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Title: Expect the unexpected: place-based protections can lead to unforeseen benefits

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Abstract

1. Protection of places important for aesthetic, ecological, and cultural values has been a goal of conservationists for over 150 years. Cornerstones of place-based conservation include legal designations, international agreements, and purchase by public or non-profit organizations.
2. In the Salmon River catchment, Oregon, protections were initially developed in the 1930s for the freshwater riparian corridor and forestry research in the uplands. Over time, additional protections in the estuary and nearshore marine environments were added, motivated by local desire to protect and restore habitats and fish populations.
3. Removal of three levees in the Salmon River estuary occurred over three consecutive 9-year time-steps, and provided the opportunity for research on tidal marsh recovery in the framework of a space-for-time chrono-series. Elevation, channel morphology, and vegetation all exhibited trajectories toward reference conditions. Fish and macroinvertebrates also served as indicators of tidal marsh recovery, although their recovery patterns were not strictly related to the chrono-series trajectories. The extent of

restoration provided a novel opportunity to measure a significant response of biotic indicators at the site and catchment scales.

4. Salt marsh restoration augmented protected freshwater habitats by expanding rearing habitats for juvenile salmonids and increasing expression of life-history diversity for both Chinook and coho salmon. This finding highlights linkages between freshwater and marine habitats and populations, and has the potential to influence important policy advances and changes in management of Pacific salmon.
5. Restoration promoted collaborations among stakeholders, community involvement, and inspiring educational opportunities that enabled more comprehensive research than any single sponsor could have accomplished.
6. Protected status designations have fostered a wealth of opportunities that were not specifically envisioned when the protections were first put in place. In particular, dedicated scientific investigation of landscape-scale change did not occur by design, but was pieced together as funding opportunities arose over time.

INTRODUCTION

For more than 150 years, conservationists have actively invested in place-based environmental protection. Historically, protections tended to be focused on areas of great scenic value or critical habitat for threatened wildlife (Stolton, 2010). As the essential services of diverse natural ecosystems became more clearly understood, ecological motives for preservation became drivers for legislated protections (Dudley and Parish, 2006). Looking to the future, place-based protection of dynamic ecosystems with strong capacity to adapt to a changing climate will come to the forefront.

In fact, some places already preserved for scenic or ecological values may become vital for understanding, moderating, and adapting to the effects of climate change. For example, since estuaries dynamically link fresh and salt water on daily, seasonal, and decadal time-scales, estuaries and linked freshwater areas where protection is already in place could be used to provide insights into the mechanisms of ecosystem functioning and the potential effects of climate change. Intact estuaries with functioning tidal wetlands accumulate sediments, materials, flood waters, and nutrients washed from upstream tributaries while assimilating inputs from the ocean, and could potentially become more important as buffer zones for adjacent ecosystems as weather patterns change and sea levels rise. Estuarine ecosystems play an important ecological role for freshwater biota, serving as nursery and rearing areas and providing connectivity along the gradient of habitats from fresh water to the ocean that is critical for diadromous species such as salmon and trout, char, and sturgeon (*Oncorhynchus* spp., *Salvelinus* spp., and *Acipenser* spp. respectively). Recognition of the critical importance of intact habitats along the fresh to salt-water continuum has evolved in recent years, with greater focus on the functional role of these systems.

The unforeseen value of protected catchment landscapes and estuaries in light of climate change illuminates the key principle addressed in this paper: place-based protection can create opportunities that were not anticipated when protections were first put in place. An example of this principle comes from the Salmon River catchment, estuary, and nearshore ocean (Oregon, USA), where a series of independent management actions beginning in the 1930s have collectively advanced catchment restoration, conservation, research, education, and community engagement.

In the Salmon River catchment, Oregon, the scale of protections and restoration created opportunities for research on recovery of plant assemblages and aquatic biota, including macroinvertebrates, endangered Pacific salmon, and other native fish. Innovative research at Salmon River has the potential to advance Pacific salmon policy and ecosystem-based management by demonstrating key linkages between freshwater and estuarine habitats. Estuary restoration has also promoted community involvement in habitat projects; collaborations among stakeholders from public, private, and non-profit sectors; and novel educational experiences.

This paper presents key elements of the Salmon River story as an example of unexpected research paths and community engagement that can be realized with place-based protections. First, the diversity of legislation that created the framework of protection for upland and freshwater areas, estuary ecosystems, and marine reserves is reviewed. Next, the active restoration of tidal marshes is described. Important research that has occurred here is highlighted, beginning with small-scale, detailed studies predominantly focused on estuary restoration. The 'space-for-time' chrono-series in the estuary that serves as a basis for chronicling recovery is described, and studies that provide measures of ecosystem functioning are reviewed. Continuing macroinvertebrate research that provides novel experiences for undergraduates is described, and the use of macroinvertebrate communities is assessed as an extremely sensitive indicator of recovery condition. The research section is concluded by summarizing population-scale studies of salmon, focusing on changes in life-history diversity related to tidal marsh restoration. These catchment-scale studies of salmon offer insight into linkages between freshwater and estuarine habitats, both critical components for long-term population resilience. Salmon populations act as an indicator of habitat functioning across habitat types and are one of many threads tying together freshwater and estuarine protection and restoration throughout the Salmon River catchment. Finally, the implications of this research beyond the boundaries of the Salmon River are presented, providing lessons learned and the broader science and policy implications of the work.

Protection and restoration — Cascade Head, Salmon River and the nearshore ocean

Development of the protection framework

Conservation protection for portions of the Salmon River and adjacent headlands occurred through incremental actions from public agencies and legislation, spurred by private citizens (Figure 1). Protections were driven by a host of separate goals, and championed by a diverse group of entities.

Research on coastal Sitka spruce–western hemlock (*Picea sitchensis*/*Tsuga heterophylla*) forests initially led to USFS designation of 4815 ha of the Siuslaw National Forest as the Cascade Head Experimental Forest in 1934. The research was used to aid in the management of both old-growth and younger temperate rainforests. This designation also created additional protections during active timber harvest in the majority of freshwater streams in the lower Salmon River catchment, possibly reducing sedimentation rates in these stream systems. The State of Oregon established the H.B. Van Duzer Forest State Scenic Corridor by land purchases from 1935–1942 (continuing to 1984) to preserve 19.3 km of freshwater and riparian ecosystems. This area now contains some of the most functional western hemlock–Douglas-fir riparian forest in the state of Oregon.

