

SALMON AND ESTUARIES

The Salmon River Estuary, north of Lincoln City on the central Oregon coast, has been the site of intensive research focused on salmon use of estuaries.



Vital linkages learned at Salmon River

By Paul Hoobyar

Forty-five million years ago, when the Pacific Ocean lapped against the beaches of what is now western Idaho during the Eocene Period, the earliest ancestors of Pacific salmon swam in isolated lakes of British Columbia.¹ These early fish lived entirely in freshwater. However, their destiny was not to exist only in the protected waters of remote mountain lakes. Instead, the Pacific Northwest experienced catastrophic geological upheavals during the intervening eons and forced these fish and their progeny to develop the rich diversity that salmon exhibit today.

For instance, salmon persisted while the Oregon Coast Range, which originally hugged the Cascade Mountains to the east, shifted to the west and north to form what we describe today as the Oregon coast. Salmon ancestors

also exploited the Klamath Mountain Range, which originated as a volcanic archipelago offshore in the Pacific, as it merged with the continent. While other fish species succumbed to these cataclysms, salmon survived by adapting to local watersheds, migrating to the sea for much of their life cycle and finding alternatives when their natal streams were blocked by lava flows, volcanic eruptions, or earthquake-triggered landslides. All the while, salmon evolved into superb opportunists and survivors. Their ability to successfully adapt to adverse and changing conditions became mythical in many cultures and folklore.

Despite this history of success, salmon today are threatened by challenges unknown to their ancestors. Spawning and rearing habitats traditionally available to them, including estu-

aries and coastal wetlands, are being transformed rapidly by urban development and agriculture. According to the National Ocean Service, the United States has lost over 6 million acres of coastal wetlands since Europeans first settled here. In coastal states, about 55 million acres of tidal wetlands have been damaged or destroyed.² And in Pacific Northwest estuaries, from 50 to 90 percent of wetlands have been converted to commercial, agricultural, and residential uses.³ As human population grows in coastal areas, estuaries and coastal wetlands continue to be filled, dredged,



Tidegates, such as this, are historically one of the tools used to convert estuaries for agriculture. In Pacific Northwest estuaries, between 50 and 90 percent of wetlands have been converted to commercial and residential as well as agricultural uses.

drained, and developed. Hurricane Katrina and the Asian tsunami in 2004 gave lethal testimony to the consequences of destroying the ecological capacity of coastal estuaries and wetlands—the storms' impacts were exacerbated by losses of mangroves and wetlands that once functioned as natural buffers.

Yet, research into how healthy estuaries and watersheds function is still nascent. This is partly due to the perception that estuaries are simply marshlands of little benefit unless they are dredged or diked for more utilitarian uses. Partly, too, estuaries don't neatly fit the traditional research interests of oceanographers or river scientists. But neglect of estuaries also reflects a bias that technology is a panacea for many environmental challenges. In many ways, management of estuaries and salmon fisheries over the past 150 years provides a case study in the unintended consequences of an exuberant

reliance on technology to fix complex ecological problems.

An Agrarian Approach

One example of this reliance on a technology cure-all was our society's response to salmon harvest declines, which first became obvious in the Pacific Northwest in the late 1800s. At the time, managers believed these declines were the result of freshwater mortality in rivers and streams. The solution, they thought, lay in hatcheries. "Fish culturists," as they were called, reasoned that providing thousands of additional eggs hatched and protected through the early life stages of a young salmon's life would result in greater numbers of harvestable, returning adults. As a recent U.S. Department of Commerce technical report noted, managers borrowed this strategy from agricultural models.⁴ They buttressed the shortcomings of this approach by measuring outputs easily documented, such as pounds of salmon caught or numbers of days anglers fished, and ignored the underlying, and more complex, ecological processes less amenable to analysis and understanding.

Developing a more biologically based understanding of how watersheds function has been relegated to a footnote in the canon of American and European fisheries management, despite efforts by some to shed light on the fallibility of the underlying assumptions. As recently as the 1930s, fisheries scientists thought that salmon had no ability to home to their natal streams. These experts postulated that salmon wandered a mere 20 to 40 miles from the mouths of their natal streams and randomly selected streams for spawning.⁵ Behind these notions was a belief that all salmon are alike and that humans, using agrarian models and hatcheries, could replicate--or improve upon--nature.

