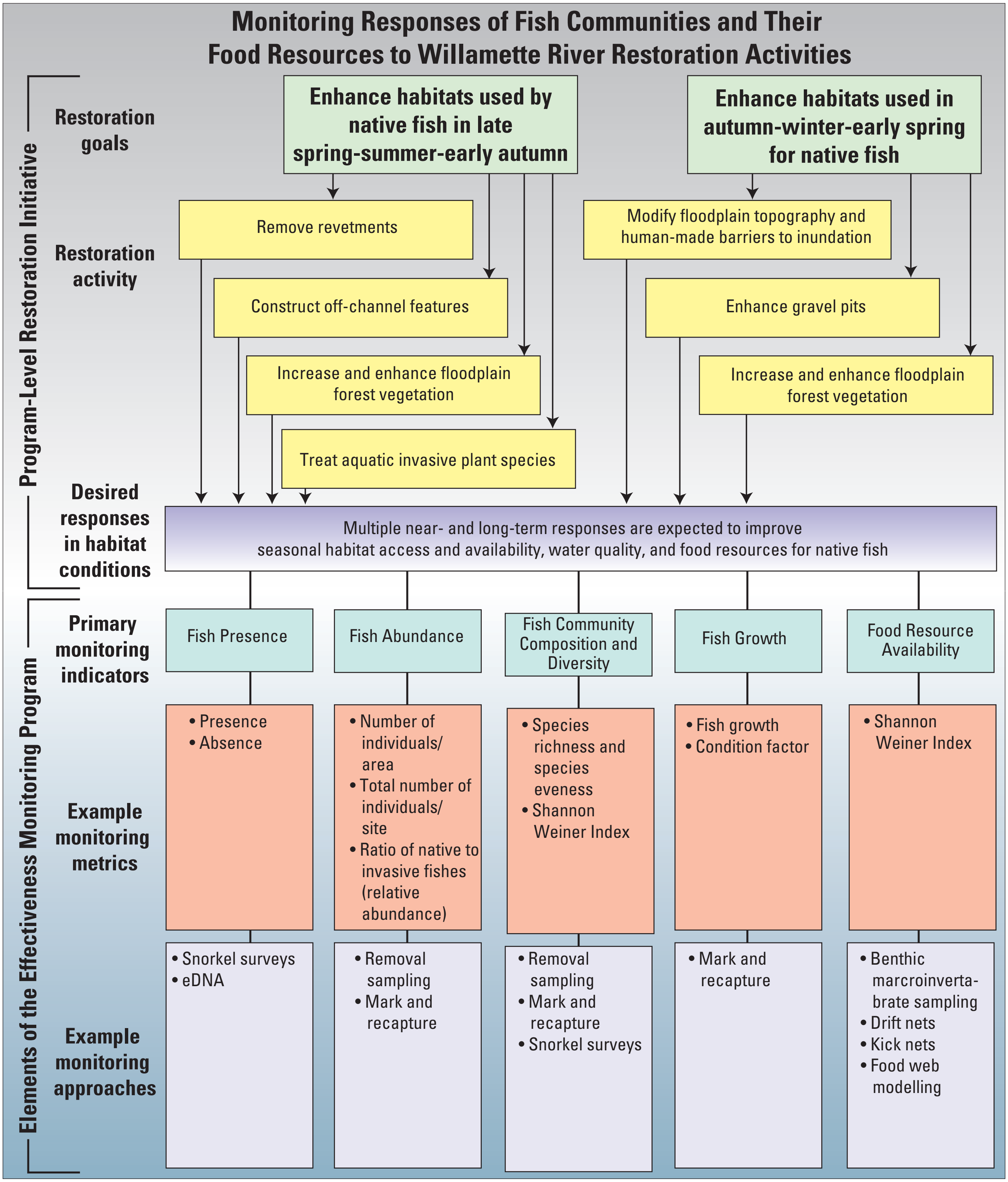

Figure B1. Linkages between restoration activities and hypothesized responses in fish habitat with fish monitoring indicators, metrics, and approaches. Refer to table A8 for specific indicators, metrics, and approaches that can be applied to each restoration activity.

Fish Monitoring Considerations

To evaluate fish responses to Willamette River restoration activities, it is important to understand the spatial and seasonal distribution of native and non-native fish species along the river corridor, differences in fish traits (such as habitat preferences, water temperature tolerances, and diet requirements), and differences in life history requirements among species (Williams and others, 2022). Additionally, fish monitoring activities should consider how restoration projects may affect fish use and fish communities throughout the year. Bonar and others (2009) and Zale and others (2012) provided thorough reviews of fish sampling methods that are broadly useful for aquatic scientists and restoration practitioners involved with fish monitoring. The following monitoring considerations are provided to illustrate conditions and factors that should inform the development of fish sampling activities.

- Longitudinal patterns in native fish communities in the Willamette River, along with site-specific conditions, will influence the types of fish likely to be sampled in a particular restoration site. Upstream reaches in the Willamette River tend to be dominated by native fish species while non-native species comprise a greater proportion of the fish community in downstream reaches (Hughes and Gammon, 1987; Gregory, Wildman, and others, 2002), likely reflecting differences in habitat preferences and physiological tolerances. These considerations mean that, for example, a hypothetical off-channel restoration project intended to increase surface-water connectivity between main channel and off-channel habits near Salem (river mile [RM] 84) during summer months would be expected to proportionally benefit non-native fish because of warm water temperatures and abundant non-native species that reside in this reach. However, a similar hypothetical project near Harrisburg (RM 161) may provide proportionally greater benefits to native fish in summer months, because this reach has cooler water temperatures and fewer non-native fish (tables A2 and A5; fig. A4).

- Hypotheses should be developed to articulate anticipated benefits to particular fish species, or groups of fish species, for each restoration project. Hypothesis development should consider factors such as the location of the project along the Willamette River, the type of habitat targeted by the restoration project, and fish community composition. Causal mechanisms driving the anticipated benefits for fish along with timelines over which those benefits are likely to occur should be described. More information on the importance of quantitative restoration goals and objectives to guide effectiveness monitoring is provided in appendix 3.

- The physical characteristics of a restoration site may not be indicative of the density or occupancy of fish at the site due to other factors that influence fish use. For example, interactions between native and non-native fish, fish behavior, and population status of the species present may complicate the ability to detect fish responses to restoration activities.

- Fish monitoring will be most successful when used to evaluate spatially and temporally explicit hypotheses describing anticipated outcomes for restoration actions (appendix 3). With such hypotheses in place, monitoring plans can be developed to anticipate the temporal and spatial scales needed to detect changes in fish use or fish communities, which may require multiple sampling years (for example, Polivka and others, 2019). In particular, choosing the appropriate spatial scale for fish sampling is critical for all fish monitoring activities, but especially when trying to determine if restoration activities result in increased population abundance or species richness (for example, Polivka and others, 2019).

- Likewise, restoration objectives often include season-specific goals for fish habitats and fish use. Fish sampling consistent with seasonal goals is recommended because habitat use by fish is likely to vary throughout the year (as shown by Nickelson and others, 1992; Sol and others, 2019). However, fish sampling challenges may occur in different seasons. Warm stream temperatures in summer may make fish sampling too stressful for fish, while high discharge, water velocity, and turbidity, when streamflows are high in winter months, may compromise rigorous assessment methods.

- Assessments of changes in fish habitat, fish use, or fish abundance are most effective when conditions prior to implementation of restoration projects have been quantified (Roni and others, 2003, 2013, 2019). However, at many Willamette River restoration sites, pre-project fish monitoring data are often unavailable. Therefore, comparisons of fish monitoring data between representative restored and non-restored sites may provide a suitable way to discern the effectiveness of certain restoration activities. Often, sites that are adjacent to or in similar reaches of the river may be comparable because they have similar availability to fish communities, water quality, potential floodplain habitat, riparian vegetation, flood history, and geomorphic processes.

Fish Indicators and Approaches

Fish Presence

Fish presence monitoring can be a simple approach to assess how various fish species respond to habitat restoration. Presence monitoring determines whether individual fish species are detected at a specific location. For restoration monitoring, species assemblage data from a site prior to and after restoration can be compared to determine if a given restoration activity positively or negatively affected the numbers and types of native fish detected at a site. Fish species assemblage describes the group of fish species which are present at a location at given time without consideration for how those species interact at the site (Stroud and others, 2015). Documenting fish presence is a straightforward process if fish can be effectively collected or observed, but practitioners must consider the potential for undocumented species to be present at a site because sampling methods commonly fail to capture or observe all fish that are present. Seasonality of pre- and post-restoration sampling also is important for interpreting results because many fish move among habitat types in response to changing river conditions and life-history needs. Fish presence monitoring may detect effects that result from restoration activities conducted on instream habitats such as with large wood placement or reconnection of off-channel habitats. Restoration activities that target increasing or expanding floodplain forest vegetation or other areas outside of the low-streamflow channel may have indirect effects on fish that are unlikely to be detected using presence monitoring.

Fish presence data can be collected using a variety of methods including snorkeling, monitoring with underwater cameras, genetic assessment to determine if a particular species is present based on environmental DNA (eDNA), fish capture techniques such as electrofishing or seining, and detection of tagged fish (for example, PIT tags, acoustic transmitters, radio transmitters) using arrays located within restoration sites (table B1). Count data can be obtained using all approaches described, except for eDNA. Metrics such as catch per unit effort (CPUE) (Bannerot and Austin, 1983; Maunder and others, 2006) can be used to assess how fish presence is affected by restoration activities. Regardless of technique, it is important to consider how capture/detection efficiency affects the interpretation of results obtained when assessing fish presence.

Monitoring Fish Presence with Snorkel Surveys

Snorkel surveys provide an efficient, low-cost means of evaluating fish presence with minimal impact to sampled fish (fig. B2). Ideally, snorkel surveys should be designed to include sampling of all habitat types within a site, but if this is not possible, snorkel surveys could target specific habitats within a site (for example, several pools within a site) to reduce inter-habitat variability (Thurow, 1994). If a subset of habitat types is sampled, then the snorkeled habitats must be representative of the major types of habitats at the site, accurately represent the habitats used by all fish at the site, and be physically measured to adjust for habitat differences among sites. If the restoration site is too large to be sampled completely, a random series of sections within the site could be subsampled if these small zones adequately represent target habitat found throughout the site (Pinnix and others, 2019). For example, if the restoration site includes several large (greater than 1 km in length) side channels where restoration activities include channel deepening and placement of large wood structures, snorkel surveys could target a subset of smaller areas within two or three of the channels. Because fish presence at a restoration site likely fluctuates daily and seasonally, snorkel surveys should be conducted at different times of the day to assess diurnal use and throughout the year if there is interest in characterizing seasonal changes. Because snorkeling is based on visual observations, factors such as turbidity, vegetation density, vegetation, habitat complexity (such as large wood), time of day, and others can affect snorkelers' ability to observe fish. Additional information on snorkel surveys, detection efficiency, and data corrections for survey methods are described in Hillman and others (1992), Dolloff and others (1996), Dunham and others (2009), and Weaver and others (2014).

Monitoring Fish Presence with Environmental DNA Sampling

Genetic sampling for species presence using eDNA from water samples is an emerging method in ecological research (Dejean and others, 2011; Jerde and others, 2011; Thomsen and others, 2012; Rees and others, 2014) that can be applied to restoration monitoring (fig. B3). Fish presence in rivers, as determined by a positive eDNA sample, indicates that a given species is present at some location upstream from a sampling site. Benefits of eDNA sampling include simplicity of sampling gear, ability to sample under all streamflows, lack of influence of environmental conditions and habitat complexity on detection, and time efficient field sampling. Challenges with this method include the downstream transport of eDNA in the water column that can confound inferences about the presence of fish at a particular location (for example, Evans and Lamberti, 2018), accumulation of eDNA in alcove and other slow-water habitats (Evans and Lamberti, 2018), contributions of eDNA from all upstream sources (such as tributary junctions), and sample contamination (yielding false positive results). Various sources describe specific field protocols for accurate collection of eDNA samples (for example, Carim and others, 2016). Sampling validation and calibration processes should identify the downstream persistence of eDNA to the degree possible.

Figure B2. *A*, U.S. Forest Service biologist and *B*, Oregon State University student conducting snorkeling surveys. Photograph *A* by U.S. Forest Service, September 12, 2011, and Photograph *B* by U.S. Forest Service, courtesy of by Kristin Kirkby, August 27, 2011.

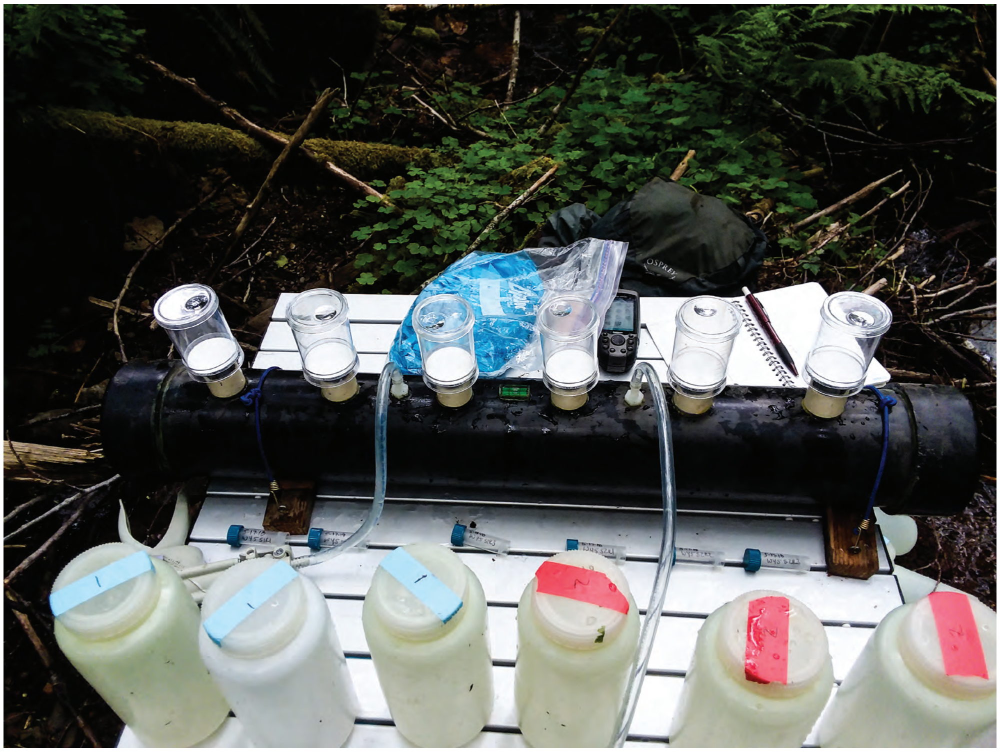

Figure B3. Environmental DNA sampling to identify the organisms and plants that occupy water. By taking a water sample, filtering the water to capture the DNA, and then processing the sample at the laboratory, scientists can determine the presence or absence of different biota that have come into contact with the water. In this photograph, six samples of water are being filtered simultaneously to speed sample processing time in a project led by Brooke Penaluna from the U.S. Forest Service, PNW Research Station. Photograph by Brooke Penaluna, U.S. Forest Service, May 17, 2018.

Fish Abundance

Fish abundance can be represented by either the density of individuals (number per unit area) or the standing stock (biomass per unit area). Changes in abundance are commonly used to make inferences about habitat and environmental conditions. For example, decreasing abundance generally indicates that conditions have worsened for a particular fish species, whereas increasing abundance generally indicates that conditions have improved for that species. The reverse applies for undesired species (such as non-native fish species). Although multiple methods are available for estimating fish abundance, three approaches—removal sampling, mark-recapture sampling, and calculating catch per unit effort (CPUE)—have the greatest potential use for Willamette River effectiveness monitoring.

Removal sampling and mark-recapture sampling provide estimates of population abundance and rely on data collected during repeated sampling events. Fish abundance surveys should be inclusive of all habitat types within a given restoration site. Seasonal changes in streamflow, water temperature, turbidity and other factors are likely to influence both fish use of a given site and sampling effectiveness (Peterson and others, 2004). Although these two approaches are useful in assessing restoration actions, they can be challenging to implement in areas where water is too deep, is high in velocity, or is too turbulent for wading during backpack electrofishing or netting during boat electrofishing. Thus, these methods may be challenging in main-stem areas of the Willamette River, and in some lateral habitats during winter, but may be suitable in areas with slow moving water (such as swales and floodplain channels where many Willamette River restoration actions occur; figs. B4 and B5).

Removal sampling does not require fish tagging and consists of recording numbers of fish that are collected and removed from the study site in successive sampling events that occur during a short time interval (usually during a single day). Abundance estimates from removal sampling studies are calculated based on the rate in which the number of fish sampled declines (termed "depletion") in repeated sampling events. For additional information on removal sampling readers are referred to Simonson and Lyons (1995), Heimbuch and others (1997), Peterson and others (2004), Rosenberger and Dunham (2005), and Saunders and others (2011) among others.

Figure B4. Electrofishing, a common fish sampling method. A small electrical current momentarily immobilizes fish allowing for their capture in nets. In this photograph, crews from the U.S Forest Service are sampling for fish using a back-pack electrofishing unit in McRae Creek, HJ Andrews Experimental Forest, Oregon. Photograph by Lina DiGregorio, U.S. Forest Service, 2019.

For mark-recapture sampling, a group of fish is initially collected, marked, and released, then allowed to redistribute in a site. The site is then resampled later (usually a day or more later) and the number of marked and unmarked fish are recorded. Abundance estimates from mark-recapture studies are calculated using the proportion of tagged fish recaptured in relation to the total number of fish (tagged and untagged) collected. For additional information on mark-recapture sampling we refer the reader to Zubik and Fraley (1988), Skalski (1996), Isely and Tomasso (1998), Cowley and Whitfield (2001), and Rosenberger and Dunham (2005) among others. Fish marking with Passive Integrated Transponder (PIT) tags or active transmitters (radio or acoustic) has the added benefit of providing information about how fish use specific locations if antennas are also installed at the site, although this increases monitoring expenses.

Assumptions for estimating population size using mark-recapture or removal methods include: (1) the population being sampled is closed, which means that fish are not moving into or out of the site during the sampling period, (2) all fish (marked and unmarked, fish remaining in subsequent passes) are equally vulnerable to capture, (3) all fish in the population are vulnerable to capture and there is sufficient mixing within the population to make the samples representative of the entire population. For mark-recapture estimation, sufficient time must be allowed between marking and recapture to allow all marked fish to randomly disperse throughout the site. These assumptions are difficult to satisfy in large rivers where habitats cannot be blocked to eliminate movement into or out of the sampling area, fish can move to avoid recapture, or major portions of the habitat cannot be sampled (for example, deep sections of a river, areas of high water velocity, dense vegetation, log jams). Other methods (Cormack-Jolly-Seber model; Cormack, 1964; Jolly, 1965; Seber, 1965) can be used for open populations based on three or more sampling periods, but these models are more quantitatively complex and require unique individual marks, such as PIT tags.

Population estimation can be challenging in a large river environment where assumptions are difficult to meet, so other metrics are commonly used instead. One of the most frequently used indices of abundance is catch per unit effort (CPUE), which is based on the number of fish captured during a specified period (for example, effort) using consistent methods and sampling effort (Bayley and Austen, 2002, Reynolds and Koltz, 2012). Although CPUE data do not provide direct estimates of population size, results obtained using this method can be interpreted in the same manner. For example, if CPUE estimates increase following restoration, one could infer that the restoration resulted in improved conditions for fish at the site. Factors that influence capture efficiency (such as gear type, sampling duration, or crew size) must be consistent between sampling periods to estimate CPUE reliably, thus standardized protocols have been developed (Thompson and others, 1998) and are recommended for use. Multiple gear types can be used to increase the types of habitats that can be sampled and numbers of species that can be captured,

Figure B5. Team-based approach to electrofishing. To speed electrofishing of a larger area of stream, sometimes a team of individuals using electrofishing shockers work together to capture fish in a specific area. In this example, several individuals with the U.S. Forest Service (not affiliated with U.S. Geological Survey) are using electroshockers within a unit that is constrained with a block net that keeps fish from moving out of the sample area. This work was completed by Brooke Penaluna’s laboratory with the U.S. Forest Service, Pacific Northwest Research Station. Photograph by Doni McKay, U.S. Forest Service, Pacific Northwest Research Station, July 27, 2017.

but consistent effort is essential. Results can be reported in a variety of metrics, including numbers of fish, biomass, community composition, or diversity of fish captured. For example, biomass can be estimated using fish length data and length-weight regressions for the species of interest. Length-weight regressions determined from the local population are more accurate than regressions that use literature-based values reported for fish from other regions. Interpretation of CPUE indices requires explicit description of the habitats and capture methods, reporting of limitations of the method, and a clear statement that the results are not true estimates of the population abundance or community composition.

At many Willamette River restoration sites, fish capture may be difficult due to the presence of deep water, high water velocities, and complex habitats which can limit the effectiveness of fish capture methods. Some techniques such as seines and electrofishing (figs B4–B6) may be effective in restoration sites where water is shallow and free of obstructions (such as gravel pits or floodplain swales in agricultural fields). But in locations that contain dense macrophytes, woody vegetation, or large accumulations of wood, other approaches should be considered (table B1).

Fish Community Composition and Diversity

Willamette River restoration efforts are primarily focused on protecting and enhancing diverse and healthy native fish communities, so restoration monitoring efforts should include assessments of community composition and diversity (table B1). The composition of a community can be described by the number of species (termed species richness) and their relative abundances (termed species evenness). Species evenness is an important component—a community that contains numerous species but only has high abundances of one or two species is considered less stable than a community in which numerous species are represented by high abundances in the majority of species present. Diversity of available biota has been linked with ecosystem health and can be quantified using an index of biotic integrity such as the Shannon Weiner Index (Spellerberg and Fedor, 2003). Such indices are driven by assessments of species richness, which can be interpreted to reflect ecological function in aquatic environments (Herlihy and others, 2005). In the Willamette River Basin, restoration monitoring can include efforts to estimate the relative abundance of various species in a community, number or diversity

Figure B6. A seine deployed in an estuary by U.S. Forest Service personnel (not affiliated with U.S. Geological Survey) to sample fish at location with deep, slow water. Fish sampling in large alcoves, gravel pits or side channels on the Willamette River may require the use of sampling approaches such as a seine. Photograph by Rebecca Flitcroft, U.S. Forest Service, PNW Research Station, July 18, 2015.

of salmonids (or other sensitive species), and the number of native fish species relative to non-native fish species (fig. B1; table B1). Assessment of fish community composition and diversity requires counting individual fish and identifying the species type for each counted fish. Monitoring approaches include snorkeling, electrofishing, seining, removal sampling, and mark recapture, although eDNA also can be used to assess species richness (see chap. B, section, "Fish Abundance," for descriptions of each fish sampling approach).

Fish Growth

Assessment of fish growth can be used to detect changes in either food availability for individual fish or in the numbers of fish present in a site (Simenstad and Cordell, 2000; Rosenfeld, 2003; Zale and others, 2012; Roni and others, 2014). Growth can be assessed using one of three general approaches: capture and recapture of fish cohorts over time (Deangelis and others, 1993; Vilizzi, 1998); calculation based on predictable growth in hard body parts (Watson and Balon, 1985; Francis, 1990; Vigliola and Meekan, 2009); and recapture of previously marked individuals (Baker and others, 1991; Eveson and others, 2004). Restoration efforts designed to increase food resources for fish communities may use fish growth as an evaluation metric, but more fully understanding the responses of the fish community to increases in food resources requires coupling fish growth with other metrics to determine how changes in fish growth relate to abundance. Examples of potential outcomes for different fish growth and abundance scenarios include:

- Increased individual growth, increased survival, and abundance with no change in individual size,
- Increased survival and growth coupled with migration out of the local habitat, and
- Increased growth and abundance of predators with no change in the prey population.

Each approach for assessing fish growth has specific requirements that should be considered when designing a monitoring plan. For example, assessment of cohort growth requires the collection and handling of large numbers of individuals to ensure that fish size data represent the cohort over a given period. The use of hard body parts for growth assessment typically requires lethal sampling to obtain body structures for analysis. Mark-recapture methods include efforts to mark a large number of individuals initially to ensure that a sufficient number of fish are recaptured during subsequent sampling periods. As with other fish sampling methods, recapturing a sufficient number of fish is challenging, particularly in a large river environment where individuals can move large distances. However, some Willamette River restoration sites (such as restored gravel ponds or other slow-water off-channel habitats) may provide suitable environments for sampling.

In addition to fish growth, other metrics related to fish size also can be useful for assessing restoration effectiveness. For example, condition factor (and its derivatives; Lima-Junior and others, 2002; Froese, 2006; Nash and others, 2006) is a metric that summarizes the body weight-to-body length ratio of individual fish. Condition factor values greater than 1.0 are generally associated with "good" fish growth conditions and values less than 1.0 generally are associated with "poor" fish growth conditions. Comparing condition factor values for fish before and after restoration activities can be insightful for understanding how restoration affected fish at a site. Increases in condition factor values would indicate that fish at the site experienced better conditions as a result of the restoration activity, whereas decreases in condition factor values would indicate that conditions worsened for fish. Condition factor is most effective when comparing fish of the same species and length. We refer readers to Pope and Kruse (2007) for a comprehensive review of condition factor.

Food Resource Availability

Several Willamette River restoration activities are specifically implemented to increase access to floodplain habitats, which may indirectly affect food resources for native fish (table A7). Food resources for native fish vary seasonally and can originate outside of the stream, when terrestrial matter (plant matter and terrestrial invertebrates) falls directly into a stream and is carried downstream. Aquatic food resources also originate within the river and include plants (algae and periphyton) and animals (benthic macroinvertebrates, macroinvertebrates carried by streamflow, and small fish). Composition and availability of food resources in streams have been shown to affect fish growth and population size (for example, Filbert and Hawkins, 1995; Johansen and others, 2005).

