

An annotated bibliography for legacy tidal marsh restoration projects along the US West Coast

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OVERVIEW

Well over half the historical area of tidal wetlands along the West Coast of the United States have been lost to other land uses (Brophy et al. 2019, Endris et al. 2024). To compensate for this loss of habitat area and ecosystem function, restoration actions have been implemented in many estuaries, and the pace of restoration is accelerating as coastal communities seek to meet goals of restoring habitat, improving coastal ecosystem services, and making estuaries more resilient to climate change. To date, there have been dozens of tidal wetland restoration projects in numerous estuaries across California, Oregon, and Washington, with more in the planning stages. Lessons learned from older projects through ecological monitoring and assessment can provide valuable information for future project design, implementation strategies, and monitoring approaches.

As part of a project funded by the NERRS Science Collaborative to assess the status of legacy restoration projects along the US West Coast, we have assembled this annotated bibliography of information on select tidal marsh restoration projects located in nine estuaries in California, Oregon, and Washington. In the project we focused on restoration sites at least 20 years old (Figure 1, Table 1). The information sources included in this bibliography are drawn from a wide range of published and unpublished document types, including peer-reviewed journal articles, theses and dissertations, books, reports, websites, and datasets.

Most citations included in this bibliography focus on conditions in restoration sites themselves, but some are also general information about the ecology or management of the estuary in which the restoration projects are located. This bibliography is not comprehensive, but should be a good gateway into further information about these tidal wetlands. For each source, we include an on-line link (where feasible) and a short description of the resources, especially as it pertains to one or more of the older restoration sites featured in our project. An overview of our project's findings can be found in a restoration brief by Cornu et al. (2025), with more detail in anticipated forthcoming peer-reviewed publications. Production of this bibliography was funded by the NERRS Science Collaborative (grant NA19NOS4190058, SUBK00018014).



Figure 1. Map of estuaries along the Pacific coast of the US included in this bibliography.

Table 1. List of legacy tidal marsh restoration sites along the US West Coast included in our NERRS Science Collaborative study and featured in this bibliography. Age refers to the length of time between a site’s restoration implementation and the year 2023, when most field sampling for our project was conducted.

Estuary (state)	Legacy restoration site (age)	Location
Tijuana Estuary (CA)	Model (Friendship) Marsh (23 yr)	32.5460° N, 117.1216° W
Carpinteria (CA)	Ash Avenue Marsh (26 yr)	34.3969° N, 119.5283° W
Elkhorn Slough (CA)	Parsons Slough (40 yr)	36.8112° N, 121.7414° W
South San Francisco Bay (CA)	Faber Marsh (53 yr)	37.4658° N, 122.1222° W
San Francisco Bay (CA)	Muzzi Marsh (47 yr)	37.9277° N, 122.5070° W
San Pablo Bay (CA)	Sonoma Baylands (27 yr)	38.1204° N, 122.4835° W
Coos Bay (OR)	Fredrickson Marsh (25 yr)	43.2746° N, 124.3201° W
Coos Bay (OR)	Kunz Marsh (27 yr)	43.2818° N, 124.3202° W
Salmon River Estuary (OR)	Mitchell Marsh (45 yr)	45.0333° N, 123.9824° W
Columbia River Estuary (OR)	Netul River Marsh (62 yr)	46.1309° N, 123.8795° W
Nisqually Estuary (WA)	Phase 1 Marsh (22 yr)	47.0851° N, 122.7037° W
Nisqually Estuary (WA)	Pilot Marsh (28 yr)	47.0871° N, 122.6993° W
Skagit Estuary (WA)	Deepwater Slough (23 yr)	48.3215° N, 122.3715° W

Citations

Brophy LS, Greene CM, Hare VC, Holycross B, Lanier A, Heady WN, O’Connor K, Imake H, Haddad T, Dana R. 2019. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. *PLoS ONE* 14:e0218558. [Link](#)

Cornu C, Janousek C, Williams T, Schmitt J, Schroeder J, Kirkland J, Wasson K, Rybczyk J, Poppe K, Crooks J, Schooler S, Ferner M, Siegel S, Brophy L, Comet S. 2025. Tidal Marsh Restoration Brief: Long-term outcomes of tidal marsh restoration efforts on the U.S. West Coast. Corvallis, OR: Institute for Applied Ecology, Oregon State University, Western Washington University, South Slough National Estuarine Research Reserve, Elkhorn Slough National Estuarine Research Reserve, Tijuana River National Estuarine Research Reserve, San Francisco Bay National Estuarine Research Reserve. [Link](#)