Recognizing the need to conserve the rare and threatened plant and butterfly species found on the grassy headlands on the north side of the Salmon River estuary spit, The Nature Conservancy raised funds to purchase Cascade Head Preserve (109 ha) in 1966. Shortly thereafter (1968), the Oregon Islands National Wildlife Refuge was established by Executive Order and Public Land Orders to protect seabirds and pinnipeds (Figure 2). The establishment of the Cascade Head Preserve raised public awareness of rare species and their habitats on the Salmon River headlands. When the area was threatened by residential development, public pressure was applied, resulting in unique federal legislation. The Cascade Head Scenic Research Area (CHSRA), covering approximately 3916 ha (of which more than half was in private ownership), was established by Public Law 93-535, signed by President Gerald Ford on December 22, 1974 (Figure 1, 2). The USFS was granted authority to acquire lands inside the boundary through willing-seller arrangements. The bill required the development of a land-use plan and recognized four subareas: estuary and associated wetlands; lower-slope dispersed residential; upper timbered slopes; and coastline and sand dune-spit. The adopted plan was based on a carrying-capacity analysis and developed management prescriptions for each of the subareas, with an emphasis on estuary and wetland restoration and the protection of the scenic quality of the area (USFS, 1977).

In 1980, Cascade Head, OR, and Olympic National Park, WA, became a Biosphere Reserve of the United Nations Educational, Scientific and Cultural Organization (UNESCO) as part of the Man and the Biosphere Program. Additional protections have come from the State of Oregon, with funding in 2006 for a conservation easement (in cooperation with the Westwind Stewardship Group) over more than 202 ha of headlands, dunes, and shorelands on the south side of the mouth of the Salmon River. This was followed by the State's adoption, in 2010, of the Cascade Head Marine Reserve, a 25 km^2 marine protected area surrounded by a reserve (59.8 km^2).

Restoration and enhancement of the estuary and headlands of the Salmon River catchment

Protections led to mandated restoration efforts in the Salmon River catchment that have occurred over decades in different locations including the headlands, fresh water, and estuary. In the past decade, the Nature Conservancy has worked on the headlands to enhance rare coastal salt-spray meadows that are host to the endangered Oregon silverspot butterfly (*Speyeria zerene hippolyta*). Efforts have included the re-introduction of prescribed fire, invasive plant removal, and the planting of native species. Work continues in collaboration with the U.S. Fish and Wildlife Service, Lewis and Clark College, and the Oregon Zoo to increase abundance of the local population of this endangered butterfly species. In addition, beginning in 2007, the Salmon Drift Creek watershed council began riparian planting to stabilize banks and enhance riparian functioning in protected freshwater habitats along tributaries of the Salmon River.

The most extensive restoration work has been completed in the protected portions of the Salmon River estuary. In the past century, more than 65% of estuarine tidal marsh area in the U.S. Pacific Northwest (Oregon and Washington) has been lost through diking, drainage, or fill (Boule and Bierly, 1987; Good, 2000; Dahl and Stedman, 2013). At Salmon River, various projects have rehabilitated approximately 75% of the estuary. The USFS, Oregon Department of State Lands, the U.S. Fish and Wildlife Service Coastal Wetlands Program, and the Oregon Watershed Enhancement Board provided significant funding for the restoration work. Coordinated efforts by the Oregon Department of Transportation and Lincoln County expanded restoration of the estuary beyond USFS boundaries. The restoration occurred in roughly three phases, but at no time was a deliberate plan in place for long-term restoration at Salmon River. Rather, these phases of restoration evolved organically under the legislated mandates of the CHSRA.

The first phase of marsh restoration began in 1978, when the USFS removed artificial levees in tidelands (21 ha) on the north bank of the Salmon River (1978 Marsh, Figure 3). In 1987, the USFS removed the levee from a 25.5-ha pasture on the south side of the estuary (1987 Marsh, Figure 3). This was followed in 1996 by levee removal from a 31-ha intertidal area on the north bank of the Salmon River, upstream from the 1978 rehabilitated marsh (1996 Marsh, Figure 3). Altogether, this series of large, artificial levee-removal projects, completed at regular 9-year intervals, established a sequence of wetland treatments in successive recovery stages that presented a unique 'space-for-time substitution' opportunity (Pickett, 1989; Gray *et al.,* 2002; Morgan and Short, 2002) for research into the trajectories of estuary ecosystem recovery, which are summarized in later sections of the manuscript.

A second phase of marsh restoration began in 2006, when an interdisciplinary team of graduate students worked to identify remaining restoration projects in the Salmon River estuary. This planning process was initiated by the USFS, but was led by a diverse group of partners. The students conducted weekly meetings with the local community to capture and address interests and concerns expressed by the public, and regularly met with a multiagency technical advisory group. This process allowed the students to create, with public ownership and support, the Lower Salmon River Project Report (Anderson *et al*., 2006), which prioritized the remaining restoration opportunities in the most-altered portions of the estuary and provided a framework for securing grant funding necessary for further restoration of the Salmon River estuary. By January 2008, partnerships and funding were secured to begin a new 8-year restoration effort. The highest priority restoration identified was an area that had been filled, leveed, and severely altered for a housing development (Tamara Quays) and amusement park (Pixieland, constructed between 1966–1969) (Stone, 2010). Between 2009 and 2011, the amusement park and associated subsurface infrastructure were removed, restoring approximately 23 ha of tidal marsh.

The third phase of marsh restoration occurred in 2012 and 2014, with a county road culvert replacement and small levee-removal project, followed by restoration of tidal conditions in an abandoned boat basin that had been carved out of an intertidal marsh (Ellingson and Ellis-Sugai, 2015).

The largest remaining levee in the estuary is the road fill of U.S. Highway 101, which was built in 1960–1962 before the CHSRA was designated. This levee bisected the estuary, restricting connection between freshwater and estuary habitats. The oligohaline upper estuary and the mesohaline lower estuary were separated from each other, and Salmon Creek was redirected from entering the 1996 Marsh, its historic outlet, into a borrow ditch on the north side of the highway. While a minor channel reconnection of Frazier Creek across the levee is currently being constructed, it has not been determined whether the highway will be relocated, modified, or otherwise changed to allow greater hydrologic connectivity between the estuary and fresh water.

In summary, conservation and restoration efforts in the CHSRA span nearly 80 years. Moreover, this sustained effort has been accomplished by shifting assemblages of dedicated participants and funding partners, and reflects the evolution of conservation philosophies and restoration methods.

A natural laboratory

The Salmon River catchment and surrounding headlands are small enough for exhaustive inventories, and yet large enough to support a full complement of anadromous fish populations and other biota (Figure 1). Furthermore, the management history at Salmon River has created a rare natural laboratory for investigating the mechanisms and trajectories of ecosystem development and recovery at multiple spatial and temporal scales.

The estuary ecotone is a key link in the habitat continuum for anadromous salmonids, but it also is only as good as the strength of its connections to freshwater habitats in the rest of the catchment. The restored estuary habitats effectively leveraged high quality freshwater mainstem habitat for both Chinook and coho salmon populations. Salmon naturally integrate across habitat types and reflect the mosaic of ecotones in a diversity of life-history strategies that increase population resilience. Restoration in the lower end of the catchment may be a useful conservation approach, beyond the traditional idea of simply working downstream from intact headwater tributaries (Bottom *et al.*, 2009).