The use of food resource monitoring for assessing Willamette River restoration activities will vary depending on season and streamflow level so these factors must be considered during study design (table A8). For example, planting floodplain forests in former agricultural fields is hypothesized to provide greater food resources than would otherwise be available in a seasonally flooded agricultural field. Monitoring can compare food resource availability in several settings or seasons to determine (A) differences between newly planted floodplain forests and agricultural areas (to provide an indication of increases in food resources after planting), (B) differences between newly planted areas and the main channel (to confirm hypotheses about floodplain forests providing greater food resources than the channel), and (C) differences between mature floodplain forests and newly planted sites (to provide an indication of food resources provided by restoration sites in future years). For all other restoration activities, monitoring can determine if the availability and quality of food in restored sites is adequate to support the life stage and species of interest. Monitoring can also help determine whether other food-rich areas are proximal to the restoration site and if fish can readily move between sites. Monitoring of food resources alone will not indicate that the action benefitted fish populations, so interpretation of restoration effectiveness will require monitoring of both the food resources and fish communities that utilize them.

Monitoring Food Resource Availability

Monitoring of food resources can be carried out by sampling benthic macroinvertebrates (fig. B7), drifting macroinvertebrates, leaf matter, stable isotopes, diatoms, terrestrial insects, and other terrestrial and aquatic resources used as food for the fish species of interest. Sampling approaches can include drift nets for macroinvertebrates carried by streamflow (Leung and others, 2009), kicknets for capturing benthic macroinvertebrates (Frost and others, 1971), insect nets (Jackson and Fisher, 1986), benthic substrate samplers (Brown and others, 1987), periphyton collection (Biggs, 1995), and measurement of primary production rates (Wooten and Powers, 1993). These sampling approaches can be applied to zones of different land uses or vegetation communities within a restoration site to assess differences in food resources that may reflect the age or type of floodplain vegetation communities. Seasonal sampling can characterize changes in food resources that reflect many factors, such as canopy cover, input of terrestrial insects (in sites located on floodplains and other seasonally inundated areas), presence of aquatic emergent vegetation, primary production, and life stages of benthic macroinvertebrates (in aquatic sites). Specific protocols that include consideration of sites for sampling, sampling intensity, and repeatability of sampling are critical for macroinvertebrate sampling to be a useful indicator of changes due to restoration at a given location. Additionally, protocols for assessing food resource availability will need to reflect seasonally varying site conditions and the challenges of working on a large river like the Willamette River. Most sampling protocols were developed for small, wadable streams and may not be feasible in some areas of the channel or certain seasons. For example, wadable side channels with cobble substrate could be sampled for periphyton and benthic macroinvertebrates in summer months and during low-flow periods of the autumn, winter, and spring using standard approaches listed above. However, water velocities in these areas may preclude sampling during winter high-flows, so high-streamflow sampling could focus on inundated floodplain areas where water velocities are slow and fish are more likely to seek refuge.

Figure B7. Macroinvertebrate sampling that can be used to assess food resource availability. Sampling of macroinvertebrates provides important datasets to document diversity and health of aquatic ecosystems. Here, a stream ecologist from the U.S. Forest Service samples for macroinvertebrates in a small stream channel at Mount St. Helens, Washington. Photograph by U.S. Forest Service, July 21, 2015.

Metrics that can be derived from food resource monitoring that are relevant for understanding the effect of restoration include diversity measures and biomass. Although diversity has been previously discussed, biomass is also an important metric because it can help to understand food abundance which, along with water temperature, influence fish growth (Weber and others, 2014). Two widely used methods for assessing invertebrate communities are models of taxonomic completeness (expected versus observed community structure; Hawkins and others, 2000; Hawkins, 2006) and multi-metric indices (Index of Biological Integrity; Karr and Chu, 1997; Hughes and others, 2011). Both approaches can provide useful information on the overall condition of the aquatic ecosystem.

Collection of benthic macroinvertebrates also can be used to track functional groups of organisms (scraper, shredder, collector-gatherer, collector-filterer, predator) or to analyze tropic positions (primary producer, primary consumer, secondary consumer, tertiary consumer). Benthic macroinvertebrate community composition has been shown to change in response to stream restoration (Muotka and others, 2002). Ratios of functional groups can inform assessments of species turn-over and have been used to describe ecosystem conditions (Merritt and others, 2002).

Modeling Food Resource Availability with Food Webs

Food webs, which describe relationships among food resources and consumption, are the foundation of stream ecosystems (Pimm, 1982) and restoration programs that focus solely on physical habitat availability without considering food webs may not achieve desired improvements in fish populations (Naiman and others, 2012). Although not specifically a monitoring approach, a food-web study may holistically describe the ecosystem response to a restoration project and would be useful for considering whether a river system can support current and restored fish populations (Naiman and others, 2012). Food-web studies require more extensive data collection and analytical modeling than is needed to monitor terrestrial and aquatic food availability. However, monitoring data can be used as inputs into extensive food-web models that can identify critical factors to track (fig. B8).

A food-web study is designed to quantify relationships among nutrients, periphyton, terrestrial and aquatic inputs, macroinvertebrates, and fish (Pimm, 1982). Food-web studies may examine all these elements together, or portions of them separately to construct and examine different relationships among inputs. Typically, food webs show links or connections among species and elements of the food web (for example,

Figure B8. Field sampling to assess stomach contents of fish. In food-web studies, diet contents of fish are often sampled to determine what the fish are eating. In this figure, a graduate student is taking a sample of what a trout has eaten using gastric lavage, a technique in which water is used to flush out fish stomach contents. The stomach contents will be analyzed in the laboratory to determine the type and quantity of food items consumed by the fish. Photograph by U.S. Forest Service, 2019.

Townsend and others, 1998; Zatkos, 2019). A food-web study may be combined with indicators of fish presence, fish abundance, or fish growth. As an effectiveness monitoring indicator, fish growth links more closely to a food-web study than other indicators.

Food-web studies based on empirical data are expensive because they require multiple sampling methods, intensive collection and processing of samples, and expert evaluation. Models used to represent food webs allow for representations of connections among nutrient inputs and aquatic biota and in some cases, simple models with limited data collection may prove informative for monitoring. Food source availability, the diversity of food sources and quantity of food may be determined and presented using graphs and summary tables (Pimm, 1982).

Fish Monitoring Synthesis

The overarching goal of restoration activities implemented under the WFIP restoration initiative is to increase and enhance habitats used by native fish. Effectiveness monitoring should evaluate changes in fish communities and their food resources to confirm that restoration actions are having desired outcomes. However, fish monitoring poses several challenges, including: (1) fish monitoring in restored floodplain and off-channel sites is often logistically challenging and cost prohibitive, (2) it is difficult to establish causal linkages between restoration activities and changes in fish communities due to the many factors that influence fish communities, and (3) restoration projects comprise a small portion of available floodplain habitats. Despite these challenges, fish monitoring can supplement physical habitat monitoring (chaps. C–F) and be used to evaluate the many outstanding questions about overall benefits of restoration for native fish communities. For example, for a given restoration site, monitoring can determine the presence of focal fish species, confirm hypotheses about seasonal patterns of fish use, assess diversity of the fish community, the potential for predation by non-native fish, and document food resources and potential growth rates for fish utilizing restoration sites. Ultimately, information from fish sampling will aid in the refinement of hypothesized linkages between restoration program goals, restoration activities, anticipated changes in physical habitats, and anticipated outcomes for native fish communities.

Although a variety of monitoring indicators can be used to assess restoration effectiveness for improving fish populations and fish habitat, this report focuses on five monitoring indicators that best align with the goals of the WFIP restoration initiative to improve fish habitat and can be evaluated within the likely resources for Willamette River Basin effectiveness monitoring. These monitoring indicators of fish communities and their food resources include (1) fish presence, (2) fish abundance, (3) fish community composition and diversity, (4) fish growth, and (5) food resource availability (table B1; fig. B1). Of these, the most appropriate fish monitoring indicators for individual restoration activities could be identified and paired with suitable metrics to develop site-specific monitoring activities. The hypothesized outcomes of individual restoration activities, along with site-and reach-scale considerations for fish communities and site conditions should influence the selection of monitoring activities implemented at restoration sites. Examples of fish monitoring indicators for various categories of Willamette River restoration activities are shown in tables A8 and B1, and figure B1. To aid in the selection of fish monitoring indicators and methods, monitoring considerations, field sampling approaches, and analytical metrics associated with each monitoring indicator were reviewed (fig. B1; table B1).

The highest priority indicator is fish presence, which can be used for all restoration activities implemented under the WFIP restoration initiative (table A8; fig. B1). Fish abundance is more challenging to assess and requires more intensive sampling methods that are most feasible at sites such as gravel pits or off-channel features (rather than broad floodplain areas with shallow inundation). Fish abundance would perhaps be targeted at sites where large-scale, and particularly expensive restoration actions (such as enhancement of gravel pits, or construction of off-channel features) are implemented with the specific purpose of increasing habitat for a focal species such as ESA-listed juvenile spring-run Chinook salmon (table A8; fig. B1). The composition and diversity of fish communities are important to monitor because the WFIP and previous restoration programs have sought to improve fish habitats to benefit the overall community of native fish. Community composition assessments will complement abundance estimates that may focus on juvenile spring-run Chinook salmon or other species of interest and may provide additional insights. For example, this approach could address predation potential by non-native fish in restoration sites or assess how restoration actions may affect habitats used by predatory non-native fish species. All Willamette River restoration activities are hypothesized to benefit rearing habitats for juvenile spring-run Chinook salmon, particularly in the autumn, winter, and spring when these fish are most likely rearing and migrating the river (Schroeder and others, 2016). Monitoring of fish growth and food resources is thus potentially useful at many restoration sites to determine if these sites provide anticipated rearing benefits. Because fish growth requires intensive sampling and is only feasible at certain types of sites, this monitoring can focus on sites such as restored gravel pits or areas where large-scale human-made barriers to inundation were removed, so that the benefits of these expensive large-scale projects to fish growth and rearing can be evaluated (table A8; fig. B1). Monitoring of food resource availability could focus on two types of sites where restoration was hypothesized to increase fish access to food-rich areas: (A) floodplain sites where inundation was increased through topographic modifications (such as swale deepening) or modification of human-made barriers (culvert removal) and (B) floodplain forest planting sites (table A8; fig. B1).

Chapter C. Monitoring Hydrogeomorphic and Water Temperature Responses to Restoration Activities that Directly Modify Hydrogeomorphic Processes

By Mackenzie K. Keith[1] and J. Rose Wallick[1]

Many Willamette River restoration activities to improve native fish habitat consist of alterations to floodplain topography or human-made structures to influence hydrologic, hydraulic, and geomorphic processes at those sites (figs. C1 and C2). Collectively, ‘hydrogeomorphic processes’ (Sidle and Onda, 2004) include physical interactions between landforms and water and encompass many of the processes affected by restoration activities. Four restoration activities to meet the initiative goals and objectives outlined in the WFIP Strategic Action Plan (AHWG, 2015) affect hydrogeomorphic processes and are summarized in figures A9, A10, and C1 and in table A7:

1. Modify floodplain topography and human-made barriers to inundation,
2. Enhance gravel pits,
3. Remove revetments, and
4. Construct off-channel features.

Monitoring physical responses to hydrogeomorphic restoration activities is a primary focus for this framework because (A) many restoration projects have been implemented to influence hydrogeomorphic processes, with a particular focus on increasing rearing habitats for juvenile spring-run Chinook salmon, (B) monitoring data and evaluation provide an indication of whether restoration activities are creating suitable habitat conditions for native fish, and (C) the physical responses typically can be observed in the near-term (within about 1–5 years; table A7) and feasibly monitored within the timeframes of most monitoring programs. Four hydrogeomorphic monitoring indicators to evaluate effectiveness of restoration activities on enhancing or increasing native fish habitat are described in this chapter: (1) floodplain inundation, (2) planimetric changes in channel features, (3) vertical changes (deposition and scour) in channel and floodplain features, and (4) water temperature (table A8; fig. C1).

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Hydrogeomorphic Monitoring Indicators and Approaches

Floodplain Inundation

Inundation, or areas where water is covering land or the channel bed, varies with streamflow conditions and underlying channel and floodplain morphology. Floodplain inundation is a useful indicator of effectiveness for restoration activities, because various native fish species at different life history stages require access to floodplain habitats and suitable inundation conditions for survival. Monitoring can be used to evaluate whether restoration goals for inundation are achieved and place changes in inundation within broader temporal, spatial, and hydrological context so the relative importance of the restoration activities can be assessed and compared with other processes affecting floodplain habitats. Understanding the hydrogeomorphic context (streamflows and floodplain connection) of a particular project site is helpful for evaluating the total area of usable habitat for focal fish species and the amount of time that the site provides habitat. Understanding those conditions over a broader scale can provide information on the amount of additional habitat available in a subreach (about 10 km; fig. A13) of the river where the restoration project is located. Effectiveness monitoring also can be used to track changes in inundation over time that indicate evolving morphological conditions that can lessen project effectiveness. If a deepened floodplain swale fills with sediment, monitoring can indicate whether sediment deposition has reduced the desired inundation conditions such that sediment removal is warranted. Six general monitoring approaches are described to characterize multiple aspects of inundation pertinent to fish habitats including water-surface elevation depth, and inundation extent, timing, frequency, and duration using: (1) field-based surveys, (2) continuous loggers, (3) crest-stage gages, (4) mapping aerial photography, (5) repeat ground-based photography, and (6) hydraulic modeling.

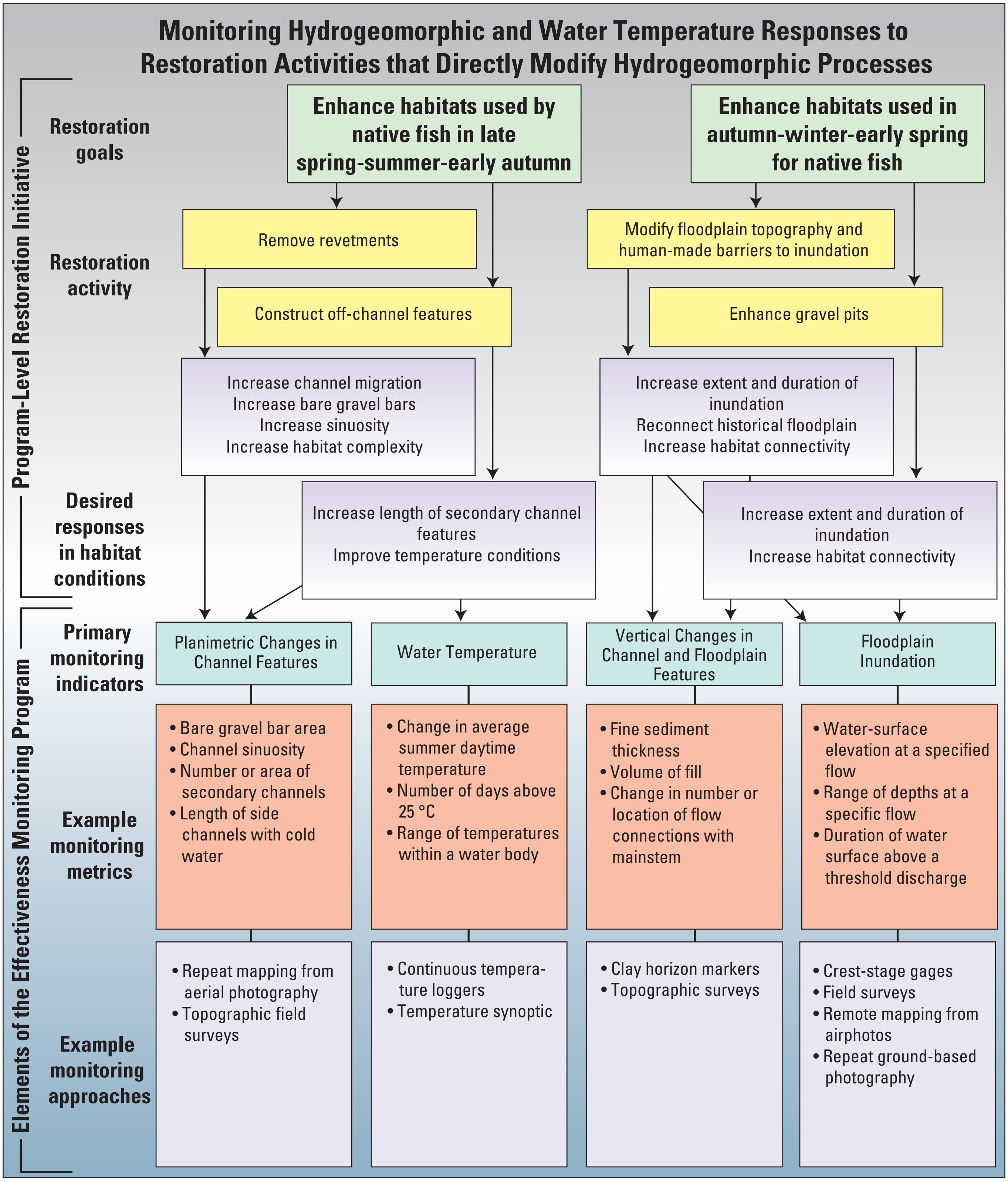

Figure C1. Linkages between hydrogeomorphic restoration activities and hypothesized responses in physical habitats used by native fish with associated monitoring indicators, metrics, and approaches.

Figure C2. The Willamette Confluence Preserve along the Middle Fork Willamette River showing post-restoration floodplain modification and removal of a levee at a series of gravel pits. Photograph by BCI Contracting, August 7, 2017, provided by The Nature Conservancy.

Measuring Water-Surface Elevations, Depths, and Extent with Field-Based Surveys

Field-based topographic surveys are used to map water-surface elevations, high-water marks, water depths, or areal extent of inundation for specified streamflows. Example metrics for evaluating Willamette River restoration activities include:

- Water-surface elevation or depth at a single point over a range of streamflows,
- Water volume from area of inundation and depth,
- Range of depths usable by native fish within a water body, and
- Duration of water surface above a threshold streamflow at which fish can access the floodplain.

Field-based topographic surveys can be used to delineate inundated areas at various streamflows. Surveys using high-resolution global positioning systems (GPS) (for example, Rydlund and Densmore, 2012) are recommended for documenting small changes in water depth or extent and provide greater detail for building high-resolution datasets. Relating observed patterns of inundation to streamflow and stage at nearby gages allow assessment of the frequency and duration of inundation. At low streamflows, the edge of water (outline), water-surface elevation, and depth of shallow areas can be surveyed directly when inundation extent is not readily detectable from aerial imagery. At high streamflows, the scale of overbank inundation on large rivers like the Willamette River, and the complexity of site access can preclude field-based surveys at some restoration sites. When site conditions are unsafe or inaccessible during high streamflows, high-water marks can be used to indicate inundation elevation and extent and can be surveyed after streamflows have receded.

The timing and frequency of surveys depends on site-specific condition and goals for inundation, but surveys should coincide with streamflows above a defined threshold (perhaps the targeted design inundation event) and less frequent flood events if they occur (such as during the April 2019 flood, when peak streamflows exceeded the 10-year recurrence-interval flood; fig. C3). Multiple surveys over time would help characterize various streamflow conditions whereas a single survey effort can be used to characterize conditions at a specific streamflow condition. Repeat topographic surveys also would document changes in channel morphology and associated changes in inundation. Surveys also can provide information on other channel features important to fish habitats or to collect data useful for calibrating hydraulic models.

Figure C3. Inundation extent of the Harkens Lake site (river mile 153.5) during flood conditions, April 8, 2019. Photograph by River Design Group, Inc.

Measuring Water-Surface Elevations or Connectivity with Continuous Water-Level Loggers

Continuously logging water-level instruments, often pressure transducers, can be deployed at a site to record seasonal or annual water-surface elevations (or lack of inundation) at hourly to subhourly intervals. Specific metrics to monitor restoration activities can include:

- Discharge at which a site becomes inundated (using discharge from a nearby gage),
- Number of consecutive days that water depth is suitable for particular fish species or life stage,
- Number of inundation events per year that water depth is suitable for particular fish species or life stage, and
- Area of inundation corresponding to selected streamflows (requires streamflow information and continuous elevation data, like lidar).

The use of continuous water-level loggers is ideal for answering questions regarding hydraulic connectivity, particularly of constructed or reconnected channels, connected gravel pits, and sites where floodplain topography was modified. Protocols and guidance on deploying loggers are well documented (for example, Freeman and others, 2004; EPA, 2014; ODEQ, 2020). At gravel pit or constructed channel restoration sites, documenting surface-water connections throughout the high-streamflow season with continuous loggers may be practical, whereas inundation monitoring at floodplain sites that are infrequently inundated might be more suited to alternative monitoring approaches discussed in this chapter. Year-round monitoring in gravel pits also can help characterize low-streamflow conditions.

Deployment of continuous loggers should reflect the monitoring questions, hydrology, and other considerations at a site. At long-term monitoring sites (months to years) water-level data can be measured at larger intervals (hourly) to account for logger storage and battery life. At restoration sites where inundation is sensitive to rapid change (such as influence from streamflow of a small, unregulated tributary), water levels can be recorded at finer intervals (15 minutes) and summarized at coarser intervals. Water levels in many Willamette River restoration sites can be monitored using a single water-level logger, but sites with complex hydraulics (where inundation patterns are influenced by multiple connections with the main channel or tributary inputs) would require multiple loggers to characterize water-level variation that relates to inundation from these various sources. Multiple water-level loggers are useful for understanding the upstream and downstream connectivity within a side channel or floodplain channel; for example, one water-level logger placed near the downstream end to measure water levels associated with backwater and one at the upstream higher/drier point to document when an upstream surface-water connection is made.

Measuring Water-Surface Elevations at High Streamflows with Crest-Stage Gages

Crest-stage gages (for example, Friday, 1965; Sauer and Turnipseed, 2010) can be deployed at sites to record the water-surface elevation associated with peak streamflows at a specific location where flooding is infrequent. Specific metrics to monitor restoration activities can include:

- Stage or water-surface elevation associated with high streamflows and
- Inundation extent when the water-surface elevation data are compared to a digital elevation model (DEM).

At locations where barriers are removed or floodplain topography has been modified to increase hydraulic connectivity, crest-stage gages can be used to confirm that inundation has occurred at high streamflows. However, continuous water-level loggers would be of more utility for answering questions about timing and duration of inundation events. Sauer and Turnipseed (2010) provide guidance on the location, operation, and maintenance of crest-stage gages that are used to build stage-streamflow relations; although less intense applications to determine stage or elevation would be sufficient for restoration activities. Periodic site visits are required to check a crest-stage gage, but the peak streamflow record is retained so site visits can be coordinated when site conditions allow access.

Mapping Inundation Extents Remotely from Aerial Photography

Inundation extent can be monitored through repeat mapping from aerial photographs acquired at specific streamflows. Aerial photographic mapping characterizes conditions at single points in time and provides a basis to determine if restoration projects have successfully met goals for inundation. Metrics to support effectiveness monitoring with this approach can include:

- Inundated area that native fish can access,
- Perimeter length (or wetted edge) of inundated area that is preferable habitat for native fish, and
- Area where water depths are usable and accessible by native fish (when inundation maps are combined with DEMs).

Inundation extent mapped for multiple streamflows can facilitate building a relation between inundation area and streamflow recorded at a nearby gage. Inundated areas can be digitized manually in a geographic information system (GIS; for example, Wallick and others, 2010, 2011; Keith and Gordon, 2019) or completed with automated image classification approaches (for example, Breiman, 2001; Demarchi and others, 2016; Overstreet, 2020). Acquiring aerial photographs from flights with onboard pilots during high streamflows can rapidly survey multiple large restoration sites along the river corridor. High-resolution imagery from unoccupied aerial systems (UAS) can characterize inundation at a single restoration site; this platform may be easier to rapidly mobilize than flights with onboard pilots. Both platforms may have limitations in inclement weather. Publicly available satellite imagery may provide inundation information between periods of regularly scheduled acquisitions and during conditions when other platforms are unable to fly. Each of these platforms can miss capturing peak flood and maximum inundation events if those events occur for a short period or when daylight is insufficient for image acquisition. For large rivers like the Willamette River where streamflows are regulated and generally rise and recede slowly, image acquisition during daylight hours may document inundation extent similar to the maximum extent for that specific event.

Inundation mapping from remote-sensing data is ideal for monitoring changes in floodplain areas where low-relief topography permits greater areal increases in inundation with increasing streamflows compared to side channels, where wetted width is confined by steep channel walls (fig. C3). Image resolution is an important part of data collection and dictates the level of detail and types of features that can be mapped. Images with a higher resolution (with a pixel size less than 0.5 m) can support a detailed evaluation of inundation patterns at individual restoration site. However, slightly lower resolution imagery (pixel size of 1 m) could be acceptable for many applications particularly if the scale of inundation is large. Many Willamette River floodplain restoration sites encompass former agricultural fields where inundation at high streamflows may extend across multiple hectares, and lower resolution imagery could be timed to encompass multiple mapping sites during a specific streamflow event.

Documenting Inundation with Ground-Based Photography

Ground-based photography can be used to monitor inundation at a wide range of streamflow conditions. Photographs acquired from fixed cameras on timers or taken manually at repeat photograph locations during site visits provide a qualitative method for tracking changes in inundation over time. The approaches and considerations for ground-based photography are well established, such as those summarized by Ciannella and others (2021). Resulting analyses may be largely qualitative with simple comparisons of wetted versus non-wetted periods at the time of the photograph. Key considerations include selecting photograph point locations where the image frame contains a large, immobile target from which to reference repeat photographs. Additionally, the longer-term visibility of the feature of interest should be considered; if the objective is to monitor water-surface level, evaluating whether vegetation might grow and obscure the frame would be useful. Repeat photographs are cost-efficient and typically easy to implement but may have drawbacks including site access issues, sufficient daylight for image acquisition, and personnel safety during high streamflows. For ground-based photography designed to track changes in inundation, the timing and frequency of photograph acquisition should be considered. At sites where side channels have re-connected to the main channel, photograph locations might focus on the inlet and outlet, and photograph timing can be paired with streamflow gage data to document surface-streamflow connections at streamflows. At sites where the restoration goal is to increase floodplain inundation, images with a large field of view can be collected during inundation.

Modeling Inundation with Hydraulic Models and High-Resolution Topography

Hydraulic models developed with high-resolution topographic data of a restoration site (from field surveys, lidar, or both) can characterize inundation patterns or evaluate variation in inundation under different streamflow scenarios. A hydraulic model that accurately predicts inundation at restoration sites also can be useful for evaluating project effectiveness. The model can simulate inundation (extent, duration, and water depth) at various streamflows to characterize changes that result from the restoration project or compare inundation at restored and non-restored sites. Hydraulic models are useful for characterizing inundation conditions at large sites or sites with complex topography that would be challenging to measure in the field and can complement field-based activities. Model results can be verified with field data to improve and refine the model over time. Detailed two-dimensional models developed for the Willamette River (White and Wallick, 2022; White, 2022) can be used as a starting point evaluate inundation at restoration sites and updated to reflect changes in floodplain conditions.

