RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration

UN DECADE ON ECOSYSTEM RESTORATION

TECHNICAL ARTICLE

Adaptive management of large-scale ecosystem restoration: increasing certainty of habitat outcomes in the Columbia River Estuary, U.S.A.

Chanda Littles[1,2], Jason Karnezis[3], Katie Blauvelt[4], Anne Creason[3], Heida Diefenderfer[5], Gary Johnson[6], Lynne Krasnow[7], Phil Trask[4]

Ecological restoration programs in dynamic coastal environments can benefit from adaptive management, including an iterative process for identifying and addressing critical uncertainties. We highlight key developments under the three pillars that have increased the rate of restoration by the Columbia Estuary Ecosystem Restoration Program (CEERP) over 20 years: science, coordination, and management. We show how such programs can be institutionalized to ensure that estuary ecosystems are better understood, conserved, and restored. The principal conservation effort under CEERP is to reconnect historical floodplain wetlands to the mainstem. The program also supports other restoration actions that demonstrate a high potential to benefit ecosystem function and endangered salmon populations; however, there is greater uncertainty regarding these less-utilized techniques. Through adaptive management, we address technical uncertainty regarding benefits to the environmental resource and programmatic uncertainty pertaining to decision-making. Here, we examine three periods of CEERP growth to establish how complementary research and restoration actions have improved program outcomes over time. We highlight the tools and processes that were developed and integrated into the program to refine program strategy, improve project design, and maximize ecological benefits. CEERP supported 77 restoration projects and reconnected over 7,000 acres of floodplain habitat to the lower Columbia River between 2004 and 2021. Building on these successes, we outline current plans to better engage landowners and local communities, solicit new project types, and maintain enough flexibility within the program to adapt to new priorities.

Key words: connectivity, coordination, floodplain, juvenile salmon, restoration, wetlands

Implications for Practice

- Managers can optimize restoration program effectiveness by linking science that addresses uncertainties to program management and implementation.
- Coordination of key scientific and management tools and processes supports effective program policy and decision-making.
- A science-driven adaptive management framework benefits from an established management team that values independent scientific review and regularly synthesizes and evaluates monitoring and research results.
- Continued nourishment of long-term relationships with local communities lays the groundwork for future restoration opportunities.
- Program managers, restoration practitioners, and researchers must document the results of adaptive management programs so that lessons learned are readily accessible, provide institutional memory, and benefit programs elsewhere.

Introduction

Ecological restoration programs benefit from adaptive management (AM) that actively refines the program based on new

Author contributions: CL led manuscript development; JK, KB, GJ, PT outlined adaptive management implementation and progress; CL, PT conducted sponsor interviews and evaluated programmatic uncertainties; JK, KB, AC, HD, GJ, PT summarized tools, processes, and scientific advancements; CL, JK, KB, AC, HD, GJ, LK, PT wrote and edited the manuscript.

[1]U.S. Army Corps of Engineers – Portland District, Environmental Resources Branch, 333 SW 1st Avenue, Portland, OR 97204, U.S.A.
[2]Address correspondence to C. Littles, email chanda.j.littles@usace.army.mil
[3]Bonneville Power Administration, Environment, Fish & Wildlife Program, 905 NE 11th Avenue, Portland, OR 97232, U.S.A.
[4]PC Trask & Associates, Inc., 1220 SW Morrison, Suite 1300, Portland, OR 97205, U.S.A.
[5]Pacific Northwest National Laboratory, Coastal Sciences Division, 1529 West Sequim Bay Road, Sequim, WA 98382, U.S.A.
[6]Pacific Northwest National Laboratory, Energy and Environment Directorate, 620 SW 5th Avenue, Portland, OR 97204, U.S.A.
[7]National Oceanic and Atmospheric Administration – Fisheries, West Coast Region, 1201 Northeast Lloyd Boulevard, Suite 1100 Portland, OR 97232, U.S.A.

doi: 10.1111/rec.13634
Supporting information at:
http://onlinelibrary.wiley.com/doi/10.1111/rec.13634/suppinfo

learning (Zedler 2017; Ellison et al. 2020). The now 20-year effort organized by the Columbia Estuary Ecosystem Restoration Program (CEERP) institutionalized restoration, monitoring, and learning initiatives integral to the AM process (Ebberts et al. 2017). CEERP managers and researchers coauthored this case study to elaborate on CEERP's AM cycle and three legs supporting those efforts: Science, Coordination, and Management (Fig. 1). The assessment herein demonstrates how program managers—Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (USACE), and National Marine Fisheries Service (NMFS)—support each leg to achieve long- and short-term goals. CEERP stakeholders—restoration sponsors, monitoring practitioners, research entities, advisory groups, and affiliates—then implement the program under the science and coordination legs. Collaboration between program managers and stakeholders is iterative and essential to successful AM (Webb et al. 2018). We highlight key developments that are replicable elsewhere and offer lessons for reducing uncertainty and improving restoration outcomes.

Our focus is the 234-rkm (river kilometer) long floodplain of the Columbia River Estuary (CRE) (Fig. 2). CEERP aims to *understand, conserve, and restore ecosystems in the estuary*, driven by Endangered Species Act (ESA) considerations and the Northwest Power and Conservation Council (2000) Fish and Wildlife Program. Early federal directives (e.g. the Pacific Northwest Electric Power Planning Conservation Act of 1980, NMFS 2000) were initial drivers for CRE restoration. CEERP adjustments have addressed restoration design optimization, the science underlying salmon benefit indices, and local versus large-scale ecosystem responses. CEERP recognizes structural (technical) uncertainty pertaining to environmental resources, and institutional (programmatic) uncertainty about the decision-making cycle (Williams & Brown 2018). This article outlines AM improvements in both arenas throughout CEERP's evolution and discusses efforts to leverage lessons learned to maximize benefits from aquatic ecosystem restoration.

Figure 1. CEERP's adaptive management process (i.e. learning, monitoring, and restoration) and its supporting legs. Each element of the AM cycle relies on continuous management, coordination, and science activities, and informs all three. The management team for CEERP is composed of representatives of the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers Portland District (USACE), and National Marine Fisheries Service (NMFS).

Methods

Three main periods characterize the program's evolution to date (Fig. 3) based on major learning milestones and their influence on restoration projects implemented: Foundational AM (2000–2008), Emerging AM (2009–2013), and Maturing AM (2014–2021). Coauthors identified tools and processes (Table 1) instrumental to the program's supporting legs, fostering an evolution in sophistication of projects between 2000 and 2021. Coordination with CEERP stakeholders is crucial to CEERP's AM and to fully evaluate future AM needs, we conducted qualitative, semi-structured interviews (Drury et al. 2011) with the five primary CEERP restoration project sponsors. We sent questions to sponsors asking about effective landowner engagement, critical support from CEERP managers, barriers to project implementation, and the top ingredients for successful restoration. Coauthors scheduled 1-hour meetings with each sponsor organization and asked them to respond to the questions provided. All sponsors previewed the final table summarizing their feedback before article submission and our evaluation of those responses is discussed under Future AM.