Endris C, Shull S, Woolfolk A, Brophy LS, Brumbaugh DR, Crooks JA, Reinl KL, Fuller R, Sanger DM, Stevens RA, Almeida M, Wasson K. 2024. Lost and found coastal wetlands: Lessons learned from mapping estuaries across the USA. *Biological Conservation* 299:110779. [Link](#)

ANNOTATED BIBLIOGRAPHY

TIJUANA ESTUARY

California State Parks and US Fish and Wildlife Service. 2021. Restoration update. Tijuana Estuary Tidal restoration program II Phase I (TETRP II Phase I). [Link](#)

This document briefly describes two proposed alternatives for additional future tidal wetland restoration adjacent to the Model Marsh which was restored in 2000.

Crooks J, MuCullogh J. 2014. TRNERR Vegetation Monitoring Metadata, October - December, 2012. Centralized Data Management Office. [Link](#)

The Centralized Data Management Office (CDMO) is a repository of data collected across the National Estuarine Research Reserve system. The CDMO hosts water quality, meteorological, and plant monitoring data from several estuaries in this study: Tijuana Estuary, Elkhorn Slough, San Francisco Bay, Coos Bay (South Slough).

Coats R, Swanson M, Williams P. 1989. Hydrologic analysis for coastal wetland restoration. *Environmental Management* 13:715-727. [Link](#)

In this peer-reviewed publication, the authors review hydrologic restoration case studies in San Francisco Bay and discuss the breaching (and increase in the tidal prism by dredging) of Tijuana Estuary in 1984 after large storms cut off the estuary from tidal circulation for nearly nine months.

Janousek CN, Currin CA, Levin LA. 2007. Succession of microphytobenthos in a restored coastal wetland. *Estuaries and Coasts* 30:265-276. [Link](#)

This journal article discusses the development of benthic microalgal communities (diatoms, cyanobacteria) in the restored Model Marsh during the first few years following restoration implementation.

Morzaria-Luna HN, Zedler JB. 2022. Salt marsh restoration surprise: A subordinate species accumulated and shared nitrogen while outcompeting salt marsh dominants. *Frontiers in Ecology and Evolution* 10:851055. [Link](#)

In this study, Morzaria-Luna and Zedler (2022) combined greenhouse and lab experiments to better understand salt marsh species interactions, particularly between *Triglochin concinna* and other dominants and sub-dominant species present on the marsh plain. They found that *T. concinna* competitively reduced the biomass of other plant species but that it also effectively stored nitrogen and enriched soils with nitrogen (benefitting other plant species) when it decomposed. The field experiment was conducted in the restored Model Marsh in 2002-2004, shortly after it was opened to tidal exchange. Data from the Model Marsh include soil salinity, plant survivorship, root and shoot biomass, %N in plant tissues, and ¹⁵N.

Moseman S. Nd. The Model/Friendship Marsh. [Link](#)

This website briefly provides background information on the Model Marsh restoration including project goals and timeline.

Nordby C. 2018. 40 years of restoration at Tijuana Estuary, California. Lessons Learned. Report Prepared for the Coastal Conservancy. [Link](#)

This document contains detailed information about wetland and non-wetland restoration in the Tijuana River Estuary, including the Model Marsh project and experiments included in that site to test the effects of tidal creeks, planting, and soil amendments.

Safran SM, Baumgarten SA, Beller EE, Crooks JA, Grossinger RM, Lorda J, Longcore TR, Bram D, Dark SJ, Stein ED, McIntosh TL. 2017. Tijuana River Valley Historical Ecology Investigation. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA. [Link](#)

Safran et al. (2017) detail the history of the Tijuana River Estuary and its watershed, providing valuable historical context for changes to the estuary and wetland restoration. Mapping of historical habitat extent in the estuary (~1850) suggests that the area including and around the Model Marsh was formerly extensive salt marsh, most of which has since been lost. Additionally, the course of the Tijuana River itself has changed frequently since the middle of the 19th century.

Tijuana Slough National Wildlife Refuge. 2010. Tijuana River National Estuarine Research Reserve Comprehensive Management Plan. [Link](#)

This management plan document for the Refuge and Border Field State Park provides an introduction to the Tijuana Estuary, discussion of management issues, monitoring, and other topics. Included in the document is a brief overview of restoration projects in the estuary (the “Tijuana Estuary Tidal Restoration Program”).