Planimetric Changes in Channel Features

For gravel-bed rivers like the Willamette River, planimetric changes (defined here as geomorphic changes related to horizontal adjustments independent of elevation and that can be observed using aerial photographs or other two-dimensional maps) include changes in channel position, gravel bars, and side channels. These changes are indicative of river channel lateral stability and sediment supply (for example, O'Connor and others, 2014). Channel features such as gravel bars, side channels, and alcoves contribute to the overall aquatic and floodplain habitat complexity (for example, Hall and others, 2007; Harrison and others, 2011; Williams and others, 2020). Planimetric changes also are indicative of the geomorphic and vegetation processes that create and sustain complex habitats over time (for example, Jones and others, 2016; Wallick and others, 2018; Gregory and others, 2019).

Willamette River restoration activities likely to cause planimetric changes in channel features include revetment removal, construction of off-channels features, modifications to floodplain topography, and gravel pit enhancements. Repeat mapping of channel and floodplain features can quantify changes that result directly from implementation of the restoration project, as well as subsequent geomorphic evolution of those features. Planimetric change can be monitored with quantitative mapping of the active channel and floodplain from remote-sensing data or be field-based topographic surveys or with more qualitative approaches using repeat, ground-based photography.

Mapping Channel and Floodplain Features from Remote Sensing Data

Channel and floodplain features such as bare gravel bars, vegetated bars, floodplains, side channels, and alcoves can be mapped remotely to evaluate geomorphic changes over time. Examples of metrics useful for effectiveness monitoring include the following:

- Channel length or side channel length that fish can occupy,
- Number of low- or high-streamflow channels available for habitat,
- Bank erosion/lateral migration distance, and
- Gravel bar area.

Approaches for mapping channel and floodplain features in gravel-bed rivers are well established for both manual digitization techniques (Wallick and others, 2010, 2011; Jones, Keith, and others, 2012; Keith and Gordon, 2019) and automated techniques (Breiman, 2001; Demarchi and others, 2016; Overstreet, 2020). Both mapping approaches can use remote sensing datasets, such as aerial photographs, lidar, or satellite imagery, if image resolution and quality (for example, features are not obscured by vegetation, shadows, clouds) are sufficient for mapping. Frequency of repeat mapping will depend on the timescales over which channel changes are expected to occur, types of streamflows spanning a period, and the availability of underlying datasets. Ideally, mapping would be completed for a period prior to restoration project implementation, soon following implementation, then repeated every 1–5 years depending on streamflows between mapping periods and available datasets. Planimetric changes over short periods (1–5 years; regardless of streamflows) may be hard to detect due to geomorphic stability of the Willamette River and because many restoration projects occur on floodplains that are infrequently flooded (Wallick and others, 2013), so longer mapping intervals (decadal) may be needed. A lack of planimetric change is still informative and can reflect (A) a lack of flood events, (B) geomorphic stability, or (C) restoration project objectives to stabilize the site. Some side channels are deepened to increase water depths with large wood, boulders, or root wads installed at channel inlets to prevent bank erosion, so geomorphic stability is expected at these sites and would indicate the project is performing as expected. In contrast, other restoration projects remove revetments to encourage channel migration, so geomorphic stability may reflect a lack of high streamflow events that can trigger bank erosion.

Repeat mapping of channel and floodplain features from remote-sensing datasets is useful for evaluating changes in channel morphology at sites where the restoration project goal was to facilitate geomorphic processes of lateral migration over channel segments greater than about 2 km by removing stabilizing revetments and levees that prevented bank erosion. At these sites, repeat mapping can quantify changes in the position of channel banks and wetted channels (indicating lateral migration and erosion) as well as changes in gravel bars (indicating deposition). Repeat mapping also can be used to monitor other restoration activities that involve major hydrogeomorphic modifications to the floodplain, such as enhancements of gravel pits, where monitoring channel and floodplain features would be useful for evaluating implementation, project longevity, and long-term evolution of the site. This approach can be combined with floodplain vegetation mapping (see chap. B, section, “Mapping Canopy Cover from Remote Sensing Sources”) efforts with the same datasets to further characterize conditions at the restoration site, because most hydrogeomorphic restoration sites are subsequently planted. Although repeat mapping should focus on restoration sites, the mapping will be more informative if extended to include non-restoration sites to create a continuous map of channel and floodplain features throughout the reach and compare geomorphic changes within the restoration site to those occurring along the broader reach.

Mapping Channel and Floodplain Features with Field-Based Topographic Surveys

Field-based topographic surveys are useful for measuring small-scale planimetric changes that may not be detectable from remote-sensing datasets or for recording conditions at a specific time when remote-sensing imagery is not available or if the site is obscured by overhanging vegetation. Determining landform mapping units for which channel and floodplain features within a restoration site to survey can be modified from remote approaches. Detailed protocols for surveying stream habitats at restoration sites have been developed for the Columbia Habitat Monitoring Program (2014) and could be readily adapted for Willamette River restoration sties. Additionally, Kennedy (2013) provides considerations for pre-field planning and the types of equipment that can be used for topographic field surveys. Ground-based topographic surveys can be collected at temporal frequencies similar to remote mapping approaches (1–5 years depending on streamflows). Because of the large size of Willamette River restoration sites and the effort involved in field-based topographic surveys, surveys are best suited for detailed characterization of smaller areas within a restoration site or mapping large channel or floodplain features in less detail. For example, surveys of the channel bed, banks, and adjacent floodplains can target specific features along a 2-km long side channel, or a less detailed survey of the entire channel can focus solely on the thalweg and edge of banks.

Field surveys are appropriate for evaluating restoration activities that facilitate lateral changes (revetment removal) or activities that have less certainty in the expected responses. Where revetments or levees are removed, surveys might focus on bank segments where the removal occurred. At sites where side channels have been constructed or reconnected with the main channel, floodplain topography has been modified, or gravel pits have been enhanced, surveys can provide information on changes to features that were directly modified, such as floodplain swales or upstream connections between water features and the main stem.

Documenting Channel and Floodplain Features with Ground-Based Photography

Ground-based photography can qualitatively monitor morphologic changes and the potential influence of streamflows, vegetation growth, and other factors on channel and floodplain features. Examples of metrics that can be assessed changes in channel and floodplain features with ground-based photography include:

- Presence of gravel bars,
- Number of large wood pieces,
- Percentage of frame covered by sediment versus vegetation,
- Channel position relative to a fixed point, and
- Channel width relative to a fixed point.

Ground-based photography to monitor changes in channel features can follow the approaches and considerations described previously for inundation (chap. C, section, “Documenting Inundation with Ground-Based Photography”; Ciannella and others, 2021). The locations for repeat photograph point monitoring should be established so the image frame contains channel features of interest and characterizes features at low- and high-streamflow conditions. For example, photographs for a newly deepened side channel at low streamflows can show the entire channel cross section to detect bank erosion and substrate changes on the channel bed. Multiple photograph locations at a site can provide an inventory of channel or floodplain features and site topography.

Vertical Changes in Channel and Floodplain Features

The Willamette River channel and floodplain are subject to inundation and sediment transport during high streamflows, which can trigger erosion, deposition, and corresponding vertical changes in channel bed or floodplain surfaces.

Because many restoration projects seek to increase frequency, duration, and magnitude of inundation, they potentially also alter erosion and deposition patterns compared to pre-project conditions. Vertical changes in channel and floodplain features from incision (lowering of channel bed or floodplain caused by erosion) and aggradation (increase in elevation caused by deposition) can be beneficial for habitats as new channels are created and floodplains are constructed; although there also are concerns that incision and aggradation can minimize habitat benefits of restoration projects by disconnecting features and fish access or reducing the longevity of restoration activities. Deposition can reduce channel capacity, water depths, and inundation extents whereas both incision and deposition can create unintended barriers to fish migration between the restoration site and main channel.

Effectiveness monitoring is useful for determining the spatial extent, magnitude, and type of vertical changes that occur within coarse bed material of channel features (such as side channels with gravel and cobble substrate) and finer sediments within floodplain features (such as swales with sand and silt substrate). Monitoring approaches for measuring vertical changes should be appropriate for the geomorphic conditions and magnitude of vertical change anticipated for a particular feature (channel versus floodplain). For example, topographic surveys within active channel features can characterize channel bed incision or deposition of more than about 0.1 m, whereas finer resolution approaches, such as horizon markers, can be used to detect and measure millimeter- to centimeter-scale changes in fine sediment deposition on floodplains features.

Measuring Vertical Changes to Assess Sediment Deposition and Erosion with Field-Based Topographic Surveys

Vertical changes resulting from deposition and erosion along channel and floodplain features can be monitored with repeat topographic field surveys as described in Wallick and others (2018). Example metrics that are useful for evaluating vertical changes include the following:

- Change in elevation at a point over time along thalweg,
- Gradient (or bed slope) along a constructed channel or modified floodplain swale, and
- Range of elevations within a feature or landform.

Topographic field surveys should follow techniques described in previous sections. Monitoring vertical changes of features would complement monitoring planimetric mapping of channel features and can occur at similar spatial and temporal scales. Because vertical changes in channel or floodplain features can result from all restoration activities that influence hydrogeomorphic processes, topographic field surveys of vertical stability can be used for many projects (appendix 4). However, assessing vertical changes in restored channel and floodplain features is particularly important where vertical stability is highly uncertain, and the consequences of vertical changes substantially reduce the benefits of the restoration project. At sites where floodplain topography has been modified (such as swale deepening), field-based surveys can indicate areas where fine sediment deposition is occurring and where finer resolution approaches (such as horizon markers) can be used to track deposition in relation to various streamflow events. Monitoring channel bed elevations with surveys through heavily modified or constructed channels can provide information on the locations, sizes, and diversity of geomorphic features that support fish habitat or be used to track changes in those features over time.

Measuring Fine Sediment Deposition with Horizon Markers

Horizon markers are an artificial layer, commonly composed of brightly colored clay, placed on the ground surface to measure aggradation above that layer (fig. C4), because the marker is easily identifiable and differentiated from sediments (for example, Gellis and others, 2015; Keith, 2019). Example metrics for monitoring hydrogeomorphic restoration activities can include the following:

- Average depth of sediment following each period of inundation,
- Average depth of sediment following the high-streamflow season,
- Average depth of sediment above specific high-streamflow thresholds,
- Range of sediment depths across floodplain features within a site,
- Presence or absence of sediment on the horizon marker (also an indicator of inundation), and
- Organic matter content of a deposit (possibly in conjunction with other floodplain forest monitoring activities).

Seasonal or event-based floodplain deposition can be measured by installing horizon markers along low energy channel and floodplain features such as swales or vegetated bars to characterize fine sediment accumulation rates, organic matter content, or depositional patterns that relate to inundation and sediment transport processes (Wallick and others, 2018). Alternatively, deposition plates or discs (for example, constructed from plastic or plexiglass) can be used when more detailed analyses of grain sizes or organic matter are desired and when particles introduced from clay markers would influence those findings (for example, Kleiss, 1996; Keith and others, 2014; Wallick and others, 2018). The horizon markers can be deployed in the autumn prior to high streamflows that inundate the site, and sediment thickness can be

Figure C4. Clay horizon marker illustrating the contrast between fine sediment deposition over brighter clay. Photograph by U.S. Geological Survey, March 31, 2016, along Fall Creek, a tributary to the Middle Fork Willamette River, northwestern Oregon.

measured between high-streamflow events in the winter and spring before vegetation becomes established on the marker, obscuring the sediment deposit. Grain sizes or organic matter analyses provide information on sediment textures and organic matter content, which can influence water quality and aquatic food webs. Because horizon markers can be completely buried under newly deposited sediment or scoured by erosion, locating the horizon markers can be challenging. Reference systems (such as rebar or other static post) will facilitate recovery of the site and future sediment measurements; however, it is important that the reference system does not interfere with local streamflow and sediment dynamics.

Restoration activities that alter inundation patterns can warrant monitoring of fine-sediment deposition with horizon markers. At sites where modifications to floodplain topography (such as deepening of floodplain swales) or to human-made streamflow and fish passage barriers (such as culvert or road crossing modifications) occur, geomorphic processes are conducive to fine-sediment deposition and clay horizon markers are likely to be effective at characterizing sediment deposition. For some restoration sites, the measurements at horizon markers can be coupled with assessments of plant material (for example, leaves or detritus from floodplain forests) that fall on the markers, especially if there are questions about food resources or food webs at certain sites (see chap. B, section, “Food Resource Availability”).

Water Temperature

Water temperature is a water-quality parameter useful for evaluating hydrogeomorphic responses to restoration activities. Water temperature is influenced by solar radiation, hydrologic processes, and geomorphic conditions that may be affected by restoration activities. Water temperature can vary spatially across a site and with depth and temporally throughout the day and seasons with air temperature, day length, and hydrologic conditions (Poole and Berman, 2001; Caissie, 2006). Water temperature monitoring can determine whether a restoration site provides suitable conditions for native fish, because water temperature can affect fish health, behavior, predation potential and survival, particularly for cool-water fish like salmonids (Brett and others, 1982; McCullough, 1999; Perry and others, 2015).

The hydrogeomorphic restoration activities most likely to influence stream temperature are those that modify hydrogeomorphic conditions during summer months, such as increasing water depth, duration of inundation, or connectivity between side channels and the main channel. Although few restoration projects in the Willamette River floodplain are implemented with the sole purpose of improving summer water temperatures, water temperature monitoring is an important effectiveness indicator for nearly all Willamette River restoration activities (appendix 4). Water temperature data can characterize the extent and duration of conditions that may be harmful or beneficial for fish and help to understand seasonal conditions that influence fish growth and survival. Gravel pit enhancements and projects that modify floodplain topography can change the hydraulic geometry of features ponded in summer months (for example, converting a small deep pond to a wide shallow pond), thereby affecting solar heating in those features. Water temperature monitoring should prioritize data collection in summer months. Water temperature monitoring also can continue through the late autumn, winter, and spring, which include critical periods for rearing and outmigration of juvenile spring-run Chinook salmon (Schroeder and others, 2016) because extended periods of very cool temperatures can create suboptimal conditions for fish growth during periods when rapid growth is important for future survival (table A3). The water temperature monitoring approaches described here include continuous loggers deployed at a single point for long periods and synoptic surveys that cover larger areas but are limited to streamflow and stream temperature conditions at the time of the survey.

Measuring Water Temperature at a Point with Continuous Loggers

Continuous measurements of water temperature within a water body can be monitored with sensors that record temperature subhourly to daily throughout the season of interest or throughout the year. Examples of metrics useful for evaluating water temperature include the following:

- Mean daily summertime water temperature,
- Maximum (or minimum) daily water temperature,
- Duration and frequency of ‘rest periods’ when water temperatures during warm months are supportive to cool-water fish for a portion of the day,
- Duration of exceedance of thresholds pertaining to fish growth, behavior, predation potential and survival,
- Vertical water temperature variation where multiple nested loggers are used at multiple depths at a single location, and
- 7-day moving average of daily maximum (7dADMax).

Resources are available describing quality of loggers (ODEQ, 2020), logger types, and processes for deployment (Wagner and others, 2006; Isaak and others, 2017; Heck and others, 2018). Site selection for logger deployment should reflect restoration goals for a particular site, as well as local conditions, recognizing a single location may not represent conditions for the whole site. Because water temperature varies within a water body, conditions near the logger placement, such as the presence of shading, aquatic plants, or inflows, should be considered to assess how logger location may affect water temperature. In large, deep waterbodies where water temperature is likely to vary horizontally and vertically, multiple logger locations or loggers at multiple depths at a single location may help to document spatial variability (figs. C5 and C6). Within semi-regularly inundated floodplain sites (such as restoration sites where barriers to inundation or floodplain topography are modified), monitoring water temperatures with continuous loggers in winter months would be a low priority but can provide data to evaluate fish growth and survival, especially if water temperature monitoring is coupled with fish or inundation monitoring. In some cases, the water temperature loggers (including those with lower accuracy standards) can be used to infer timing and duration of inundation signaled by distinct fluctuations in the water temperature record that indicate whether the site is dry (air temperature is recorded) or wet (logger is recording water temperatures; Mangano and others, 2018; Smith and others, 2020).

Measuring Water Temperature across a Waterbody with Synoptic Sampling

Because multiple influences, including solar radiation, subsurface water flows, and upstream water sources, affect water temperature, it can vary across off-channel features along the Willamette River (Mangano and others, 2018; Smith and others, 2020; Carpenter, 2022). Spatially distributed measurements of water temperature (synoptic measurements; Wilde, 2008; Heck and others, 2018; Mangano and others, 2018) taken at multiple depths and within a short time span (typically a day) are useful for characterizing water temperatures across a waterbody and determining whether conditions at that point in time are supportive for native cool and cold-water fish. Metrics can be evaluated with one or more repeat synoptic surveys and include the following examples:

- Range of water temperatures within a water body, laterally and vertically,
- Presence of optimal summer water temperature conditions for juvenile Chinook salmon (table A3), and
- Location of anomalously low or suboptimal water temperatures during cooler late autumn, winter, or spring months when juvenile Chinook salmon rear.

Synoptic surveys would ideally be timed to coincide with seasonal changes in streamflow, water temperature, and rearing conditions for spring-run Chinook salmon (Schroeder and others, 2016). Seasonal sampling could occur in: (A) late summer during low streamflows and high air temperatures; (B) early autumn as air temperatures cool, streamflows increase, and juvenile spring-run Chinook salmon begin migrating from tributary rearing areas into the Willamette River; (C) winter to characterize conditions of higher streamflows and cool air temperatures when many juvenile spring-run Chinook salmon are likely to rear in the Willamette River; and (D) spring, to characterize decreasing streamflows, warming air temperatures and the period of peak outmigration for juvenile spring-run Chinook salmon.

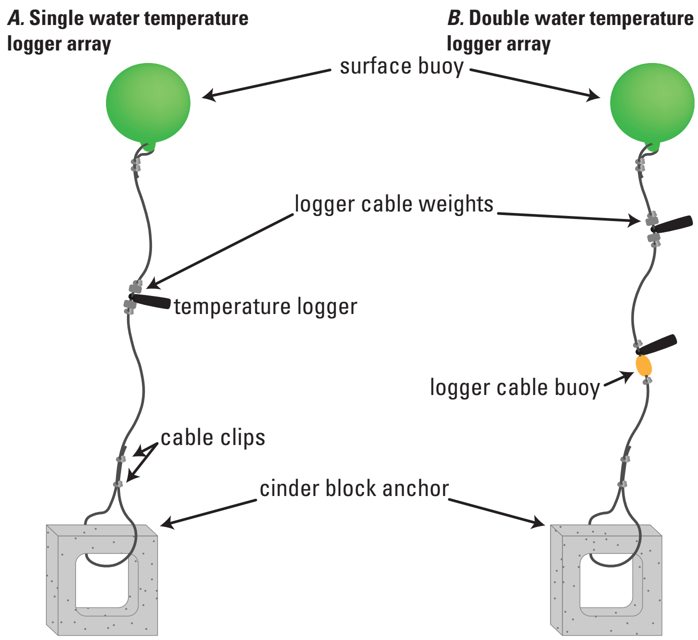

Figure C5. Single (*A*) and double (*B*) continuous water temperature logger monitoring arrays. Continuous water temperature loggers suspended between an anchoring concrete block and floating buoy permit measurement of water temperature at one or more locations within the water column.

Figure C6. Buoy suspending nested water temperature array anchored with a cinder block to record stratified water temperatures at multiple depths. Photograph by U.S. Geological Survey August 14, 2020, at Bowers Rock State Park along the Willamette River, northwestern Oregon.

Hydrogeomorphic Monitoring Synthesis

Four monitoring indicators were identified to evaluate the effectiveness of hydrogeomorphic restoration activities along the Willamette River (tables A7 and A8; fig. C1; appendix 4)—floodplain inundation, planimetric changes in channel features, vertical changes in channel and floodplain features, and water temperature. Examples of approaches and metrics for each of the indicators are provided in this monitoring framework; however, specific approaches and metrics will depend on site conditions, monitoring resources (funding, equipment, personnel), and the development of new, more efficient approaches. Many of the hydrogeomorphic monitoring metrics should be linked to streamflows and channel features of interest to facilitate linkages between restoration goals, restoration activities, and resulting changes in hydrogeomorphic conditions. Ideally, multiple indicators would be used to characterize site conditions and restoration effectiveness; however, resources should focus on the highest priority indicators that align with the objectives of different restoration activities.

Floodplain inundation, vertical changes in floodplain features, and floodplain and off-channel feature water temperatures are important indicators for monitoring the effectiveness of restoration activities (appendix 2) implemented to improve late autumn, winter, and spring habitats for native fish. The highest priority indicator for removing or modifying barriers to inundation (appendix 2) is floodplain inundation, whereas cold-season water temperature monitoring may provide context for fish habitat thresholds but would be a lower priority. Floodplain inundation monitoring also is a high priority for restoration activities that modify floodplain topography to increase inundation (appendix 2), but vertical changes in the modified floodplain features also are important for addressing project longevity. The highest priority monitoring indicators at restored gravel pits would depend on site-specific condition. For example, the Willamette Confluence Preserve (figs. A1 and C2) is connected year-round so water temperature is a high priority, whereas surface streamflow connections at Bowers Rock (figs. A1 and C7) occur at moderate streamflows so both inundation and water temperature are important for characterizing fish habitat conditions.

Planimetric changes in channel features, vertical changes in channel features, and water temperature are important indicators for monitoring the effectiveness of restoration activities (appendix 2) implemented to improve native fish habitat in the summer and early autumn. Water temperature monitoring is necessary at nearly all restoration sites that fish use in the warmer months to determine and document periods when thermal conditions are supportive, harmful, or lethal for focal native fish communities. Monitoring planimetric change is most useful at sites where revetments are removed to increase lateral migration (appendix 2) and the number of channel features important for native fish habitat complexity. In off-channel features constructed or reconnected to reduce water temperatures (appendix 2), water temperature is the highest priority monitoring indicator; although, given uncertainties related to anticipated physical responses at these sites, planimetric and vertical changes would be useful indicators of site conditions.

Combining one or more hydrogeomorphic effectiveness monitoring indicators with indicators of native fish use or responses to floodplain forest or AIS restoration activities also should be considered. Hydrogeomorphic monitoring can be paired with fish sampling to determine if focal fish communities are using (fish presence) or increasing their abundance at the site and whether they have sufficient food resources to support fish growth and survival and other restoration program goals (table A8).

Thresholds for hydrogeomorphic conditions that are indicative of fish health, behavior, predation potential, and survival (such as lethal water temperatures or minimum water depths) can be used to describe amount of time a restoration site supports suitable physical conditions for native fish. Because water temperature and hydraulic thresholds vary widely between fish species, thresholds for key species (such as juvenile spring-run Chinook salmon) or fish communities of interest (such as those in table A5) can be used to inform the metrics developed for future monitoring of hydrogeomorphic restoration activities. At many Willamette River restoration sites, hydrogeomorphic restoration activities are often followed by floodplain forest restoration activities, so pairing hydrogeomorphic monitoring with floodplain forest (chap. D) or avian (chap. E) monitoring might be useful for assessing the broader ecological conditions that also benefit native fish. At channel and floodplain sites that are inundated most of the year and are subject to infestations of aquatic invasive plant species (AIS) that impair conditions for native fish, indicators described in chapter F should be considered.

Figure C7. Inundation of gravel pit restoration site that reconnected the pond to the main channel during moderate- to high-streamflow events at Bowers Rock State Park, Albany, Oregon. Photograph courtesy of Matt Blakely-Smith, Greenbelt Land Trust, December 22, 2020.

Chapter D. Monitoring Vegetation Responses and Floodplain Inundation at Floodplain Forest Restoration Sites

By J. Rose Wallick,[1] Mackenzie K. Keith,[1] and Kathleen Guillozet[2]

Floodplain forest restoration activities that increase and enhance floodplain vegetation (appendix 2) are a priority along the Willamette River (AHWG, 2015; OWEB, 2019), because they provide multiple benefits for native fish including shade and cover along channel and off-channel margins, slow-water refuge on the floodplains during high-streamflow events, and year-round food resources (figs. A11 and D1; table A7; appendix 4). Planting native trees and shrubs in seasonally inundated areas, particularly in areas such as agricultural fields that lack forest cover (termed ‘floodplain forest expansion’), is a common vegetation restoration activity (appendix 2; [AHWG], 2019). The effectiveness monitoring indicators and approaches recommended in this chapter focus on floodplain forest expansion activities, because the near-term benefits of these activities on fish habitats can be readily measured across entire restoration sites using low-cost mapping and field-monitoring approaches. The native fish habitat benefits of floodplain forest enhancement activities (for example, planting shrubs under the forest canopy or treating invasive vegetation) are more challenging to quantify through either vegetation monitoring or fish sampling methods but can be efficiently assessed with avian indicators (table A7; fig. D1; chap. E).

Floodplain vegetation monitoring in this framework focuses on two indicators that directly relate to attributes of fish habitat—canopy cover and the frequency of inundation at floodplain forest restoration sites. These indicators align with monitoring approaches for evaluating structural (three-dimensional arrangement of vegetation), functional (ecological processes and vegetation history), and compositional (species richness, diversity, plant assemblages) aspects of floodplain vegetation (Lawley and others, 2016). Structural aspects of floodplain forest restoration activities are assessed through measurements of canopy cover (to document changes before and after planting) whereas functional aspects are assessed by comparing planted areas with inundation patterns. Structural and compositional aspects of floodplain vegetation at restoration sites can also be assessed through use of avian monitoring (chap. E).