However, a Stanford-educated biologist named Willis Rich established that salmon are organized into distinct populations. In a seminal paper in 1939 on the migratory habits of Pacific salmon, Rich documented their ability to return to their natal streams to spawn.⁶ He also described how each species of salmon comprises locally adapted, independent popula-

tions that are wholly reliant on the ecology and micro-climates of their natal watersheds.

Thus began a division in fisheries management that extends to the present day: on the one hand are fisheries managers who believe in a “production,” or a “sustained yield” approach to fisheries management. This school of thought views salmon primarily as a commodity with a management goal to achieve maximum production for commercial and recreational uses.

On the other hand are researchers and managers who adhere to what might be called a “population resilience” theory that views ecosystems as an integrated series of habitats that support locally adapted groups of fish, among other biological communities.

For population resilience adherents, such local adaptations are part of a fabric of complex ecological processes that ensure the survival of salmon in a dynamic, and constantly changing, landscape. These diverse, local adaptations allow salmon to survive despite varying climactic or marine conditions. While one local population may be hammered by a massive landslide or poor ocean conditions, other populations, which have adapted to a slightly different set of conditions or invoke a different strategy for survival, continue to thrive and, through straying into nearby watersheds, fill the void created by the previous loss.

Fortunately, our understanding of how different salmon species interact with the landscape also continues to evolve. Fisheries biologists have greater knowledge today of how salmon have adapted to a complex array of landscapes and ecological processes. Yet, while healthy river and terrestrial habitats are better known for their roles in supporting salmonid success, less is known about the role estuaries play in the life cycle of salmon.

Salmon River Estuary

Researchers continue to sleuth the secrets of how different ecosystems, including

estuaries, support the myriad strategies that salmon exhibit during their life. One study, in the Salmon River Estuary on the central Oregon coast, has provided a trove of new information about how estuaries create shelter, forage, and rearing habitats for juvenile salmon as they migrate to sea.

This research has generated a new understanding of estuaries and their contribution to watershed and salmonid resilience.

Today, the Salmon River Estuary is part of a unique designation--the Cascade Head Scenic Research Area. This is the *only* Scenic Research site in the United States. Created by an Act of Congress, the area is protected for many purposes, including the scenic qualities of the headland. In the Estuarine and Associated Wetlands Zone, the area is protected for sport fishing, waterfowl hunting, and salt marsh restoration. Recognizing that marsh restoration involves research, the Act included research as an important use for the scenic-research area.

In the early 1960s, however, before Congress acted, farmers diked the Salmon River Estuary for agriculture—as had been done in

Local salmon adaptations are part of a fabric of complex ecological processes that ensure their survival.



Willis Rich, pioneering salmon researcher



Tidegate removal on Salmon River.

many other estuaries on the West Coast. The dikes restricted the flow of seawater across the estuary and allowed farmers to grow hay or create pastures for cows grazing on the converted wetlands. Once the estuary became part

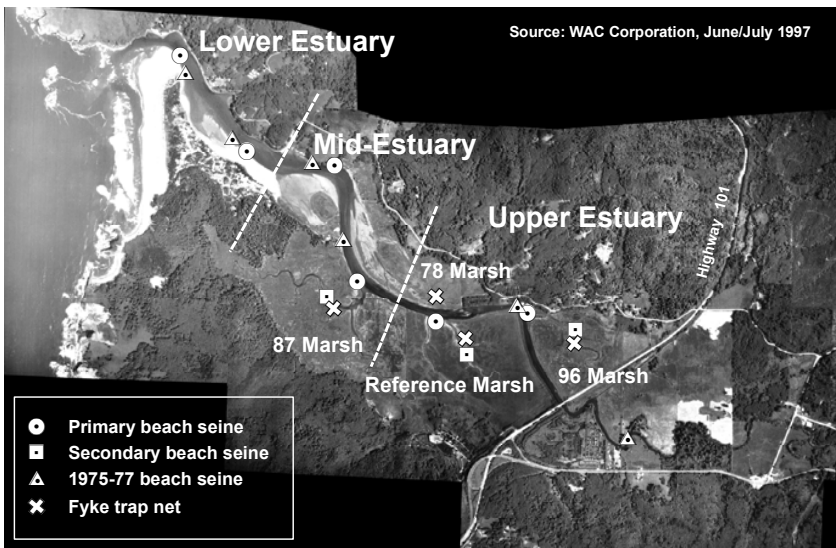
the river basin.