Wallace KJ, Callaway JC, Zedler JB. 2005. Evolution of tidal creek networks in a high sedimentation environment: A 5-year experiment at Tijuana Estuary, California. *Estuaries* 28:795-811. [Link](#)

The effects of the presence or absence of constructed tidal channels on sedimentation rates and channel development were investigated in this study conducted at the Model Marsh. The authors provide data on sedimentation and surface elevation change, channel cross-sections, and tidal prism at the developing restoration site.

Ward KM, Callaway JC, Zedler JB. 2003. Episodic colonization of an intertidal mudflat by native cordgrass (*Spartina foliosa*) at Tijuana Estuary. *Estuaries* 26:116-130. [Link](#)

This research report describes the rapid colonization of native cordgrass, *Spartina foliosa*, on unvegetated tideflats following an El-Niño linked pulse of sediment that entered the estuary. Data in the study include short-term accretion rates, the elevation of mudflat and *Spartina* marsh, and expansion rates of cordgrass clones.

Whitcraft CR, Levin LA, Talley D, Crooks JA. 2008. Utilization of invasive tamarisk by salt marsh consumers. *Oecologia* 158:259-272. [Link](#)

This study examines the impact of invasive tamarisk (*Tamarix* spp.) on the detrital food web dynamics in the estuary. The researchers found that tamarisk litter, with its high decomposition rate and relatively low carbon-to-nitrogen ratio, serves as a readily available food source for some macroinvertebrates. However, its presence alters the composition and abundance of invertebrate communities, benefiting species that utilize tamarisk detritus while being less favorable to others. The findings highlight the significant role invasive plants can play in reshaping trophic structure and ecosystem functions through changes in detrital pathways.

Zedler, J. B., Nordby, C. S. 1987. The Ecology of Tijuana Estuary, California: An Estuarine Profile. Fish and Wildlife Service, U.S. Department of the Interior.

This book provides a comprehensive overview of the ecological dynamics and environmental significance of the Tijuana Estuary, highlighting its biodiversity and the interplay of natural and human influences on its ecosystem.

CARPINTERIA ESTUARY

The Land Trust for Santa Barbara County. 2007. Carpinteria Salt Marsh Restoration Plan - Basin 1 and South Marsh. [Link](#)

This report contains an assessment and enhancement methods for the second phase of salt marsh restoration in the Carpinteria Estuary, including a section of the Ash Ave Nature Park, Basin 1, and the South Marsh areas. The plan implemented in the early 2000s included new tidal channels, removal of non-native vegetation, planting and seeding with native species, installation of flood control structures to improve tidal circulation and flood protection, and bridges and signage for visitor education. The conditions at the time are detailed, including existing vegetation and wildlife, with a focus on special species. A maintenance and monitoring guideline is outlined.

Devera L. 2021. Carpinteria Salt Marsh: A Field and Spatial Modeling Approach to Identify Wildfire-produced materials.

This masters thesis used field methods such as topographic surveying, real-time kinematic GPS and total station surveying, and sediment cores to assess the depth of ash layers and debris from the regional Thomas Fire. Unmanned Aerial Systems imaging was utilized to obtain high-resolution imagery of the marsh, which was then processed using Geographic Information Systems mapping and geostatistical analysis to generate predictive surfaces for future management and restoration efforts.

Ferren WR, University of California, Santa Barbara. 1985. Carpinteria Salt Marsh: environment, history, and botanical resources of a Southern California estuary. Herbarium, Dept. of Biological Sciences, University of California, Santa Barbara, Santa Barbara, CA : <https://doi.org/10.5962/bhl.title.63944>

This book is a comprehensive history of the geological and human factors affecting the Carpinteria Estuary.

Ferren Jr WR, Page HM, Saley P. 1996. A management plan for Carpinteria Salt Marsh Reserve. A Southern California Estuary. [Link](#)

This management plan provides valuable background information on salt marshes in the Carpinteria Estuary. Figures 11-20 include a series of aerial photographs from 1929 to 1981 showing the gradual degradation of the eastern portion of the estuary that was to later become the Ash Avenue restoration project site. The site was filled by about 1967. The aerial images also indicate that the mouth of the estuary closes, at least intermittently, to tidal influence.