Early post-restoration research primarily documented changes in vegetation and geomorphology of restored tidal marsh habitat. Later studies aimed at better understanding of ecosystem functioning and explored potential tools for assessing restoration success by tracking macroinvertebrate assemblages, fish densities and distribution, and fish foraging success (modelled potential growth). In recent years, the scope of research has expanded beyond the estuary, coincident with studies on the life-history diversity of salmon. This holistic research includes the estuary as both a location for juvenile rearing and as a critical conduit linking freshwater and marine habitats. In the following sections, selected results of Salmon River research are summarized at the wetland and catchment (i.e. salmon population) scales, following a temporal sequence with early research discussed first, and concluding with an expansion in scope of the work into the freshwater portions of the catchment.

Wetland-scale marsh recovery research

Setting up a 'space-for-time' chrono-series. Chronicling ecosystem change with restoration in the Salmon River catchment originated with the far-sighted intuition and efforts of Dr. Robert Frenkel and his graduate students at Oregon State University (OSU). Beginning with the first salt marsh restoration project, systematic sampling sites were established and progressively included all subsequent restoration efforts (Figure 3). Ultimately, these long-term monitoring locations became the foundation of a 'space for time' chrono-series that was critical in research projects of site-scale characteristics such as vegetation, geomorphology, macroinvertebrates and fish bioenergetics, but also served an important role in catchment-scale research that explored the freshwater and estuarine life history diversity of salmonids.

Elevation and channel geomorphology. The recovery trajectory of marshes in the estuary ecotone following restoration activities is a critical concern for land managers seeking to enhance connection between freshwater and marine environments. Land subsidence is one of the primary determinants of tidal wetland restoration trajectories, at least in systems where other local or landscape stressors are minimal (Roman and Burdick, 2012). As with similar leveed tidal and freshwater wetlands around the country, subsidence is probably caused by loss of accretion of suspended sediments that would otherwise have been carried in by the tides or river

(Friedrichs and Perry, 2001), oxidation of soil organic matter (Portnoy, 1999; Portnoy and Gilbin, 1997), and compaction from various land uses (Gedan *et al*., 2009). Between 1978 and 1988, recovery trajectories of 5–7 cm (low marsh) and 3–4 cm (high marsh) of sediment accretion were documented in the 1978 Marsh as a result of reintroduced tidal delivery of suspended sediment (Mitchell, 1981; Frenkel and Morlan, 1990; Morlan, 1991; Morlan and Frenkel, 1992; Frenkel, 2002). Subsequent elevation and high-precision GPS surveys continued to document increasing marsh elevation, such that by 2007, LiDAR topography of the estuary illustrated that areas of the 1978 Marsh were approaching reference marsh elevations (Figure 4).

Coincident with sediment accretion and elevation gains in the recovering marshes of CHSRA, tidal channel geomorphology progressively changed. As demonstrated in the 1978 Marsh, with restorative energy of tidal scour, marsh channels progressively became deeper (Frenkel and Morlan, 1990). In fact, by 2007, cross-sectional geomorphology of rehabilitated marshes resembled reference tidal channels with narrow, deep channels and prominent natural levees along the edges, where revegetation accentuates sediment accretion (Figure 5).

Vegetation change research. In vegetation community restoration, whether the landscape and other external conditions will allow recovery trajectories to approach pre-existing conditions, instead of turning into ‘novel’ ecosystems (Aronson and Le Floc’h, 1996) will depend on the reestablishment of critical processes (i.e., in estuary marsh restoration, characteristics of sediment accretion are critical). Although even the vegetation assemblage of the marsh that has been recovering for more than 30 years has not yet become statistically equivalent to any of the relevant reference sites, the trajectory continues to approach reference marsh conditions, both within and among the recovering marshes. In the initial 6-10 years, all recovering marshes typically demonstrated a rapid, common transition from freshwater pasture grasses and salt-intolerant wetland vegetation to low-elevation, native marsh species, such as *Carex lyngbyei*, *Salicornia virginica*, and *Distichlis spicata*. Within 15 years, the 1978 Marsh vegetation assemblage had become similar to that of adjacent reference plots, but remained statistically different because of the absence of diagnostic reference marsh species, such as *Juncus balticus*, *Agrostris alba*, and *Argentina egedii egedii*. By 1999, the vegetation assemblages of the 1978 and 1987 Marshes had become statistically similar.

Wetland-scale estuarine fish research

Fish habitat use. Research at CHSRA demonstrated that estuarine marsh restoration expanded freshwater rearing habitat for juvenile salmonids (Cornwell *et al.*, 2001) thereby enhancing population-scale survival throughout the catchment. Surveys of marsh channels in the late 1990s revealed that a full complement of estuarine fish species, together with juvenile Chinook and coho salmon (*Oncorhynchus tshawytscha* and *O. kisutch*), occupied the 1996 marsh in the first year after the levee was removed and tidal access restored. Moreover, salmon densities in each marsh were not a simple function of marsh recovery age (Cornwell *et al.*, 2001). Densities of Chinook and coho salmon were consistently low in the oldest recovering wetland (1978 Marsh) and sometimes highest at the youngest restored site (1996 Marsh) (Hering, 2009). The overall pattern of salmon habitat use was strongly influenced by the geographic arrangement of sites rather than simply the stage of ecological succession (Figure 6). The marsh closest to freshwater habitat (1996 Marsh) was most consistently used by juvenile salmon upon entering the estuary from upstream, although this marsh was the one most recently restored. This reflects the strong connection between freshwater and estuary habitat use by juvenile salmon.

Chinook and coho salmon use the estuary extensively during their seasonal migrations. The earliest juvenile Chinook salmon migrants to the estuary each year remained in marsh habitats or in the mid to upper estuary channel for much of the spring, often demonstrating strong site fidelity (Hering *et al*., 2010), and only venturing into the more highly saline lower estuary after weeks or months of growth (Volk *et al.*, 2010). Large coho smolts that entered the estuary after a year of freshwater growth were widely distributed during their spring outmigration. However, smaller subyearling migrants were restricted primarily to wetland channels and the upper mainstem estuary except during high-flow (low-salinity) periods in the late autumn, winter, and spring. Although the seasonal distributions of Chinook and coho salmon reflect different patterns of juvenile life-history, both species reared extensively in the restored estuary wetlands, regardless of the time elapsed since levee removal (Figure 6).