[1]U.S. Geological Survey

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Floodplain Forest Monitoring Indicators and Approaches

Floodplain Forest Canopy Cover

Canopy cover is formed by the crowns of plants. Within floodplain forests, tree canopy can cover much of the vegetation and ground below. As canopy cover of the overstory increases, shade beneath the tree canopy also increases, aiding in the development of shade tolerant understory shrubs that are typically planted alongside trees during floodplain forest planting activities. As the young trees and shrubs grow, the density of woody stems and branches increases (fig. D2), which provides hydraulic roughness to slow floodwaters. Additionally, these young floodplain forests provide plant matter and insects that provide high energy food sources and additional habitat complexity (for example, Gregory and Ashkenas, 1990). In floodplain areas that are only inundated at high streamflows, changes in canopy cover provide an indication of (A) whether planted areas are changing in composition from former land cover classes toward floodplain forest, (B) the likelihood that these areas could provide refuge during high streamflows, and (C) the potential changes in food resources for native fish. When measured along off-channel features that are wetted in summer months, canopy cover provides an indication of (A) increases in shade and the potential to reduce solar heating of water bodies and (B) potential increases in food resources for native fish. Changes in canopy cover also can signify benefits for other avian and wildlife communities that use floodplain forests and other ecological processes (Hawkins and others, 1982; Riparian Habitat Joint Venture, 2004; Rockwell and Stephens, 2018).

Canopy cover should be assessed prior to and after restoration planting to document changes in forest cover where bare land, agriculture fields, or other sites with minimal woody vegetation is converted to floodplain forests. Canopy cover can be evaluated at a range of spatial scales, making it a useful for characterizing changes at individual restoration sites, multiple restoration sites within a restoration program, or along the entire Willamette River floodplain corridor. If mapped along the river corridor, canopy cover changes at individual restoration sites can be compared with river-scale patterns of floodplain forest to determine whether restoration activities are influencing the overall status of floodplain forests (BPA, 2019). Repeat measurements of canopy cover from restoration sites can be compared with reach- or river-scale conditions to provide context for considering the relative increase in forest cover due to restoration planting activities compared with gains and losses from other anthropogenic or natural causes. Because canopy cover monitoring approaches characterize only the upper layer of the tree canopy, these approaches are not typically useful evaluating the effectiveness of restoration activities that enhance floodplain forest vegetation below the tree canopy.

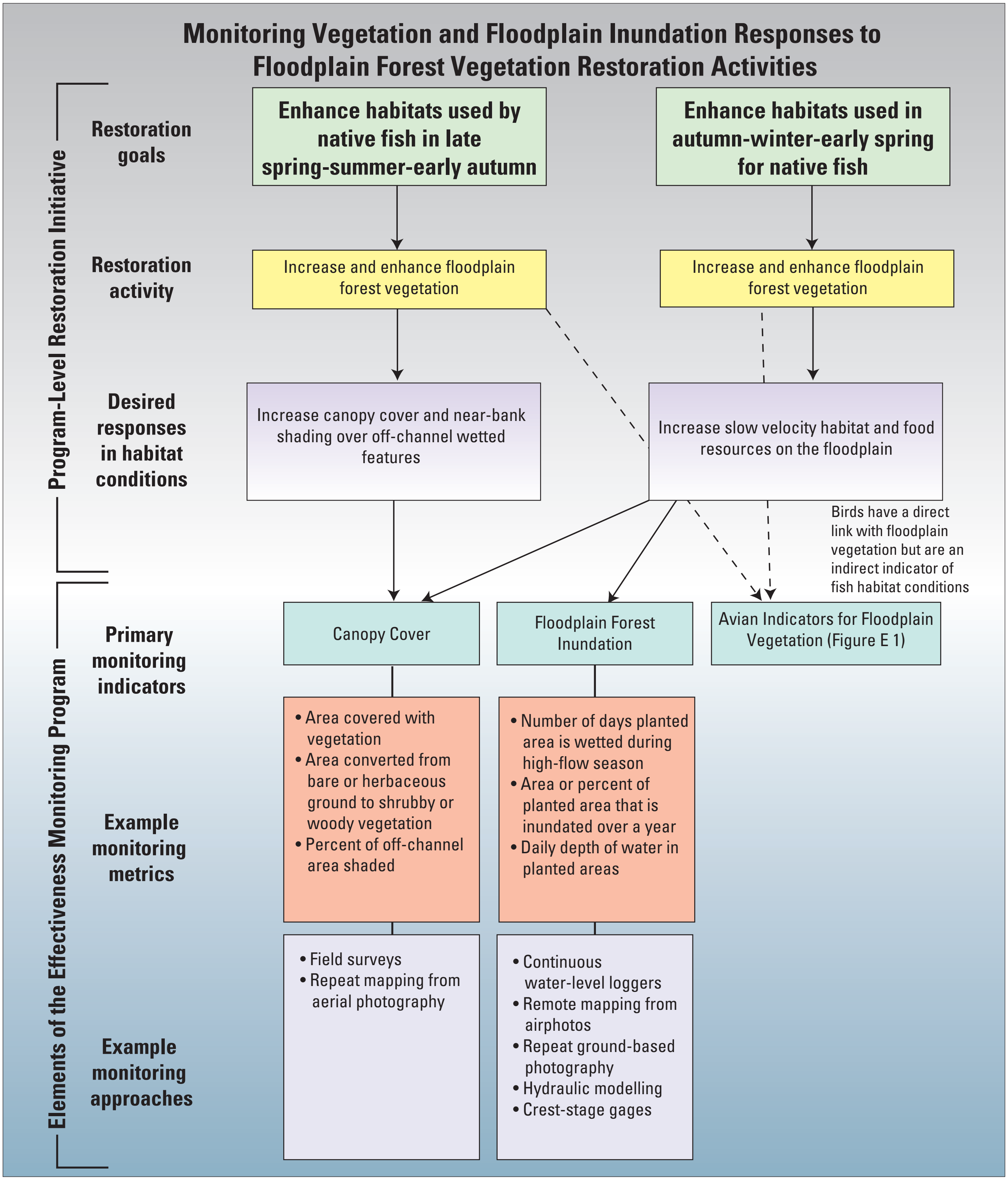

Figure D1. Linkages between floodplain forest restoration activities and hypothesized vegetation responses with monitoring indicators, approaches, and metrics.

Figure D2. Floodplain forest vegetation at a repeat photograph monitoring point at the Luckiamute State Natural Area along the Willamette River, northwestern Oregon. *A*, first year of growth on new plants in summer 2013, *B*, revegetation efforts after a few years of plant growth in autumn 2017, and *C*, multi-storied canopy resulting from revegetation in autumn 2019. Photographs acquired by and used with permission from the Luckiamute Watershed Council.

Mapping Canopy Cover from Remote Sensing Sources

Similar to planimetric mapping of features from remote sources, canopy cover can be mapped at the subdecadal to decadal scale to quantify land-cover changes that have resulted from floodplain forest planting activities and signify if the floodplain forests at the restoration site are providing intended benefits for fish habitats. Metrics can focus on determining changes in the area and density of woody vegetation cover (trees, shrubs) that have resulted from restoration planting by measuring canopy cover prior to and after planting. Examples of potentially useful metrics for canopy cover can include the following:

- Area of newly planted restoration site that has young forest or shrub canopy cover that native fish can access during seasonal inundation,
- Density of canopy cover at a newly planted restoration site that native fish can access during seasonal inundation, and
- Rate of canopy cover change in areas that were planted with trees and shrubs.

Canopy cover can be characterized through manually digitizing different areas and stands of vegetation or through automated approaches within a GIS framework. Canopy cover is best evaluated at areas sufficiently large (a few hectares) to apply remote-sensing mapping approaches. The time frame needed to detect post-planting changes in canopy cover will depend upon mapping methods, plant growing conditions, and the size class of seedlings planted at the restoration site, but in most cases changes in canopy cover could be detected with remotely sensed imagery within 3–5 years after planting. Because publicly available aerial photographs such as those collected by the National Agriculture Imagery Program (NAIP) (0.5 to 1-m pixel) typically encompass the entire Willamette River Basin, river-scale mapping efforts can be repeated every 5 to 10 years to evaluate restoration sites and compare these sites to unrestored areas. However, higher resolution imagery from an unoccupied aerial system (UAS) or other platforms can be collected more frequently for characterizing site-scale changes that occur over shorter time scales and require detailed imagery for detection. Additionally, high-resolution imagery also can be useful for capturing flood-induced scour through new and established floodplain forests and for characterizing other floodplain forest restoration activities, such as interplanting or thinning. Repeat mapping from lidar data provides physical measures of canopy, such as forest height and density and can assess changes in forest growth, succession, and structural complexity. Mapping vegetation species distribution and succession also can be completed by using lidar data with multispectral imagery (Hakkenberg and others, 2018).

Documenting Canopy Cover with Ground-Based Photography

Ground-based photography can be used to qualitatively monitor local canopy cover floodplain forest restoration sites. Approaches and considerations are similar to those described in chapter D, section, “Documenting Inundation with Ground-Based Photography,” but the frequency of photograph acquisition could occur annually at similar leaf-on periods each year. Repeat photographs of canopy (or vegetation) illustrate the establishment, growth, and survival of plantings (figs. D2*A*, D2*B*, and D2*C*) and whether invasive plants have established that may need further restoration actions (fig. D2*C*).

Floodplain Forest Inundation

Evaluating spatial and temporal patterns of inundation in floodplain forest restoration sites (fig. C3) is necessary to understand the potential benefits of floodplain forest restoration for native fish habitats. Inundation indicates potential for fish to access and use floodplain forests as slow-water refuges during high-streamflow periods and may signify other ecological benefits (such as transfer of nutrients and food resources between floodplain forests and the main channel). Inundation within floodplain forest restoration sites is a useful monitoring indicator because it can be used to determine whether floodplain forest activities were implemented in places where flooding, and thereby fish access, occurs for sustained periods each year or for shorter durations and frequencies. As a planning tool, inundation frequency can be used to select floodplain forest restoration sites likely to provide sustained, annual benefits for native fish. Inundation can be assessed for floodplain forest restoration sites that increase or enhance native vegetation. Three general monitoring approaches are described to characterize the spatial extent, frequency, and duration of inundation in floodplain forest restoration sites—hydraulic modeling, continuous loggers, and ground-based photography. The approaches addressed here parallel those outlined and are more fully described in chapter C, section, “Monitoring Responses to Hydrogeomorphic Restoration Activities,” but include modifications for monitoring and evaluating fish habitat benefits of floodplain forest planting activities.

Characterizing Floodplain Forest Inundation with Hydraulic Models and High-Resolution Topography

Hydraulic models for the Willamette River floodplain can be used with streamflow and stage data from gages to assess inundation in floodplain forest restoration sites. Metrics for quantifying inundation in newly planted floodplain forests can include:

- Number of days per year when floodplain forest restoration site is inundated to a depth suitable for focal fish species,
- Area of floodplain forest that is inundated at specified flood events (such as exceeding the 50 percent annual exceedance probability interval flood or smaller magnitude event that occurs on average several weeks per year),
- Daily depth of water in planted areas, and
- Ratio of frequency to duration of inundation within floodplain forest restoration site.

Hydraulic models are useful for characterizing inundation at large floodplain vegetation restoration sites that are challenging to measure remotely or with field-based approaches particularly over a range of streamflows. Using existing hydraulic models for the Willamette River floodplain, maps of inundation extent and water depths for various streamflows can determine the threshold streamflow when floodplain forest restoration sites are inundated to supports native fish. Criteria to determine inundation conditions suitable for fish species might include water depths, ground slopes, and the minimum area of inundation. For example, the threshold streamflow when a floodplain vegetation restoration site provides suitable habitat for juvenile spring-run Chinook salmon can be established by determining the streamflow needed to inundate 80 percent of a planted area to a depth of 1 meter (m).

Characterizing Floodplain Forest Inundation with Continuous Loggers

Water-level loggers can be deployed to measure water-surface elevation at frequent intervals and enable estimates of inundation (chap. C, section, “Measuring Water-Surface Elevations or Connectivity with Continuous Water-Level Loggers”) at floodplain forest restoration sites. This approach is ideal for answering questions regarding floodplain forest connectivity to the main-stem river channel and whether the logger is dry or under water. Inundation extent is estimated by overlaying measurements of water-surface elevations with land-surface topography from digital elevation models (DEMs). Streamflows that result in inundations can be identified when water levels from continuous loggers are related to streamflow and stage data from nearby gages. Because floodplain surfaces may only be inundated a few days out of a year, seasonal deployment and retrieval of loggers may be more efficient than year-round monitoring.

Documenting Floodplain Forest Inundation with Ground-Based Photography or Unoccupied Aerial Systems

Ground-based photography (chap D., section, “Documenting Inundation with Ground-Based Photography”) can be used to monitor inundation in floodplain forest restoration sites. Ground-based photography provides a qualitative dataset regarding frequency, duration, and extent of inundation and when the inundation support winter, high-streamflow habitat for native fish. Combining photographs with elevation reference markers, such as staff plates, and DEMs can provide more quantitative information on the water depth and extent.

Measuring Maximum Depth of Floodplain Forest Inundation with Crest-Stage Gages

Crest-stage gages (chap. C, section, “Measuring Water-Surface Elevations at High-Streamflows with Crest-Stage Gages”) can be used to record maximum depth of floodplain forest inundation. This approach is ideal for documenting the depth and water-surface elevation at sites where flooding during high streamflow events is infrequent. Water levels from peak streamflow events are retained so site visits can occur after flooding when site conditions allow access. At floodplain sites that have been converted from bare fields to forest or at sites where existing forests have been treated for invasive species, monitoring inundation with crest-stage gages can provide an assessment of whether restoration activities have occurred in sites that accessible/meet a sufficient depth for fish.

Floodplain Forest Monitoring Synthesis

Canopy cover and floodplain inundation indicators (supplemented with avian indicators, chap. E) were identified to assess the effectiveness of floodplain forest restoration activities (appendix 2) at improving native fish habitat along the Willamette River (fig. D1; tables A7 and A8; appendix 4). Canopy cover monitoring will efficiently quantify increases in floodplain forest cover that resulted from planting activities, whereas floodplain inundation assessments would indicate whether those activities have occurred in areas accessible to fish during seasonal flooding as well as the frequency of flooding and spatial extent of accessible habitat. Both indicators are important to monitor and evaluate the effectiveness of floodplain restoration activities on late autumn, winter, and spring seasonal habitats for native fish. Canopy cover over, or adjacent to, low-streamflow channel features indicate potential increases in shade, cover, and food resources afforded by streamside plantings important to native fish in the summer and early autumn. The community composition within floodplain forest restoration sites can be assessed through avian indicators (table E1), but survival measures typically used in restoration effectiveness monitoring are not included, because they are more appropriate for assessing various planting practices rather than overall improvements for fish habitat conditions. Additionally, most restoration practitioners accept mortality as a natural process and rely upon dense plantings (Guillozet and others, 2014).

The overall suite of monitoring indicators and approaches suitable for floodplain forest restoration sites (table A8) focuses on monitoring near-term responses to restoration but recognizes that floodplain forest restoration projects contribute to broader goals for long-term restoration of the overall floodplain ecosystem because forests enhance nutrient cycling, and contribute large wood to the river, which in turn also benefits native fish communities. However, those long-term, indirect benefits of floodplain forest expansion cannot be feasibly evaluated within the timeframes and resources of most effectiveness monitoring programs. The effectiveness monitoring activities for floodplain forest restoration sites should reflect (A) the specific floodplain forest restoration activity that will be evaluated (enhancement or expansion), (B) the season when fish habitat benefits from this action are likely to be greatest and measurable, and (C) timescales over which vegetation responses are likely to be detected using the monitoring approaches of this framework. Canopy cover and inundation monitoring can be paired with fish monitoring to determine whether restoration resulted in an increase in fish use (for native and non-native species; tables A8 and B1; chap. B).

Chapter E. Monitoring Avian Responses to Floodplain Forest Vegetation Restoration Activities

By Joan C. Hagar,[1] Mackenzie K. Keith,[1] and Kathleen Guillozet[2]

Floodplain forest restoration activities are widely implemented along the Willamette River with recognition that increasing the diversity and structural complexity of floodplain vegetation enhances the habitat available to native fish, birds, and other wildlife (AHWG, 2015). Restoration activities to increase and enhance floodplain forest (appendix 2) can be monitored with direct vegetation monitoring (chap. D), but because many traditional approaches for monitoring vegetation can be expensive, time-consuming, and yield uncertain results, avian monitoring can provide practical indicators of the effectiveness of floodplain forest restoration activities. Additionally, the scale of floodplain vegetation restoration activities can span tens to hundreds of hectares that would be more practical to monitor with birds that can be effectively monitored with fewer sample points within a site than field-based vegetation monitoring (chap. A, section, “Overview of the Willamette Focused Investment Partnership [WFIP] Effectiveness Monitoring Program”; fig. A13; appendixes 2 and 3). Because the composition of avian communities reflects the structure and condition of floodplain vegetation, monitoring birds in Willamette Valley floodplain habitats allows inferences about the current status and future trajectory of these habitats and provides an objective measure of restoration success for entire floodplain ecosystems.

Birds associated with floodplain habitats are highly responsive to environmental elements that influence habitat for fish (table E1). Long-term monitoring for the Trinity River Restoration Program (since 2000) has shown that avian monitoring is an effective way to evaluate the success of channel and floodplain restoration projects (Stephens and others, 2016). Monitoring birds can inform restoration activities that support the long-term maintenance of floodplain and aquatic habitats along the Willamette River. Features of healthy floodplain vegetation that are key habitat elements for focal bird species (Altman, 2000; Rockwell and others, 2022) are those that influence in-channel aquatic habitats, maintain favorable water temperature for fish through shading, filter runoff, and deliver nutrients to the aquatic environment (ODFW, 2016). Monitoring of birds can be used specifically to evaluate the results of restoration activities that directly alter vegetation structure and composition (both increasing and enhancing floodplain forest vegetation; table A7; fig. E1; appendix 2).

[1]U.S. Geological Survey

[2]Bonneville Environmental Foundation

Three avian monitoring indicators useful for evaluating floodplain forest planting activities of Willamette River restoration programs (fig. E1) are abundance of floodplain focal species, species richness of floodplain-associated birds, and avian productivity and survival.

Avian Monitoring Indicators and Approaches

Abundance of Floodplain Focal Species

Partners in Flight (PIF), a network of organizations in the western hemisphere working on landbird conservation, promotes the use of focal species (table E1) to guide and evaluate conservation implementation (Rosenberg and others, 2016). PIF focal species are selected to meet the following criteria—(A) representative of a range of desired future conditions for healthy ecosystems; (B) cost-effective to monitor; and (C) responsive to management actions and therefore useful for setting and measuring habitat-based conservation goals for whole ecosystems (Rosenberg and others, 2016). Focal species listed in this monitoring framework (table A6) are listed in the PIF Conservation Plan for lowlands and valleys of western Oregon and Washington (Altman, 2000; Rockwell and others, 2022). Additionally, the floodplain species for this monitoring framework are territorial during the breeding season. Territoriality also supports the inference that greater abundance indicates higher quality habitat, although there may be exceptions to this relationship (Van Horne, 1983). The focal species selected (table A6) are excellent indicators of a naturally functioning floodplain ecosystem, which ultimately supports native fish species.

Floodplain focal species along the Willamette River (for example, figs. E2 and E3) are associated with various floodplain habitat attributes (table E1). For example, the willow flycatcher (*Empidonax traillii*) utilizes dense shrubs under open canopy whereas the Swainson’s thrush (*Catharus ustulatus*) utilizes dense shrub understory in forests. An abundance of focal species associated with different habitat attributes represents a functioning ecosystem and elements of biodiversity (Chase and Geupel, 2005; Rockwell and others, 2022). Focal species are expected to colonize or increase in abundance after desired floodplain vegetation conditions are achieved. For example, the presence of willow flycatchers in a field restored to a forest indicates successful transformation of habitat at an ecologically meaningful spatial scale, because willow flycatchers would not occur in a field dominated by invasive annual plants, but they may colonize after restoration involving actions such as planting of woody floodplain forest vegetation.

Table E1. Avian indicators of floodplain vegetation condition in the Willamette Valley linking associated habitat attributes to floodplain vegetation processes that influence aquatic habitat for fish.

[Floodplain habitat attribute and avian indicator species are based on Partners in Flight sonservation strategy (Altman, 2000; Rockwell and others, 2022). These species can serve as focal species for monitoring the effects of restoration activities that alter ecosystem processes]

Restoration activity	Floodplain ecosystem processes	Floodplain habitat attribute	Avian indicator species
Increase and enhance floodplain forest vegetation	Erosion and runoff control, contribution of nutrients, filter sediment	Dense shrubs, open canopy	Willow flycatcher Song sparrow
	Bank stabilization, shading, nutrients, structure for channel	Dense large canopy trees in woodland	Brown creeper Warbling vireo
		Scattered large canopy trees in woodland	Bullock's oriole
	Bank stabilization, shading, nutrients, trophic webs	Woodland subcanopy, tall shrubs	Yellow warbler
	Nutrients, trophic webs	Native flowering plants	Rufous hummingbird
		Mixed hardwood and conifer trees (tree species diversity)	Black-headed grosbeak
		Dense shrub understory in woodland	Swainson's thrush
		Scattered shrubs with herbaceous openings	Spotted towhee
	Structure for channel, nutrients, erosion control	Snags in closed woodland	Downy woodpecker
		Snags in open woodland	Black-capped chickadee
Increase and enhance floodplain forest vegetation; modify floodplain topography and human-made barriers to inundation	Maintenance of floodplain processes	Interspersion of bare ground and native herbaceous vegetation	Spotted sandpiper
		Regularly inundated side-channels, ox-bows, with productive early seral vegetation and snags	Tree swallow
		Large patches of structurally diverse woodland	Yellow-billed cuckoo

Consistent with PIF's simple, proactive mission of "keeping common birds common," almost all the floodplain focal species (table E1), except for the yellow-billed cuckoo, are common in floodplain habitats. PIF's approach of focusing on common species was adopted as a logical and cost-effective business model to halt and reverse bird population declines before species become so rare as to require listing as threatened or endangered. An advantage of focusing monitoring on relatively common avian species that do not have special legal status is that these species "are indicators of desired future conditions, and not subject to numerous regulations," offering "an effective approach to engaging partners in voluntary conservation actions" (Rosenberg and others, 2016, p. 99).

Monitoring determines whether individual avian species occur at a specific location. The presence of each of the floodplain focal species (table E1) at a restoration site (see chap. A, section, "Overview of the Willamette Focused Investment Partnership (WFIP) Effectiveness Monitoring Program"; fig. A13; appendix 3) indicates availability at an appropriate spatial scale of the habitat attributes with which each species is associated (Rockwell and others, 2022). Abundance of focal species quantifies the number of individuals representing each species and is commonly used as indicator of the site's ability to provide necessary resources for birds (Johnson, 2007), which also can signal functional systems that support native fish habitat. Abundance is assumed to be positively associated with the amount of suitable habitat, and therefore can indicate the relative availability of habitat attributes with which each species is associated (table E1) when evaluating changes over time at one site or comparing among sites.

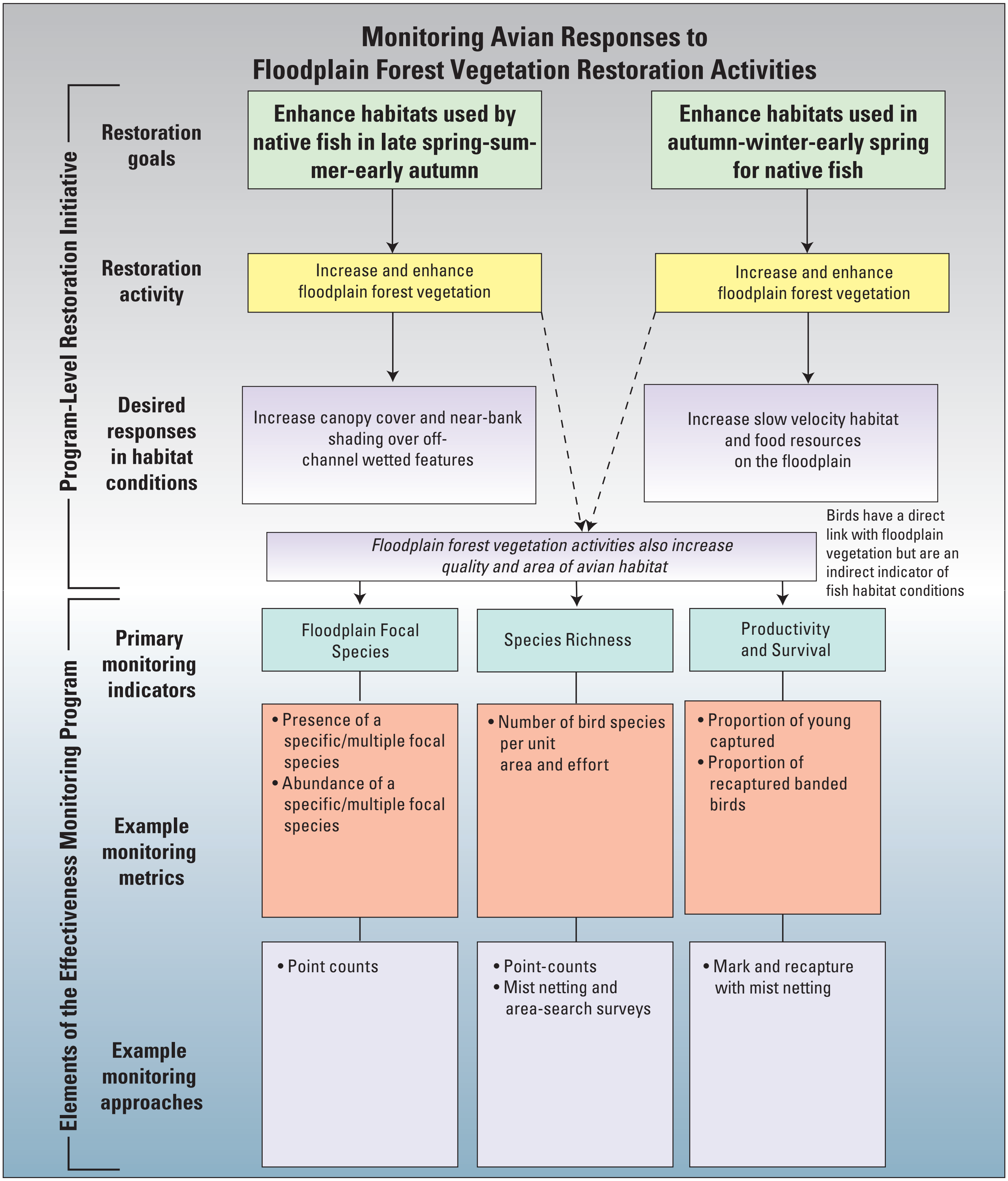

Figure E1. Linkages between restoration activities and hypothesized avian responses with associated monitoring indicators, approaches, and metrics to evaluate avian responses to floodplain forest restoration activities.