Herring ML. 2001. Legacy of stewardship flourishes at urban preserve - and beyond. Transect 19:5-8. [Link](#)

Herring (2001) provides a short article about the Carpinteria salt marsh and the Ash Avenue restoration project in the University of California Natural Reserve System journal, the *Transect*.

Page HM. 1997. Importance of vascular plant and algal production to macro-invertebrate consumers in a southern California salt marsh. Estuarine, Coastal and Shelf Science 45:823-834. [Link](#)

This study was conducted in the least-disturbed reference salt marsh near the Ash Avenue restoration site. Using stable isotopes of tidal wetland consumers, the study concluded that much of the carbon fueling benthic invertebrates is derived from microalgal sources rather than vascular plants.

ELKHORN SLOUGH

Mayer MA. 1987. Flowering plant recruitment into a newly restored salt marsh in Elkhorn Slough, California. M.S. Thesis, Moss Landing Marine Laboratories and San Jose State University. [Link](#)

This Masters thesis discusses plant colonization in the Parsons Slough complex just a few years after it was restored to tidal influence.

Silberstein M, Oliver JS. 1985. Monitoring ecological changes in a restored salt marsh on the Elkhorn Slough National Estuarine Sanctuary. Elkhorn Slough National Estuarine Sanctuary. [Link](#)

This document is the first monitoring report produced for the Parsons Slough site following restoration implementation. Monitoring efforts described in the report include abiotic conditions (temperature, salinity, and dissolved oxygen), aerial imagery, benthic invertebrate communities, fish composition and size, bird counts, and plant seedlings.

Van Dyke E, Wasson K. 2005. Historical ecology of a central California estuary: 150 years of habitat change. *Estuaries* 28:173–189. [Link](#)

This journal article provides information on the historical ecology of the estuary, including diking and marsh loss. It shows how areas east of the railroad, including the Parsons Slough complex and North Marsh, used to be salt marsh then subsided to mudflat elevation.

Wasson K, Jeppesen R, Endris C, Perry DC, Woolfolk A, Beheshti K, Rodriguez M, Eby R, Watson EB, Rahman F, Haskins J, Hughes BB. 2017. Eutrophication decreases salt marsh resilience through proliferation of algal mats. *Biological Conservation* 212:1-11. [Link](#)

Increased nutrient loading from agricultural and urban runoff has significantly impacted estuaries worldwide, leading to the proliferation of macroalgae and adverse effects on ecosystems like salt marshes. This study in Elkhorn Slough found that rising fertilizer use correlated with increased algal wrack, which diminished salt marsh vegetation, promoted bank erosion, and contributed to habitat loss, highlighting the need to reduce nutrient inputs to protect these critical ecosystems.

Wasson K, Woolfolk A. 2011. Salt marsh-upland ecotones in Central California: Vulnerability to invasions and anthropogenic stressors. *Wetlands* 31:1–14. [Link](#)

This study of the high marsh to upland ecotone throughout Elkhorn and Moro Cojo Sloughs showed that ecotone habitat area was very limited. Data showed that Parsons Slough and North Marsh have a narrow bathtub ring of tidal marsh due to elevation subsidence.

Wasson K. 2020. Elkhorn Slough (ELK) NERR Vegetation Monitoring Metadata - September 2016. [Link](#)

As noted under entries for Tijuana Estuary, vegetation and water quality monitoring data are available for Elkhorn Slough through CDMO.

Wright K. 1992. The 1983 south marsh project: A case study in salt marsh restoration at Elkhorn Slough, California, Senior Thesis, University of California Santa Cruz. [Link](#)

This document is an informal student report draft discussing restoration at Parsons Slough.

(Additional materials about Elkhorn Slough can be found in their reference library at: <https://www.elkhornslough.org/research-program/references/>.)

SAN FRANCISCO BAY

Chapple DE, Faber P, Siding KN, Merenlender AM. 2017. Climate variability structures plant community dynamics in Mediterranean restored and reference tidal wetlands. *Water* 9:w9030209. [Link](#)

This study examined long-term vegetation change between 1990 and 2015 in transects at Muzzi Marsh (restored in 1976) and China Camp State Park (reference site). The authors found temporal changes in sub-dominant plant species such as a decline in *Salicornia depressa* at the restored site, and increases in sub-dominants at the reference site during a low salinity period (1995-1999) characterized by two El Niño events. In the time series, subdominant species only appeared in the Muzzi marsh transect in 1996 (20 years following restoration).

