Salmon Abundance and Diversity in Oregon

Are We Making Progress?

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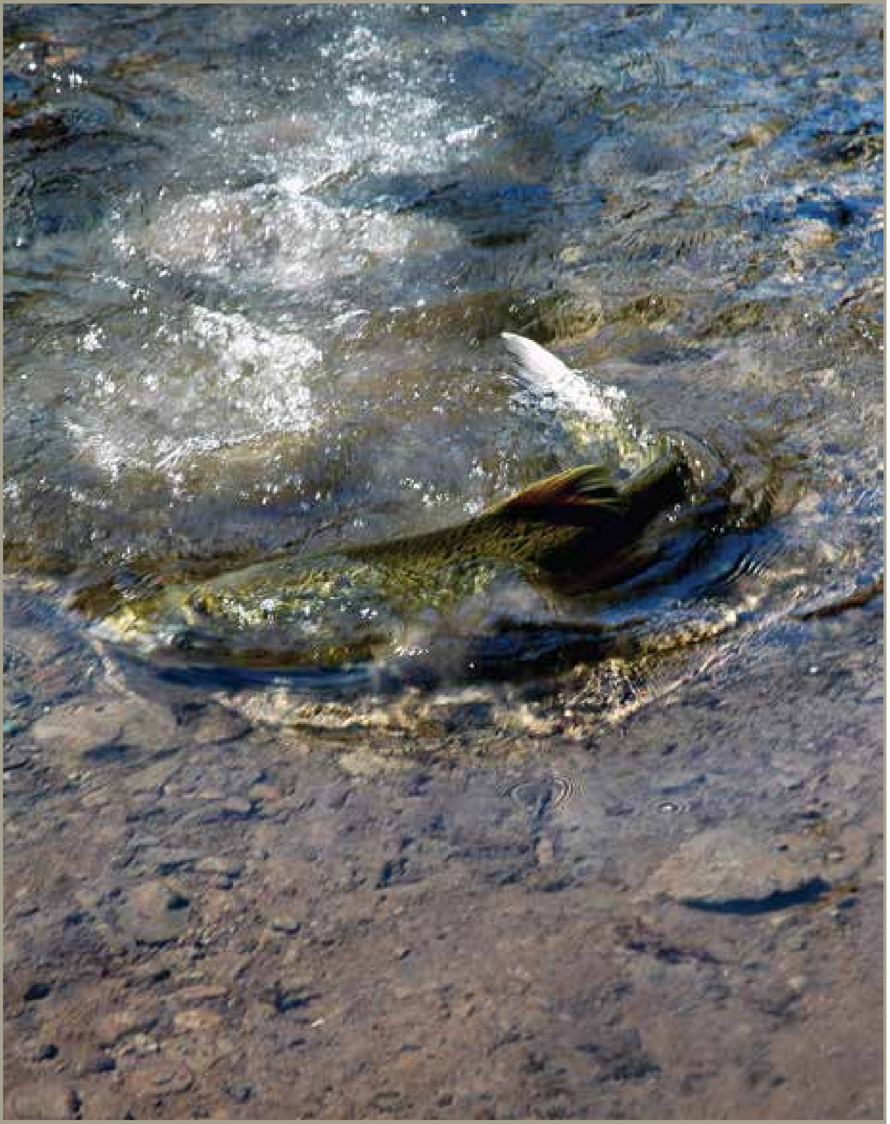

Sea Grant
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Cover photo of spawning salmon by Courtland L. Smith.

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Reviews of this manuscript by Daniel Bottom, Joseph S. Cone, Rick Cooper, Michael J. Ford, and Greg Ruggerone provided extensive help in shaping and improving the presentation. Greg Ruggerone was especially helpful in the production of Figure 2. None of the reviewers fully accepts or agrees with the ideas presented. All have offered helpful counsel and provided additional insights.