Results

This manuscript documents CEERP progress toward achieving restoration goals throughout three AM periods. CEERP's understanding of the CRE and effective habitat restoration has increased through research and tools developed and refined to address uncertainties. Table 1 and Figure 4 are complimentary; the former providing greater details for tools and processes that were especially significant to the program's advancement, a few of which are highlighted below.

Foundational AM (2000–2008)

The scientific foundation for cohesive ecosystem restoration in the CRE began during 2000–2008. Key advances included a conceptual ecosystem model, studies linking juvenile salmon ecology to habitat attributes, initiation of a digital ecosystem classification system, establishing monitoring protocols, and sampling at reference wetlands (Thom et al. 2004; Bottom et al. 2005, Roegner et al. 2008, 2009; Borde et al. 2011; Diefenderfer et al. 2011; Simenstad et al. 2011). Early regional coordination resulted in the CRE's acceptance into the Environmental Protection Agency's National Estuary Program. Investments in research and involvement in forums such as the Lower Columbia Estuary Partnership's Science Work Group, USACE's Anadromous Fish Evaluation Program, and the Northwest Power and Conservation Council's Fish and Wildlife Program

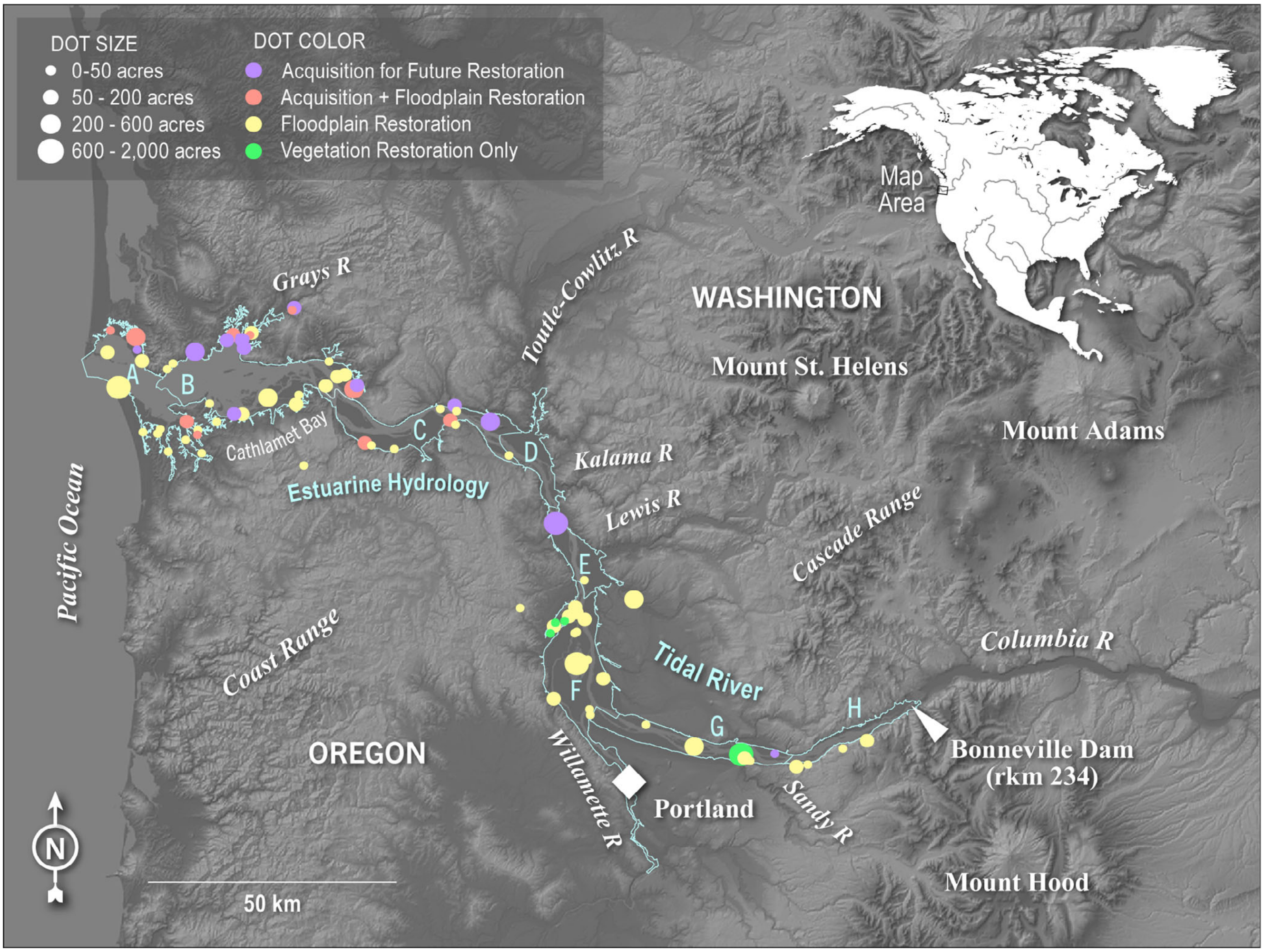

Figure 2. Map of the Columbia River Estuary showing the size and type of acquisition and restoration projects implemented by CEERP, 2000–2020. Hydrogeomorphic reaches (Simenstad et al. 2011) A through H are labeled. "Floodplain Restoration" refers to hydrological restoration (i.e. breach levees or upgrade culverts, etc.) and "Vegetation Restoration Only" refers to invasive vegetation removal, native plantings, and riparian enhancements. One project with acquisition and vegetation restoration only was lumped into the "Acquisition + Floodplain Restoration" category. [Correction added on 28 March 2022, after first online publication: In Figure 2, the labels for Mount St. Helens and Mount Adams in the map have been corrected in this version.]

expanded coordination and established important momentum and structure for continued program development (Fig. 4).

Limited funding and lack of a strategic framework resulted in a piecemeal approach to restoration projects before 2009. Projects typically were ecologically simple and limited in size and scope (Fig. 5), e.g. Sandy River Delta revegetation (Supplement S1). NMFS' 2008 Endangered Species Action Biological Opinion emphasized the need for a more formal program structure , additional implementation capacity, and greater support for the learning and restoration components of the AM process (NMFS 2008, Fig. 1). CEERP refined its implementation strategy to meet those needs.

Emerging AM (2009–2013)

Leading into the Emerging AM period (2009–2013), NMFS (2008) identified the loss of floodplain habitat as the most essential limitation for juvenile salmonid rearing and migration. A synthesis of scientific research suggested that levee breaches reconnecting large floodplain areas close to the mainstem river would benefit interior Columbia Basin juvenile salmon more than actions like tide gate upgrades (Thom et al. 2013). Program managers incorporated this understanding into their implementation strategy (BPA & USACE 2012). This tested the program's ability to overcome formidable social and technical constraints related to existing land uses behind the levees. To address these constraints, BPA increased program funding nearly fivefold.