Figure E2. Yellow breasted chat (*Icteria virens*)—a monitoring focal species for the Willamette River associated with dense shrubs. Photograph by U.S. Geological Survey, May 8, 2015.

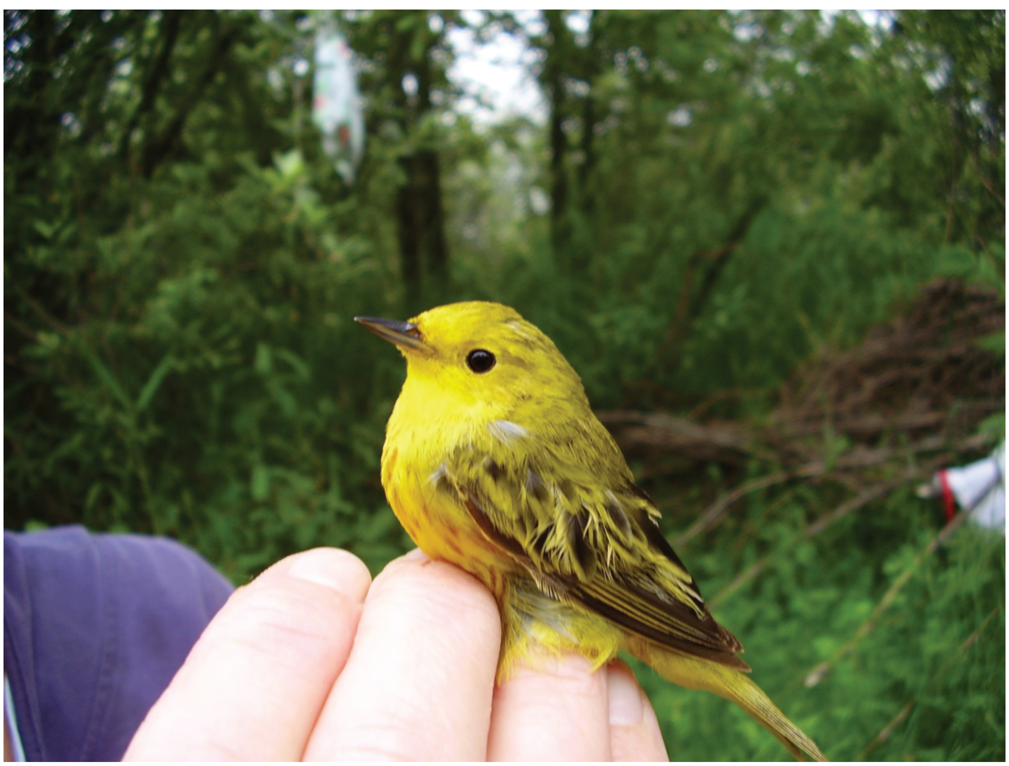

Figure E3. Yellow warbler (*Setophaga petechia*)—a monitoring focal species for the Willamette River associated with floodplain woodland subcanopy. Photograph by U.S. Geological Survey, July 21, 2006.

Monitoring Floodplain Focal Species with Point-Count Surveys

Point count surveys for monitoring species richness will provide data on the following metrics to evaluate restoration effectiveness for focal species:

- Presence or absence of each focal species during the breeding season at a site and
- Abundance of each focal species during the breeding season; abundance is the number of detections of each species at each site, standardized by effort (effort is the number of visits per season multiplied by the number of point count stations).

The use of point counts is a standardized method to monitor multiple aspects of songbird communities (Ralph and others, 1995). Because point counts involve little more than an observer visiting designated stations and recording all birds seen or heard (fig. E4), this approach is an efficient method of counting birds, and is the preferred method in forested habitats or difficult terrain. The avian assemblage should be sampled at multiple sample points (stations systematically located with a random starting point) within a site to represent variation in major vegetation types at the site scale. In general, a sampling density of approximately one station per 4–8 hectares is sufficient. Coordinating this approach with other biotic sampling (for example, vegetation and aquatic indicators) would contribute to understanding of indirect linkages between bird responses to restoration and native fish habitats. Point counts can be conducted at locations within restoration sites to derive metrics during the breeding season. Three to five surveys at each location per season across multiple years are suggested to account for within-season and interannual variation. Multiple years of data also are necessary to quantify trends. Using point count data in combination with data from mist-netting (this chapter, sections “Monitoring Species Richness with Mist-Net and Area-Search Field Surveys” or “Monitoring Avian Productivity and Survival with Mist-Netting”) can provide a stronger basis for linking avian indicators to changes resulting from habitat restoration activities. Abundance data alone from point counts do not necessarily reflect habitat quality and, like all other monitoring indicators, should be interpreted with consideration of and in context of other influences such as species phenology or habitat patch connectivity and scale (other general consideration provided in appendix 3).

Figure E4. Photograph showing an observer conducting a point count survey. Photograph by Oregon State University, summer 2015.

Species Richness of Floodplain-Associated Birds

Each bird species occupies a unique niche in an ecosystem, making the number of avian species present in an environment, or avian species richness, positively correlated with habitat complexity (MacArthur and MacArthur, 1961). Higher species richness indicates greater complexity of floodplain vegetation and implies collective representation of multiple key floodplain habitat attributes (for example, large canopy trees, dense shrub thickets, coarse woody debris). Because complexity of vegetation structure has been positively linked to ecosystem function (Sukma and others, 2019), species richness of floodplain birds is a key indicator of the health of floodplain ecosystems.

Based on the Partners in Flight conservation plans (Altman, 2000, appendix B; Rockwell and others, 2022), 32 avian species can be categorized as associated with floodplain habitats along the main-stem Willamette River and lower tributaries (table A6). This list of floodplain-associated species (table A6) includes 15 focal species identified as indicators of floodplain vegetation conditions in the Willamette Valley (table E1; Altman, 2000; Rockwell and others, 2022) along with an additional 8 species that reach their highest abundance in floodplain habitats (“Highly Associated”), and 9 species that commonly occur in floodplain habitat (“Associated”).

California's Riparian Bird Conservation Plan (Ballard and others, 2004) suggested that locations supporting 8 or more of 16 floodplain focal species (50 percent) are biodiversity "hotspots." Applying this definition to avian communities along the Willamette River, restoration sites (those comprising at least 20 hectares) with 16 or more of the 32 species in table A6 would be considered to have very high species richness and indicate relatively high-quality conditions, while sites with 10 to 15 of these species can be considered adequate, and sites with less than 10 floodplain associated species suggests a need for improvement of floodplain conditions.

Data from monitoring species richness can effectively be used to evaluate restoration that enhances floodplain forest vegetation, as ecological effects of actions like removal of understory invasive species and interplanting cannot be as efficiently tracked with approaches suggested in chapter D, section, "Mapping Canopy Cover from Remote Sensing Sources." Because some bird species may not be influenced by a change in plant species composition as long as adequate cover is provided, combining measures of avian species richness with other indicators would allow for more robust evaluation of the effectiveness of actions that enhance floodplain forest vegetation. Performing avian monitoring in areas where fields have been restored to forest would be useful for monitoring both long-term trends in species richness and change in bird species composition as young plants mature and begin to provide increasingly productive habitat for floodplain focal species; although, some bird species will use new plantings immediately. Avian species richness is expected to increase as the complexity of floodplain vegetation structure increases and species associated with mature trees colonize the site.

Monitoring Species Richness with Point-Count Field Surveys

Monitoring species richness is typically conducted with field surveys using standardized protocols, such as point counts to detect species, record their presence, and estimate species richness and abundance. Data from point-count field surveys (this chapter, section, "Monitoring Floodplain Focal Species with Point-Count Surveys") allow assessment of occupancy and abundance of multiple bird species (table A6) and of yearly changes in these indicators, and yield data on species presence/absence, species richness, and abundance of individual focal species (table E1). A recommended metric to evaluate restoration effectiveness for increasing species richness of floodplain-associated birds using the point-count approach is the number of species detected per unit area and effort (effort measured in person hours).

Data for evaluating floodplain focal species presence and abundance are derived from the same dataset as the species richness indicator, making point counts efficient for collecting data for multiple indicators simultaneously. Point counts are most useful for monitoring species richness during the breeding season, when birds are territorial and most detectable, but other approaches can be used for monitoring species richness during the non-breeding season (this chapter, section, "Monitoring Species Richness with Mist-Net and Area-Search Field Surveys"). Bird surveys are conducted using multiple spatial subsamples at each restoration site to derive site-level metrics for each season—breeding season (May through July) and non-breeding and migration seasons (approximately mid-July through April). Multiple years of surveys (minimum of 3 to 5 per decade) at each site are recommended to account for interannual variation and to quantify trends.

Monitoring Species Richness with Mist-Net and Area-Search Field Surveys

During the post-breeding and migration seasons, point counts are not as effective for detecting birds because most species are no longer vocalizing to defend territories. Therefore, other methods that do not rely on detection by territorial singing are used, including mist-netting and area-search methods. Mist nets are used to live-capture wild birds in the field (fig. E5) so demographic and physiological data can be collected (Dunn and Ralph, 2004). Most species also are permanently marked with leg bands at the time of capture (fig. E6), allowing survival data to be obtained through analysis of recapture rates over time. The MoSI Program (*Monitoreo de Sobrevivencia Invernal*; Monitoring Overwintering Survival; DeSante and others, 2005) has developed a mist-net protocol for collecting data on migratory landbirds during the winter that can be adapted for use during post-breeding and migration seasons in northern latitudes. To complement mist-netting for monitoring species richness, area-searching conducted during mist-net station hours of operation can increase species' detection probabilities. Area-searching involves listing all species observed during the hours while the mist-netting station is operating, along with estimating the number of individuals observed for each species. Specific metrics derived from these approaches include the following:

- Capture rates of floodplain-associated species by age and sex and
- Number of bird species per unit of area and effort (effort for mist-netting is the number of mist-nets deployed multiplied by the number of hours nets were open; effort for area searching is the hours of operation of the station).

Figure E5. A song sparrow (*Melospiza melodia*) captured in mist-net. Photograph by U.S. Geological Survey, August 09, 2007.

Figure E6. Application of a leg band on a common yellowthroat (*Geothlypis trichas*). Photograph by U.S. Geological Survey, August 09, 2007.

The use of mist-nets for bird monitoring in general is described in Dunn and Ralph (2004), and the MoSI field protocol is described by DeSante and others (2005). The area-search method is described in Ralph and others (1993) and Roberts and Schnell (2006). Data are collected at the spatial scale of approximately 20 hectares (ha), based on the size and mobility of songbirds. Ten to sixteen mist-nets are distributed across approximately 12 ha within the core of each 20-ha site, to ensure sampling of intended habitat while minimizing influence from adjacent environments. During the post-breeding and migration seasons (mid-July through April), mist-net and area-search surveys are conducted on two to three consecutive days at least once per month. As with other avian monitoring approaches, coupled biotic sampling, such as for vegetation or aquatic indicators, would enable assessment of the linkages among responses. This approach also can be used to expand seasonal monitoring of avian productivity and survival (this chapter, section, “Avian Productivity and Survival”), because use of floodplain habitats by many focal species extends into the post-breeding season. Also, more northern populations of focal species (for example, Swainson’s thrush, *Catharus ustulatus*) may use the Willamette River corridor during migration. Limitations of using mist-nets include a bias toward species that can be captured within 2 m of the ground in dense cover, requirements for State and Federal permits, approval by an Institutional Animal Care and Use Committee, and proper training for all personnel that handle wild birds. Additionally, mist-netting cannot be used during extreme air temperatures (greater than 29 °C and less than 5 °C) or when there is more than light precipitation because of safety concerns for the birds, and is therefore, generally suspended in the winter months (November–March).

Avian Productivity and Survival

Productivity (proportion of young captured) and survival (proportion of banded birds that are subsequently recaptured) are demographic parameters that provide information on population change and can help link population change to environmental factors (DeSante and others, 2018). Productivity and survival are more directly linked to habitat quality than abundance or density and are therefore more reliable indicators of changes in habitat quality, such as those resulting from restoration activities intended to improve floodplain habitats. In addition, measures of body condition and morphometric data collected from captured birds (fig. E7) can reflect habitat quality (Johnson, 2007). Therefore, avian productivity and

Figure E7. Morphometric data measurement of a downy woodpecker (*Dryobates pubescens*) captured in a mist-net at Luckiamute State Natural Area along the Willamette River, northwestern Oregon. Photograph by U.S. Geological Survey, August 22, 2018.

survival response to floodplain forest restoration activities can provide a robust measure of the effectiveness of conservation strategies.

Productivity and survival collected at individual sites inform habitat quality, and when collected across the spatial scale of multiple sites, for example, three or more project sites along the Willamette River corridor can contribute to evaluation of population-level dynamics.

Monitoring Avian Productivity and Survival with Mist-Netting

Monitoring productivity and survival of selected focal species through mist-netting is useful for evaluating the effectiveness of vegetation restoration activities. Metrics used to evaluate the productivity and survival rates of avian species associated with floodplain areas (tables A6 and E1) include the following examples:

- Number of individuals captured of each focal species by age and sex,
- Ratio of young to adults captured for each focal species, and
- Interannual recapture rates (proportion of banded birds recaptured in subsequent year) for each focal species.

Field surveys to collect productivity and survival data with mist nets are similar to those previously described in this chapter (section, “Monitoring Species Richness with Mist-Net and Area-Search Field Surveys”). During the breeding season, the standard protocol for the Mapping Avian Productivity and Survival (MAPS) program (DeSante and others, 2019) is followed, with mist-nets operated once out of every 10-day period (periods are defined by MAPS) from the third week of May through the first week of August. Productivity and survival can be calculated for each focal species with sufficient sample size. Given cyclical life history events for songbirds, productivity and survival parameters are measured on an annual basis. Multiple consecutive years of surveys (at least 5) at each site are necessary to estimate these parameters.

Avian Monitoring Synthesis

Avian communities reflect the structure and condition of floodplain vegetation. Changes in avian communities following floodplain forest restoration (appendix 2) can reflect changes in the vegetation conditions that also improve native fish habitat and are indicative of restoration effectiveness. Focusing avian monitoring on abundance, species richness, and productivity and survival indicators (tables A7 and A8; fig. E1; appendix 4) is a cost-efficient way to monitor ecological responses to vegetation improvements. Avian responses to restoration activities may be influenced by the spatial scale of restoration projects (appendix 3) and connectivity to other habitat patches and should be considered when interpreting monitoring results. Establishing baseline avian metrics prior to project implementation is ideal; however, where floodplain forest restoration projects have already been implemented, post-implementation baseline metrics would be useful for evaluating long-term responses (table A7; appendixes 2 and 3). Priority indicators may be identified for individual restoration activities. For example, the highest priority monitoring indicator for sites where bare agricultural fields were planted with native shrub vegetation is the presence of shrub-associated bird species, such as willow flycatcher and song sparrow (fig. E5); whereas the highest priority monitoring indicators for interplanting and invasive plant removal are species richness and productivity of focal species. Species’ phenological patterns are incorporated into the sampling methods and design (hence the different methods for breeding season and post-breeding seasons) and should be considered when developing site-specific monitoring plans.

Combining data from avian monitoring with data for other indicators (fish, chap. B; hydrogeomorphology, chap. C; floodplain vegetation, chap. D) will facilitate interpretations of links between near- and long-term avian and vegetation responses with changing fish habitat conditions. Some species of birds also can be indicators of effectiveness of other hydrogeomorphic or AIS treatments. For example, restoration of hydrogeomorphic processes, including flooding and channel migration, should increase nesting opportunities for cavity-nesting species by creating snags, and an increase in richness and density of floodplain-associated bird species over time (Ballard and others, 2004).

In addition to using birds as indicators of floodplain habitat conditions for native fish, monitoring birds can inform ecosystems, support management, and provide connection to broader human outreach. Linkages between the current status and future trajectory of avian communities in the Willamette Valley with restoration success for the entire floodplain ecosystem can be inferred from avian monitoring. Data from bird monitoring can be used to assess management needs, set measurable targets, design management to meet these targets, and measure the effectiveness of restoration activities for avian species (Rosenberg and others, 2016). The substantial cultural and economic importance of birds and their popularity with the public can help raise awareness and promote public investment in restoration and stewardship of natural areas.

Chapter F. Monitoring Aquatic Vegetation, Dissolved Oxygen, and Substrate Responses to Aquatic Invasive Plant Species Treatment Activities

By Rich Miller,[1] Laura A. Brown,[2] and Mackenzie K. Keith[3]

Aquatic invasive plant species (AIS) can outcompete native emergent and submerged plant species (Stiers and others, 2011; Thouvenot and others, 2013), influence water-quality conditions (Smith and others, 2020), reduce aquatic invertebrate abundance (Stiers and others, 2011), and make it difficult for recreational boaters to access impacted waterbodies. Willamette River restoration activities include mechanical (fig. F1) and chemical treatments (fig. F2) to remove or kill AIS in off-channel waterbodies like side channels and alcoves and improve water quality and physical habitat conditions for native fish. Aquatic plants (see chap. A, section, “Vegetation of the Willamette River Floodplain and Low-Streamflow Channel”) growing in off-channel features influence fish habitat, and their presence has been linked to higher fish diversity and abundance in the Willamette River (Williams, 2014) and elsewhere (Dibble and others, 1997). However, the horizontal, vertical, and diel variations in dissolved oxygen (DO) and water temperature within dense AIS beds, particularly for emergent plant beds, can produce conditions unfavorable for fish growth and survival (Miranda and others, 2000; Bradshaw and others, 2015).

Restoration activities to treat AIS can improve water-quality conditions for native fish and other aquatic species in warmer summer and autumn months (fig. F3; table A7). Multiple sites along the Willamette River have undergone herbicide treatments to reduce AIS and improve fish habitat. As with other restoration activities, there are many uncertainties in the linkages between AIS treatment and benefits for fish habitat, especially because many of the channel features downstream from Corvallis where AIS are most prevalent also are places where water temperatures in summer months are more likely to be harmful to cool and cold-water fish and where predation pressure from non-native fish is greatest. Data and evaluation from effectiveness monitoring provide an indication that AIS treatments are enhancing suitable habitat conditions for native fish (tables A7; appendix 4). Four AIS monitoring indicators to evaluate effectiveness of this restoration activity on fish habitat are described in this chapter—emergent and floating leaf plant cover, plant community composition, dissolved oxygen concentration, and substrate characteristics (table A8; fig. F3).

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[3]U.S. Geological Survey

Aquatic Invasive Plant Species Monitoring Indicators and Approaches

Emergent and Floating Leaf Plant Cover

Invasive emergent and floating leaf aquatic plants can out-compete beneficial native emergent and submerged vegetation and expand into open-water habitats important for native fish. Chemical, and to a lesser degree, mechanical control of invasive emergent and floating leaf aquatic plant beds reduce the spatial coverage of those plants and increase the area of open water and submerged plants (figs. F4A and F4B). Two general approaches are used to assess changes in the coverage of emergent aquatic plants, submerged aquatic plants and open water—(1) collection of point-intercept field survey data and (2) analysis of remote sensing imagery (Madsen and Wersal, 2017). Field surveys can identify the type of emergent, floating leaf, and submerged plants but are time consuming and expensive to implement over large areas. Remote sensing can assess larger areas for less cost, but at the expense of survey resolution and detail regarding plant type, particularly submerged aquatic plant. A key component of both approaches is that they include objective methods and similar metrics that can be compared over time using robust statistical methods.

Mapping Cover with Point Intercept Field Surveys

Point-intercept field surveys are conducted by documenting the occurrence of different species or categories of plants at random points within an area and calculating the frequency of occurrence. Repeat point-intercept surveys within the same area allows for statistical comparisons of change in frequency of occurrence between surveys. Example metrics that are useful for evaluating emergent and floating leaf coverage include:

- Percent cover by plant type (submerged, emergent, and floating leaf species),
- Percent cover by AIS,
- Percent of area without emergent or floating leaf plants,
- Percent of area without aquatic plants, and
- Presence or absence of floating mat cover.

Figure F1. Volunteers mechanically removing Uruguayan water primrose (*Ludwigia hexapetala*) in an off-channel feature along the Willamette River, northwestern Oregon (river mile 134). Photograph by Fred Joe Photography, provided by Benton Soil and Water Conservation District, July 30, 2019.

Figure F2. Chemical treatment to kill Uruguayan water primrose (*Ludwigia hexapetala*) in Collins Bay, an off-channel feature along the Willamette River, northwestern Oregon (river mile 122.5). Photograph by C. Durbecq, Benton Soil and Water, Conservation District, July 29, 2014.

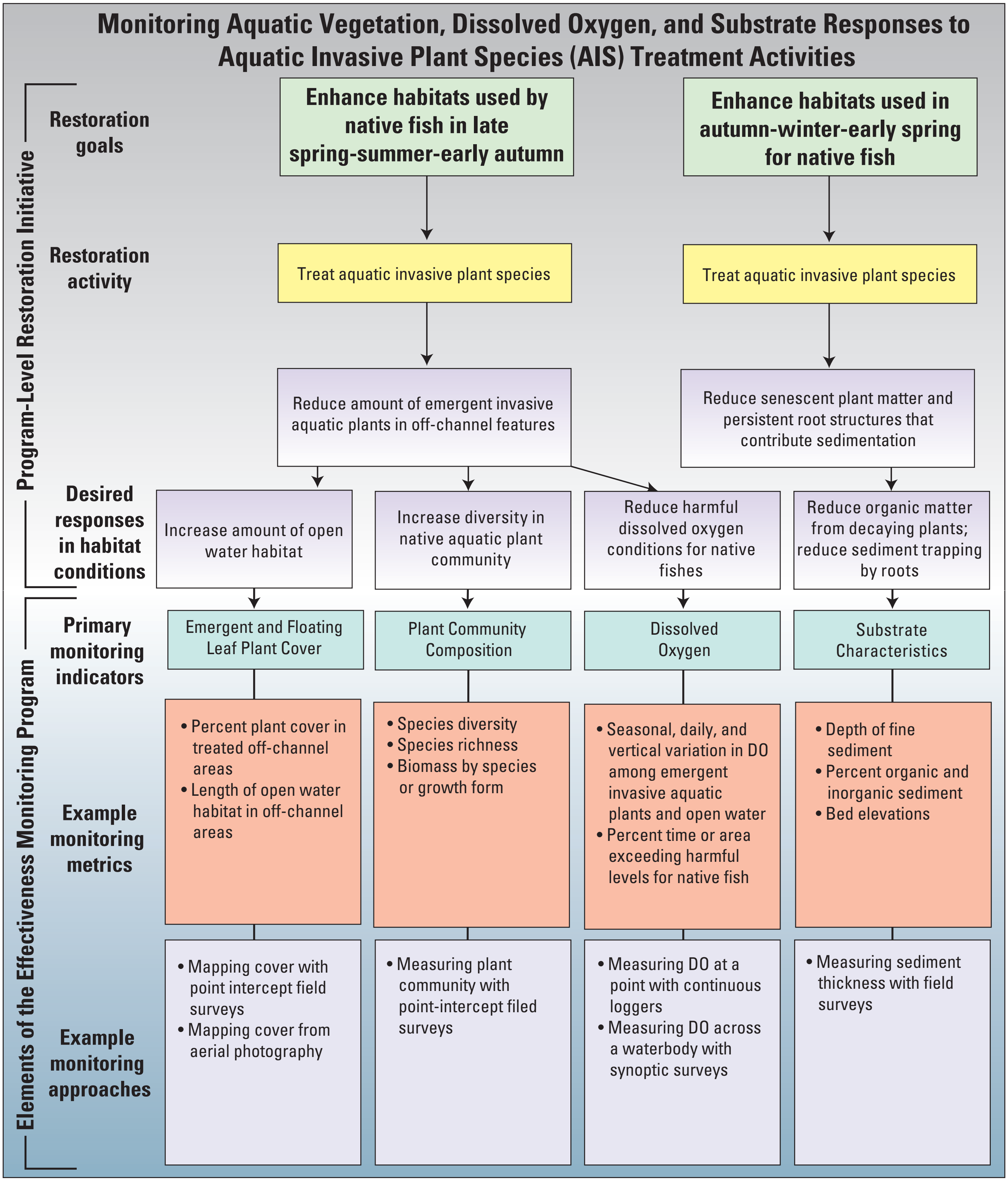

Figure F3. Linkages between aquatic invasive plant species restoration activities, and hypothesized responses with associated monitoring indicators, approaches, and metrics.

Figure F4. Aquatic invasive plant species restoration site at Collin's Bay (river mile 122.5) *A*, before chemical treatments were applied on July 29, 2014, and *B*, after restoration activities to reduce aquatic invasive plant species were implemented on July 12, 2019. Photograph *A* by C. Durbecq, Benton Soil and Water Conservation District and photograph *B* by L. Brown, Benton Soil and Water Conservation District.

Three point-intercept survey requirements must be satisfied to make statistically valid and meaningful assessments of change—(A) observation points are randomly located within the area of interest, (B) points are spatially balanced across known environmental gradients that influence plant growth (for example, depth) in the area, and (C) sufficient points are sampled to detect changes in occurrence at a minimum targeted effect level and statistical power (Kermorvant and others, 2019). For example, sampling of approximately 100 random points is required to detect a 20 percent change in species or categorical occurrence with an 80 percent probability of detection. The required sample size for detecting smaller changes increases substantially; for example, detection of a 15 percent change in occurrence would require up to 200 sample points.

The method used to observe species occurrence at each random point depends on whether plants are emergent/floating or submerged (Madsen and Wersal, 2017). Fixed area round, square, or rectangular quadrats are used for assessing presence of emergent or floating leaf species. A double-sided thatch rake attached to a graduated pole is used to sample points with or without submerged vegetation. Submerged plants can be sampled using scuba gear, but this method is beyond the scope of this framework. Measures such as percent coverage by each species within the quadrat area or rake provide more detail about observed changes relative to metrics derived from remote-sensing approaches; however, statistical changes in coverage in an area of interest are best detected using presence/absence data. Depth measurement data at each point using the graduated rake pole also provide context to the coverage estimates. For example, invasive water primroses typically are most abundant from just above the waterline to depths of 1 m (Thouvenot and others, 2013; Miller and Sytsma, 2018a).