The drafting of this manuscript was stimulated by Bruce Rieman et al. (in press). This publication's goal is to explain changes in historical abundance and the importance of diversity to salmon restoration activities and is designed for a general audience. I am responsible for the ideas and any misstatements expressed here. Salmon abundance and diversity is a very controversial topic on which many fishery biologists and ecological scientists disagree. As an anthropologist, my main interest is the relationship between salmon and cultures that depend upon them.

Courtland L. Smith

Salmon Abundance and Diversity In Oregon

Are We Making Progress?

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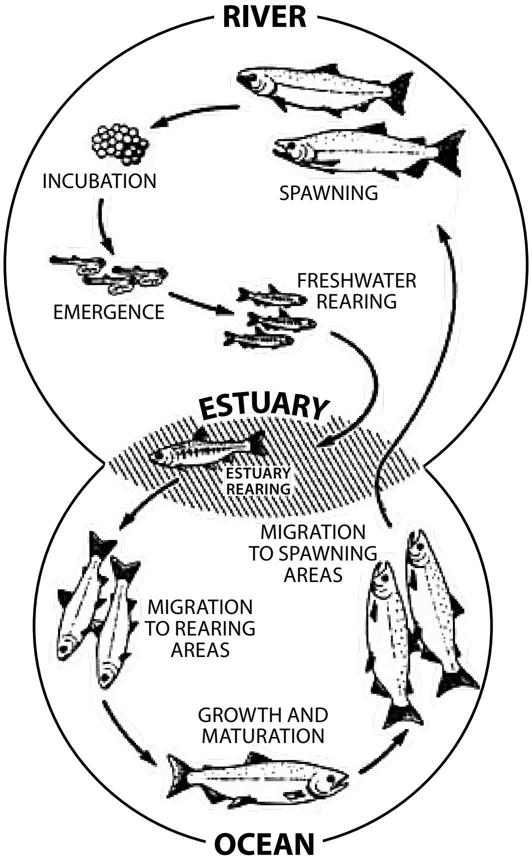
Salmon Abundance and Diversity

"Salmon have moved from the sports page to the front page," was a common comment by Jim Martin in the 1990s. Martin was an advisor to Governor Kitzhaber about *The Oregon Plan for Salmon and Watersheds*, and he knew about salmon as former Director of Fisheries for the Oregon Department of Fish and Wildlife. His comment reflects a change in the significance of salmon to people in Oregon. Being on the front page means greater engagement by Oregonians in salmon and steelhead trout issues. Salmon are seen as important culturally and as an indicator of regional ecological health. Media coverage has varied from questions about the amount spent and the results achieved to reports of record runs passing Bonneville Dam. To know the status of salmon and how their situation has changed, comparing past with present is helpful. Too often, however, emphasis has been only on comparing salmon abundance, not the diversity of runs or habitats used by salmon.

How is the question, "Are salmon populations in Oregon improving" answered? National Oceanic and Atmospheric Administration reviews from the early 1990s to the first decade of the 21st century conclude that most of the threatened and endangered salmon populations under their review show no overall trend (Ford 2011, Stout et al. 2012). In one sense, this is good news. Expenditure of large amounts of effort and money by the Oregon Watershed Enhancement Board; by landowners; local, state, and federal governments; and by nongovernmental organizations appears to have stopped the downward trend. The downward trend began after World War I, when all species of salmon were overfished and extensive modification of the Northwest landscape accelerated with the introduction of steam power in railroads for timber harvest and the gasoline engine for fishing vessels. A century-and-a-half of historical data shows that the decline in salmon populations hit bottom in the mid-1990s.

Because of natural and economic variability, the general pattern of salmon harvests and escapements is highly variable. Trends are difficult to decipher and depend on the time period selected. Most often, salmon and steelhead abundance attracts the most attention; yet for the future, diversity between and within salmon populations may become more important as climate conditions change, new species enter the region, and economic change alters the relationship salmon have with local cultures.