Scientific understanding of a large and dynamic system such as the CRE requires a proactive approach to project design, study implementation, and data synthesis. There were several important contributions to the program's scientific basis during the Emerging AM period highlighted by Ebberts et al. (2017) (Table 1). The benefits of regular exchanges among program participants including the Expert Regional Technical Group (ERTG; see below), its Steering Committee, project sponsors,

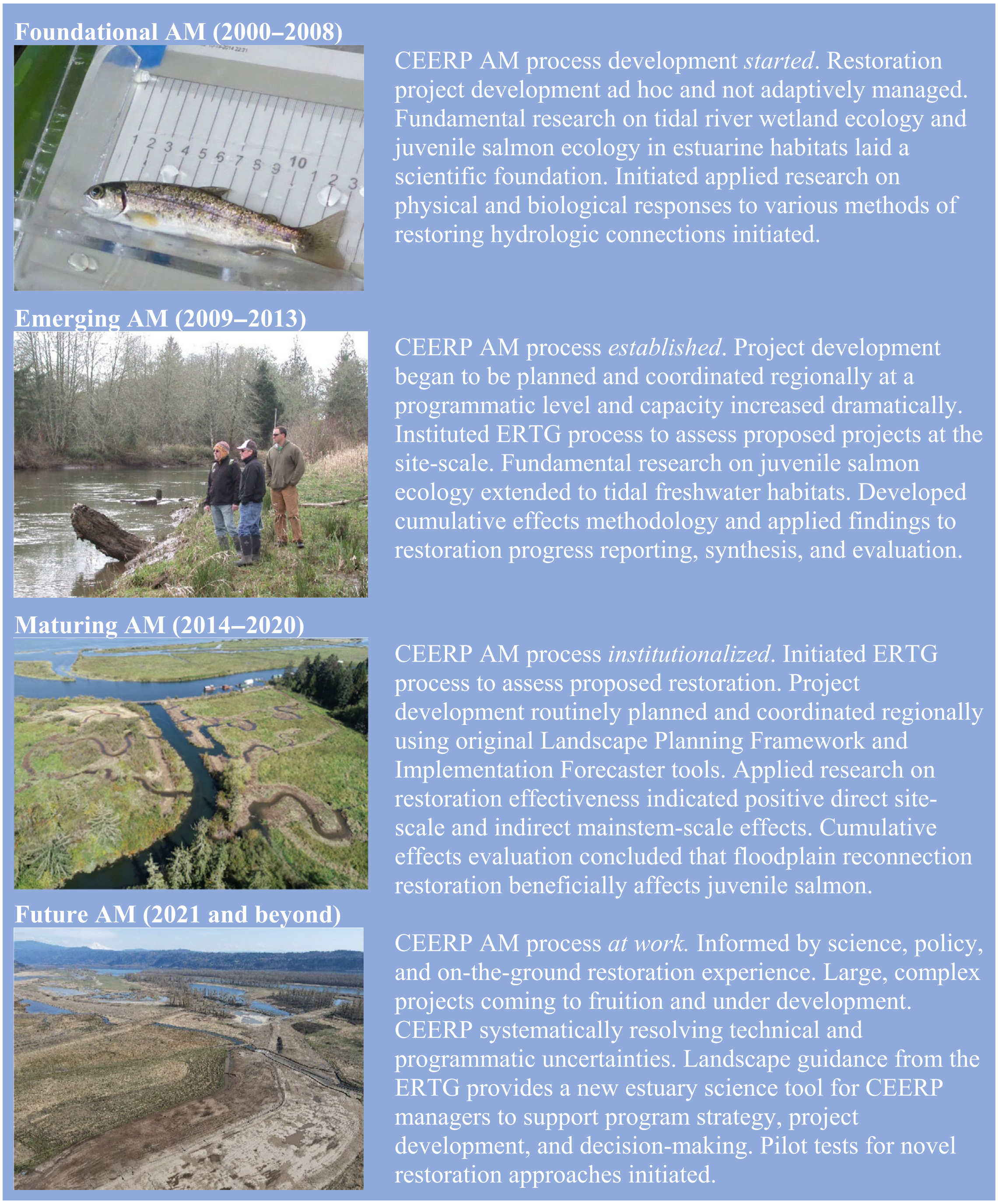

Figure 3. Overview of the CEERP AM periods. Image sources: (1) Pacific Northwest National Laboratory; (2) Gary Johnson; (3) Jason Smith; and (4) Doug Kreuzer.

and other scientists reinforced the notion that reflection is a key component of successful AM (Webb et al. 2018).

Projects implemented in the beginning of the Emerging AM period were generally small (<15 ha) with simple designs, sometimes resulting in minimal salmonid benefits (Fig. 5). Two new factors began to influence project selection and implementation: (1) The ERTG, in 2009, started to review the merits of proposed projects based on an expanding body of research and (2) The capacity, expertise, and dedication of project sponsors grew. Both factors led to an increase in acreage acquired and restored compared to the Foundational AM period (Fig. 5A). More tidal channels and wetland areas were

Table 1. CEERP tools and processes suitable for large-scale ecosystem restoration programs that have been iteratively developed through ongoing science, coordination, and management activities among CEERP stakeholders.