Head Start Programs for Salmon

We now know that healthy tidal estuaries act as nurseries for juvenile salmon by providing shelter,

abundant food, and a mix of sea and freshwater that affords these fish a place to gradually transition from rivers and lakes to the ocean. Tidal wetlands are composed of a network of small, narrow, complex channels that provide shelter from predators, as the channels are too shallow for larger fish, and the thick overhanging vegetation offers shelter from birds and other predators. In naturally functioning wetlands, these channels act like arteries and capillaries for the landscape, with smaller, shallower channels rendering

shelter for smaller fry, and larger channels providing habitats and forage for larger juveniles.



Dike removal in 1978, 1987, and 1996 provided an ideal opportunity to study marsh restoration on the Salmon River.

of the Scenic Research Area, the Forest Service, which manages the area, began removing the dikes. Through happenstance, one dike was removed every nine years over a two-decade period. The three undiked tidal wetlands, each in varying states of transition, created a prime opportunity to study how native plants help tidal wetlands function, the ways that juvenile salmon use these habitats during their migration to the sea, and how rapidly restoration proceeds.

Researchers at the United States Forest Service's Pacific Northwest Research Station and Oregon State University recognized the unique opportunity the Salmon River Estuary afforded and contacted Dan Bottom, a fisheries biologist who had been researching salmonid use of estuaries. Bottom, who works for the National Marine Fisheries Service, and a team of colleagues saw the Salmon River Estuary as an ideal outdoor laboratory for testing two hypotheses: (1) that once tidal dikes are removed, estuary wetlands will gradually restore themselves toward highly functioning (or reference) conditions; and (2) that removal of tidal dikes and redevelopment of marshes create new habitat opportunities for young salmon to rear within the estuarine portion of



A 1997 aerial photograph of the estuary and marshes shows the major side-channels.

Healthy tidal wetlands are also highly productive areas with abundant prey for young salmon. Juveniles can feast on the insects, small crustaceans, and other food sources that abound in these habitats.

Having an “all-you-can-eat buffet” at this stage of their lives is important for young salmon, as research shows that adding weight and size before they enter the sea directly improves their chances of survival in the ocean. In addition, the continual mixing of fresh and salt water in estuaries offers young salmon a place to gradually acclimatize and adapt to the demands inherent in switching their biological and metabolic engines from a life immersed in freshwater to one immersed in the sea—a transition that some fisheries biologists liken to undergoing chemotherapy. And new research suggests that the ocean’s ebb and flow in and out of estuaries helps these young fish become attuned to the cycles and currents of the sea, as well as



Plant species diversity decreased but above-ground productivity increased in the restoring marshes.

imprints the scent of their natal streams, which is crucial to their homing success as adults.

Because the Salmon River tidal dikes were removed in approximately nine-year intervals, the research team could track the progression of plant species on the wetlands and compare these changes, along with changes to channel structure, to a nearby wetland that had never been diked in the Salmon River (known as the “reference” marsh). The reference site retained its native plant species and composition, as well

as the shape of the creek channels, since cattle grazing and other practices had not damaged it. In addition, they could see how juvenile salmon used these wetlands at varying stages of transition after dike removal and the beginning of marsh recovery.

Key Findings

The results of the team’s research, after eight years of investigation, have supported or confirmed both of their original hypotheses.

First, the plant communities on the three wetlands have been undergoing recovery. While variations occurred at each site due to hydrologic and other factors, salmon have derived immediate benefits at all three sites from having regained access to these wetland habitats and prey resources.

Robert Frenkel, an OSU professor of Geosciences who has been studying the Salmon River marshes for three decades, has observed certain shared features of their recovery:

- All have become completely revegetated with *Carex lyngbyei* (a low marsh species only observed in the reference marsh at creek margins).
- A convergence toward a low *Carex* marsh followed a different trajectory in each marsh but took from five to seven years to develop.
- Plant species diversity decreased but above-ground productivity increased

Although the *Carex* grass is present in the reference marshes as in the recovering marshes, Frenkel argues that recovery of the undiked

marshes to original high marsh structure and composition is unlikely in the short run. This is largely due to an elevation loss in the diked marshes on the order of one foot. A diked marsh rapidly subsides due to dewatering, compression, and loss of organic matter resulting in increased soil bulk density. Most of these properties are slow to recover.