In changing environments and economies, diversity is important because it provides many different ways that populations can adapt (McElhany et al. 2000). First, diversity allows salmon populations to use a greater variety of spawning habitats and have different life histories. Salmon life-history diversity is the multitude of life-history pathways (how the fish move in space and time through streams, estuaries, and ocean habitats). The pathways allow salmon to complete their life cycles. Second, life-history diversity protects salmon populations against short-term environmental changes. Having salmon populations with many different life



Salmon begin their lives in rivers, grow and adjust to saltwater in estuaries, reach full size in the ocean, and return to rivers to spawn. (Graphic courtesy of OSU Extension.)

histories allows more options for survival and reproduction in the face of environmental change. Diversity has the effect of spreading risk between populations and protecting against poor environmental conditions or catastrophic losses. Thus, diversity maintains abundance and promotes stability. Third, genetic diversity provides the raw material for surviving long-term environmental changes. Genetic diversity enables adaptation to natural and human environmental changes. Salmon have experienced substantial environmental change during the five million years they have existed in the Pacific Northwest (Pearcy 1992:6).

Losses appear to have stabilized, with salmon abundance at an average well below what is estimated to have existed before World War I.

Nineteenth-century declines in salmon abundance led to the introduction of agricultural techniques to produce salmon. Hatcheries reduce early life-cycle losses by releasing many more and often larger juvenile fish to graze and grow in riverine, estuarine, and marine waters. Actual salmon farming, where the entire production process is controlled in net pens, is not allowed by Oregon law. Instead, hatcheries have been a major tool for maintaining abundance. Hatchery and farmed production of salmon have the effect of reducing diversity in favor of maximizing abundance.

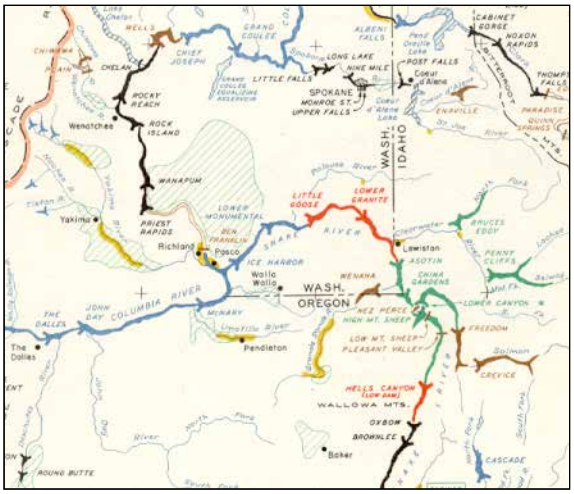
The salmon life cycle adapts to three major ecosystems: streams, estuaries, and the ocean. The anadromous life cycle of spawning and rearing in freshwater but migrating through estuaries to the ocean for adulthood provides the opportunity to use each of these ecosystems differently. Life history and genetic variability allow for adapting to different ocean currents and productivity; variable climate patterns affecting rainfall and temperature; estuarine habitat changes; catastrophic events such as landslides, floods, and fire; and land modifications and uses adjacent to estuaries and streams. About the year 1440, the Columbia River was completely blocked at the Cascades of the Columbia, near where Bonneville Dam is now (O'Connor and Burns 2009:246). For an unknown number of years, salmon did not rise into the upper Columbia, but they were not blocked in other areas and, ultimately, large populations were reestablished in the basin. When explorers entered the region in the early 19th century, they reported abundant runs of salmon.

Columbia River Salmon Abundance

Historical analysis (NPCC 1986) has shown that salmon abundance in the Columbia Basin prior to the 20th century might have been 10 to 16 million adult fish before significant commercial harvest started in the 1860s. An analysis by Chapman (1986) sets the figure at 7.5–8.9 million adult salmon returning annually.

Determining salmon abundance is complex because of the wide range of factors affecting it: ocean conditions, riverine and terrestrial habitat quality, the geographic distribution of harvest areas, condition of predators, impact of diseases, and the fragmented structure of the current habitats available. General patterns for the Columbia Basin and Oregon coastal basins help show changes that have taken place regarding salmon abundance.