Tool/Process	*Description*	*Significance/Use/Application*
	Foundational AM	
CRE Ecosystem Classification System	Digital hierarchical ecosystem classification (Simenstad et al. 2011) used by CEERP as a foundation to create more detailed juvenile salmon-specific data products (i.e. Landscape Planning Framework and Landscape Principles)	Provides the foundation for mapping species-specific habitats across the estuary; delineates distinct hydrogeomorphic reaches of the CRE; used in several other data products
Basic Ecological Research	Basic research on the ecology of juvenile salmon and steelhead in shallow water habitats of the LCRE to determine spatial and temporal distributions, genetic stock compositions, densities, feeding habits, prey availability, etc.	Provides a scientific foundation for the benefits of wetland habitat restoration
	Emerging AM	
Expert Regional Technical Group (ERTG)	A CEERP-funded group of geomorphologists, restoration ecologists, and fish biologists that independently assesses potential benefits of proposed restoration projects for juvenile salmon, synthesizes data to establish technical guidance, and helps clarify technical uncertainties (Krueger et al. 2017)	Provides unbiased, independent expert guidance to aid program strategy and project planning, design, and prioritization. ERTG products are used by CEERP managers, sponsors, and other stakeholders
Project Goal Maps	Site-scale standardized GIS-based maps and metrics depicting proposed restoration activities for a project. These maps were specified by ERTG and are produced by the sponsors to facilitate management review and ERTG evaluation	Allows consistent evaluation and direct comparison of potential restoration projects by illustrating specific project actions and quantifying the predicted affected area
Estuary-wide Terrain Surface	A LiDAR- and bathymetry-derived 1-m resolution terrain surface covering the entire CRE floodplain. Produced by the USACE and used by sponsors to assess potential restoration sites, model restoration alternatives, build detailed landcover products, and map estuary-wide juvenile salmon habitat (i.e. Landscape Planning Framework, see below)	Provides a critical foundation to systematically and consistently map restoration projects, conduct essential project feasibility, and provide a basis for regional-scale data products
Modeling of 2-year flood elevations (i.e. 50% annual exceedance probability stage profile)	A model output of the 50% annual exceedance probability elevation at every third CRE river mile extrapolated into a polygon representing all areas inundated at the 2-year flood event. Produced by USACE and used by sponsors to delineate subaction polygons and define areas hydrologically benefited by the proposed restoration actions	Allows consistent delineation of areas predicted to be inundated by restoration projects
"Get-After-It-List"	Initial inventory and coarse assessment (e.g. benefits, cost, and constraints) of all known potential acquisition and/or restoration projects estuary-wide. Created by sponsors and managers to help guide project selection, estimate resource needs, and improve landowner coordination	Organized project opportunities by identifying potential implementation constraints for each project. Provided a basis for sponsor and landowner engagement
Landscape Planning Framework	Geodatabase that adapts the structure of the CRE Ecosystem Classification to identify sites with potential to benefit juvenile salmon. Developed through CEERP for use by sponsors and managers to inform project goal maps, estuary-scale research, and evaluation of habitat distribution and connectivity	Provides a digital platform for quantifying the distribution of habitats across the estuary. May be used to identify potential restoration project sites
"CBFish" Database	A web-based database that is regularly updated and maintained for an official record of ERTG project evaluations and work products, project feasibility information, and a geodatabase of project subaction features. Developed by BPA, CBFish is used by managers and sponsors to track project history, reference ERTG documents, and maintain a library of CEERP products. Also used by the public to view completed CEERP projects	Provides a centralized database to maintain institutional knowledge and facilitate communication and outreach with stakeholders. The database aids regional coordination and promotes program transparency
Master Matrix of Learning	As part of the annual CEERP AM cycle, the master matrix summarizes new learning and associated adjustments/implications/actions to CEERP restoration and monitoring. Sources include journal articles, technical reports, ERTG work products, conferences, workshops, and inputs provided by CEERP project sponsors	Provides a systematic, thorough accounting of relevant new literature and findings that managers can use to adjust a program's restoration and monitoring strategies
	Maturing AM	
Implementation Forecaster	An outgrowth of the Get-After-It-List with an updated project inventory for 139 potential projects. The Implementation Forecaster includes current information of implementation constraints, costs, and benefits including ERTG landscape maps and is reflected in the CBFish project subaction geodatabase. A dashboard supports queries and pertinent statistics	Provides a tool for managers, sponsors, and scientists to strategically inform which potential projects to invest limited outreach, reconnaissance, and feasibility resources

Table 1. Continued

Tool/Process	*Description*	*Significance/Use/Application*
Landscape Principles	Theory and application of landscape principles to map fish habitat patches, distances between patches, and functional shoreline habitat relative to critical hydrogeomorphic and tributary transitions, for both an existing and historical condition of the CRE. Developed by ERTG and used by managers to make implementation funding decisions, and by sponsors to describe a proposed project's potential landscape benefits. References the Ecosystem Classification and Landscape Planning Framework	Provides a method of characterizing a project's landscape value. Helps inform program strategy by identifying priority areas for restoration, as wells as areas where pilot applications of novel restoration techniques may be warranted due to a lack of traditional project opportunities
Project Landscape Maps	Standardized landscape-scale maps showing the location of a restoration project within the estuary relative to existing habitat patches, tributaries, hydrogeomorphic reach transitions, and the mainstem Columbia. These maps include data for various landscape metrics as specified by ERTG (e.g. shoreline gap filled, distance to critical transition zones for migrating juvenile salmon). The maps are produced by project sponsors to facilitate management review and ERTG evaluation	Allows consistent evaluation and direct comparison of potential restoration projects by illustrating the project's potential benefits from a landscape perspective

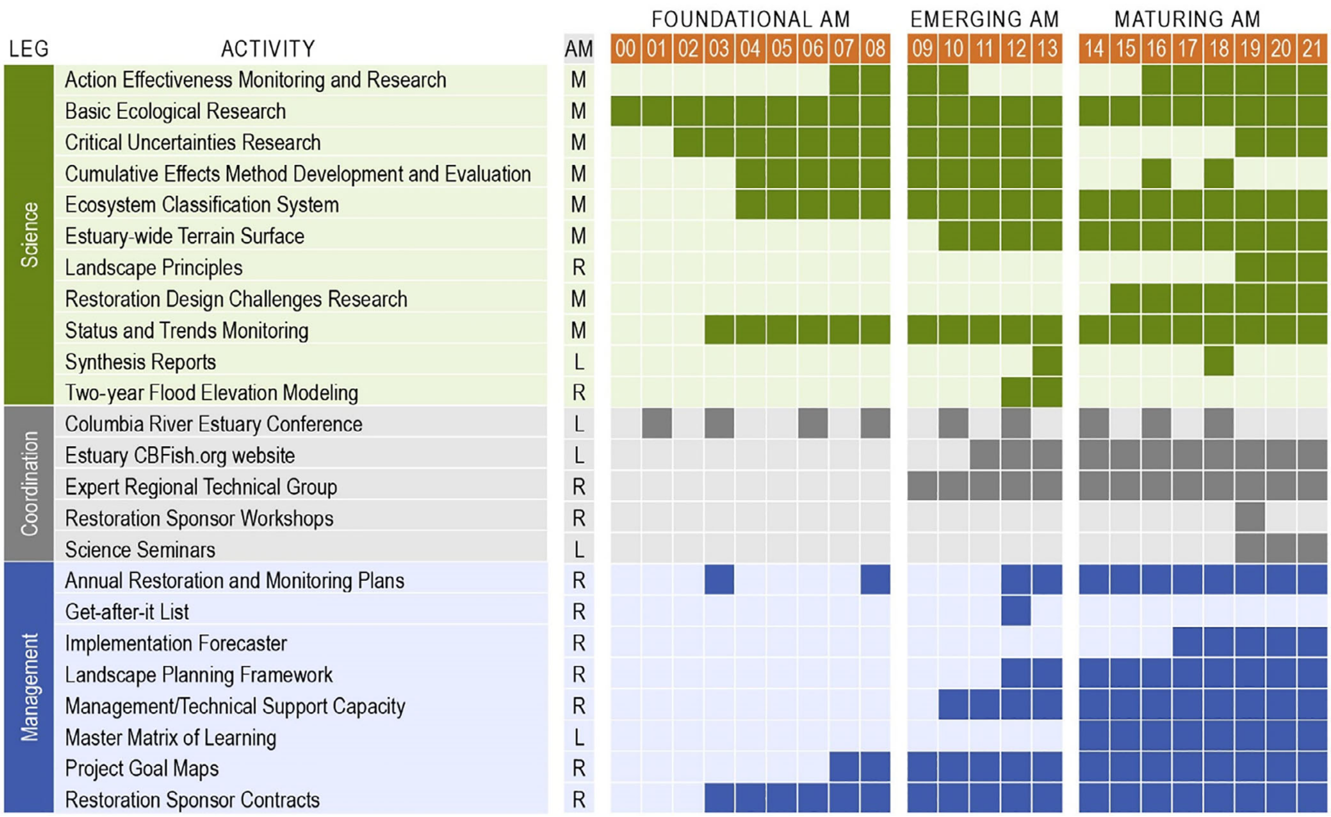

Figure 4. Timeline for CEERP activities organized by AM period and supporting leg with reference to CEERP AM component (R = restoration; M = monitoring; L = learning). Descriptions of some of these activities and their effects on success are included in Table 1 and the main text. Activities not included in Table 1 or main text are described in Ebberts et al. (2017).

reconnected, and invasive plant removal and native revegetation became complementary to hydrological restoration rather than stand-alone projects. The Ruby Lake project, which included removal of a water control structure, tidal channel excavations, and invasive plant control, was typical for the 2009–2013 time period (Supplement S2).