Mapping Cover from Remote Sensing Data

Remote sensing data, such as aerial photography, can be used to map the extent of aquatic vegetation to determine the effectiveness of reducing the presence of emergent and floating leaf AIS from restoration activities. Mapping can be used to distinguish areas with emergent and floating leaf plants from areas of open water or submerged plants. The overall approach can be similar to that used for mapping planimetric features or floodplain vegetation (chap. D, sections, “Mapping Channel and Floodplain Features from Remote Sensing Data” and “Mapping Canopy Cover from Remote Sensing Sources”) although AIS responses to restoration activities might occur over shorter timescales (seasonally to annually). Examples of potentially useful metrics for plant cover within a channel feature include:

- Percent cover by emergent or floating leaf species,
- Percent cover by open water or submerged plants,
- Cross-channel ratio of emergent or floating leaf cover to open water or submerged plant cover,
- Connection between open water or submerged plant cover in an off-channel feature, and
- Presence or absence of floating mat cover.

Remote sensing imagery analysis techniques for assessing aquatic plant coverage have been developed using aerial photographs, medium- and high- resolution hyperspectral data, radar data, and lidar data (Guo and others, 2017). National Agriculture Imagery Program (NAIP) aerial photography, consisting of four high spatial resolution bands, are publicly available and provide coverage for the Willamette River. Maxwell and others (2017) provided best practices for working with NAIP data for mapping aquatic vegetation, including challenges regarding illumination conditions and plant growth status during image acquisition. Supervised and unsupervised pixel- and object-based classification methods can distinguish emergent and floating leaf aquatic plants from submerged plants or open water, sand and gravel, and upland vegetation.

Plant Community Composition

Plant community composition is an important monitoring indicator as increased native plant diversity increases habitat and food resources for native fish. AIS often displace native species and produce monocultures, lowering species richness and diversity, while subsequently reducing diversity and density of native fish and invertebrates (Stiers and others, 2011). Recent studies (Mosaic Ecology, L.L.C., 2017; Miller and Sytsma, 2018a, 2018b, 2018c) in the Willamette River have detected reduced presence of native species in areas where invasive water primroses flourish, and increased presence of native species in areas where water primroses were treated. For example, aquatic plant monitoring of Scatter Bar Pond, an oxbow near Corvallis; Mission Lake, an oxbow lake near Salem; and Windsor Island Slough, a side channel near Salem confirmed that invasive water primroses formed near monocultures in water shallower than 1 meter (m). In contrast, Collins Bay, an alcove near Corvallis where the water primrose beds were chemically treated, has a diverse assemblage of native and non-native plant species in addition to reduced water primrose beds (Miller and Sytsma, 2018a, 2018b, 2018c). Reduction of invasive emergent and floating leaf aquatic plants from restoration activities is expected to result in increases in native emergent and submerged species as space becomes available; therefore, monitoring plant community composition can be used to evaluate the effectiveness of AIS restoration activities.

Measuring Plant Community Composition with Point Intercept Field Surveys

Like mapping cover, point-intercept surveys (this chapter, section, "Mapping Cover with Point-Intercept Field Surveys") can be used to measure plant community composition. All taxa encountered, however, are identified to species using taxonomic keys (for example, Flora of North America, 1993; Hitchcock and Cronquist, 2018; Jepson Flora Project, 2019). Representative samples of plant species (voucher specimens) are pressed and archived for verification of identification. Example metrics that might be useful for evaluating aquatic plant community composition include:

- Percent occurrence of native species,
- Percent occurrence of non-native species,
- Species diversity indices, and
- Presence or absence of indicator species (such as wapato, *Sagittaria latifolia*).

By identifying a change in plant community composition from a community dominated by aquatic invasive species to a community dominated by native species, or at least to a community with increased species diversity, the effectiveness of aquatic invasive species treatment can be evaluated. Many species diversity indices can be calculated from the point intercept survey data and consider the number of species present (richness) and the relative abundance of each species (evenness). Diversity indices such as Simpson's Index emphasize evenness over richness and thus are useful for documenting changes in more abundant species in a community (Daly and others, 2018). Indices such as the Shannon-Wiener Index, however, put more emphasis on rare species as well as abundant species. Both types of indices are useful for documenting changes in Willamette River off-channel habitats. For instance, a Simpson-type index would be useful for tracking changes in water primrose monoculture whereas a Shannon-Wiener-type index would be useful for assessing plant community diversity following water primrose reductions.

Dissolved Oxygen Concentration

Dissolved oxygen (DO) concentration is a measure of how much oxygen gas is dissolved in the water and available to fish and other aquatic organisms. Different minimum concentrations of DO are required to support aquatic life depending on the type of organism. The State of Oregon has adopted criteria for different minimum DO concentrations for different locations and times of the year to protect cold-, cool-, and warm-water aquatic life (ODEQ, 2019; see chapter A, section, "Water Temperature and Dissolved Oxygen Considerations for Native Fish"). Low concentrations of DO can be detrimental for native fish in the Willamette River. Although the main channel of the Willamette River is largely well mixed with suitable DO, off-channel habitats can have areas with low DO concentrations unsuitable for native fish where they are dominated by AIS and water temperature is stratified relative to the main channel (Smith and others, 2020). DO concentrations in water are determined by physical factors such as water temperature, pressure, and atmospheric exchange rates, and biological factors such as production by aquatic plant and algal photosynthesis and respiration by plants and heterotrophic organisms (Rounds and others, 2013). AIS are not distinct from other non-native or native plants in terms of the processes affecting DO. However, AIS tend to have greater biomass, and therefore, can have a larger effect on DO. In addition, as emergent and floating leaf plants perform most of their oxygen exchange directly with the atmosphere, and limit penetration of light to support submerged plants, dense mats of emergent and floating aquatic plants can deplete DO concentrations in the water column by inhibiting photosynthetic oxygen production by submerged plants while adding to respirative oxygen consumption (Frodge and others, 1990; Dandelot and others, 2005; Caraco and others, 2006; Hussner, 2009; Bunch and others, 2010; Stiers and others, 2011).

Aquatic plants display strong seasonal patterns in growth and decomposition based primarily on seasonal changes in water temperature and light. High accumulated plant biomass is generally from mid- through late summer, which also is the period with the lowest streamflow. During this period, aquatic plants can have large impacts on DO and water temperature conditions. The impacts of decomposition of aquatic plant beds as water temperatures and light decrease during the autumn has a negative impact on DO concentrations; however, higher streamflows and colder water temperatures mitigate the influence of decomposition on DO conditions. Monitoring activities associated with plant cover, species composition, and water quality should therefore be focused on the July through September periods.

Variation in DO can be substantial in off-channel features, particularly at sites with dense aquatic vegetation due to the horizontal, vertical, and temporal balance between photosynthetic DO production and respirative DO consumption. Horizontally, DO varies from low values in dense emergent plant beds where photosynthesis occurs primarily in the air and respiration processes dominate below the water surface, to high values in areas dominated by submerged vegetation with high in-water photosynthesis. Vertical variation in DO also can be substantial, primarily in submerged vegetation beds where there is high production in the well-lit shallow water canopy and low in the dark under the submerged plant canopy. Temporally, DO concentrations can vary substantially with diel patterns of light and photosynthesis, particularly in submerged plant beds. During the daylight hours, photosynthetic DO production rates can outpace respirative DO consumption resulting in increasing DO concentrations. During nighttime when photosynthesis is not occurring, DO consumption results in decreasing DO concentrations. Very low dissolved oxygen concentrations within water primrose beds in Willamette River off-channel habitats have been observed (Mosaic Ecology, L.L.C., 2017), and water-quality monitoring conducted in off-channel habitats during 2017 showed extreme diel swings in dissolved oxygen near the surface in submerged beds and low to anoxic DO concentrations within water primrose beds (Carpenter, 2022). Monitoring also revealed an overall decrease in dissolved oxygen concentrations over the course of the summer and variations at small spatial scales, particularly with depth (Mosaic Ecology, L.L.C., 2017; Carpenter, 2022).

These spatial and temporal variations in DO are important to consider when designing and carrying out monitoring. Monitoring can be prioritized during the summer and autumn when plants have the greatest biomass and low DO conditions can be a limiting factor for native fish. Two approaches for measuring DO are outlined for this monitoring framework—(1) continuous DO logging at sites representative of emergent plant and submerged plant beds and (2) synoptic monitoring at higher spatial resolution across plant bed types and densities and across depths.

Measuring Dissolved Oxygen with Continuous Loggers

DO sensors at point locations within a water body can be deployed, similar to continuous water temperature logger deployments (see chap. C, section, “Water Temperature”). Example metrics that might be useful for evaluating continuously monitored DO within and outside emergent plant bed can include the following:

- Daily minimum, maximum, and range of DO,
- 7-day mean-daily minimum,
- Monthly mean-daily minimum DO,
- Occurrence and duration of hypoxic conditions, and
- Percent of time with conditions that support native fish.

Continuous DO measurements can identify when periods of low DO unsuitable for native fish exist, both inside and outside of dense emergent aquatic plant beds. Rounds and others (2013) provided detailed protocols for instrument quality specifications, deployment, retrieval, and data correction (for example, correcting for salinity). Wagner and others (2006) provided guidance on longer-term deployment of water-quality sensors. Additional resources for monitoring DO can be found at the ODEQ volunteer monitoring website (ODEQ, 2020).

Measuring Spatially Distributed Dissolved Oxygen Across a Waterbody Using Synoptic Surveys

Monitoring the spatial variability in DO throughout a water body, both horizontal and vertical, also can be useful for evaluating the effectiveness of AIS treatment. Example metrics to inform summer-autumn native fish habitats can include the following:

- Minimum, maximum and range of DO across and within each aquatic plant bed type and depth,
- Occurrence of hypoxic conditions across and within each aquatic plant bed type and depth, and
- Percent of the cross-sectional area with DO conditions that support native fish.

Techniques and methods described by Rounds and others (2013) can be used to guide DO synoptic surveys. Collection of discrete DO measurements with a multi-parameter sonde provides a snapshot of within-site conditions. Because DO varies with photosynthesis throughout a day, particularly within submerged plant beds, measurements early in the day will be an indicator of the most unfavorable DO conditions during a diel period. Performing synoptic surveys with a multi-parameter sonde allows for collection of DO, water temperature, and other parameters, such as specific conductance and pH, at high vertical and horizontal spatial resolution.

Substrate Characteristics

Substrate, or the bottom surface material of active and off-channel areas, is composed of inorganic particles ranging from fine sediment to coarse gravel and cobble and organic materials such as decomposing organisms, leaves, plants, and wood. Off-channel habitats of the Willamette River often contain fine sediments and organic materials that overlay gravel and cobble. Dense beds of emergent water primroses senesce during the autumn but leave behind a perennial mass of woody stems and roots that can trap sediment and lead to accretion within the dense beds in winter. Accumulation of fine sediment in off-channel features used by native fish may physically reduce the area of available habitat. Increases in the bed elevation can (1) create a shallower water body that may eventually lead to dewatered native fish habitat during summer low-water periods and (2) increase the area that is shallow enough for AIS to grow.

The influence of dense emergent AIS on sedimentation rates in Willamette River off-channel habitats has not been studied, but the effects of aquatic vegetation on sedimentation in fluvial systems is well established (Gurnell and others, 2006; Jones, Collins, and others, 2012; Curran and Hession, 2013). In geomorphically stable off-channel features that are not regularly flushed with high velocity floods, dense stems and roots of emergent AIS can persist throughout the year, which leads to decreased water velocity and increased sediment and organic matter deposition. Through plant senescence and decay, AIS also produce, deposit, and trap more fine sediment and organic matter leading to increasing sedimentation, and thereby, the amount of substrate amenable for AIS re-establishment in the following spring and summer and reduction of important winter native fish rearing habitats.

Changes in the thickness of fine sediment and organic material can be monitored to determine how the treatment of emergent AIS plants in off-channel features influences sedimentation that may lead to a reduction in area of habitat for native fish. Bathymetric field surveys (such as with sonar) can be used to monitor changes in bathymetry related to sediment thickness and habitat availability, while cores or dredging can monitor substrate composition (for example, organic versus inorganic material) to track reductions in organic material related to seasonal AIS plant decay. Because bathymetric surveys and sediment cores can be expensive, require specialized skillsets and equipment, and may yield inconclusive results, they are not included as an approach to monitoring the effectiveness of AIS treatments. Measurements of fine sediment thickness can be used to evaluate effectiveness of AIS restoration activities on sediment accretion in dense emergent aquatic plant habitats.

Measuring Fine Sediment Thickness with Field Surveys

Measuring the thickness of fine sediment and organic material substrates in off-channel features can be completed with annual field surveys. Metrics to support effectiveness monitoring can include:

- Fine sediment thickness within an off-channel feature,
- Percent area of off-channel feature where fine sediment thickness exceeds a predefined threshold (for example, 0.5 m),
- Percent of an off-channel feature where fine sediment is detectable (for example, where thickness exceeds 0.2 m), and
- Average fine sediment thickness in an off-channel feature or within an emergent plant bed.

Fine-sediment substrate thickness can be measured by driving a graduated metal probe into a fine-grained or organic deposit until the underlying coarser substrate is encountered (Hilton and Lisle, 1993). This approach was developed for measuring fine sediment distribution in pools and has been used to assess interactions between riverine aquatic plant distributions and fine sediment thickness (Gurnell and others, 2006). Evaluation of implementing this monitoring technique and resulting datasets is necessary to verify practicality of using this approach for routine measurements over the long term. Additionally, thresholds for measuring detectable sediment thickness would need to be defined and would require refinement with evaluation of this approach.

Fine sediment thickness can be measured at spatially distributed random locations within an area to track statistically meaningful changes in sediment thickness. Substrate responses to AIS treatments should be monitored during low-streamflow periods following streamflow events that transport and deposit sediment and during the winter or early spring when biomass is low. Field surveys should be completed annually during low-streamflow periods in the late spring or early summer before AIS have expanded to limit site access. Combining fine sediment thickness measurements with aquatic plant cover monitoring in later summer months during the height of plant growth would be useful for further characterizing the relation between fine sediment thickness with AIS cover.

Aquatic Invasive Plant Species Monitoring Synthesis

In the Willamette River, aquatic invasive plant species (AIS) such as water primroses have been killed or removed through chemical and mechanical treatments to improve habitats used by native fish. The primary goals for these treatments have been to improve water quality in summer months, but AIS restoration activities (appendix 2) also are hypothesized to improve winter habitats (table A7; fig. F3; appendix 4). The highest priority monitoring indicators to evaluate the effectiveness AIS treatments for improving summer habitat conditions are emergent and floating leaf cover that can be used to directly evaluate treatments and can be evaluated at a broad scale with assessment of large or multiple sites and non-treated sites. Low DO is a limiting factor for fish in the summer and early autumn and is a seasonal monitoring priority at AIS sites. Effectiveness monitoring of substrates would be useful for describing changes in habitat availability that could result from the decay of aquatic plant material or sedimentation during the high-streamflow season (late autumn, winter, and spring) and be evaluated in the low-streamflow season (summer) for determining whether AIS treatments lead to improvements in substrate and habitat conditions.

Evaluation of effectiveness monitoring of AIS treatments should recognize that other limiting factors for native fish (for example, lethal water temperature in the summer and early autumn or presence of predatory fish) may limit improvements or expansion of available habitat for native fish even if other harmful conditions created by AIS are addressed. Pairing AIS monitoring indicators with fish sampling (chap. B) is useful for determining fish community composition at treatment sites and relative abundance of native and non-native fish in different seasons (tables A8 and B1). Water temperature monitoring (chap. C) is necessary for determining whether treatment sites provide suitable thermal conditions for focal fish communities and can be paired with thermal thresholds for fish species to document periods when water temperatures at AIS sites may be harmful or lethal (for example, table A3).

Several outstanding questions raised by the restoration community regarding AIS treatments not addressed in this monitoring framework remain (appendix 4) and will require targeted monitoring and research to evaluate the overall utility of AIS control. Examples of outstanding questions include:

- How much invasive emergent plant coverage within a waterbody needs to be removed to improve water quality for native fish?

- What are realistic outcomes of invasive emergent plant control in different hydrogeomorphic settings? What does long-term management for these water bodies look like?
- How can AIS treatment and other actions (for example, increasing scouring streamflows) be combined to maintain channel depth in off-channel habitats?
- Are there other limiting factors, such as water temperature or the presence of non-native predatory fish, at a site that might preclude effectiveness of the invasive emergent plant treatment on native fish (particularly cool or cold-water species)?
- How do contaminants from herbicide applications impact aquatic life (for example, Myers and others, 2016) and downstream water-treatment plants?

Chapter G. Conclusions for the Willamette River Restoration Effectiveness Monitoring Framework

By J. Rose Wallick[1] and Mackenzie K. Keith[1]

This monitoring framework summarizes monitoring indicators, metrics, and approaches for evaluating ecological and physical habitat responses to restoration activities implemented in or proposed for Willamette River off-channel and floodplain areas that are intended to increase or improve habitats utilized by native fish. The monitoring framework was specifically developed to evaluate the restoration goals and activities of the Willamette Focused Investment Partnership (WFIP) restoration initiative and to inform future adaptive refinement, but is also applicable to other restoration programs with similar goals and activities. Monitoring provides a basis for assessing effectiveness of restoration activities at achieving the primary goals of the restoration program—increasing and enhancing habitats for native fish. Effectiveness monitoring can be conducted at an individual restoration site for site-scale monitoring or at multiple restoration sites as part of a comprehensive program-scale monitoring effort. Monitoring described in this framework also can support other floodplain-management issues, including streamflow management for critical habitats for Endangered Species Act (ESA)-listed species or assessment of floodplain hazards such as channel migration or flood inundation.

From 2008 to 2021, the restoration projects implemented or planned for future implementation as part of the WFIP restoration initiative on the Willamette River include six restoration activities, each intended to increase and enhance habitats used by native fish:

1. Modify floodplain topography and human-made barriers to inundation,
2. Enhance gravel pits,
3. Remove revetments,
4. Construct off-channel features,
5. Increase and enhance floodplain vegetation, and
6. Treat aquatic invasive plant species (AIS).

Effectiveness monitoring indicators, approaches, and metrics are grouped into five categories that reflect distinct monitoring approaches to evaluate different ecological and physical responses to restoration activities:

1. Responses of fish communities and their food resources to all Willamette River restoration activities,
2. Hydrogeomorphic and water temperature responses to restoration activities that directly modify hydrogeomorphic processes,
3. Floodplain vegetation and inundation responses to floodplain forest restoration activities,
4. Responses of avian communities to floodplain forest vegetation activities, and
5. Aquatic vegetation, dissolved oxygen, and substrate responses to restoration activities that treat aquatic invasive plants.

This monitoring framework provides a common science foundation to support ongoing, collaborative decision making on future monitoring activities for the WFIP Effectiveness Monitoring Program. As part of this monitoring framework, linkages among restoration goals, activities, and outcomes for fish habitat were clarified to facilitate monitoring decisions and prioritize monitoring activities. Once monitoring priorities are identified, monitoring partners can select monitoring indicators and approaches from the monitoring framework that best reflect key questions, the types of restoration activities implemented, site conditions, available funding, and other factors when developing annual monitoring plans. Monitoring activities for a restoration site should include appropriate indicators that consider the broader suite of hypothesized responses in fish communities, hydrogeomorphic processes, floodplain vegetation, avian communities, and aquatic vegetation that may result from restoration. For example, effectiveness monitoring at a gravel pit enhancement site that was subsequently planted with floodplain vegetation could focus on fish sampling and hydrogeomorphic monitoring as well as floodplain forest monitoring. Annual plans describing monitoring activities should describe specific monitoring activities for various restoration sites, protocols for data collection, data storage and publication, and descriptions of the analyses to evaluate effectiveness of restoration activities to reflect goals of the overall restoration program.

To evaluate restoration effectiveness, monitoring data must be evaluated according to monitoring metrics and thresholds that permit direct comparison between habitat or fish community conditions at the restoration site, restoration program goals, and the restoration activities that were implemented. To facilitate those comparisons, this framework provides examples of monitoring metrics and thresholds for evaluating monitoring data, recognizing that the precise evaluation criteria for a particular site will need to be tailored to meet program questions and available resources. Because habitat preferences and water temperature tolerances for native fish in the Willamette River span a diverse array of conditions that reflect seasonally varying requirements by species and life stages, the monitoring metrics and analyses used to evaluate the monitoring data should reflect appropriate habitat needs for different fish species or fish communities as well as the particular site. For example, summer water temperature conditions at some restoration sites may be harmful to some native

[1]U.S. Geological Survey

cold-water fish that require cold water but suitable for other native fish that can tolerate cool water. To aid in the interpretation of monitoring data, this report includes water temperature ranges for spring-run Chinook salmon and dissolved oxygen (DO) criteria for native fish. To better anticipate the native and non-native fish that may be found in various Willamette River channel features and restoration sites, information on spatial distributions, thermal classification, and primary diets of native and non-native fish in the Willamette River are also provided in this report.

Even when monitoring data are strategically collected according to a monitoring framework and monitoring plan, and evaluated using metrics that reflect thresholds for fish habitat, determining restoration effectiveness is challenging due to the multiple factors that influence floodplain conditions and habitat availability on a large system such as the Willamette River. These conditions include physiographic controls (such as geology and river slope), environmental conditions and biological and physical processes (such as competition and predation from non-native fish and hydrogeomorphic, thermal, and vegetation processes and conditions), and human-induced factors (such as streamflow management of a large, regulated river). To aid in evaluating the importance of restoration projects relative to broader patterns of habitat availability, site-scale conditions (determined through effectiveness monitoring) can be compared with reach or river-scale conditions (potentially determined from status and trends monitoring). Monitoring based on this framework, combined with information necessary to place site-level findings within the broader context of river-scale streamflow, stream temperature, and habitat conditions, will form an important science foundation to address uncertainties and inform future restoration activities.

Refining restoration goals and activities as part of an adaptively managed process requires addressing critical uncertainties between restoration goals, restoration activities, and outcomes for habitats used by native fish. The effectiveness of restoration activities at improving fish habitat conditions have uncertainties, reflecting (A) limited scientific knowledge available when restoration program goals and activities were established, (B) complexity of drawing causal linkages between restoration activities and habitat availability on a large, regulated floodplain, and (C) limited resources for the research and monitoring necessary for reducing uncertainties. Although the monitoring activities of this framework will generate important datasets useful for evaluating restoration effectiveness, additional research and syntheses can complement these monitoring activities and identify outstanding questions. To support adaptive refinement of Willamette River restoration activities, the restoration program would benefit from (A) leveraging monitoring resources, collaborating in data collection, and sharing lessons learned from monitoring activities of the restoration stakeholders in the watershed and (B) incorporating findings made by other research programs, such as the USACE-funded monitoring and research for ESA-listed spring-run Chinook salmon and winter-run steelhead in the Willamette River Basin. Processes for data sharing among the many organizations involved with Willamette River restoration and salmon research can be improved to more efficiently answer key questions about habitat limitations and best approaches for addressing those limitations through river restoration. Additionally, developing targeted syntheses and research to address critical uncertainties would lead to refinement of restoration activities. There are syntheses underway to summarize the ‘state of the science’ and identify research questions and needs for two Willamette River restoration activities—(1) gravel pit enhancements and (2) treatment of aquatic invasive plants, but more work is needed to evaluate effectiveness of other restoration strategies and to better understand which restoration activities may be most effective at addressing critical habitat limitations for different life stages of spring-run Chinook salmon and winter-run steelhead.

This monitoring framework is intended as a resource for restoration program managers, practitioners, scientists, and contractors as they develop detailed annual monitoring plans for data collection and identify the monitoring indicators, metrics, and approaches most appropriate for evaluating effectiveness of different restoration activities. Effectiveness monitoring will inform restoration and management of the floodplain ecosystem and can ultimately support the diverse array of wildlife communities dependent upon the Willamette River floodplain through adaptive refinement of restoration activities. Lessons learned from monitoring restoration efforts can support adaptive management and refinement of future restoration and monitoring programs in the Willamette River. Although the monitoring indicators, metrics, and approaches for this framework were specifically selected to evaluate six Willamette River restoration activities of the WFIP restoration initiative, they can also be used to evaluate habitat restoration activities along other large gravel-bed rivers of the Pacific Northwest where similar restoration activities occur.

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Appendix 1. Definitions of Terms Used in This Report

Terms Describing Willamette River Floodplain and Vegetation

Active channel—in contrast with the floodplain areas of overbank flooding and fine sediment deposition, the active channel is the portion of the river corridor that regularly experiences scour, deposition, and transport of bed-material sediment (sands, gravels) during high stream flows. The active channel contains the main channel, as well as channel-flanking unvegetated gravel bars and gravel bars with varying stages of young woody shrubs.

Aquatic invasive plant species—aquatic invasive plant species (AIS) are aquatic non-native plants that invade water bodies (for example, rivers, off-channel habitats, disconnected gravel pits) outside of their natural, historical range. Although the term AIS is often used to describe a broad range of aquatic invasive plant and animal species, this report uses the term AIS to exclusively refer to aquatic invasive plant species because treatment of these plants is one of six major river restoration activities underway in the Willamette River. Excessive growth of AIS, particularly emergent floating mat species Uruguayan water primrose (*Ludwigia hexapetala*) and floating primrose-willow (*L. peploides*) and the floating leaf species yellow floating heart (*Nymphoides peltata*), can outcompete native aquatic plants and cause harmful water quality and habitat conditions for native fish.

Aquatic vegetation—in contrast with floodplain vegetation that grows in overbank areas, aquatic plants grow directly in areas of the main channel and off-channel features that are inundated throughout the year. Aquatic vegetation includes a diverse array emergent, submerged, and floating plants composed of both native and non-native plant species.

Floodplain—term for the corridor of land flanking the Willamette River and evolving by occasional overbank inundation and fine sediment accumulation resulting from flooding. Beginning in the 1940s, Willamette River peak stream flows (and resulting patterns of flood inundation and overbank sedimentation) have been substantially reduced by flood control dams that were fully operational by 1970. The present-day floodplain (area that continues to experience flooding despite flow regulation) is much narrower than the historical, or geomorphic, floodplain. The 2-year recurrence interval floodplain (mapping by River Design Group, Inc., 2012) is often used to plan and prioritize floodplain restoration and conservation efforts because the boundary is clearly defined and maps are publicly available. Unless otherwise specified, the term 'floodplain' in this report refers to the present-day floodplain.