Figure 1 shows Columbia River salmon abundance since commercial fishing began in the 1860s. The data for this figure are synthesized from many sources. In the early years, harvest data were converted into pounds of fish. Data through the 1930s come from a very detailed and classic study by Craig and Hacker (1940) using this method. Subsequently, data were developed by the Oregon and Washington Departments of Fish and Wildlife. More recent data also come from NOAA, the Pacific Fishery Management Council, and the Pacific Salmon Commission. Since the study of Columbia River abundance by Craig and Hacker (1940), the commercial harvest graph



Dams proposed for the Columbia and Snake Rivers on the left of the map were built. Not built were dams proposed for the Snake above Lewiston (south to Oxbow), the Salmon River in Idaho, and northeastern Oregon. (Clipped from Bessey 1943:Folio.)

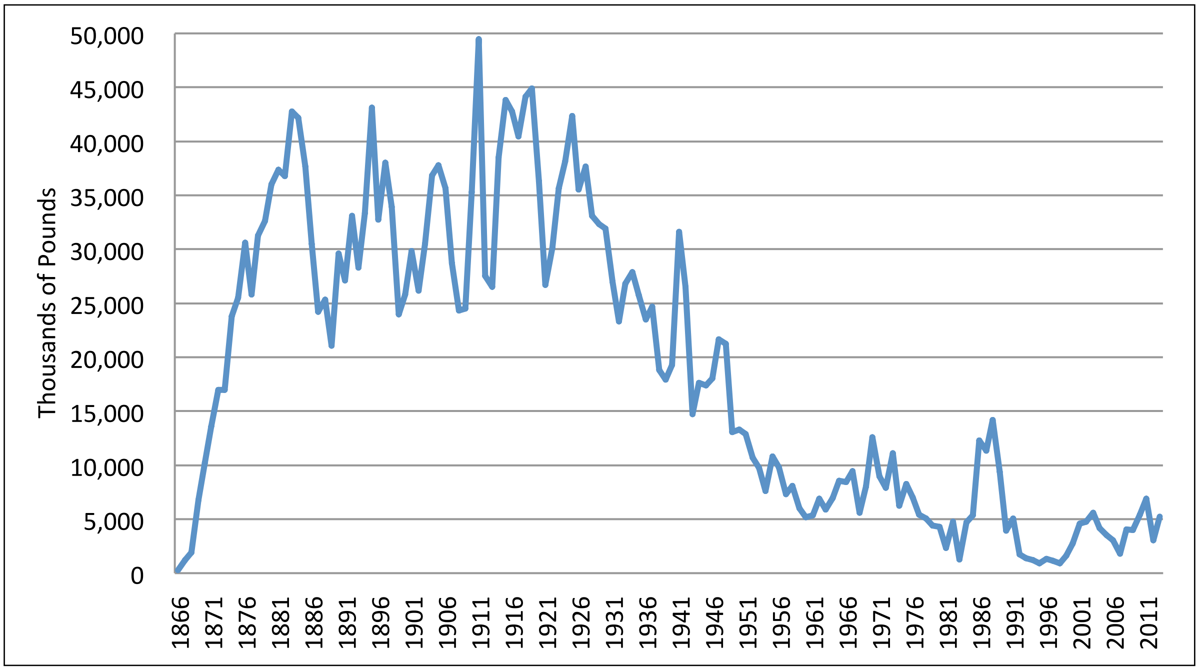


Figure 1. Columbia River commercial harvest, 1866–2013. Sum of catch statistics for all species of salmon with Columbia basin origins. Catch includes ocean and river commercial harvest, river and ocean recreational catches. Ocean fishing started near the mouth of the Columbia in the early 20th century and expanded to Canada and southeast Alaska. (Sources: 1866–1936, Craig and Hacker [1940]; 1938–1970, Cleaver [1951]; 1970–2013, Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife.)