Maturing AM (2014–2021)

The Maturing AM period (2014–2021) saw the emergence of larger, more complex projects (Fig. 5) that often had to overcome constraints related to permitting, land acquisition, conflicting land management goals, public perception, and technical issues. CEERP met the challenges of this period by completing a number of smaller projects while working on larger, more complex projects. In 2017, a shift toward landscape principles for restoration established a stepping-stone/patch framework highlighting the role of habitat patches in the estuary (ERTG 2019). Stakeholder roles and specializations became more distinct during this period, which increased cooperation directed toward complex large-scale land acquisitions and restoration (Fig. 5A). The Wallooskee–Youngs project exemplifies restoration during 2014–2021 (Supplement S3).

Action effectiveness monitoring and research showed that floodplain reconnection indirectly benefits juvenile salmon migrating in the mainstem as well as the smaller life stages that enter wetlands (Goertler et al. 2016; Thom et al. 2018), largely through the production and transport of prey from reconnected wetlands (PNNL & NMFS 2020). Research to inform restoration design (e.g. Borde et al. 2020; Diefenderfer et al. 2021) utilized landscape-scale datasets collected and developed during the Foundational and Emerging AM periods (Table 1). Similarly, the ERTG's Landscape Planning Framework (Table 1) was the foundation of our application of landscape principles to project siting and design (ERTG 2020). An evidence-based evaluation of the cumulative effects of restoration concluded that CEERP is having "a cumulative beneficial effect on juvenile salmon" (Diefenderfer et al. 2016).

The Implementation Forecaster tool (Table 1) improved project identification and strategic resource allocation. During the Maturing AM period, this tool and other adaptations led to a period of growth in on-the-ground restoration (Fig. 5A). Land acquisition decreased compared to previous periods (Fig. 5A); however, restoration proceeded on previously acquired lands. Total floodplain area restored increased from 2000 to 2021 to a cumulative total of 7,184 acres or roughly 30 km^2 (Fig. 5B). We restored 653 acres (264 ha) through the Foundational period, 848 acres (343 ha) during the Emerging period, and

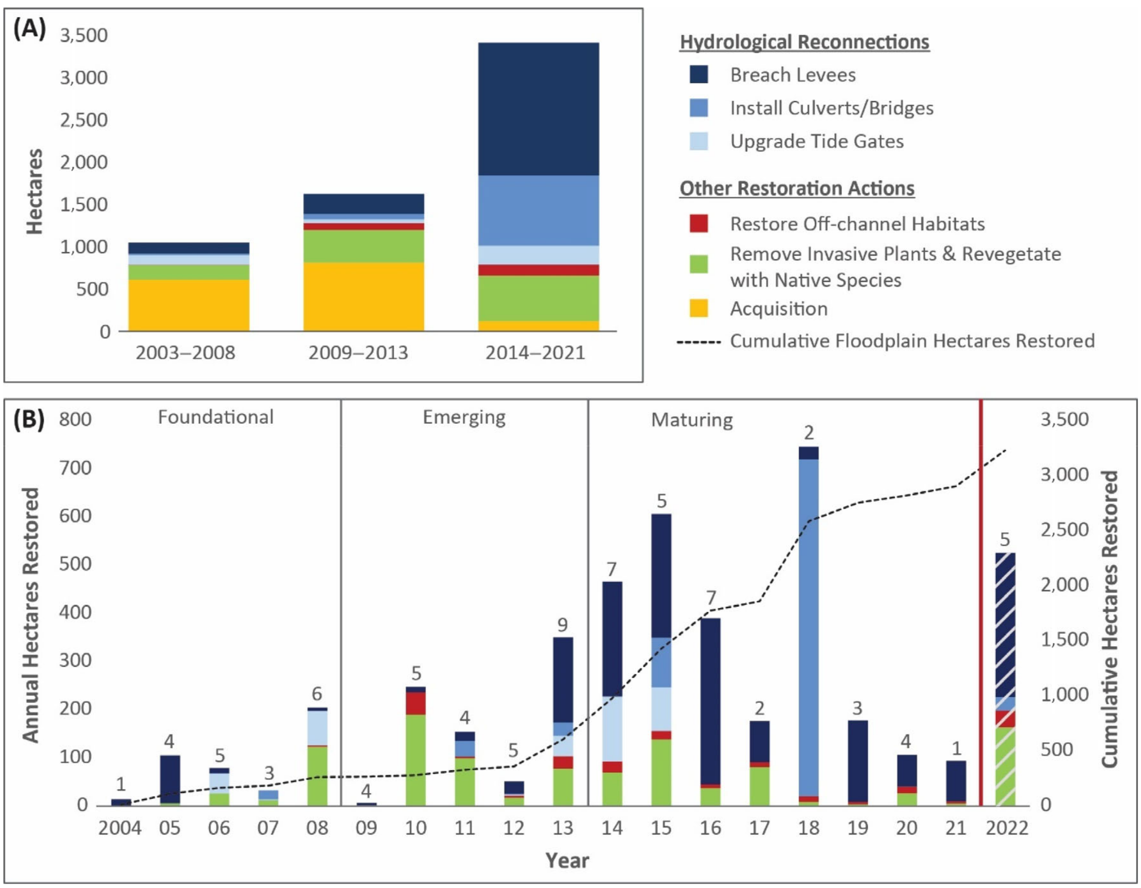

Figure 5. Floodplain area (hectares) acquired and restored during the Foundational, Emerging, and Maturing periods of AM from 2000 through 2021 (none was acquired or restored during 2000–2002). The stacked bars include area by type of restoration action. "Restore Off-channel Habitats" refers to the excavation or enhancement of tidal and floodplain channels (A–B). The hectares associated with hydrological reconnections ("Breach Levees," "Install Culverts/Bridges," and "Upgrade Tide Gates") represent the portion of the restoration area where hydrology was restored that is below the 50% annual exceedance elevation (A–B). Increasing rate of floodplain area (hectares) restoration in the CRE from 2004 through 2021 (B). No floodplain area was restored in the years 2000–2003. The number of restoration projects is noted above each bar and the final bar (i.e. left of the vertical red line) is a projection based on tentative plans for 2022 (B).

Table 2. CEERP sponsors' feedback on landowner engagement and lessons learned during project implementation, with bold text indicating a viewpoint or issue raised by at least one other sponsor. Specific questions corresponding to column headings were: (1) *How do you effectively engage landowners?* (2) *What is the most critical support you receive (or would like to receive) from CEERP managers?* (3) *What are your primary barriers to project implementation?* and (4) *What are the top ingredients for successful project implementation?* Sponsors included the Columbia River Estuary Study Taskforce (CREST), Cowlitz Indian Tribe (CIT), Washington Department of Fish and Wildlife (WDFW), Columbia Land Trust (CLT), and the Lower Columbia Estuary Partnership (LCEP).