The team’s second hypothesis was difficult to prove, partly because the strategies that Chi-

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nook salmon, in particular, exhibited in the estuary were affected by the introduction of hatchery fish from a brood stock that originated in another river—possibly introducing other life-history strategies adapted to different watersheds. However, the research team, led by Dan Bottom, Kim Jones of the Oregon Department of Fish and Wildlife, and Charles “Si” Simenstad of University of Washington, benefited from studies done by Oregon’s fisheries agency in the mid-1970s. Those studies provided basic life history information to help design the



Using a portfolio of habitats in opportunistic ways is encoded in the DNA of salmon.

hatchery program on the Salmon River.

The researchers documented how young Chinook salmon, which have the most diverse estuarine usage patterns of all the salmon species, displayed a variety of timing and use patterns in the three wetlands. Some fish came directly from their spawning redds as very small fry and stayed in the estuary for weeks or months. Other salmon stayed in the freshwater upriver for weeks or months before coming to the estuary as larger fish.

Overall, the research team noted greater use of the estuary by salmon than occurred prior to dike removal, when little peripheral wetland habitat was accessible and dikes confined the estuary into a single-channel conduit to the sea. In addition, access to productive wetland habitats provided new rearing opportunities for the smallest salmon, as expressed by an earlier time of entry into the estuary, and also expanded periods of estuarine residency within the Salmon River populations.

The researchers found that the salmon life histories displayed in the estuary are linked to where the fry originate in the basin. For in-

stance, most of the smaller fry in the estuary originate from lower-river spawning redds and enter the estuary soon after emergence. On the other hand, most upriver fish show up as larger juveniles. The researchers documented that these upriver fish generally spend more time in freshwater before they migrate to the estuary. This kind of diverse timing makes sense for a species that has evolved by distributing risk among a variety of changing, dynamic, and at times unstable conditions.

Successful Salmon Strategies

If, for instance, a river becomes lethal to salmon as a result of drought, the low stream flows impede migration and raise stream temperatures above what salmon can tolerate. Consequently, fish that emerge and migrate rapidly to the estuary may survive while their siblings that stay upriver expire. Conversely, if the estuary and ocean conditions are poor, fry that stay upriver longer have a better chance of surviving, since they appear in the estuary as larger fish, sometimes after months of freshwater rearing, and their additional size and maturation can aid in their survival. This hedging and distributing of risk to a number of life history strategies has been a key factor in the success of salmon over the millennia.

The Salmon River research team has shown that all of these diverse life history strategies contribute to the adult returns in the Salmon River. They plan to continue monitoring the spawning populations to assess the contribution of different life history strategies from year to year.

This will also give them the opportunity to test their hypothesis that the relative contributions of different life history strategies will vary with changes in environmental conditions, and thereby afford greater resilience to the population as a whole.

The team’s research shows that these recovering habitats have allowed for a fuller expression of the life history diversity of salmon. That is, the new habitat opportunities created by restoring tidal wetlands have expanded the range of rearing and migration behaviors exhibited by the Salmon River population, including juveniles that now enter the estuary early in the spring and migrate to sea over a wider range of sizes and times.

The successful strategies that Pacific salmon have evolved in order to circumscribe the Pacific Ocean have been partly due to the role of estuaries as pre-schools which proffer the necessary habitat types, food, and blending of sea and freshwater. Salmon make use of a portfolio of habitat types at different stages of their lives--freshwater streams for spawning and rearing, estuaries for rearing and smolting, and the ocean for the majority of their adult lives to prey on the abundant marine species. And estuaries are the staging areas for their transition from freshwater to the oceans.

Using this portfolio of habitats in opportunistic ways is encoded in the DNA of salmon



Restoring highly disturbed habitats results in a fuller expression of salmon life histories.

and displayed in each locally adapted population. The result has been that salmon have thrived over the eons in a dynamic, uncertain, and continually changing stew of climates and landscapes. Beneficiaries include a host of other species, including orca, seals, humans, and scores of other mammals and insects, that have co-evolved and targeted salmon as a food source throughout the ages.