(Figure 1) has been used to represent salmon abundance (Oregon Department of Fisheries and Wildlife 2002, RIST 2009).

In Figure 1, note the jagged curve. Large, year-to-year variation is common through the late 1940s. This variation came from both natural and economic factors. Overall harvest ranges from almost 50 million pounds to as low as 1 million. After 1866, reliance on the summer and spring Chinook runs expanded to early spring and fall Chinook, coho, sockeye, chum, and steelhead trout. After World War I, salmon abundance dropped from an average of more than 30 million pounds to less than 10 million pounds per year from the mid-1950s to the late 1980s.

One solution for the lost abundance was hatchery technology. The first hatcheries came into use in Oregon in 1877. By the early 1900s, hatcheries were in regular use. Hatchery managers believed they could not only restore salmon abundance but also increase it over what it had been historically (Smith 1979). With the building of main-stem dams on the Columbia beginning in the early 20th century and ending in the 1970s, hatcheries were the tool used to replace salmon abundance reduced by the dams. By 2013, an estimated 80 percent of the returning Columbia Basin adult salmon were born in hatcheries (ISAB 2013-1:26).

More than 200 hatcheries release a total of 130–150 million juvenile salmon and steelhead to the Columbia River annually (ISAB 2013-1:23). Until the 1970s, the general idea was that a greater release of hatchery fish could increase salmon harvests. When this was not the result, greater attention was paid to carrying capacity and food webs (Beamish et al. 1997, Ruggerone et al. 2010, Naiman et al. 2012). In the 1980s, policies began to question hatchery production because it competed with wild fish, was expensive, and raised questions about long-term viability of hatchery stocks (RIST 2009, ODFW 2014). The mental construct of hatchery additions for commercial and recreational harvest employs a farming metaphor. A hatchery reduces the high level of early life-cycle mortality in an effort to create greater abundance.

Figure 2a shows that since the early 1900s, as hatchery releases have increased for Columbia River Chinook, harvests have actually gone down. Still, hatchery-bred fish make up the largest proportion of the Columbia River salmon harvests.

Figure 2b covers Columbia River abundance since 1938, when counts at Bonneville Dam started. Overall, the sum of harvest plus escapement has not changed much during this time period (graph b, bottom) and is