Sponsor	*Landowner Engagement*	*Suggested CEERP Role*	*Implementation Barriers*	*Top Ingredients for Success*
CREST	**Nourish relationships** with willing landowners, managers, federal partners, and others through regular communication; Levels of engagement depends on project; **Community presence** key to identifying new opportunities	Support with regulatory requirements; Outreach with state and federal land holders; Forum for land managers to share perspectives; **Facilitating co-sponsor specialization**	(1) **Entrenched views that constrain public lands management goals** (2) State and local permitting requirements (3) **Skepticism toward new restoration approaches within CEERP**	(1) **Set of shared, realistic expectations** by CEERP and landowners (2) Regulatory support (3) Monitoring and maintenance in perpetuity, with AM in response to data and findings
CIT	From an opportunistic approach to whole-watershed planning; Staff support of projects cradle-to-grave for more **consistent communication** with landowners	CEERP managers need to work through institutional constraints that may hinder project progress	(1) **Real estate procurement policies** of funding agencies and cost relative to projected salmon benefits (2) Local policies and disparate federal and state mandates (e.g. levee breeches and ESA-species management) (3) Existing infrastructure and land use that conflicts with restoration goals	(1) A **shared vision of project goals** between landowners and sponsors (2) Long-term site conservation and maintenance to preserve restored lands in perpetuity (3) Patience among all stakeholders to see projects through
WDFW	New agency focus is on inclusivity, engaging a broader range of the community in all aspects of work; **Outreach early and often**	Support for building *and maintaining* relationships; **More flexible funding**; **Facilitating co-sponsor specialization within larger projects**	(1) Local **willingness to support broader suite of objectives on public lands** (2) **Land encumbrances** that can limit scope of future work (3) Long-term project maintenance—who assumes the risk?	(1) **Early stakeholder involvement** (2) Existing local partnerships (3) Project implementation **at a pace that makes sense**
CLT	Focus on responsible stewardship and **ongoing relationship-building**; **"good neighbor" principle**; frequency of communication varies by project and individual landowner	Acknowledging **the "slow burn" process for land acquisition**; Open dialog about new opportunities suited to CLT involvement	(1) **Agencies' inability to pay more than appraised fair market value in land acquisitions** (2) Competition with mitigation banks for potential restoration properties (3) Action Agency pressure for bigger and more complex projects raises questions of feasibility	(1) Having a **larger, multi-year contract with Action Agencies** provides latitude to **build relationships** (2) Being **thoughtful and strategic about project expectations** (3) Ongoing project monitoring to demonstrate success
LCEP	**Build on relationships** with public landowners; **Longstanding partnerships** have built trust and LCEP is now approached by landowners to initiate projects	Action Agency support for **sustained funding to build relationships** and work with landowners to establish trust	(1) Identifying new projects (2) Intertidal reconnections may require concurrent flood risk management (3) CEERP seems **too narrowly focused on salmon**; Restoration focused on maintaining biodiversity or climate resilience would allow for engagement with more stakeholders	(1) Supportive and willing landowner (2) **Flexible and supportive funding** (3) Innovative engineering staff to develop novel design solutions and be responsive to agency feedback

5,682 acres (2,299 ha) in the Maturing AM. CEERP reconnected 3% of the 344 km^2 recoverable floodplain area through mid-2012 (Diefenderfer et al. 2016), which increased to 8% by 2020 and was nearly 9% at the end of 2021. Restoration was increasingly successful due to the robust AM process that resolved critical uncertainties and effectively deployed the talents of project sponsors. CEERP began research to address critical uncertainties about habitat creation through dredge material placement in 2019, and in 2021 reengaged stakeholders in a broader dialog about the suite of uncertainties most relevant to CEERP moving forward.

Future AM (2022 and beyond)

CEERP is actively planning to initiate five restoration projects in 2022 (Fig. 5B) and program managers are committed to helping sponsors reach habitat attainment goals. When asked to provide structured feedback on the future AM of CEERP for this case study, sponsors affirmed that building shared land use values with stakeholders led to positive restoration outcomes (Table 2). They discussed the benefit of regular community engagement and maintaining transparency from project conception through implementation. Ongoing dialog with landowners between projects helped build trust and often led to new restoration opportunities. On the other hand, sponsors found that a breakdown in communication could sideline restoration opportunities. Land acquisition and stakeholder opposition are common barriers during the project feasibility phase (Table 2).

Project site visits, ERTG meetings, the Columbia River Estuary Conference, sponsor workshops, and regional science seminars (Fig. 4) are facilitating regular interchanges between stakeholders and program managers. Program managers ensure regular cross-pollination with their other habitat restoration programs so that new learning about ecosystem processes and restoration can benefit ecosystem-based management. For example, USACE has a strong interest in determining how material dredged during navigation channel maintenance could be used to offset the loss of sediment confined behind upstream dams (Gelfenbaum et al. 1999) in habitat building processes.

Discussion

CEERP managers are building on learning, tools, and processes developed throughout CEERP's evolution. They are committed to sustaining relationships, accomplishing restoration goals, and addressing issues that may inhibit program effectiveness. Restoration project sponsors based throughout the CRE have been ideal partners in vetting new opportunities and building relationships. Below we acknowledge sponsor feedback and discuss five actions that we believe will fundamentally shape how CEERP AM proceeds into the 2021–2030 United Nations Decade on Ecosystem Restoration (UNEP 2020).

Improving Landowner and Community Engagement

Results of sponsor interviews echoed findings of Gamborg et al. (2019) who noted that stakeholder views toward restoration outcomes improved when sponsors were responsive to their concerns and values. For example, reconnecting a floodplain wetland to the mainstem may improve flood risk management for a nearby road, reducing a county's infrastructure costs. Mason et al. (2020) proposed a three-step approach: mapping the services that ecosystems can provide, assessing landowner interest in those services, and identifying conservation organizations best suited to engage landowners through a social network analysis. While this type of ecosystem service tradeoff analysis has yet to be implemented in most restoration programs, including CEERP, the broader goal of finding common interests and leveraging existing relationships aligns well with the CEERP AM process and our sponsors' feedback. Enhancing program alignment with broader CRE resource management goals and being more informed about local land use priorities could produce more win-win outcomes (Gamborg et al. 2019). Sponsors highlighted the need for additional tools to support relationship building, streamlined land procurements, and multi-sponsor collaborations to maximize efficiency.

Maintaining Flexibility to Adapt to Evolving Obligations/Priorities of the Management Agencies

CEERP management agencies are dynamic institutions with intersecting programs and priorities that affect staffing and budgets. Managers must respond to shifts in priorities, while seeking opportunities to create and coordinate with related agency programs. McLoughlin et al. (2020) described a basin-wide water management process with feedback loops to facilitate information exchange and communication at multiple levels of governance. They recommended that managers reassess program objectives on an 8- to 10-year cycle and reframe or redevelop targets as needed. CEERP AM assessment occurs more frequently, according to annual budget cycles and various regional drivers. CEERP managers meet monthly to review program needs, research and monitoring updates, and pending restoration projects. These meetings create a regular and fruitful opportunity to disclose policy changes or new learning that could affect how restoration projects are pursued and evaluated.