Floodplain forest vegetation—specific type of vegetation community found on Willamette River floodplains that can be broadly termed floodplain forest but includes different seral stages and subclasses of forest types (Christy and Alverson, 2011). For this report, ‘floodplain forest vegetation’ includes young floodplain forests (willow and cottonwood shrubs) to mature, late successional forests, and includes stands formed by natural recruitment (such as vegetated gravel bars) and restoration sites where floodplain forest vegetation communities were intentionally planted to increase and enhance habitats for native fish and wildlife.

Floodplain vegetation—term for vegetation growing on the floodplains of the Willamette River and includes many vegetation communities such as emergent wetland, shrub scrub, wet prairie, and floodplain forests (summarized by Christy and Alverson, 2011). Because riparian areas near main channels and broader floodplain areas are difficult to distinguish in large alluvial river valleys (Opperman and others, 2017, p. 59), riparian and floodplain vegetation along the Willamette River are collectively referred to as floodplain vegetation.

Main channel—refers to the primary, wetted channel of the Willamette River that conveys most of the streamflow.

Off-channel feature—generalized term for the many side-channels, alcoves, sloughs, and other water bodies that were formed by historical or recent fluvial processes of the Willamette River but do not convey a substantial portion of the river’s streamflow.

Terms Describing Willamette River Restoration Activities and Programs

Anchor Habitats—many Willamette River restoration activities are clustered within areas known as ‘Anchor Habitats’ that were identified for their habitat values and restoration potential (Bonneville Power Administration [BPA], 2016). Although Anchor Habitats have been identified along the entire Willamette River and portions of major tributaries, restoration projects funded by the WFIP restoration initiative have been focused in Anchor Habitats located upstream from Willamette Falls and within lower tributaries of the Middle Fork Willamette and Coast Fork Willamette Rivers, and the Calapooia and Luckiamute Rivers (Anchor Habitat Working Group [AHWG], 2015).

Restoration activity—generalized term describing six broad categories of distinct restoration activities implemented at Willamette River restoration sites to increase spatial extent or quality of aquatic and floodplain habitats. Each restoration activity includes many small steps, using an array of methodologies and practices to achieve an ecological outcome for that activity. The six Willamette River restoration activities described in this report are primarily implemented for the purpose of expanding and enhancing habitat for native fish of the Willamette River and are based on the Strategic Actions of the Willamette Focused Investment Partnership (WFIP) restoration initiative (AHWG, 2015). These restoration activities take place on floodplains and within off-channel features rather than within the main, low-streamflow river channel. It is not feasible to restore habitats to historical (pre-Euro-American colonization) conditions (as described by Skidmore and others, 2011) due to the many historical alterations to Willamette River floodplain processes and present-day land uses; hence, restoration activities seek to expand and enhance habitats relative to current conditions (AHWG, 2015; BPA, 2016).

Restoration project—a specific plan or design with clearly defined goals and actions and includes one or more restoration activities that are implemented at a specific restoration site.

Restoration site—specific locations where restoration activities are implemented. In the Willamette River, restoration sites generally encompass tens to hundreds of hectares of floodplains or secondary channels. Restoration sites can encompass many restoration projects and a wide range of restoration activities.

Willamette Focused Investment Partnership (WFIP) restoration initiative—restoration program spanning 2016–23 that implements restoration activities to support native fish communities of the Willamette River. The WFIP restoration initiative is one component of the Willamette Mainstem Anchor Habitat Investments Funding Program, which brings together three Willamette River restoration programs, including (A) the WFIP restoration initiative funded by Oregon Watershed Enhancement Board (OWEB), (B) the Willamette River Initiative Program funded by Meyer Memorial Trust, and (C) the Willamette Habitat Program funded by Bonneville Power Administration. The program funds restoration projects at sites within Anchor Habitats dispersed along the main-stem Willamette River upstream from Willamette Falls and within lower tributaries of the Middle Fork Willamette and Coast Fork Willamette Rivers, and the Calapooia and Luckiamute Rivers. The WFIP restoration initiative follows a similar restoration program (Willamette Special Investment Partnership) that spanned from 2008 to 2015. This report uses the term ‘WFIP restoration initiative’ to refer to all restoration activities implemented under the Willamette Anchor Habitats Investment Funding Program. A more complete description of these restoration programs is provided in BPA (2016).

Willamette Focused Investment Partnership (WFIP) Strategic Actions—as part of the Strategic Action Plan for the WFIP restoration initiative, the AHWG described eight categories of restoration activities (termed “Strategic Actions”) that would be implemented along the Willamette River to expand and enhance habitat for native fish (AHWG, 2015; OWEB, 2019; see table A3 of this document). The six restoration activities of this monitoring framework are adapted from the eight WFIP Strategic Actions. For example, two of the eight WFIP Strategic Actions are (1) modify floodplain topography to increase the extent and duration of floodplain inundation and (2) modify artificial barriers to aid fish passage and increase extent and duration of floodplain inundation. These two WFIP Strategic Actions were generalized into a single restoration activity for this report—Modify floodplain topography and human-made barriers to inundation.

Terms Describing Monitoring Activities to Support Willamette River Restoration Programs

Effectiveness monitoring—monitoring to determine if restoration activities produce desired responses in physical, biological, and ecological conditions within defined periods (BPA, 2019). Effectiveness monitoring can span a range of spatial and temporal scales, ranging from project-level effectiveness monitoring that evaluates site-level responses to an individual restoration project, to program-scale effectiveness monitoring that evaluates system responses of multiple restoration projects implemented across many sites. This report describes site- and program-scale monitoring to evaluate effectiveness of the six Willamette River restoration activities. These projects have a shared objective of increasing the extent and quality of native fish habitats.

Implementation monitoring—monitoring conducted to ensure that restoration activities are conducted as planned and completed successfully (BPA, 2019). In the Willamette River, site-scale implementation monitoring is typically required by funding agencies and is conducted by the individual entities implementing restoration projects. Program-scale implementation monitoring tracks progress toward the overall goals and objectives of a restoration program by compiling information from many restoration projects within a single program. For example, the implementation monitoring for the WFIP restoration initiative, gathers information describing restoration activities implemented at specific project sites and within a given time frame, to report progress toward program-scale goals for the WFIP (AHWG, 2019).

Monitoring approach—a generalized method to measure monitoring metrics, often including information regarding the tools or equipment and spatial and temporal considerations to efficiently evaluate restoration strategy effectiveness. Approaches discussed in the monitoring framework may cite or provide examples of protocols and analyses useful for metric evaluation, but specific “evaluation approaches” are not considered.

Monitoring category—category of monitoring based on type of restoration activities. The WFIP effectiveness monitoring framework (this document) describes monitoring approaches for assessing effectiveness of WFIP restoration activities grouped according to five ecological and physical monitoring categories (fish, hydrogeomorphology, floodplain forest vegetation, birds, and aquatic invasive plant species). Within each of these five monitoring categories, the monitoring indicators, metrics, and approaches are broadly similar.

Monitoring indicator—anticipated response (or lack of response) used to signal the types and levels of change in physical habitat conditions or fisheries and wildlife communities in response to restoration activities. An indicator informs the status of the associated hydrogeomorphic or vegetation objective and broader ecological goal. Indicators can be estimated through one or more metrics analyzed over a specified spatial or temporal extent (definition modified from Pacific Northwest Aquatic Monitoring Partnership [PNAMP], 2017). For example, a good indicator for restoration activities that modify floodplain topography to increase inundation and fish access is floodplain inundation.

Monitoring metric—a specific value, with a defined unit of measure (quantitative or qualitative), obtained through direct measurement at a defined spatial and temporal scale. One or more metrics can estimate indicators (definition modified from PNAMP, 2017). For example, one metric for restoration activities that modify floodplain topography to increase inundation and fish access can be the number of days per year that water depths in a deepened swale are suitable for target fish species.

Appendix 2. Restoration Activities and Expected Ecological and Physical Outcomes

The eight restoration activities identified in the Willamette Focused Investment Partnership (WFIP) Strategic Action Plan (Anchor Habitat Working Group [AHWG], 2015) were simplified into six generalized restoration activities (table A7), which are the focus of this monitoring framework. This appendix summarizes these six Willamette River restoration activities, providing examples of specific restoration actions as well as hypothesized near-term responses in hydrogeomorphic and aquatic and floodplain vegetation conditions related to fish habitat that may ultimately result from those restoration activities.

Restoration Activity 1—Modify Floodplain Topography and Human Made Barriers to Increase Extent and Duration of Inundation on the Floodplain

Willamette River restoration projects seek to modify floodplain topography of natural floodplain features or modify human-made barriers to streamflow (such as levees, berms, or culverts) to increase the extent, duration, and frequency of floodplain inundation (fig. A9). Increasing inundation and hydraulic connectivity between the main channel and floodplain areas is assumed to enable fish to more easily access rearing habitats, food resources, and slow-water refuges during high streamflows and also facilitate the transfer of nutrients, food resources, and other aquatic organisms (AHWG, 2015). This restoration activity was identified for the Willamette River because peak streamflow reductions, human floodplain modifications, bank stabilization, and natural overbank sedimentation have collectively reduced the floodplain inundation and the availability and access to floodplain fish habitats during the late autumn, winter, and spring. Increasing access to low-water-velocity floodplain habitats (slow-water refuges) may offer juvenile Chinook salmon and other fish the opportunity to expend less energy than is required in the swifter, main-channel environment and consume more diverse and high-energy food resources than might be available in the main channel. Ultimately, access to slow-water, food-rich floodplain habitats allows juvenile fish to become larger and healthier than if solely rearing in main-stem habitats during the winter, as found in other large rivers (Sommer and others, 2001; Jeffres and others, 2008). Additionally, some native fish spawn in floodplain environments, so access to floodplains is necessary for them to complete their lifecycle (Williams and Gregory, 2018).

Floodplain topography can be modified by deepening floodplain swales and side channels, lowering natural levees and other floodplain topographic highs, and deepening the inlets of floodplain channels with the main channel. Restoration activities to remove or modify human-made barriers to streamflow include notching or lowering berms alongside agricultural fields or gravel pits, replacing culverts and improving road crossings within floodplain channels, and removing culverts and road crossings where they are no longer needed. The effectiveness of barrier modification in the Willamette River floodplain depends on the type of barrier modified, the hydrogeomorphic conditions at the site that influence the frequency and spatial extent of inundation, and the habitat conditions that result from improved passage. Modifications to natural floodplain topography are often implemented in conjunction with modifications to human-made barriers to inundation (fig. A9). These site modifications may increase floodplain inundation during moderate streamflows. Effectiveness monitoring is useful for answering key questions that seek to address increases in inundation, which fish species can access a site given defined fish passage criteria, and if new limiting factors for native fish are present in accessible habitat (for example, predator use or suboptimal water temperatures) following restoration. More specifically, monitoring is useful for understanding and evaluating the frequency and duration of inundation and the amount of new area with suitable fish habitat conditions from restoration activities or for determining sedimentation rates in deepened swales or channels to inform expectations about the longevity of these projects.

Restoration Activity 2—Enhance Former Gravel Pits to Alleviate Stranding and Improve Quality and Availability of Fish Habitat

Gravel pits, where rock and aggregate were formerly mined for commercial purposes, are common throughout the floodplains of the Willamette River and often disconnected from the river by berms, levees, and revetments to prevent flooding, bank erosion, and capture of the pit by channel avulsion. Gravel pits often fill with water from surface and subsurface flow, and because they are disconnected via surface flow from the Willamette River during most of the year can have warm water temperatures and low dissolved oxygen (DO) conditions in summer months. At high streamflows, gravel pits may become inundated by floodwaters from the main channel, carrying native fish that may become stranded during receding flows, and susceptible to predation by invasive fish or other wildlife. Gravel pits within the floodplain of the Willamette River, especially those adjacent to the main channel are often high priority sites for habitat restoration because they provide rare opportunities in a heavily populated region to substantially improve degraded habitats across large sites, without impacting other land uses (such as agriculture or developed areas).

Restoration activities at former gravel pits typically focus on enhancing habitats in late autumn, winter, and spring when water temperatures are not limiting for native salmonids, sites can function as refuges during high streamflows, and improvement can be made in fish egress from the ponds and survival in the ponds (fig. A10). Some gravel pit restoration activities also seek to provide suitable fish habitats in summer months by improving water temperature and dissolved oxygen (DO) conditions. Restoration activities can include (A) connecting the gravel pit to main river, (B) modifying existing high-streamflow swales to improve hydraulic connectivity and fish egress at specified streamflows, (C) modifying pond topography to create gentler, more natural slopes surrounding the pond or more streamlined shape, (D) filling ponds to create shallower habitats, or (E) modifying or removing levees and berms surrounding ponds to improve hydraulic connectivity with the main channel during high streamflows.

As of 2020, more than 21 former gravel pits in the Willamette River floodplain have undergone some degree of restoration to improve habitats for fish and wildlife. Of these, gravel pit restoration at The Nature Conservancy's Willamette Confluence Preserve was the only project to directly connect a gravel pit with the adjacent low-streamflow river channel; this connection was made by removing a levee and revetment, which previously blocked bank erosion and flooding between the Middle Fork Willamette River and adjacent gravel pits. Like other gravel pit restoration projects, the Willamette Confluence Preserve project included modifying pond topography, creating surface-water connections between the Middle Fork Willamette River and three different ponds, and substantial floodplain revegetation efforts on these disturbed sites. Effectiveness monitoring at restored gravel pits can document physical habitat conditions as well as native fish use and survival to determine seasonally varying benefits of different gravel pit restoration activities and potential for predation from non-native fish. Monitoring at gravel pit restoration sites in the late autumn, winter, and spring would address important questions regarding the ability and frequency of that fish access to the site, reductions in fish stranding, and risk of native fish predation by non-native fish. At gravel pits where restoration establishes a low-streamflow connection between the pit and main channel, summer monitoring would address questions such as (A) are water temperature and dissolved oxygen conditions harmful for native fish and (B) what is the potential predation risk for native fish?

Restoration Activity 3—Remove or Modify Revetments in Reaches Likely to Experience Channel Changes

Large-scale bank stabilization projects were built along extensive segments of erodible banks of the Willamette River and its large tributaries to prevent bank erosion and channel migration (Gregory, Ashkenas, Oetter, Wildman, and others, 2002; Hulse and others, 2002; Wallick and others, 2006). Additionally, in the mid-1900s, the USACE built revetments to prevent bank erosion. These stabilization projects, along with peak streamflow reductions and sediment trapping by the dams, have dampened geomorphic processes and reduced the number and area of gravel bars, side channels, and alcoves along the Willamette River between Corvallis and Eugene (Hulse and others, 2002; Wallick and others, 2007; Gregory, 2008). Removing revetments (table A7) may increase lateral channel migration and habitat forming processes that support and increase the geomorphic diversity of landform features (for example, Hall and others, 2007; Harrison and others, 2011; Williams and others, 2020), and may lead to the creation of gravel bars, alcoves, side channels, varied stands of vegetation, and other features that provide habitats suitable for native fish species. In particular, features such as alcoves and side channels may provide cold water refuges (relative to the main channel) in the summer (Fernald and others, 2001; Hulse and others, 2007; Gregory, 2008). For these reasons, revetment removal and modification has been identified as an important restoration activity to support ESA-listed salmon and steelhead as well as native resident fish (National Marine Fisheries Service [NMFS], 2008; Oregon Department of Fish and Wildlife [ODFW], 2011; AHWG, 2015).

Full or partial revetment removal will depend on present-day needs for bank protection and flood reduction and can entail substantial regulatory and logistical challenges. As of 2020, few revetment modifications had been implemented through the WSIP and WFIP restoration initiatives, although planning is underway for revetment modification at other sites. Like other restoration activities, there are many questions regarding near-term and long-term effectiveness of revetment modification, especially when considering the broad range of morphological responses that might result from different types of revetment modifications, and the timescales over which those responses might occur. Effectiveness monitoring can quantify the abundance of newly created channel features that may support fish habitats, assess physical habitat characteristics (such as water temperature and dissolved oxygen; Gregory, 2008; Gombert, 2018; Smith and others, 2020), and determine seasonal use of native and non-native fish in reaches affected by revetment modification. Monitoring also would be useful for addressing the rates and types of channel change resulting from revetment removal in different hydrogeomorphic settings (for example, Hickin and Nanson, 1984; Wallick and others, 2006, 2013).

Restoration Activity 4—Construct Off-Channel Features in Areas with a High Likelihood of Hyporheic Flow

Long sections of the Willamette River have warm temperatures in summer months that exceed the thermal tolerances of native cold-water fish like cutthroat trout and juvenile spring-run Chinook salmon, and there are few locations (especially downstream from Corvallis) that can provide cold-water refuges (Smith and others, 2020; Hulse and others, 2007). To create cold water refuges for native cool-water fish during summer, off-channel features (such as side channels or alcoves) can be constructed through areas with high potential for hyporheic flows (AHWG, 2015). During the high-streamflow season, these constructed channels also provide slow-water refuges. Previous studies suggest that some off-channel features receive cold water inputs from regional groundwater or hyporheic exchange (for example, Fernald and others, 2001; Hinkle and others, 2001; Burkholder and others, 2008; Hockenbury and others, 2013; Smith and others, 2020).

To date, no off-channel features have been constructed as part of the WSIP or WFIP restoration initiatives specifically for collecting cool, subsurface water to create cool- or cold-water habitats. However, experimental alcoves have been constructed to determine the feasibility of artificially creating cool-water habitats (Gregory and others, 2008), and low-streamflow channels have been constructed between the main channel and gravel pits as part of gravel pit restoration projects (for example, at the Green Island Restoration site managed by the McKenzie River Trust, Oregon Watershed Enhancement Board [OWEB], 2020) that may have unintentionally captured cool subsurface flows (Stan Gregory, Oregon State University, written commun., October 25, 2020). Research on the restoration of hyporheic flow within and outside the Willamette River Basin has largely focused on creating in-channel structures (such as riffle, pools, and large wood structures), modifying bedform topography, restoring geomorphic processes, or altering sediment supply conditions to establish the physical conditions necessary to support hyporheic exchange (for example, Hester and others, 2009; Hester and Gooseff, 2010; Kurylyk and others, 2015; Bakke and others, 2020).

Important uncertainties regarding the near- and long-term responses of this type of restoration activity and benefits to native fish remain—native fish use of restored sites, including timing and duration of site access for target species; physical conditions that support creation of cold-water refuges; physical conditions that create habitat for non-native predatory fish; physical conditions that result in sediment accretion at the site's connection to the main channel; and longevity of created sites. If off-channel features are constructed to increase hyporheic flow, effectiveness monitoring will help characterize these uncertainties.

Restoration Activity 5—Increase and Enhance Floodplain Forest Vegetation Through Planting and Invasive Species Control

Planting native trees, understory shrubs, and other plants and controlling invasive, non-native plant species are identified as restorative activities to address the historical losses in vegetation species diversity and area of Willamette River floodplain forests that provide seasonal habitats for fish and other floodplain-dependent wildlife (AHWG, 2015). Increasing floodplain forest vegetation communities is primarily focused on former agricultural fields, gravel pits, and other floodplain areas where historical floodplain forests have been replaced by other land uses. Enhancing floodplain vegetation restoration activities include thinning over-stocked young forests that result from intensive planting efforts and removing or killing invasive, non-native plants that can outcompete native plants (table A7; OWEB, 2019). Although activities to reduce invasive, non-native plants are primarily undertaken to support the establishment of native vegetation, there may be other benefits for native fish because native vegetation may provide better food resources (AHWG, 2015). Because many floodplain planting sites are only inundated during high-streamflow periods (typically in late autumn, winter, and spring; fig. A11), floodplain forest expansion is hypothesized to directly benefit fish habitats when these sites are flooded by increasing hydraulic roughness, providing refuge during high streamflows, providing plant and invertebrate food resources for native fish, and increasing net primary productivity (table A7; Gregory and Ashkenas, 1990; AHWG, 2015; Bonneville Power Administration [BPA], 2016; OWEB, 2019). Effectiveness monitoring is useful for answering important questions about the frequency and duration of flooding in restored sites, fish use and food resources in the newly planted forests, and how reductions in invasive, non-native plants may improve food resources or other aspects of fish habitat.

Increasing and enhancing native vegetation adjacent to off-channel features and ponds in the future can provide cover, shade, and food resources to water bodies underlying the canopy in summer. Shade is only likely to cool off-channel areas where a substantial portion of a feature is shaded and the surface-water connection with the main channel or tributary is minimal. As of 2020, few restoration projects have implemented large-scale planting efforts along off-channel features with the purpose of improving stream temperatures in summer. Even at these sites, it is challenging to determine the effect of floodplain forest shading on water temperature because water temperature is influenced by numerous factors, including subsurface flows, heat conduction from the streambed, tributary inflows, and air fluxes, so monitoring can focus on changes in canopy cover or shade along low-streamflow channel features, rather than water temperature monitoring. Monitoring floodplain vegetation plantings along off-channel features would address uncertainties regarding the effectiveness of riparian planting increasing and enhancing summer fish habitats by determining whether plantings created sufficient shade to reduce solar heating of adjacent waterbodies and contribute cover (table A8; fig. D1; appendix 4). Such monitoring can be paired with water temperature and fish monitoring to determine if water temperatures near planted sites are suitable for native fish species and whether planting activities resulted in an increase in fish use (for native and non-native species).

Restoration Activity 6—Control Invasive Aquatic Plant Species that Degrade Water Quality and Biodiversity

Reductions in peak streamflows and gravel supply imposed by flood control dams and widespread construction of bank stabilization structures have created a more geomorphically stable Willamette River, which creates conditions conducive to infestations of highly invasive, non-native aquatic emergent and floating plant species in off-channel features. These aquatic invasive plant species (AIS) can outcompete native emergent and submerged plant species (Stiers and others, 2011; Thouvenot and others, 2013), reduce aquatic invertebrate abundance (Stiers and others, 2011), inhibit wildlife, and make it difficult for recreational boaters to access impacted waterbodies. Dense mats of emergent aquatic and floating plants can decrease water column dissolved oxygen (DO) concentrations by (A) inhibiting light and photosynthetic oxygen production by submerged plants in the water column during the day, (B) consuming oxygen at night through respiration, and (C) inhibiting water movement and geomorphic scour due to dense accumulations of roots and leaves that reduce water velocity and shear stress (Frodge and others, 1990; Dandelot and others, 2005; Caraco and others, 2006; Hussner, 2009; Bunch and others, 2010; Stiers and others, 2011). Dense mats of water primroses can reduce DO concentrations to levels that are harmful for native fish (Carpenter, 2022). Many invasive aquatic emergent plants, such as water primroses, are perennial plants that can persist during high streamflows (Skaer Thomason and others, 2018), leading to increased retention of organic and inorganic material and shallowing of off-channel features (Jones, Collins, and others, 2012; Curran and Hession, 2013). The goals of restoration activities to control these emergent AIS (fig. A7*B*) are to improve water quality, increase native aquatic plant diversity, and increase the amount of open water habitat (fig. A7*A*) available for native fish use in late spring, summer, and early autumn (fig. A12).

Restoration activities have focused on (A) mechanical removal following early detection of small new infestations and (B) application of herbicides to larger established infestations because of fast growth rates and high biomass (City of Eugene, Oregon, 2012; Grewell and others, 2016; Mosaic Ecology, L.L.C., 2017). About 38 sites have been treated for AIS since 2015 (some treated multiple years), and approximately 520 to 690 hectares are treated each year as part of the WFIP restoration initiative. Several U.S. Environmental Protection Agency's (EPA) approved herbicides for use near water are effective at controlling water primroses, and to a lesser extent, yellow floating heart (Langeland and others, 2006; Sartain and others, 2015; Enloe and Lauer, 2017). Glyphosate, an herbicide, is commonly applied to dense emergent and floating-leaf beds in Willamette River off-channel habitats but is not effective in controlling submersed aquatic plants. Monitoring would inform whether mechanical and chemical treatments improve off-channel habitat and contribute to the understanding of aquatic invasive plant species impacts on off-channel areas in the Willamette River Basin. AIS restoration sites can be monitored to quantify reductions in invasive aquatic emergent and floating leaf plants, use of the site by native and non-native fish, changes in water quality that limit native fish survival, and physical habitat parameters such as sedimentation and loss of usable native fish habitat area.

Appendix 3. General Considerations for Monitoring

This monitoring framework outlines indicators, metrics, and approaches for assessing changes within five ecological and physical monitoring categories (fish, hydrogeomorphology, floodplain vegetation, birds, and aquatic invasive plant species [AIS]) following habitat restoration (fig. A2; table A7). This appendix highlights general considerations related to monitoring resources, temporal and spatial resolution, and evaluation.

Establishing Scientific Objectives as a Basis for Effectiveness Monitoring

As part of an adaptively managed restoration program, effectiveness monitoring will be most successful when restoration program goals, objectives, and actions are scientifically based and linked with hypothesized changes in physical habitat and fish benefits through a Theory of Change (Anchor Habitat Working Group [AHWG], 2015; Oregon Watershed Enhancement Board [OWEB], 2019) or another conceptual framework. The causal mechanisms for each hypothesis should be articulated and the anticipated timeframes for those responses to occur should be described. Independent scientific review of the conceptual framework by appropriate experts can help to ensure the hypotheses are based on best available science and are realistic considering the context of present-day floodplain and fisheries conditions. For Bonneville Power Administration funded restoration programs in the Columbia River Basin, the Independent Scientific Review Panel (ISRP) has supported the use of SMART objectives; these quantitative objectives are specific, measurable, attainable, relevant, and time-bound and based on explicit scientific rationale (Northwest Power and Conservation Council, 2014). As part of future adaptive refinement of Willamette River floodplain restoration programs, each hypothesis in the current WFIP Theory of Change (AHWG, 2015; OWEB, 2019) could undergo scientific review and be refined using recent research and findings from the WFIP Effectiveness Monitoring Program and related Willamette River Basin research. With refined hypotheses linking restoration actions and outcomes for fish habitats in place, SMART objectives to support future restoration program goals can be developed. Once such a framework is established (scientifically rigorous hypotheses paired with SMART objectives describing intended outcomes of the restoration program), effectiveness monitoring can focus on determining whether a particular restoration project or program is having the intended measurable benefits (Northwest Power and Conservation Council, 2014). When coupled with status and trends monitoring, findings from the effectiveness monitoring program can be used to place project or program-level outcomes within the context of river-wide floodplain or fisheries conditions (Northwest Power and Conservation Council, 2014).