Foraging results and bioenergetic modelling. Complementary to studies of salmon distribution and abundance, Gray (2005) aimed to establish metrics for assessing marsh recovery status and functioning, including foraging success and growth of juvenile salmon. This allows an assessment of how much salt marshes contribute to habitat quality along the continuum of freshwater and salt-water habitats for rearing salmonids. Initially, Gray (2005) related juvenile salmon diet composition to prey availability in different stages of the recovering marsh chrono-series (Figure 7) (Gray *et al.*, 2002). This work provided the basis for bioenergetic modelling of potential growth as a measure of ecosystem functioning. An energy-balance model of fish growth potential represents ecosystems in the common currency of expected fish growth-rate ($g\ g^{-1} day^{-1}$) under specific environmental conditions (Brandt *et al*., 1992; Tyler and Brandt, 2001).

Gray (2005) found that recovering marshes in the Salmon River estuary undergo a variety of ecological processes, including increased organic sedimentation probably due to the breakdown of former pasture grasses. This process supported a high abundance of insects, some of which (particularly the most frequently consumed trichopterans and chironomids) contained almost twice the energy value of the crustacean taxa commonly consumed in the Reference marsh. These high-energy prey resources increased growth efficiency for juvenile salmon. The shift in prey resource abundances and energy value may represent an important mechanism by which the recovering ecosystem subsidizes foraging fish, resulting in an initial, tangible benefit to populations from restored habitats.

Gray's models also incorporated physical characteristics (i.e. temperature) that may adversely affect fish production even when foraging success is high. Temperatures in the tidal channels when the marshes were flooded and available to juvenile salmon were somewhat related to restoration stage, in that conditions in the 1978 and 1996 marshes were warmer than the 1987 and Reference marshes in summer months, often by as much as ~5°C. However, the higher energy-values of insect prey served to offset the negative effect of increased water temperature (Gray, 2005). As a result, the combination of thermal regime and prey composition under some conditions resulted in much higher modelled weight gain in the recovering marshes than in the Reference Marsh.

Continuing wetland-scale macroinvertebrate research and educational opportunities

Gray (2005) also used differences in the macroinvertebrate communities as a tool to assess restoration success. Assemblages differed among recovering systems in the estuary, which suggested that the communities are sensitive indicators of marsh recovery stage. Macroinvertebrate communities have often been found to be useful indicators of ecosystem condition (Cairns and Pratt, 1993).

Continued macroinvertebrate monitoring is linked to a unique opportunity for undergraduate course-based research at Western Oregon University (WOU) that extends the studies by Gray *et al*. (2002), Gray (2005), and Bieber (2005). From April to July, 2010–2012, students in WOU's upper-division marine ecology course (and in the summer, student volunteers) set up invertebrate fallout traps, collected benthic core samples, and took ancillary physical data. In 2011, students enrolled in WOU's 'Biological Sciences for Elementary and Middle School Teachers' joined the marine ecology students in conducting field and laboratory work. Advanced undergraduates served as field team leaders. Post-grant, marine ecology students continue to assist in the collection of benthic invertebrates each May to maintain the long-term data set, which now extends from 2010 until 2015.

In 2011, marine ecology and pre-education students who had worked together in the field and laboratory formed partnerships to create K–12 lesson plans consistent with National Science Education and Ocean Literacy Standards. These lessons showcased some of the research techniques performed by the students, and emphasized marsh stewardship (www.wou.edu/~baumgare/salmonriver.html). Beyond generating K–12 lesson plans, participants significantly increased their understanding of estuarine ecology and gained skills for conducting applied research. The pre-education students greatly reduced the gap in their knowledge and efficacy when compared with their peers with more prior science experience (Orr and Baumgartner, 2012).

Clearly, this project has generated novel educational benefits, yet the scientific value of the research remains its guiding force. Preliminary results comparing diversity and community composition to the 1998–2002 data set (Gray, 2005) suggest that macroinvertebrate assemblages in the recovering marshes are on a continuing trajectory toward conditions at the reference marsh; however, distinct differences among marshes remain and there is considerable interannual variability of individual marsh communities (Haberman and Gray, unpublished data).

Salmon population catchment-scale research

Life-history diversity. Pacific salmon are distributed from the freshwater headwaters of streams to the ocean at different stages in their life cycle, with variation in timing and residence in different habitats resulting in a diversity of potential life-history patterns. This life-history variation spreads mortality risks in time and space, and may strengthen the resilience of populations in unpredictable aquatic environments (Healey, 2009; Fleming *et al*., 2014). Channel networks in tidal wetlands provide productive nursery habitat for many juvenile salmon, particularly Chinook salmon, which are considered among the most estuarine-dependent of salmon species (Levy and Northcote, 1982; Healey and Prince, 1995). In contrast to Chinook salmon, however, the juvenile life-histories of coho salmon are typically considered relatively simple, consisting primarily of individuals that develop in their natal freshwater streams for a year before migrating rapidly seaward in the spring. The recovery of a large area of potential rearing habitat in the Salmon River estuary enabled a study of life-history re-emergence by Chinook and coho salmon populations, including documenting previously unknown estuary-specific life-history strategies in this species.

Life-history re-emergence. A year after the CHSRA was authorized, the Oregon Department of Fish and Wildlife (ODFW) began salmon population and life-history studies to provide information for operating a new fish hatchery constructed along the Salmon River just above salt-water influence. The 3-year pre-hatchery survey (Mullen, 1978a, b, 1979) established a key population baseline, depicting Chinook and coho salmon abundances, distributions, and life histories in the estuary at a time when all the levees were present but before the hatchery was fully operational. Decades later, this background information opened the door for a unique research opportunity to evaluate the effect of tidal marsh restoration on life-history expression of Chinook and coho salmon populations. The life histories of salmon populations are known to be highly flexible and adaptive (Healey and Prince, 1995), but few opportunities exist to compare the life-history responses of Chinook and coho salmon to ecosystem restoration and recovery. The work at the Salmon River estuary is novel in this respect.

Mark-recapture experiments and chemical analyses of otoliths enabled researchers to reconstruct the freshwater and estuary juvenile life-histories of Salmon River fall (autumn) Chinook (Bottom *et al*., 2005; Volk *et al*., 2010) and coho salmon (Jones *et al.*, 2014) before individuals migrated to the ocean. The results showed considerable diversity in the migration ages, migration times, and freshwater and estuarine residency periods for juveniles of each species, reflecting use of all available rearing habitats across the Salmon River basin (Figure 8a). Four migrant types were observed in the Chinook salmon population, including individuals that entered the estuary immediately after emergence, and a succession of increasingly larger subyearling migrants that remained in fresh water for varying periods before entering the estuary in the spring, summer, or autumn (Jones *et al.*, 2014). Contrary to the conventional freshwater-resident life-history pattern expected for most coho salmon populations, three of the four juvenile types identified in Salmon River also involved extensive estuary development within the first year: some juveniles entered the estuary immediately after emergence (fry); some early estuary residents later moved back into lower-basin tributaries to develop (nomads'); and some individuals entered the estuary during or after the first autumn rains (parr). All Chinook salmon juveniles left Salmon River in their first year of life, whereas all coho salmon developd in the catchment for at least a full year before entering the ocean (Figure 8a).