Viewing salmon through a “population resilience” perspective acknowledges our inability to fathom, or engineer, the complexity and diversity of these creatures and the symbiotic life history strategies they have developed with local watersheds. Possibly the best help that we can provide to sustain salmon into an unknowable future is to not assume that we can enhance their chances of survival by raising them in concrete raceways and releasing them into streams and rivers that have been altered to suit

our economic and social plans. Instead, we may have more success in sustaining salmon into the future by managing that portfolio of habitat opportunities, including estuaries, that will allow salmon to realize their full potential for life-history expression.

Partnerships

The Salmon River Estuary project is notable for one other reason: the long-term partnership that has developed between the Forest Service and the Sea Grant program at Oregon State University. Sea Grant, despite its relatively small size and budget, has been the prime funder of this project during its eight-year tenure. Approximately 90 percent of Sea Grant’s funds for watershed research have been dedicated to the Salmon River Estuary project since it began. When asked why Sea Grant has made such a commitment to one project, Director Bob Malouf noted that, despite the billions of dollars spent in the Pacific Northwest for salmon restoration, very few other funders were supporting any research in estuaries and their role in salmon recovery.

Malouf, a biologist himself, also noted the unique opportunity the Salmon River Estuary provided for research, given the nine-year intervals between dike removals. Malouf thinks the significance of the Salmon River Estuary research may lie in how it conclusively shows that restoring highly disturbed habitats results in a fuller expression of salmon life histories, and that this understanding may prove to be more important to the success of salmon restoration in the future than the total numbers of fish that return in any given year.

Likewise, the Forest Service has benefited from the team’s research and the partnership with Sea Grant. The Act that created the Cascade Head Scenic Research Area gave the U.S. Forest Service broad powers to restore the estuary to its natural condition, and the team’s re-

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search has helped the Forest Service make progress toward that goal, while supporting a better understanding of the ecology of tidal wetlands in general and the Salmon River Estuary in particular.

The Salmon River team* of researchers are contributing to a road map for how society might set priorities for restoration efforts in the future and what relative priority estuaries should receive in future watershed restoration efforts. The team's research underscores a growing awareness that estuaries are one important environment in a tapestry of connected environments that includes rivers, estuaries, and the ocean. All of these environments are critical to the complex, diverse, and resilient fabric that

has sustained salmon and will continue sustaining them into the future. It is the integrity of this tapestry that must be maintained if salmon are to persist long into the future. ♦

*Team included: Dan Bottom, Paul Moran, David Teel (NOAA Fisheries); Kanani Bowden, Lisa Borgerson, Trevan Cornwell, Kim Jones, (Oregon Department of Fish and Wildlife); Alisa Bieber, Ayesha Gray, Si Simenstad (University of Washington); Lance Campbell, Bob Frenkel, Dave Hering, Lisa Krentz, Jen Taylor (OSU); Eric Volk (Washington Department of Fish and Wildlife). Pictured below are some of these team members celebrating the end of another field season with Salmon River community friends.

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¹ Lichatowich, Jim. 1999. *Salmon Without Rivers*. Washington, D.C.: Island Press. p. 11.

² NOAA's National Ocean Service Office of Coastal Resources Management:
<http://living-edge.org/ccc/conservation/welcome.html>

³ State of the Environment Report, Science Panel. 2000. *The Oregon State of the Environment Report 2000*. Salem, OR: Oregon Progress Board. 214 pp.

⁴ Bottom, Simenstad, et al. 2005. *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon*. U.S. Dept. of Commerce. p. 22.

⁵ Ricker, W. 1972. "Hereditary and Environmental Factors Affecting Certain Salmonid Populations." In *The Stock Concept of Pacific Salmon*, H. R. MacMillan Lectures in Fisheries, edited by Simon and Larkin. Seattle: U.S. Bureau of Fisheries.

⁶ Rich, W. H., 1939. "Local Populations and Migration in Relation to the Conservation of Pacific Salmon in the Western States and Alaska," in *The Migration and Conservation of Salmon*, publication no. 8, American Association for the Advancement of Science.