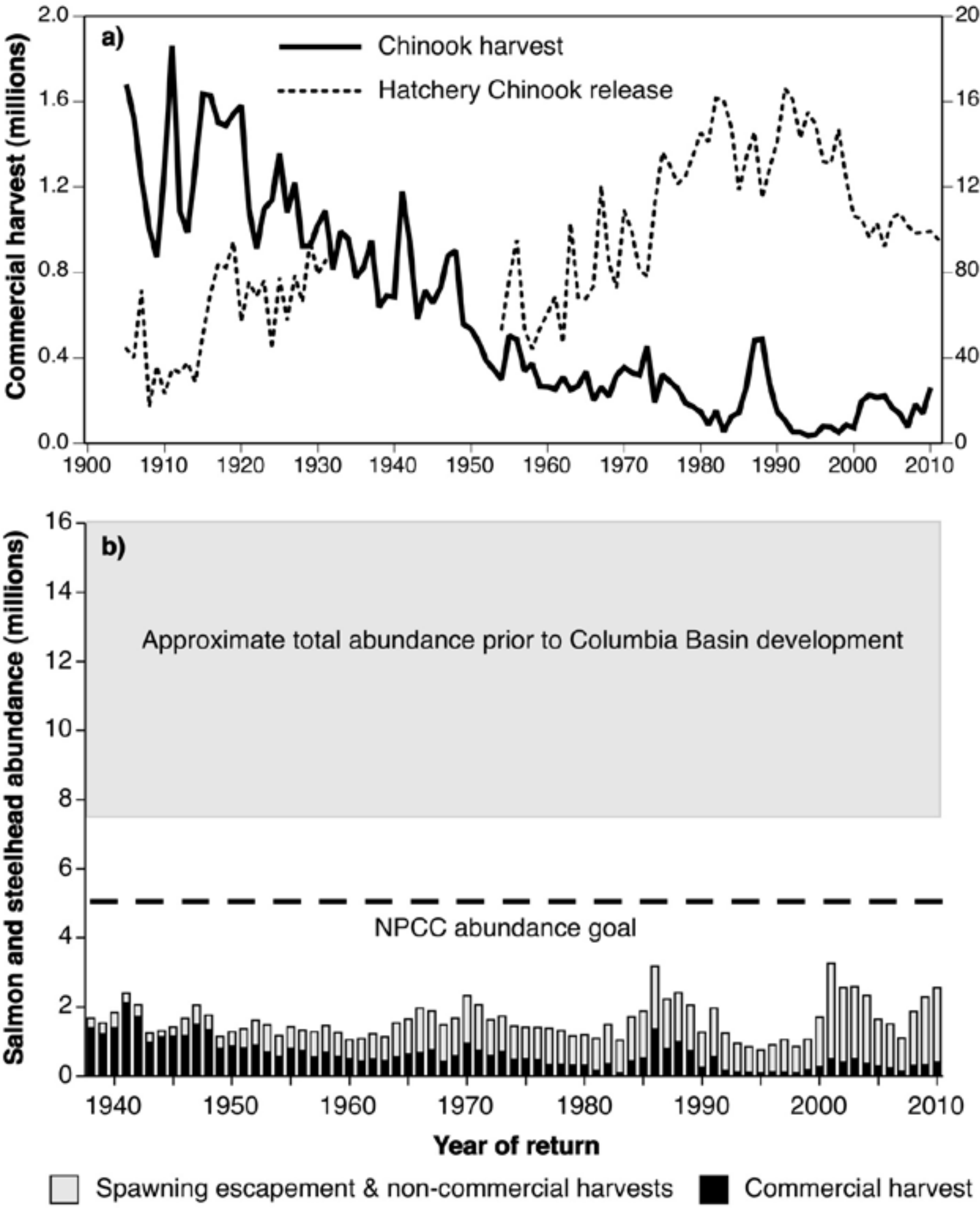


Figure 2. Abundance of Columbia River commercial harvests and spawning escapement. Panel a) shows the estimated Columbia River commercial harvests and hatchery releases of Chinook salmon since 1905. Hatchery numbers are shown three years post-release to approximate the year of return. Panel b) shows annual adult returns to the river and commercial harvest of all salmon and steelhead since 1938 after building the first dams. Noncommercial harvests were not consistently estimated in the early years and are included in escapements. (Prepared by Greg Ruggerone. Primary data sources: Cobb 1930, Chapman 1986, Mahnken et al. 1998, ODFW and WDFW 2002.)

well below pre-commercial estimates and the NPCC goal of 5 million fish. A low point in the sum of the harvest plus escapement was reached in 1995. Figure 2 shows the ratio of harvest (dark portion of bars) to escapement (light portion of bars). Harvest has declined from 80 to 90 percent of the total harvest plus escapement in the 1940s to less than 15 percent in the first decade of the 21st century.

Losses appear to have stabilized, with salmon abundance at an average well below what is estimated to have existed before World War I. Coinciding with the loss of abundance has been an even greater loss of diversity. Habitats are controlled for human activities in forestry, agriculture, and urban development.

The 2014 Northwest Power and Conservation Council goal is total returns averaging 5 million salmon and steelhead by 2025, based on an approximate doubling of peak post-dam abundance and the desire to support increased tribal and nontribal harvests, including ocean fisheries (NPCC 1986, 2009). The goal does not distinguish between hatchery and wild fish. Associated with the goal are statements about making habitat improvements, avoiding adverse impacts on native fish, restoring natural reproducing and sustainable populations, and delisting ESA-listed populations and preventing additional listings.