Comparisons of recent and historical data (Mullen, 1978b; 1979) reveal that life-history variation in both Chinook and coho salmon populations has expanded since tidal connections to most of the estuarine wetlands were re-established. For example, estuarine surveys in the mid-1970s found few Chinook salmon of any size in the mid or lower estuary before July. Early fry and fingerling migrants now enter the estuary from April until June, occupy restored wetland habitats through August, and enter the ocean over a greater range of sizes and times, compared with the period when most of the wetlands were leveed (Bottom *et al*., 2005). A total of 17% of the juveniles entering the ocean in 2001–2002 were early-migrant types (emergent fry and spring migrants) that developed in the estuary for weeks or months (Volk *et al*., 2010), life-history patterns that were not found during surveys in the mid-1970s (Mullen, 1979; Bottom *et al*., 2005). Similarly, recent coho salmon surveys have estimated that the three subyearling estuarine migrant types account for approximately 20% of juvenile and adult coho in the Salmon River population (Figure 8c). Each of these types is closely associated with restored tidal wetlands, whereas subyearling migrants of any type rarely occurred in Salmon River estuary when the marshes were fully leveed (Mullen, 1979; Jones *et al*., 2014). Juvenile coho salmon now use restored wetlands for much of the year, even during autumn and winter after juvenile Chinook salmon have left the estuary (Figure 6). Recent surveys at Salmon River thus provide evidence that restoring estuarine habitat has increased life-history diversity among juvenile coho as well as Chinook salmon, as demonstrated by the addition of multiple subyearling, estuary-resident life histories in each population.

Otolith chemical analyses have allowed researchers to reconstruct the proportions of all juvenile life-history types that survive to adulthood and return to spawn in fresh water in the Salmon River catchment. The results show that each of the estuary-resident pathways that were directly linked to recovering tidal marshes are also represented among returning adult Chinook and coho salmon (Figure 8). For example, slightly more than 30% of the Chinook salmon spawners during the 2004–2005 return years were the survivors of emergent fry or spring-migrant life histories, suggesting that estuary restoration contributed to a significant proportion of the adults returning in those years (Figure 8b). An additional 30–40% of the adults were summer migrants that spent more than 30 days, and up to 120 days, in the estuary (Figure 8b).

The increased connections between freshwater and estuary habitats resulting from estuary restoration (and freshwater protection) have led to the re-emergence of a diversity of juvenile life histories, contributing to adult returns and strengthening the resilience and productivity of both the Chinook and coho salmon populations at a catchment scale. Restored rearing habitat in the estuary is probably supporting juvenile coho salmon that could not survive upstream (Jones *et al.*, 2014). The estimated annual number of yearling coho leaving the upper catchment was similar for a wide range of juvenile abundances and environmental conditions, suggesting that upstream coho production may be at or near capacity for the available winter rearing habitat. In 2008–2011, subyearling migrants from the three estuary-resident juvenile life histories accounted for ~25% of the adult coho returning to spawn in the Salmon River basin (Figure 8c). The results also suggest that the conventional (yearling–smolt) pathway is more or less fully utilized under current freshwater conditions; that is, the annual production of yearling coho smolts from the catchment remained consistent (~20,000) over a wide range of spawner abundances and river conditions, implying limits to overwinter survival. Further enhancement of the yearling–smolt pathway might thus require restoration of winter habitats upstream.

Salmon productivity and diversity are a function of the number and variety of freshwater-estuarine habitat pathways potentially available for juvenile migrants to traverse throughout a river basin. Additional freshwater connections may also be needed in the lower basin to more fully accommodate the 'nomad' life-history variant, which depends on a direct connection between the estuary and small freshwater tributaries. The Hwy 101 road fill, for example, eliminated a direct route for autumn migrants to move back into fresh water from the 1996 Marsh. Given the high proportion of autumn and winter migrants that enter the restored 1996 marsh, the disconnection of Salmon Creek channel from the estuary may undermine full expression of the nomad life history by the Salmon River population.

A fortuitous management "experiment"

In 2007, the ODFW discontinued all coho salmon releases from the Salmon River Hatchery because of concerns that hatchery operations were undermining viability of the naturally spawning population (Chilcote *et al.*, 2005; ODFW, 2007). Subsequent coho salmon surveys from 2008 to 2014 provided juvenile and adult population data for the first 6 years after this latest change in fisheries management. The first two generations of returning adults of entirely naturally produced coho salmon suggest relatively stable or higher numbers of returning naturally produced adults in Salmon River, despite the removal of an annual subsidy of ~200,000 hatchery-reared juveniles. Hatchery selection for early spawning may have been an important factor in the poor survival of Salmon River coho salmon. Adult returns following cessation of the hatchery programme show a gradual but steady expansion of adult spawning times to successively later dates, a pattern that is more characteristic of other Oregon coastal coho salmon, including the historical Salmon River population.

Sea-level rise and climate change

Predicting future conditions in coastal catchments is inherently complex owing to interactions among freshwater, estuarine, and ocean systems. Catchment-wide predictions of climate effects are particularly important for salmonids who need habitats across the continuum of fresh and salt water. Present climate projections predict sea-level rise, alterations in type, timing, and intensity of precipitation, and increases in water temperature (NRC Committee on SLR, 2012).

Sea-level rise may flood currently productive salt-marsh habitats (depending on their ability to naturally adapt by rising in the tidal frame) and into freshwater areas. To predict reliably the effect of sea-level rise on estuarine marshes, a number of variables need to be well understood, including present elevation, vertical land movement, accretion rates, storm-induced erosion, and the effect of marsh vegetation on sediment capture and retention. The long history of research at Salmon River over many decades positions this system to inform many of these relationships and will be relevant across the coastal plain.

LiDAR data sets were used to map potential changes in mean high tide and marsh configuration across tidal inundation regimes at Salmon River and elsewhere in Oregon (Flitcroft *et al*., 2013). If salt marshes at Salmon River cannot accrete fast enough to keep pace with sea-level rise, it is possible there will be a decrease in marsh complexity into the future. Another element of the continuing recovery of tidal marshes relevant to discussions of future climate is the capacity of existing marshes to absorb storm surges and ocean-surface elevation change associated with El Niño events. Marsh restoration at Salmon River has already been shown to increase the capacity of the system to store tidal flow (Ellingson and Ellis-Sugai, 2015). The ability of marsh habitat to buffer freshwater areas against intense storms is another benefit of legislative protections that allow the restoration of natural ecosystems and processes.