Postscript:

Some online resources about the Salmon River Estuary and salmon resilience

Oregon Sea Grant: Resilience and salmon
<http://seagrants.oregonstate.edu/themes/resilience/>

U.S. Forest Service:
Cascade Head and Salmon River
<http://www.fsl.orst.edu/chef/about2nd.htm>

NOAA Fisheries: Estuarine Ecology
<http://www.nwfsc.noaa.gov/research/>

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Pathways to Resilience: Sustaining Pacific Salmon in a Changing World

In April, 2007, Oregon Sea Grant hosted an interdisciplinary forum to explore the concept of resilience and its application to ecosystem management in general and salmon recovery in particular. This page takes off from where that conference wound up.

The intent of the conference was to bridge traditional boundaries between the natural and social sciences and to broaden the discussion among scientists, resource managers, practitioners, and policy makers.

Conference participants considered both the attributes of resilient ecosystems in which salmon populations thrive and the implications for developing alternative approaches to conservation.

Interest in continuing the dialog and reflections, begun so well at the Portland conference, is high, and this page will serve as a gateway to additional information on the topic of resilience, both from the conference and as it emerges.

What's new?

[Start video interviews](#) with key conference participants on elements of resilience.



Keynote address: Imagining a different world built with different tools, former Governor John Kitzhaber, M.D.
[.pdf][HTML]

Cascade Head Experimental Forest and Scenic Research Area

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ENVIRONS

Introduction: Cascade Head Experimental Forest and Scenic Research Area (Cascade Head) is located on the north-central Oregon coast (8m (5 mi) north of Lincoln City, in Lincoln and Tillamook counties). It lies entirely within the Hebo Ranger District of the Siuslaw National Forest, though there are private lands included within the Scenic Research Area. The area is dominated by the large headland, Cascade Head, which juts into the Pacific Ocean just north of the Salmon River. US Highway 101 bisects the area in a north-south direction.

Site Description: Located at 45.2 degrees north latitude and 123.58 degrees west longitude, Cascade Head is in the Oregon Coast Range ecoregion and lies within the Salmon River and Neskeon Creek drainages. The Salmon River drains to the south of the experimental forest and its estuary is included in the scenic research area. One upper tributary and most of Neskeon Creek lies within the experimental forest. Elevation ranges from sea level to approximately 530 m (1750').

The forests are fairly representative of the Sitka spruce-western hemlock and Douglas-fir zones of the Oregon Coast Range. The headlands and ocean front areas are mostly basalt. Soils, derived primarily from tuffaceous strata, are fine textured, moderately well drained, and very deep (up to 100+ cm). Soils under forest stands are fertile, rich in organic matter, and contain high levels of nitrogen. Sediments in the estuary reveal surfaces buried from previous earthquakes, the last one occurring about 350 year ago.

Because of the Pacific Ocean influence, Cascade Head has a moderate



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Estuarine and Ocean Ecology Program

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Ecosystem Indicators of Salmonid Ocean Survival
[Estuarine Ecology](#)
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The Estuarine and Ocean Ecology (EOE) Program researches links between natural fluctuations in climate and estuarine and oceanic processes that affect distribution, abundance, growth, and survival of anadromous and marine fishes in Pacific Northwest coastal estuaries and marine waters. The abundance of many coastal fishes is related to variations in climate conditions, but this relationship is poorly understood. By focusing on ecosystem studies, researchers are able to examine the causal connections among components of the ecosystem (habitat characteristics, climate-driven estuary and ocean conditions, plankton production, and fish community structure). Through these studies, researchers expect to gain better understanding of the control of coastal resource production, make better predictions of resource status, and better assess the effects of human management on these systems.

The EOE Program is focused primarily in two areas.

1. Understanding the nearshore ocean ecology of Pacific salmon. Researchers are evaluating the role of the Columbia River plume as an important transition habitat for juvenile salmon and the impact of the California Current on abundance, distribution, growth, and survival of juvenile salmon in coastal waters of southern Oregon and northern California.
2. Studying the estuarine ecology of juvenile salmon. This project area evaluates habitat links in the Columbia River and Puget Sound estuarine ecosystem and ascertains the benefits of habitat restoration to salmon recovery in the Salmon River estuary along the central Oregon coast.