Marcus L. 2000. Restoring tidal wetlands at Sonoma Baylands, San Francisco Bay, California. *Ecological Engineering* 15:373–383. [Link](#)

This article provides a comprehensive description of the Sonoma Baylands restoration project in San Pablo Bay which used dredge material to increase the elevation of the wetland and accelerate ecosystem development. The article touches on the project's history, design, conflicts, and political concerns.

SER (Society for Ecological Restoration). Nd. USA: California: Restoring tidal wetlands at Sonoma Baylands, San Francisco Bay. Restoration Database. [Link](#)

This restoration database entry provides an overview of the history, design, and implementation of the Sonoma Baylands tidal marsh restoration project in San Pablo Bay. It details the political and policy considerations of this pioneering project which used dredge spoils from port expansion in Oakland, CA to create a 138 ha tidal wetland site. A small amount of additional non-tidal seasonal wetland was also created nearby. Dredge spoil placement was tested in a small 16 ha pilot site opened to tidal flow in January 1996 while the remainder of the site was opened to tidal inundation in October of the same year. The estimated cost of the project was \$6 million.

Williams PB, Orr MK, Garrity NJ. 2002. Hydraulic geometry: A geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. *Restoration Ecology* 10:577-590. [Link](#)

This paper develops a model for tidal channel evolution for the San Francisco Estuary. In Table 3 and Figure 3, some data on the early development of a tidal channel in the Pilot Unit at the Sonoma Baylands project are presented.

Williams PB, Orr MK. 2002. Physical evolution of restored breached levee salt marshes in the San Francisco Bay Estuary. *Restoration Ecology* 10:527-542. [Link](#)

This paper provides a review of 15 tidal marsh sites restored in the San Francisco Estuary between 1972 and 1998 including Sonoma Baylands, Muzzi Marsh, and Faber Marsh. Table 1 contains useful background information about the projects including the date of restoration and estimates of initial site elevations.

Zedler JB (principal author). 1996. Tidal wetland restoration: a scientific perspective and southern California focus. California Sea Grant College System, University of California. Publication T038. [Link](#)

This handbook focuses on tidal wetland restoration along the US Pacific coast, particularly in southern California. A brief entry on p.36-37 also reviews the Muzzi Marsh project in San Francisco Bay.

COOS ESTUARY

Cornu CE, Sadro S. 2002. Physical and functional response to experimental surface elevation manipulation in Coos Bay's South Slough. *Restoration Ecology* 10:474-486. [Link](#)

In this journal article, the authors describe early post-restoration conditions in the Kunz marsh restored in summer 1996 in the South Slough National Estuarine Research Reserve. The marsh was divided into four cells with elevation intentionally raised in three cells by the addition of sediment. The study includes measurements of pre-restoration elevation; early post-restoration accretion, subsidence, and wetland elevation change; tidal channel morphology; plant frequency of occurrence and composition; and fish communities.

Cornu CE. 2005. Restoring Cox, Dalton, and Fredrickson Creek Marshes. South Slough NERR Coastal Resource Management Series. CRMS-2005-2. Coos Bay, Oregon. [Link](#)

This document details restoration design and implementation at three tidal wetland restoration projects conducted at the South Slough National Estuarine Research Reserve in the 1990s: the Cox, Dalton, and Fredrickson projects. At the Fredrickson site, a tidal marsh was restored in a 2 ha area that had been diked and converted to agricultural uses in the early 1900s. The tide gate had been failing at the time of restoration in 1998 leading to a muted tidal wetland. Restoration involved partial levee removal along Winchester Creek, fill of one linear ditch, and addition of root wads to a remaining channel.

Cornu C, Harris H, Helms A. 2011. NOAA Reference Sites: Measuring salt marsh plant, soil and hydrologic response to restoration using performance benchmarks from local reference sites. South Slough NERR Site Report. 59 pp. [Link](#)

This report is part of a larger scale tidal marsh restoration assessment conducted in several Atlantic coast National Estuarine Research Reserves and in two estuaries on the Oregon coast, including the South Slough NERR. Information is provided on the history of Kunz Marsh and its reference site at Danger Point as well as vegetation, soil pore water salinity, groundwater level, elevation, and soil properties.