Policy implications — lessons learned

The federal designation of the CHSRA was a place-specific legislative approach prompted by citizen concern about the future of the environment, especially coastal areas. Placing private lands under federal land-use authority was a novel and possibly unique way to 'stop the clock' on the development pressures existing at the time. The mandates of research and estuarine protection in a federal agency whose core functions and expertise lay in the terrestrial forest environment created the need and opportunity for others to explore the meaning and process of estuarine restoration and relationship to upstream freshwater habitats. Fortunately, a series of researchers created a climate of inquiry and acquired the necessary funding to explore these questions more deeply. Their research led in unforeseen directions resulting in new information about recovery of tidal-marsh vegetation and geomorphology, as well as the role of the marshes in the aquatic food web and as habitats for juvenile Pacific salmon, and a more holistic perspective that links functional estuary ecosystems to freshwater habitat condition.

There is a counterintuitive lesson from the Salmon River story, which is that lack of administrative focus creates an opportunity for collaborative learning. Estuarine management is not a USFS mandate, but by allowing and creating the opportunity for research, the agency has helped to build a better understanding of estuarine recovery, the importance of restoration technique, and the role of the linkages between estuarine and freshwater habitats in the life cycle of salmon. Similarly, although management action by the ODFW on hatchery production of coho salmon developed independently of CHSRA mandates, it fortuitously enabled the exploration of salmon response to both levee removal in the estuary and the effects of artificial production on the entire coho salmon population.

One of the more important lessons learned at Salmon River is the benefit of spatially concentrated restoration actions. Economic theory has suggested that ecological effects from concentrated restoration actions are an optimal allocation of conservation funds (Wu and Boggess, 1999). The protection status of the CHSRA allowed a concentration of restoration actions that created a real-world test of the theory. Had the same amount of restoration funding been distributed among all or many of Oregon's coastal systems, ecological benefits may never have been detectable.

Looking to the future, the federal designation of the CHSRA and associated research opportunities makes the Salmon River catchment an ideal site for evaluating the effects of a changing climate on estuary and freshwater ecosystems. The Salmon River is sufficiently small that it can serve as a microcosm of some elements of much larger systems of the Pacific Northwest.

Conclusions

At the Salmon River, OR, the protections provided by incremental actions to accomplish disparate purposes has led to an opportunity to explore system changes and responses that are not available in other places where the combination of protections are not available. The individual protection actions focused on specific concerns (visual, forest management, land development, marine resource exploitation, etc.) but as a group allowed for actions to evaluate and accomplish system-scale ecological change.

A rare combination of attributes (including extremely dedicated individuals) and historical opportunities has established the Salmon River catchment as a model system for understanding coastal ecosystem dynamics and ecological responses to management manipulations. This outcome was facilitated by the novel legislation of the CHSRA that included the mandate to rehabilitate the system and research its recovery. With no specific research outcome anticipated or designed, the science that emerged followed an almost organic pathway of development. One set of ideas led to another and resulted in unforeseen scientific benefits. The early date of protection and relatively unfunded legislative mandates for monitoring and research set the system apart from other protected areas in the Pacific Northwest (such as the National Estuarine Research Reserve System (NERRS)). Interestingly the multi-sector model used by the NERRS emerged naturally at the Salmon River, with interest and actions in research and stewardship (restoration) integrating naturally into community involvement and educational opportunities.

Protection, research and restoration work in the Salmon River catchment has been inherently collaborative, perhaps because the legislative mandate to rehabilitate and research the estuary is not a particular driving force for either the USFS or ODFW, the two agencies with the greatest management influence on the system. The inclusion of independent collaborators was required to bring needed expertise, and opened the door to the influence of 'champions' of research and management. The continuing restoration programme of the estuary is of sufficient duration and magnitude to produce measurable changes at ecosystem and landscape scales. Long-term alignment of large-scale treatments and monitoring activities has allowed researchers to draw inferences about ecosystem responses to management actions. Indeed, the Salmon River provides the opportunity for adaptive management (Walters, 1986; Walters and Holling, 1990) informed by research that is enabled by an unusual sequence of ecosystem manipulations and subsequent recovery.

Coastal ecosystems of the Pacific Northwest are resilient and dependent on disturbance processes, but managers need to understand how recovery occurs and which factors are most important in developing ecosystem functions indicative of intact systems. At Salmon River, restoration of pathways connecting freshwater to functional estuary habitat led to catchment-scale effects seen in the re-emergence of life-history diversity of salmonids and enhanced population resilience. Continued learning from the management experiments at Salmon River, or other protected systems, will depend on sustained restoration and recovery of habitats and sufficient monitoring to measure continuing ecological responses. An additional line of inquiry at Salmon River and elsewhere would be to determine the relative timescale and trajectory for processes in recovering systems compared with natural ones. Fully understanding ecosystem mechanics may elevate priority of conservation efforts, as some qualities of natural systems may not be recoverable.

The Salmon River story continues to evolve. The CHSRA provides fertile ground for further exploration of the effects of management actions, recovery from human disturbance, and impact of climate change on estuaries, entire riverscapes, and the species that use them. If satisfactory monitoring and educational efforts can be sustained, the unique protection, management and research history at Salmon River offers continued opportunities to learn about the intrinsic connections between freshwater and estuarine areas in coastal ecosystems.

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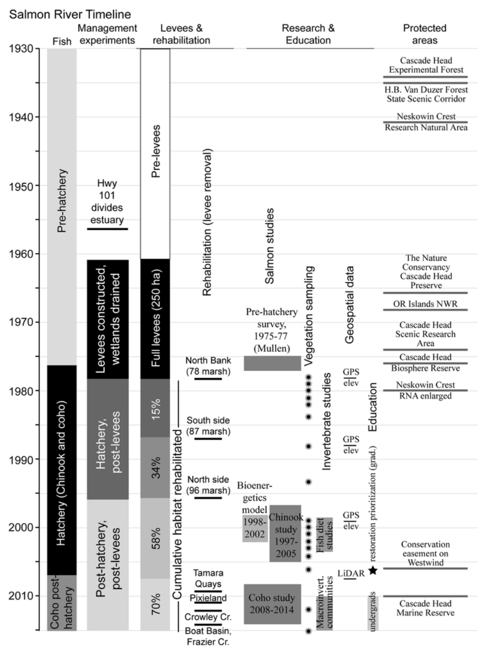