Identifying New Restoration and Management Opportunities

There is an upfront risk associated with attempting new techniques; however, novel approaches are essential to CEERP's growth. For example, projects such as habitat creation through dredged material placement and shoreline enhancement may benefit salmon and numerous other species, but they have their own risks. Moreover, lessons learned from pilot projects and experiments (Sinks et al. 2021) serve as a springboard for other new ideas.

Institutionalizing Program Knowledge

CEERP has benefitted from a relatively high level of continuity of dedicated professionals over two decades. Nonetheless, staff changes are inevitable and it is essential to catalog decisions. Project sponsors requested more documentation for decisions that result from resource limitations or shifts in top-down priorities. To meet these needs, CEERP managers are improving the way this type of institutional knowledge is tracked such that key findings are retained, as appropriate, and decision documents are easier to reference.

Addressing Additional Uncertainties

Two uncertainties yet to be resolved with respect to program strategy are the effects of vertical land motion and sea level rise (Peterson 2014) on restoration outcomes. These uncertainties present a paradox for CEERP to simultaneously manage for increased habitat availability at current and future land elevations. While projected sea level rise at some project sites may be highly uncertain (Talke et al. 2020), restoration project designs must consider potential future conditions. CEERP managers are working with the ERTG, scientists, and restoration practitioners to develop strategies for risk assessment and optimizing long-term resiliency. Linking the science addressing technical uncertainties to program management and implementation will continue to be an integral part of CEERP.

Ecosystem restoration under CEERP has continuously improved resulting in a faster rate of floodplain reconnection, in part due to program features that have also been highlighted in other AM contexts (Zedler 2017; McLoughlin et al. 2020). Tools and processes developed for CEERP such as the ERTG, the master matrix of learning, and the implementation forecaster are integral to planning and directly transferrable to programs elsewhere. CEERP demonstrates that maintaining diverse stakeholder relationships is as essential as building technical acumen and making science-informed decisions when addressing emerging uncertainties in a large-scale ecosystem restoration program in any stage of development.

Acknowledgments

The authors greatly appreciate the graphical expertise and assistance from N. Johnson, T. Oatts, and A. Wilson in developing the figures for this manuscript. The authors thank C. Corbett, N. Czarnomski, T. Josephson, R. Salakory, and I. Sinks for their candid feedback during sponsor interviews and ongoing work implementing CEERP restoration projects. The authors appreciate the review comments provided by G. Hood, K. Jones, and R. Thom in helping to bring this manuscript to fruition. Lastly, the authors would like to acknowledge the late B. Ebberts for his longstanding commitment to making CEERP a robust, science-based adaptive management program. CEERP's success was built on the work of Blaine and others who pursued opportunities to bring together scientists, program managers, and practitioners to achieve long-term restoration benefits. The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the views of the U.S. federal government.

LITERATURE CITED

Borde AB, Diefenderfer HL, Cullinan VI, Zimmerman SA, Thom RM (2020) Ecohydrology of wetland plant communities along an estuarine to tidal river gradient. Ecosphere, 11. https://doi.org/10.1002/ecs2.3185

Borde AB, Zimmerman SA, Kaufmann RM, Diefenderfer HL, Sather NK, Thom RM (2011). Lower Columbia River and Estuary Restoration Reference Site Study: 2010 Final Report and Site Summaries. PNWD-4262, prepared for the Lower Columbia River Estuary Partnership and the Bonneville Power Administration by Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, WA

Bottom DL, Simenstad CA, Burke J, Baptista AM, Jay DA, Jones KK, Casillas E, Schiewe M (2005) Salmon at River's end: the role of the estuary in the decline and recovery of Columbia River Salmon. Pages 246. In: NOAA fisheries, northwest fisheries science center. NOAA Technical Memorandum NMFS-NWFSC-68, Seattle, WA

BPA, USACE (2012) Columbia estuary ecosystem restoration program: 2013 strategy report. Final report. Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, OR. https://www.cbfish.org/EstuaryAction.mvc/Documents (accessed 19 March 2021)

Diefenderfer HL, Borde AB, Cullinan VI (2021) Floodplain wetland channel planform, cross-sectional morphology, and sediment characteristics along an estuarine to tidal river gradient. Journal of Geophysical Research: Earth Surface 126:e2019JF005391. https://doi.org/10.1029/2019JF005391

Diefenderfer HL, Johnson GE, Thom RM, Borde AB, Woodley CM, Weitkamp LA, Buenau KE, Kropp RK (2016) Evidence-based evaluation of the cumulative effects of ecosystem restoration. Ecosphere 7:e01242. https://doi.org/10.1002/ecs2.1242

Diefenderfer HL, Thom RM, Johnson GE, Skalski JR, Vogt KA, Ebberts BD, Roegner GC, Dawley EM (2011) A levels-of-evidence approach for assessing cumulative ecosystem response to estuary and river restoration programs. Ecological Restoration 29:111–132. https://doi.org/10.3368/er.29.1-2.111

Drury R, Homewood K, Randall S (2011) Less is more: the potential of qualitative approaches in conservation research. Animal Conservation 14:18–24. https://doi.org/10.1111/j.1469-1795.2010.00375.x

Ebberts BD, Zelinsky BD, Karnezis JP, Studebaker CA, Lopez-Johnson S, Creason AM, Krasnow L, Johnson GE, Thom RM (2017) Estuary ecosystem restoration: implementing and institutionalizing adaptive management. Restoration Ecology 26:360–369. https://doi.org/10.1111/rec.12562

Ellison AM, Felson AJ, Friess DA (2020) Mangrove rehabilitation and restoration as experimental adaptive management. Frontiers in Marine Science 7:327. https://doi.org/10.3389/fmars.2020.00327

ERTG (Expert Regional Technical Group) (2019) Landscape Principles for CEERP Restoration Strategy. ERTG Doc #2017-02, prepared for the Bonneville Power Administration, U.S. Army Corps of Engineers, and NOAA Fisheries, Portland, Oregon https://www.cbfish.org/EstuaryAction.mvc/Index (accessed 19 March 2021)

ERTG (Expert Regional Technical Group) (2020) Landscape Principles: Applications and Operations for CEERP Restoration Strategy. ERTG #2019-01, prepared for the Bonneville Power Administration, U.S. Army Corps of Engineers, and NOAA Fisheries. Portland, Oregon. https://www.cbfish.org/EstuaryAction.mvc/Documents (accessed 19 March 2021)

Gamborg C, Morsing J, Raulund-Rasmussen K (2019) Adjustive ecological restoration through stakeholder involvement: a case of riparian landscape restoration on privately owned land with public access. Restoration Ecology 27:1073–1083. https://doi.org/10.1111/rec.12955