Gonzalez JA. 2023. Ecological and societal considerations in marsh restoration and adaptation to sea-level rise. PhD Dissertation, University of California, Davis. [Link](#)

This dissertation includes a chapter on the ecological outcomes and perceived societal benefits of wetland restoration, with a focus on marshes in Oregon including the Kunz and Fredrickson projects in the Coos Estuary. The study highlights that there can be a mismatch between social values (e.g., fish and bird use) and what ecological outcomes are actually usually monitored in restoration (vegetation and hydrology).

Schultz MA, Janousek CN, Brophy LS, Schmitt J, Bridgman S. 2023. How management interacts with environmental drivers to control greenhouse gas fluxes from Pacific Northwest coastal wetlands. *Biogeochemistry* 165:165-190. [Link](#)

Using small portable chambers, this study investigated greenhouse gas fluxes from tidal marshes in the Coos and Tillamook estuaries in Oregon, including in three elevation cells within Kunz marsh in South Slough. The study found that air temperature, salinity, and groundwater level were relatively important factors affecting methane fluxes, while air and soil temperature and pH were relatively important for nitrous oxide fluxes.

Williams T, Janousek CN, McKeon MA, Diefenderfer HL, Cornu CE, Borde AB, Apple J, Brophy LS, Norwood M, Schultz MA, Bridgham SD. 2025. Methane and nitrous oxide fluxes from reference, restored, and disturbed estuarine wetlands in Pacific Northwest, USA. *Ecological Applications* 35:e70011. [Link](#)

A second recent study of greenhouse gas emissions from tidal wetlands in the PNW, this paper also sampled gas fluxes in small chambers at Kunz Marsh, Fredrickson Restored Marsh, and nearby least-disturbed tidal wetlands in the South Slough National Estuarine Research Reserve (in addition to many other sites in other PNW estuaries). The paper concluded that wetland elevation, salinity, and groundwater level were among the important ecological drivers of methane fluxes.

SALMON RIVER ESTUARY

Bieber A.J. 2005. Variability in juvenile chinook foraging and growth potential in Oregon estuaries: Implications for habitat restoration. MS thesis, University of Washington, School of Aquatic and Fisheries Sciences.

This thesis highlights the importance of habitat diversity and number of wetlands in supporting juvenile Chinook salmon growth and resilience, emphasizing natural variability in habitat functions and the role of lower-elevation marshes in fostering faster growth.

Bottom DL, Jones KK, Cornwell TJ, Gray A, Simenstad CA. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). *Estuarine, Coastal and Shelf Science* 64:79–93. [Link](#)

Bottom et al. (2005) investigated changes in juvenile Chinook salmon life history following the restoration of 145 ha of salt marsh habitat in the Salmon River Estuary. Overall, the restoration of marsh habitat enhanced the variability in juvenile salmon life histories, providing more opportunities for estuarine rearing and contributing to the recovery of Chinook salmon in the region.

Ellingson KS, Ellis-Sugai BJ. 2014. Restoring the Salmon River Estuary. Journey and Lessons Learned Along the Way 2006-2014. U.S. Department of Agriculture, U.S. Forest Service.

This is a government report that documents the history of sites, plans, implementation and maintenance of major restoration projects in the Salmon River Estuary.

Flitcroft RL, Bottom DL, Haberman KL, Bierly KF, Jones KK, Simenstad CA, Gray A, Ellingson KS, Baumgartner E, Cornwell TJ, Campbell LA. 2016. Expect the unexpected: place-based protections can lead to unforeseen benefits. *Aquatic Conservation* 26:39–59. [Link](#)

This paper includes a history of conservation efforts in the Salmon River catchment since the 1930s, expanding from freshwater and forestry protections to estuarine and marine habitats, with restoration projects like levee removals facilitating tidal marsh recovery and benefiting fish populations. It highlights the enhanced ecological linkages between freshwater and marine environments as well as social links between end-users, scientific research, and policy advancements beyond the initial conservation goals.

Frenkel RE, Morlan JC. 1991. Can we restore our salt marshes? Lessons from the Salmon River, Oregon. *The Northwest Environmental Journal* 7:119-135.

This paper provides valuable data for elevation and vegetation composition in the restored Mitchell Marsh during its first decade of development. Table 1 has data on average percent cover and frequency of occurrence for plant species at the restoration site and two nearby remnant reference marsh patches. Figure 4 shows change in

wetland elevation. Other data in the publication include plant biomass and a channel cross section elevation profile.