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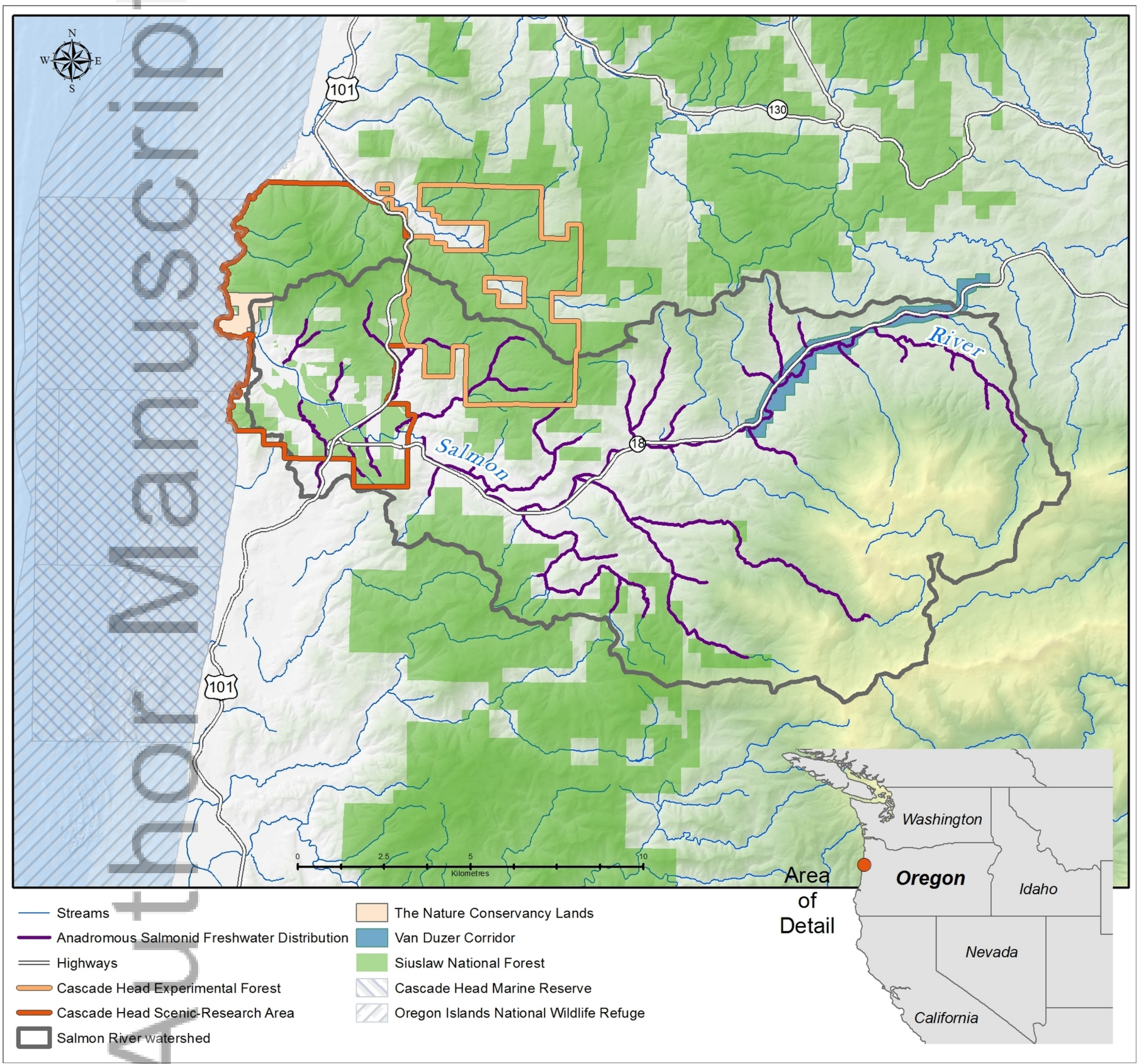

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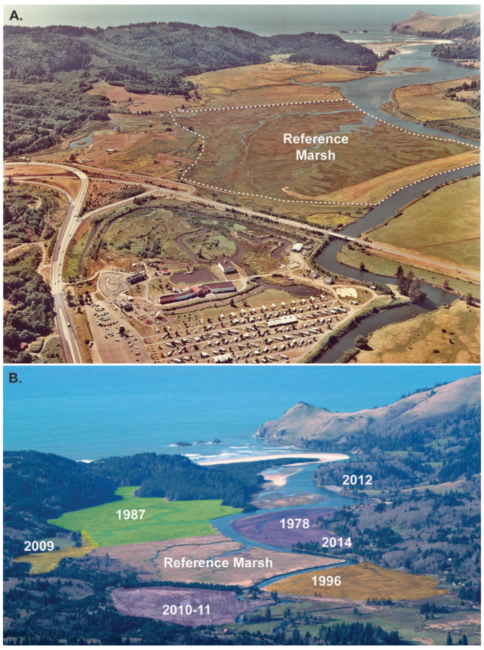

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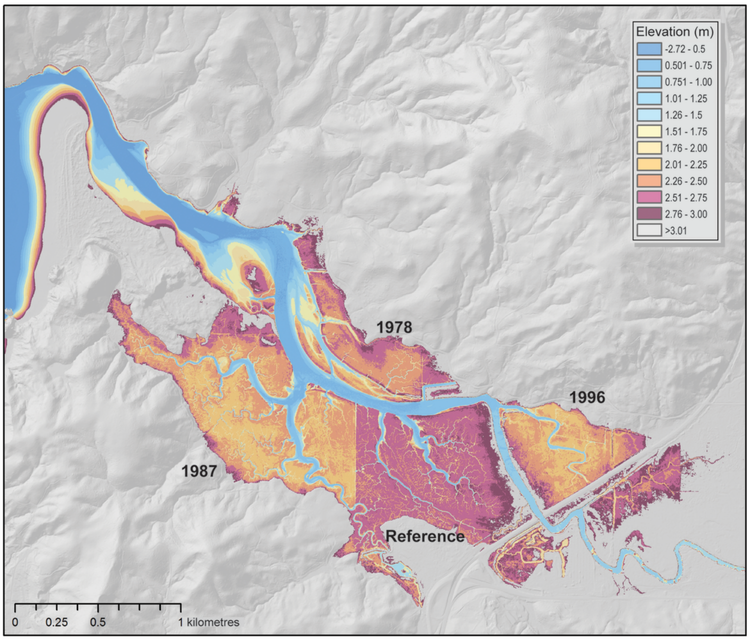

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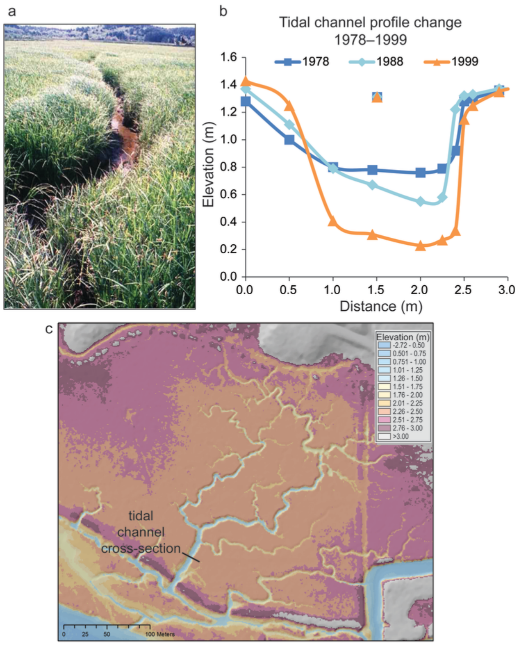