Monitoring Resources Considerations

- This monitoring framework identifies low-cost approaches where possible. However, successful implementation of monitoring to evaluate restoration effectiveness for the Willamette Focused Investment Partnership (WFIP) restoration initiative will depend on monitoring staff having well defined protocols, training in standardized data-collection protocols, appropriate equipment for monitoring, and support for data quality control, archiving, and analyses. In particular, having well defined protocols and standardized data collection is essential for ensuring consistency in the resulting data over time and across the restoration program area.

- Logistics regarding site conditions or permitting may influence the selection of specific approaches. For example, stream flow, weather, and site conditions can create safety hazards, impact site access, and pose logistical challenges for many of the field data collection efforts described in this monitoring framework. Additionally, several monitoring approaches, particularly those involving direct contact with aquatic or avian species or those conducted on State or Federal lands, likely require permits. Permitting is not specifically addressed in this monitoring framework.

- All six restoration activities target improvements for native fish habitat. Therefore, data regarding fish responses to restoration would ideally provide the most direct link of site- and program-scale effectiveness, particularly if pre-restoration baseline data were available. However, the types of approaches to monitor fish responses may be limited based on seasonal conditions (water temperature) and species (stage of life and use for species), and results may be confounded by outside factors (for example, presence of non-native fish, annual ocean conditions for anadromous fish species).

- The importance of establishing baseline conditions and setting quantitative goals within realistic timeframes is critical for evaluating effectiveness of restoration programs and projects. Given that several restoration activities have already been implemented along the Willamette River, pre-project baseline data for one or more of the indicators discussed in this monitoring framework may not be available. Pre-project data for physical monitoring metrics could potentially be measured or estimated from existing datasets (for example, canopy cover from aerial photographs that pre-date restoration), but establishing pre-project ecological metrics (for example, abundance of avian focal species) may be challenging without pre-project monitoring. Post-project implementation conditions may need to serve as a baseline but are still important for tracking relatively slow responses (for example, vegetation growth) or long-term responses (for example, sedimentation in a constructed swale).

Spatial and Temporal Data Collection Considerations

- The frequency (such as continuous, event-based, or periodic monitoring at annual, sub-decadal, or decadal timescales) and timing (seasonally or year-round) of data collection varies depending on the goals and type of restoration activities. Continuous data are repeatedly recorded at some defined interval (for example, 15-minute to hourly intervals), and periodic collection may be seasonal or year-round depending on objectives. Monitoring floodplain inundation may only be practical during the winter and spring high-streamflow season (table A2) when the streamflows access the floodplain, although water temperature monitoring throughout the year in enhanced gravel pits can be used to identify summer conditions harmful to fish (table A3) and winter warm-water refuges. Event-based monitoring following specific streamflows of interest may be more useful for measuring responses from sudden changes related to floods or other major disturbances. Periodic monitoring over longer timescales, such as subdecadal (3–5 years) or decadal scales, would be useful for monitoring slower responses (like vegetation growth) or long-term responses to restoration activities (table A7).
- This monitoring framework generally describes data collection within channel or floodplain features at restoration sites. Findings from individual restoration sites can be placed within a broader program-scale context by considering conditions and ecological responses to habitat restoration along long segments of Willamette River with broadly similar hydrogeomorphic conditions or within Anchor Habitats (2–8 km zones of the Willamette River designated for the WFIP restoration initiative where restoration activities are prioritized; fig. A1; AHWG, 2015) as illustrated in figure A13.

Considerations for Evaluating Restoration Effectiveness

- Restoration activities along the Willamette River off-channel and floodplain areas seek to partially restore the habitat functions and processes that support the native fish and wildlife instead of restoring sites to historical conditions. As such, historical geomorphic, vegetation, and habitat conditions provide important context for understanding habitat functions and processes but are not suitable references for determining the effectiveness of habitat restoration activities.
- Where multiple restoration activities occur at a site, monitoring may be not be able to distinguish between the effectiveness of an individual restoration activity.

Appendix 4. Hydrogeomorphic, Floodplain Forest Vegetation, and Aquatic Invasive Plant Species Restoration Activities and Examples of Monitoring

The following sections describe hydrogeomorphic, floodplain forest, and aquatic invasive species restoration activities and examples of monitoring activities for restoration along the Willamette River for the Willamette Focused Investment Partnership restoration initiative. The sections are generally organized by the following elements and structure.

Generalized terminology for restoration activities

Ecological objective

- **Examples of typical restoration activities**
    - **Hypothesized near-term responses (1–5 years)**
    - **Hypothesized long-term responses (greater 10 years)**
    - **Examples of measurable questions to evaluate with monitoring**
        - **Example monitoring indicators**
        - **Example monitoring metrics**
        - **Example monitoring approaches**
        - **Seasonal focus for monitoring**

Restoration Activities that Influence Hydrogeomorphic Processes and Examples of Associated Monitoring Indicators, Metrics, and Approaches

Modify floodplain topography and human-made barriers to inundation

Ecological objective

Increase floodplain connectivity at moderate to high streamflows to increase the area and frequency of inundation and habitat used by native fish

- **Example of typical restoration activities:** Deepen floodplain swales
    - **Hypothesized near-term responses (1–5 years):** Frequency and spatial extent of inundation will increase, enabling fish to have more frequent access to these habitats.
    - **Hypothesized long-term responses (greater 10 years):** Swale will gradually fill with fine sediment and inundation patterns observed immediately after restoration project will diminish over time.
    - **Examples of measurable questions to evaluate with monitoring:** How did spatial extent and frequency of inundation increase after restoration? How does increased inundation relate to increases in fish habitat for target species?
        - **Example monitoring indicators:** Floodplain inundation
        - **Example monitoring metrics:** Number of days per year that water depths suitable for target fish species are achieved.
        - **Example monitoring approaches:** Continuous water-level loggers deployed for autumn-winter-spring. Event-based inundation mapping from remote sensing or field surveys at specific streamflows.

        - **Seasonal focus for monitoring:** Autumn, winter, spring
    - **Examples of measurable questions to evaluate with monitoring:** What is the rate and spatial pattern of aggradation in the deepened swale? How quickly will the deepened swale return to pre-project conditions?
        - **Example monitoring indicators:** Vertical changes
        - **Example monitoring metrics:** Depth of fine sediment deposition for different streamflow events. Net deposition over high-streamflow season.
        - **Example monitoring approaches:** Horizon markers installed at multiple points along swale; depth of sediment deposition measured after high streamflow events and at end of high-streamflow season.
        - **Seasonal focus for monitoring:** Autumn, winter, spring
- **Example of typical restoration activities:** Deepen and widen inlets of side channels
    - **Hypothesized near-term responses (1–5 years):** Frequency of surface-water connection between main channel and side channel will increase; water depth within side channel will increase; water temperatures within side channel will be similar to main channel.
    - **Hypothesized long-term responses (greater 10 years):** Side channel may deepen or aggrade in response to erosion or deposition that results from increased inundation. Vertical changes may be accompanied by planimetric changes (channel widening, bank erosion, bar formation) within side channel.
    - **Examples of measurable questions to evaluate with monitoring:** How did frequency of inundation and water depths change after restoration? How does increased connection to main channel relate to increases in fish habitat for target species?
        - **Example monitoring indicators:** Floodplain inundation
        - **Example monitoring metrics:** Number of days per year side channel provides suitable hydraulic conditions for target fish species. Area of additional fish habitat provided at design discharge.
        - **Example monitoring approaches:** Continuous water-level loggers deployed year-round or as appropriate for site.
        - **Seasonal focus for monitoring:** Autumn, winter, spring
    - **Examples of measurable questions to evaluate with monitoring:** Is restored channel experiencing planimetric or vertical adjustments that compromise longevity of the project or create detrimental conditions for target fish species?
        - **Example monitoring indicators:** Vertical; planimetric changes
        - **Example monitoring metrics:** Magnitude and spatial extent of incision, aggradation, and vertical stability. Magnitude, extent of channel widening, and bank erosion.
        - **Example monitoring approaches:** Repeat field surveys to measure small-scale vertical and horizontal changes; repeat planimetric mapping of entire side channel from remotely sensed datasets; ground-based photographs for qualitative changes.
        - **Seasonal focus for monitoring:** Autumn, winter, spring
    - **Examples of measurable questions to evaluate with monitoring:** How does water temperature vary throughout the year in the restored channel? Did temperature in summer months substantially improve for target fish species?
        - **Example monitoring indicators:** Water temperature
        - **Example monitoring metrics:** Number of days per year that the restored side channel provides suitable temperature conditions for target fish species.
        - **Example monitoring approaches:** Continuous temperature loggers deployed year-round; seasonal synoptic surveys to characterize spatial variation along the side channel.
        - **Seasonal focus for monitoring:** Autumn, winter, spring

- **Example of typical restoration activities:** Lower natural levees and other topographic highs
    - **Hypothesized near-term responses (1–5 years):** Frequency, duration, and spatial extent of overbank flooding will increase. Removing impediments to inundation will reduce fish stranding during hydrograph recession.
    - **Hypothesized long-term responses (greater 10 years):** Fine sediment deposition during floods may cause natural levees to gradually re-build, but this could take decades or longer.
    - **Examples of measurable questions to evaluate with monitoring:** How does frequency, spatial extent and depth of inundation change after natural levee lowered? How are patterns of floodplain dewatering and fish egress improved?
        - **Example monitoring indicators:** Floodplain inundation
        - **Example monitoring metrics:** Number of days per year when hydraulic conditions are suitable for target fish species. Number of hectares that meet hydraulic criteria for target fish species at specified streamflow.
        - **Example monitoring approaches:** Continuous water-level loggers, repeat mapping from remotely sensed imagery acquired during flood events. Repeat ground-based photographs, hydraulic modeling.
        - **Seasonal focus for monitoring:** Autumn, winter, spring
- **Example of typical restoration activities:** Lower or notch human-made levees and berms
    - **Hypothesized near-term responses (1–5 years):** Frequency, duration, and spatial extent of overbank flooding will increase. Removing impediments to inundation will reduce fish stranding during hydrograph recession.
    - **Hypothesized long-term responses (greater 10 years):** Fine sediment deposition in features previously blocked by berms will increase and resulting changes in inundation may be gradual.
    - **Examples of measurable questions to evaluate with monitoring:** How does frequency, spatial extent, and depth of inundation in channel features formerly blocked by berm changed? How are patterns of floodplain dewatering and fish egress improved? How do these changes relate to fish habitat?
        - **Example monitoring indicators:** Floodplain inundation
        - **Example monitoring metrics:** Number of days per year when hydraulic conditions are suitable for target fish species. Number of inundated hectares that meet hydraulic criteria for target fish species at specified streamflow.
        - **Example monitoring approaches:** Continuous water-level loggers deployed for autumn-winter-spring; Event-based inundation mapping from remote sensing or field surveys at specific streamflows.
        - **Seasonal focus for monitoring:** Autumn, winter, spring
- **Example of typical restoration activities:** Remove or modify culverts, road crossings, and other structures that impede inundation and fish passage
    - **Hypothesized near-term responses (1–5 years):** Frequency, duration, spatial extent of inundation may increase. Increased hydraulic connectivity will facilitate fish passage.
    - **Hypothesized long-term responses (greater 10 years):** Vertical and planimetric changes may result from barrier modification and resulting increases or decreases in streamflow and fish access to the floodplain.
    - **Examples of measurable questions to evaluate with monitoring:** How does frequency, spatial extent and depth of inundation change? How does increased hydraulic connectivity relate to fish habitat for focal species?
        - **Example monitoring indicators:** Floodplain inundation
        - **Example monitoring metrics:** Number of days per year when hydraulic criteria for target fish species are achieved.
        - **Example monitoring approaches:** Continuous water-level loggers deployed for autumn-winter-spring. Event-based inundation mapping from remote sensing or field surveys at specific streamflows.
        - **Seasonal focus for monitoring:** Autumn, winter, spring, summer

- ◦ **Examples of measurable questions to evaluate with monitoring:** Are planimetric or vertical adjustments occurring that compromise longevity of the project or create detrimental conditions for target fish species?
  - ▪ **Example monitoring indicators:** Vertical; planimetric changes
  - ▪ **Example monitoring metrics:** Magnitude and spatial extent of incision, aggradation, and vertical stability. magnitude, extent of channel widening and bank erosion.
  - ▪ **Example monitoring approaches:** Repeat surveys to measure small-scale vertical and horizontal changes; repeat planimetric mapping of entire side channel from remotely sensed datasets for large channel features; ground-based photographs for qualitative changes.
  - ▪ **Seasonal focus for monitoring:** Autumn, winter, spring

Enhance gravel pits

Ecological objective

Increase hydraulic connectivity between former gravel pits and main channel to create slow water refuges and improve egress after flooding

- Examples of typical restoration activities: Connect gravel pit to river by creating side channels or deepening existing channel features between pond and river
  - ◦ **Hypothesized near-term responses (1–5 years):** Frequency, duration of hydraulic connection with main channel may increase; allowing fish to access these slow water habitats more frequently.
  - ◦ **Hypothesized long-term responses (greater 10 years):** Channel connecting gravel pit with river may experience bank erosion, incision or aggradation or other morphological adjustments over time.
  - ◦ **Examples of measurable questions to evaluate with monitoring:** How frequently is restored pit hydraulically connected to the river? How does area and availability of habitat for focal fish species vary seasonally with hydraulic connectivity and water temperature?
    - ▪ **Example monitoring indicators:** Floodplain inundation; water temperature
    - ▪ **Example monitoring metrics:** Number of days per year when pit is hydraulically connected to river, and water depths, temperatures in connection channel suitable for target fish species. Number of days per year when pit provides temperatures suitable for target fish species.
    - ▪ **Example monitoring approaches:** Water-level loggers in channel connecting pond and river to assess frequency that pond is connected to river and water depths during connection. Continuous temperature loggers in pond installed year-round to assess seasonal temperature variability.
    - ▪ **Seasonal focus for monitoring:** Autumn, winter, spring, summer
- **Examples of typical restoration activities:** Modify pit topography and adjacent levees and berms to improve hydraulic connectivity and alleviate fish stranding
  - ◦ **Hypothesized near-term responses (1–5 years):** Flood water will spread across the pit and adjacent area more easily, allowing greater transfer of sediment, fish and other organisms; regrading pond topography can facilitate fish egress after floods and create shallow margins that facilitate vegetation establishment.
  - ◦ **Hypothesized long-term responses (greater 10 years):** Former mining sites are heavily disturbed with little topsoil, so increases in flooding and fine sediment deposition may support floodplain formation and vegetation establishment.
  - ◦ **Examples of measurable questions to evaluate with monitoring:** How does spatial extent and inundation depths during specified streamflow events change after topographic modifications?
    - ▪ **Example monitoring indicators:** Floodplain inundation
    - ▪ **Example monitoring metrics:** Spatial extent, frequency of flooding.

        - **Example monitoring approaches:** Event-based inundation mapping from remote sensing or field surveys at specific streamflows.
        - **Seasonal focus for monitoring:** Autumn, winter, spring
    - **Examples of measurable questions to evaluate with monitoring:** What is magnitude and spatial extent of fine sediment deposition?
        - **Example monitoring indicators:** Vertical changes
        - **Example monitoring metrics:** Magnitude and spatial extent of incision, aggradation and vertical stability in connection channel. Magnitude, extent of channel widening and bank erosion in connection channel.
        - **Example monitoring approaches:** Repeat surveys to measure small-scale vertical and horizontal changes. Repeat ground-based photographs for qualitative changes.
        - **Seasonal focus for monitoring:** Low-streamflow conditions with anticipated changes occurring during high streamflows.

Remove revetments

Ecological objective

Initiate channel change to create low-flow habitat for native fish and increase channel complexity

- **Examples of typical restoration activities:** Revetment removal to expose erodible banks to erosion
    - **Hypothesized near-term responses (1–5 years):** Bank erosion and lateral channel shifting and associated changes in channel position and planform (magnitudes dependent on streamflows and other factors).
    - **Hypothesized long-term responses (greater 10 years):** Increases in gravel bars and increased bathymetric complexity that results from lateral migration and deposition of newly liberated sediment can support diverse array of fish habitats at different streamflows.
    - **Examples of measurable questions to evaluate with monitoring:** How did channel position and morphology change? Were there increases in gravel bars and other features that provide bathymetric complexity changes? How do morphologic changes relate to fish habitat for target species?
        - **Example monitoring indicators:** Planimetric mapping
        - **Example monitoring metrics:** Area of gravel bars and other features that relate to complex aquatic habitats. Number of days per year that the site provides suitable fish habitats for target species. Rate of bank erosion or lateral migration.
        - **Example monitoring approaches:** Repeat channel or landform mapping from lidar or aerial photography.
        - **Seasonal focus for monitoring:** Low-streamflow conditions with anticipated changes occurring during high streamflows.

Construct off-channel features

Ecological objective

Create or increase connectivity with side channels and alcoves to create or enhance low-streamflow, cool- to cold-water habitat

- **Examples of typical restoration activities:** Construct or deepen side channel through forested bars or low floodplains for specific purpose of collecting hyporheic flows

- **Hypothesized near-term responses (1–5 years):** Increasing the area and length of time when an off-channel feature has cooler water temperatures than main channel will provide more summer habitats for cool and cold-water fish.
- **Hypothesized long-term responses (greater 10 years):** Overtime, hyporheic flux, and water temperature in restored areas may change; other morphologic adjustments (erosion, deposition) may influence habitat availability and temperature patterns. Hyporheic streamflows also may influence DO.
- **Examples of measurable questions to evaluate with monitoring:** How has magnitude and spatial patterns in summer water temperatures changed? How do changes in water temperature relate to suitability for different fish species? Are dissolved oxygen conditions suitable for target fish species?
    - **Example monitoring indicators:** Temperature; planimetric mapping; vertical change; floodplain inundation
    - **Example monitoring metrics:** Number of days per year that channel provides suitable thermal and hydraulic conditions for cool and cold-water fish. Magnitude and spatial extent of channel that experienced incision, aggradation, vertical stability. Magnitude, extent of channel widening, bank erosion
    - **Example monitoring approaches:** Continuous temperature loggers deployed year-round; seasonal synoptic surveys to characterize spatial variation in temperatures. Water-level loggers to characterize variation in water depths. Repeat surveys to measure small-scale vertical and horizontal changes.
    - **Seasonal focus for monitoring:** Late spring, summer, early autumn

Floodplain Forest Restoration Activities and Examples of Associated Monitoring Indicators, Metrics, and Approaches

Increase and enhance floodplain forest vegetation

Ecological objective

Increase hydraulic roughness, cover, and food availability in floodplain areas inundated in winter months to enhance and expand slow-water refuges; create shade, cover and food resources in off-channel areas inundated in summer months

- **Examples of typical restoration activities:** Plant native trees and shrubs in former agricultural fields inundated in winter months
    - **Hypothesized near-term responses (1–5 years):** Newly planted trees and shrubs provide some cover and food resources during moderate- to high-flow periods when floodplain surfaces are inundated.
    - **Hypothesized long-term responses (greater 10 years):** Forest vegetation matures increasing food resources and the stem density that creates slow-water refuges for native fish during moderate- to high-flow periods when surfaces are inundated.
    - **Examples of measurable questions to evaluate with monitoring:** Was there an increase in the amount of riparian vegetation and cover?
        - **Example monitoring indicators:** (a) Canopy cover, (b) Floodplain forest inundation
        - **Example monitoring metrics:** (a) Area of canopy cover over time, (b) Number of days per year when newly planted floodplain forest is inundated
        - **Example monitoring approaches:** (a) Repeat mapping of floodplain forest vegetation canopy cover every 3–5 years from aerial photographs. (b) Continuous water-level loggers [could be] placed on different elevation floodplain surfaces within a floodplain forest to measure inundation during the high-flow season.
        - **Seasonal focus for monitoring:** (a) Summer, (b) Late autumn, winter, spring
- **Examples of typical restoration activities:** Plant native trees along off-channel areas inundated in summer months

- **Hypothesized near-term responses (1–5 years):** Newly planted trees and shrubs provide food resources to adjacent aquatic habitats.
- **Hypothesized long-term responses (greater 10 years):** Forest vegetation matures and canopy cover blocks direct solar radiation to off-channel feature reducing local temperature conditions.
- **Examples of measurable questions to evaluate with monitoring:** Has the amount of floodplain forest canopy cover blocking off-channel features increased?
  - **Example monitoring indicators:** (a) Canopy cover, (b) Abundance of floodplain focal species
  - **Example monitoring metrics:** (a) Area of canopy cover over time, (b) Presence or absence of each focal species during the breeding season at a site
  - **Example monitoring approaches:** (a) Repeat mapping of floodplain forest vegetation canopy cover every 3–5 years from aerial photographs and overlaying mapping with polygons of the off-channel feature. (b) Annual point count field surveys during the breeding season to document floodplain-associated focal species to track changes in avian communities as vegetation evolves.
  - **Seasonal focus for monitoring:** (a) Summer, (b) May through early July

- **Examples of typical restoration activities:** Treat invasive plants to facilitate establishment and survival of native plants
  - **Hypothesized near-term responses (1–5 years):** The amount of invasive plant species that outcompete native vegetation within existing floodplain forests are reduced.
  - **Hypothesized long-term responses (greater 10 years):** The amount of native shrubby and woody vegetation increases, thereby increasing food resources and the stem density that creates slow-water refuges for native fish during moderate- to high-flow periods when surfaces are inundated.
  - **Examples of measurable questions to evaluate with monitoring:** (a) Has the overall floodplain forest and ecosystem health improved? (b) Have invasive plant treatments occurred in areas of inundation that might be used by fish?
    - **Example monitoring indicators:** (a) Species richness (avian indicator), (b) Floodplain forest inundation
    - **Example monitoring metrics:** (a) Number of species per unit area and effort (effort measured in person hours), (b) Number of days per year when floodplain forest restoration site is inundated to a depth suitable for focal fish species
    - **Example monitoring approaches:** (a) Point count field surveys during the breeding season or the combination of mist-net and area search surveys during the non-breeding season to monitor floodplain-associated bird species. (b) Hydraulic models developed with high-resolution topographic data for modeling multiple flow scenarios and overlaying inundation with polygons or restoration activities.
    - **Seasonal focus for monitoring:** (a) May through early July or mid-July through April depending on approaches, (b) Late autumn, winter, spring

- **Examples of typical restoration activities:** Interplant existing floodplain forest.
  - **Hypothesized near-term responses (1–5 years):** Newly planted trees and shrubs provide some cover and food resources during moderate- to high-flow periods when floodplain surfaces are inundated.
  - **Hypothesized long-term responses (greater 10 years):** The amount of native shrubby and woody vegetation increases, thereby increasing food resources and the stem density that creates slow-water refuges for native fish during moderate- to high-flow periods when surfaces are inundated.
  - **Examples of measurable questions to evaluate with monitoring:** (a) Has canopy cover increased?, (b) Has the overall floodplain forest and ecosystem health improved?
    - **Example monitoring indicators:** (a) Canopy cover, (b) Avian productivity and survival
    - **Example monitoring metrics:** (a) Density of canopy within a restoration site, (b) Number of individuals captured by age and sex. Ratio of young to adults captured

- **Example monitoring approaches:** (a) Repeat mapping of floodplain forest vegetation canopy cover every 3–5 years from aerial photographs. (b) Mist-net and area search surveys to[m] measure avian demographics [could be implemented] in the non-breeding season.

- **Seasonal focus for monitoring:** (a) Summer, (b) Late autumn, winter, spring

Restoration Activities that Address Aquatic Invasive Plants and Examples of Associated Monitoring Indicators, Metrics, and Approaches.

Treat aquatic invasive plant species (AIS)

Ecological objective

Improve water quality in off-channel features where AIS that create harmful dissolved oxygen conditions; increase open water areas where dense plant beds restrict fish movement

- **Examples of typical restoration activities:** Chemical or mechanical control to kill or remove aquatic invasive plant species.
    - **Hypothesized near-term responses (1–5 years):** Emergent aquatic invasive plants are reduced or removed from off-channel features resulting in decreased decomposition of vegetation matter thereby increasing dissolved oxygen.
    - **Hypothesized long-term responses (greater 10 years):** Aquatic invasive plant remains reduced contributing to suitable dissolved conditions for native fish. Reduced root densities of aquatic invasive plant species trap less sediment leading to reduced re-growth of future infestations, and where streamflows flush fine sediment out of the off-channel feature native fish habitat area is increased or maintained.
    - **Examples of measurable questions to evaluate with monitoring:** Did the chemical treatment reduce the amount of invasive water primroses in the off-channel feature?
        - **Example monitoring indicators:** (a) Emergent and floating leaf plant cover, (b) Plant community composition
        - **Example monitoring metrics:** (a) Percent area of off-channel feature is covered by emergent or floating leaf species. (b) Percent occurrence of non-native species within off-channel feature.
        - **Example monitoring approaches:** (a) Repeat annual mapping of aquatic vegetation cover from aerial photographs spanning treatments. (b) Completing field surveys before and after treatment with the point-intercept method identifying plants to the species level.
        - **Seasonal focus for monitoring:** Summer, early autumn
    - **Examples of measurable questions to evaluate with monitoring:** Do off-channel sites containing AIS include suitable dissolved oxygen conditions for native fish?
        - **Example monitoring indicators:** Dissolved oxygen concentration
        - **Example monitoring metrics:** Daily range in dissolved oxygen within and outside emergent plant beds. Percent of time with conditions that support native fish in emergent plant beds
        - **Example monitoring approaches:** Continuous dissolved oxygen loggers deployed at multiple locations within an off-channel site with logger placement targeting AIS and non-AIS portions of the site.
        - **Seasonal focus for monitoring:** Summer, early autumn
    - **Examples of measurable questions to evaluate with monitoring:** What is the substrate within an off-channel feature? Has the thickness of fine sediment decreased?
        - **Example monitoring indicators:** Substrate characteristics

- **Example monitoring metrics:** Percent area of off-channel feature where thickness exceeds a predefined threshold (for example, 0.5 m).
- **Example monitoring approaches:** Field surveys driving graduated metal probes into substrates to measure the locations and thickness of fine sediment throughout an off-channel feature.
- **Seasonal focus for monitoring:** Summer

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