Gray A, Simenstad CA, Bottom DL, Cornwell TJ. 2002. Contrasting Functional Performance of Juvenile Salmon Habitat in Recovering Wetlands of the Salmon River Estuary, Oregon, U.S.A. *Restoration Ecology* 10:514–526. [Link](#)

Gray et al. (2002) evaluated the development of juvenile salmon habitat in restoring marshes of differing age and in reference marsh in the Salmon River Estuary. Results showed differences in fish densities, prey resources, and diet composition among the restored sites and a reference marsh. The newly restored marshes exhibited a pulse of productivity, indicating efficacy of restoring estuarine marshes for juvenile salmon habitat. However, further analysis is needed to fully understand the benefits that consumers experience in these recovering systems.

Hering D, Bottom D, Prentice E, Jones K, Fleming I. 2010. Tidal movements and residency of subyearling Chinook salmon (*Oncorhynchus tshawytscha*) in an Oregon salt marsh channel. *Canadian Journal of Fisheries and Aquatic Sciences* 67:524–533. [Link](#)

This study was conducted on Chinook salmon in a large tidal channel in a reference marsh south of the restored Mitchell Marsh. The authors tracked fish movement and showed that tagged Chinook salmon entered and exited the study channel primarily with tidal currents, with peak movements occurring around high slack tides. Most fish used the channel for brief periods within a few tidal cycles, while some displayed fidelity or sporadic use over longer durations. Residence time correlated weakly with tidal magnitude, and fish typically exited at shallower depths than they entered.

Mitchell DL. 1981. Salt marsh reestablishment following dike breaching in the Salmon River estuary, Oregon. PhD dissertation, Oregon State University, 187 pp. [Link](#)

This PhD dissertation describes pre-restoration and early post-restoration vegetation communities in the Mitchell Marsh, restored in 1978. Following resumption of tidal exchange, the author documents the decline in less salt-tolerant species and increases in typical brackish marsh species of the Oregon coast. The thesis also documents subsided wetland elevation at the site (due to diking) and changes in other soil properties. Additional data includes plant biomass, general information on the Salmon River Estuary watershed, and the history of land use in the area.

Jones KK, Cornwell TJ, Bottom DL, Campbell LA, Stein S. 2014. The contribution of estuary-resident life histories to the return of adult *Oncorhynchus kisutch*. *Journal of Fish Biology* 85:52–80. [Link](#)

Jones et al. (2014) document use of least-disturbed and restored wetland areas by different life stages of coho salmon in the Salmon River Estuary. The authors conclude that wetland restoration leads to a greater diversity of salmonid life stages.

Zedler JB (principal author). 1996. Tidal wetland restoration: a scientific perspective and southern California focus. California Sea Grant College System, University of California. Publication T038. [Link](#)

This handbook focuses on tidal wetland restoration along the US Pacific coast, particularly in southern California. An entry on p.37-38 also briefly reviews the Mitchell Marsh project.

COLUMBIA RIVER ESTUARY

Littles C, Karnezis J, Blauvelt, Creason A, Diefenderfer H, Johnson G, Krasnow L, Trask P. 2022. Adaptive management of large-scale ecosystem restoration: increasing uncertainty of habitat outcomes in the Columbia River Estuary, U.S.A. *Restoration Ecology* 30:e13634. [Link](#)

This journal article provides a broad overview of tidal wetland restoration implementation in the Columbia River Estuary over the last several decades.

National Park Service. 2012. Colewort Creek wetland restoration environmental assessment. National Park Service, Pacific West Region. [R] [Link](#)

This document provides details about the Colewort Creek restoration project (implemented in 2007) in Lewis and Clark National Historical Park, a younger restoration site adjacent to the “Netul Landing” older restoration site that we studied in our NERRS Science Collaborative project (Colewort Creek is also known as South Clatsop Slough). The “Netul Landing” site to the northeast of Colewort Creek has also served as a reference marsh for monitoring work conducted by the National Park Service.

NISQUALLY ESTUARY

Belleveau L, Takekawa J, Woo I, Turner K, Barham J, Takekawa J, Ellings C, Chin-Leo G. 2015. Vegetation community response to tidal marsh restoration of a large river estuary. *Northwest Science* 89:136-147. [Link](#)

This study examined the distribution of low and high marsh plant communities finding two main plant assemblages. In the restoration site, about half the area had suitable elevations for tidal marsh vegetation development. The authors conclude that vegetation establishment is important for trapping sediment and building marsh elevation, underscoring the need to understand local plant community tolerances for factors like elevation and salinity which can inform restoration design.