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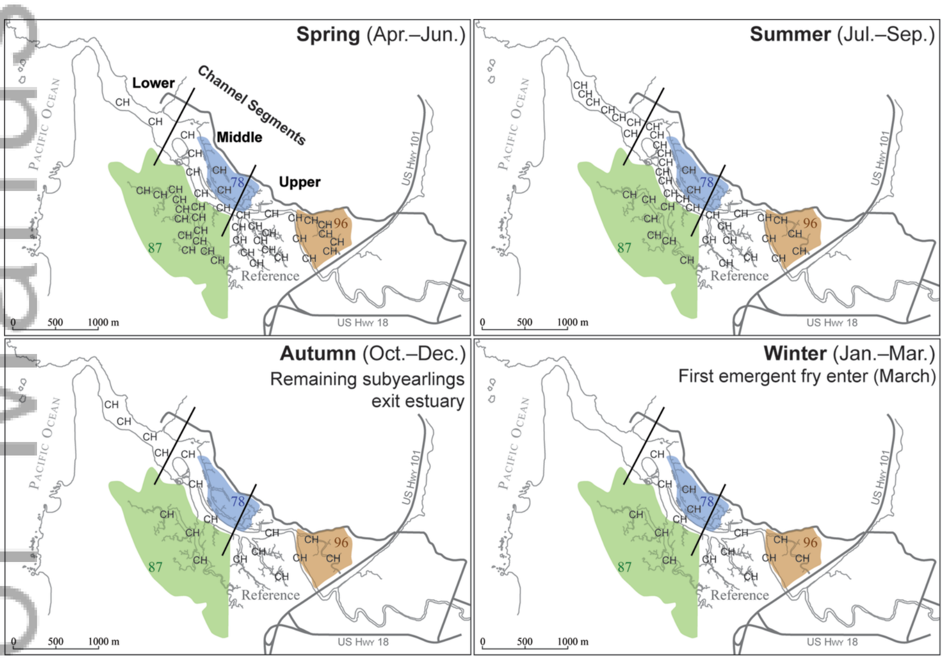

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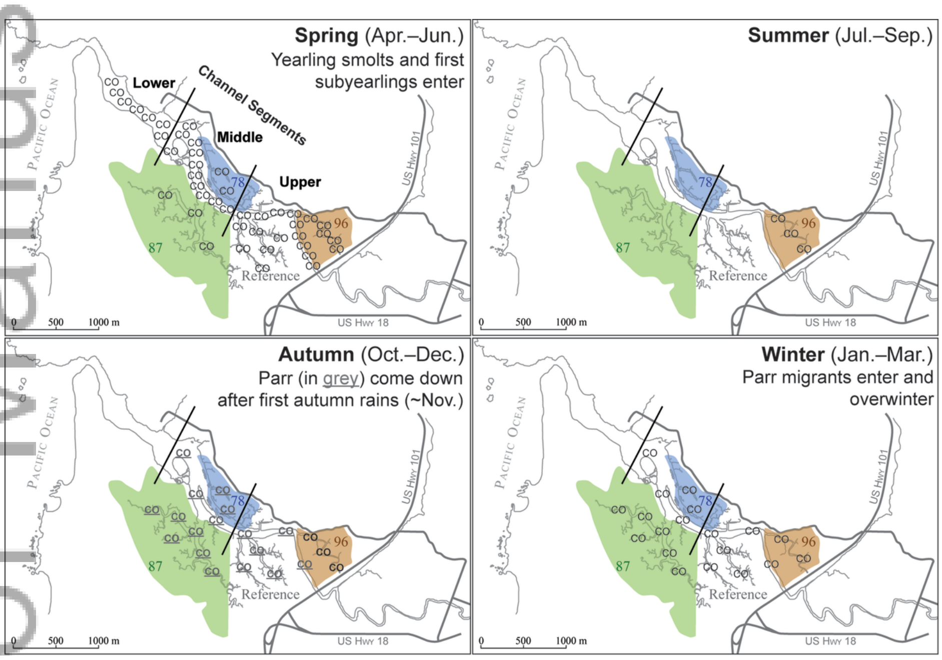

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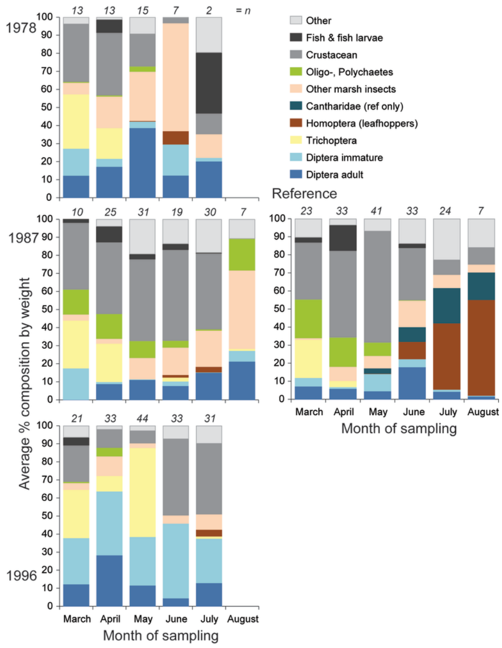

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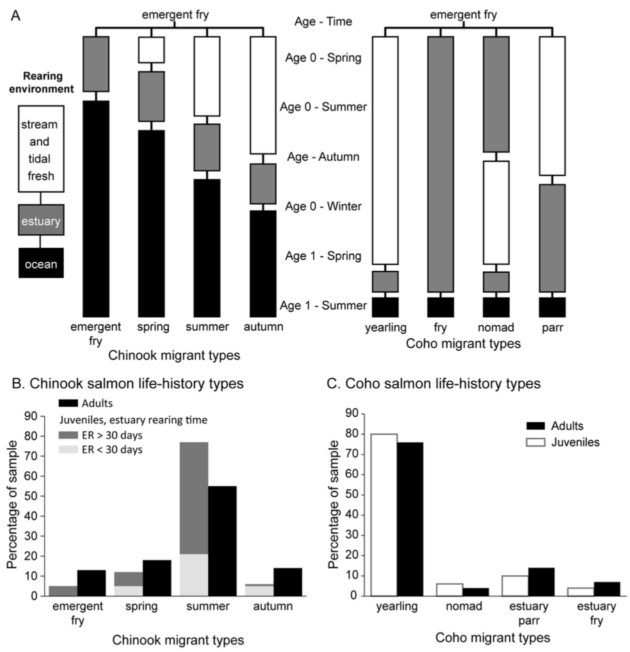

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