Gelfenbaum G, Sherwood CR, Peterson CD, Kaminsky GM, Buijsman M, Twichell DC, Ruggiero P, Gibbs AE, Reed C (1999) The Columbia River littoral cell: a sediment budget overview. Proceedings of Coastal Sediments 99:1660–1675. https://pubs.er.usgs.gov/publication/70197389 (accessed 23 February 2021)

Goertler PAL, Simenstad CA, Bottom DL, Hinton S, Stamatiou L (2016) Estuarine habitat and demographic factors affect juvenile Chinook (Oncorhynchus tshawytscha) growth variability in a large freshwater tidal

estuary. Estuaries and Coasts 39:542–559. https://doi.org/10.1007/s12237-015-0002-z
Krueger KL, Bottom DL, Hood WG, Johnson GE, Jones KK, Thom RM (2017) An expert panel process to evaluate habitat restoration actions in the Columbia River estuary. Journal of Environmental Management 188: 337–350. https://doi.org/10.1016/j.jenvman.2016.11.028
Mason SA, Olander LP, Grala RK, Galik CS, Gordon JS (2020) A practice-oriented approach to foster private landowner participation in ecosystem service conservation and restoration at a landscape scale. Ecosystem Services 46:101203. https://doi.org/10.1016/j.ecoser.2020.101203
McLoughlin CA, Thoms MC, Parsons M (2020) Reflexive learning in adaptive management: a case study of environmental water management in the Murray Darling Basin, Australia. River Research and Applications 36:681–694. https://doi.org/10.1002/rra.3607
NMFS (National Marine Fisheries Service) (2008) Consultation on remand for operation of the Federal Columbia River Power System, 11 Bureua of Reclamation projects in the Columbia Basin and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program (Revised and reissued pursuant to court order, NWF v. NMFS, Civ. No. CV 01-640-RE (D. Oregon)). Biological Opinion. National Marine Fisheries Service, Northwest Region, Seattle, Washington
NMFS (National Marine Fisheries Service) (2000) Reinitiation of consultation on operation of the Federal Columbia River Power System, including the juvenile fish transportation program, and 19 Bureau of Reclamation projects in the Columbia Basin. Biological Opinion. National Marine Fisheries Service, Northwest Region, Seattle, Washington
NPCC (Northwest Power and Conservation Council) (2000) Columbia River basin fish and wildlife program: a multi-species approach for decision making. Document 2000-19. Document 2000-19. Northwest Power and Conservation Council, Portland, OR https://www.nwcouncil.org/fish-and-wildlife/previous-programs/columbia-river-basin-fish-and-wildlife-program-2000 (accessed 15 February 2021)
Peterson C (2014) Late Holocene geomorphology of the Columbia River estuary, Oregon and Washington, U.S.A. Journal of Geography and Geology 6:1. https://doi.org/10.5539/jgg.v6n2p1
PNNL (Pacific Northwest National Laboratory), NMFS (National Marine Fisheries Service) (2020) Restoration Action Effectiveness Monitoring and Research in the Lower Columbia River and Estuary, 2016–2017. Final technical report submitted by PNNL and NMFS to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon
Roegner GC, Baptista A, Bottom DL, Burke J, Campbell L, Elliot C, et al. (2008) Estuarine Habitat and Juvenile Salmon—Current and Historical Linkages in the Lower Columbia River and Estuary, 2002–04. Report prepared for the U.S. Army Corps of Engineers, Portland District, Northwest Division, Portland, Oregon, and Bonneville Power Administration, Environment, Fish, and Wildlife Division, Portland, Oregon, by the Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, Washington
Roegner GC, Diefenderfer HL, Borde AB, Thom RM, Dawley EM, Whiting AH, Zimmerman SA, Johnson GE (2009) Protocols for monitoring habitat restoration projects in the lower Columbia River and estuary. NOAA Technical Memo NMFS-NWFSC-97, U.S. Department of Commerce, Seattle, Washington
Simenstad CA, Burke JL, O'Connor JE, Cannon C, Heatwole DW, Ramirez MF, et al. (2011) Columbia estuary ecosystem classification – concept and application. U.S. Geological Survey Open File Report 2011-1228 U.S. Geological Survey, Portland, Oregon
Sinks IA, Borde AB, Diefenderfer HL, Karnezis J (2021) Assessment of methods to control invasive reed canarygrass (*Phalaris arundinacea*) in tidal freshwater wetlands. Natural Areas Journal 41:172–185. https://doi.org/10.3375/043.041.0303
Talke SA, Mahedy A, Jay DA, Lau P, Hilley C, Hudson A (2020) Sea level, tidal, and river flow trends in the lower Columbia River estuary, 1853–present. Journal of Geophysical Research: Oceans 125:e2019JC015656. https://doi.org/10.1029/2019JC015656
Thom RM, Borde AB, Evans NR, May CW, Johnson GE, Ward JA (2004) A Conceptual Model for the Lower Columbia River Estuary. Final report to the U.S. Army Corps of Engineers by Pacific Northwest National Laboratory, Richland, Washington
Thom RM, Breithaupt SA, Diefenderfer HL, Borde AB, Roegner GC, Johnson GE, Woodruff DL (2018) Storm-driven particulate organic matter flux connects a tidal tributary floodplain wetland, mainstem river, and estuary. Ecological Applications 28:1420–1434. https://doi.org/10.1002/eap.1759
Thom RM, Sather NK, Roegner GC & Bottom DL (2013) Columbia Estuary Ecosystem Restoration Program: 2012 synthesis memorandum. Final report. Pacific Northwest National Laboratory and National Marine Fisheries Service, U.S. Army Corps of Engineers, Portland, Oregon https://www.cbfish.org/EstuaryAction.mvc/Documents (accessed 19 March 2021)
UNEP (United Nations Environment Programme) (2020) The UN Decade on Ecosystem Restoration 2021-2030: Prevent, halt and reverse the degradation of ecosystems worldwide. UNEP/FAO Factsheet. https://wedocs.unep.org/bitstream/handle/20.500.11822/30919/UNDecade.pdf?sequence=11 (accessed 4 May 2021)
Webb JA, Watts RJ, Allan C, Conallin JC (2018) Adaptive management of environmental flows. Environmental Management 61:339–346. https://doi.org/10.1007/s00267-017-0981-6
Williams BK, Brown ED (2018) Double-loop learning in adaptive management: the need, the challenge, and the opportunity. Environmental Management 62:995–1006. https://doi.org/10.1007/s00267-018-1107-5
Zedler JB (2017) What's new in adaptive management and restoration of coasts and estuaries? Estuaries and Coasts 40:1–21. https://doi.org/10.1007/s12237-016-0162-5

Supporting Information

The following information may be found in the online version of this article:

Supplement S1. Sandy River Delta Project exemplifying restoration actions completed during the AM Foundations period 2000-2008.
Supplement S2. Ruby Lake Project exemplifying restoration actions completed during the Emerging CEERP AM period 2009-2013.
Supplement S3. Wallooskee –Youngs Project exemplifying restoration actions completed during the Maturing CEERP AM period 2014-2021.

Coordinating Editor: Stephen Murphy

Received: 15 June, 2021; First decision: 19 November, 2021; Revised: 13 January, 2022; Accepted: 13 January, 2022