Drexler JZ, Woo I, Fuller CC, Nakai G. 2019. Carbon accumulation and vertical accretion in a restored versus historic salt marsh in southern Puget Sound, Washington, United States. *Restoration Ecology* 27:1117-1127. [Link](#)

Drexler et al. (2019) compared vertical accretion and carbon accumulation rates in a recently restored marsh (Six Gill Slough) in the Nisqually Delta to measurements in an undisturbed reference marsh (Animal Slough). Six Gill Slough sediments had higher bulk density and lower organic carbon content compared to Animal Slough, which was attributed to the absence of deeply rooted plants in the restored area, resulting in denser, more inorganic sediment. Vertical accretion at Six Gill Slough was higher, due to inorganic sediment deposition, while Animal Slough was accreting at a slower rate with more organic material. Despite these differences, carbon accumulation rates were not statistically different between the sites. The study concludes that while restored marshes can quickly begin accreting and storing carbon, their ecosystem development may be hampered by factors like insufficient vegetation development, leaving them more susceptible to erosion and slower to fully develop ecosystem services.

Rubin SP, Davis MJ, Grossman EE, Woo I, De La Cruz SEW, Nakai G, Takekawa JY. 2024. Benthic macroinvertebrate response to estuarine emergent marsh restoration across a delta-wide environmental gradient. *Frontiers in Ecology and Evolution* 12:1356679. [Link](#)

The study examined how benthic macroinvertebrate communities responded to the restoration of an estuarine emergent marsh across an environmental gradient in the Nisqually River Delta. After dike removal, marine

invertebrate taxa rapidly colonized the newly restored marsh areas. Over time, the invertebrate communities in the restored marsh converged with those in previously restored and undisturbed reference marsh sites. Invertebrate communities also varied along an onshore to offshore gradient, with higher biomass and diversity near the delta front compared to the inner tidal flats. The invertebrate community composition was strongly associated with environmental factors like elevation, salinity, and sediment characteristics.

Nisqually Delta Restoration. Nd. Nisqually National Wildlife Refuge, Nisqually Indian Tribe, Ducks Unlimited, and USGS Western Ecological Research Center. [Link](#)

This Nisqually Delta Restoration Partnership website describes the restoration projects and phases of tidal marsh restoration in the estuary and provides useful maps and various links. Monitoring data includes information on tidal water level; wetland elevation change; tidal marsh plant composition; and invertebrate, fish, and bird observations.

SKAGIT ESTUARY

Beamer EM, Henderson R, Wolf K. 2006. Effectiveness monitoring of the Deepwater Slough restoration project for wild juvenile Chinook salmon presence, timing, and abundance. Skagit River System Cooperative. [Link](#)

This salmon monitoring study found that juvenile chinook salmon quickly used restored habitat after dike removal, with often higher densities compared to reference areas, though with significant variability. The restored habitat was being used by juvenile chinook at similar levels to other available habitat in the broader Skagit Estuary when accounting for landscape connectivity.

Clifton BC, Hood WG, Hinton SR. 2018. Floristic development in three oligohaline tidal wetlands after dike removal. *Ecological Restoration* 36:238-251. [Link](#)

Clifton et al. (2018) detail vegetation composition in three oligohaline tidal marshes in the Skagit Delta - Deepwater Slough, Wiley Slough, and Milltown Island - using remote sensing data (aerial imagery) and field surveys relative to two reference marshes. The Deepwater Slough project (80 ha) was restored in 2000. Wiley Slough (63 ha) was restored in 2009 after being first diked between 1959-1962. Field sampling in this study was conducted in 2001 and 2012-2013 and consisted of circular vegetation plots spaced 15 m apart along transects at Deepwater Slough. The team also measured plot elevation using RTK-GPS. In 2011, Deepwater Slough was dominated by cattails, but also had areas of reed canarygrass, other herbaceous species, and shrubs and trees.

Hood G. 2004. Deepwater Slough restoration monitoring report: 2000-2003. Skagit River System Cooperative. [R] [Link](#)

This is a detailed report outlining the Deepwater Slough restoration site and methods and preliminary monitoring of vegetation and channel morphology. Also included are benthic organism and beaver surveys.