Oregon Coastal Abundance

Compared to the Columbia River, few dams block Oregon coastal streams, and there is less involvement with hatcheries. Beginning in the early 1990s, coastal harvests have been cut back significantly. Compared with historical experience, the abundance of Oregon coastal salmon bears a pattern similar to that of the Columbia Basin.

Figure 3 shows recruit and spawner patterns very similar to those of the Columbia. There is high variability and a general pattern of decline in abundance. Recruits are the total spawners that would have returned to spawn in a year if there had been no harvest. Recruits are a measure of the total run size. Spawners are those who return to produce the next generation. Up to 1960, the recruit and spawner patterns are quite similar. From 1960 to 1977, the number of recruits is much greater than the number of spawners. Further, from 1960 to 1977, the number of recruits was high relative to the post-1977 period, but still well below historic levels.

Figure 3 is produced by Stout et al. (2012). The early data are from Mullen (1981:2–6), who made estimates from cannery records for 1892–1922. These records did not separate harvest by species, nor did they include other modes of sale.

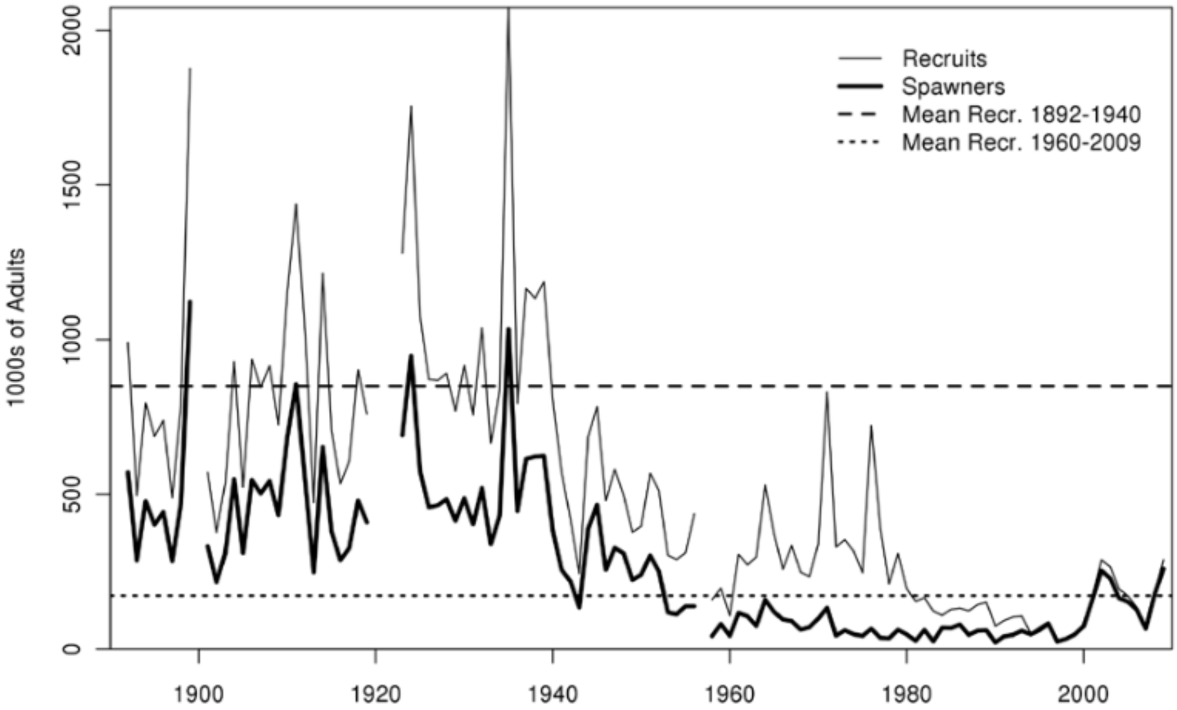


Figure 3. Coastal Oregon coho salmon in numbers of recruits and spawners from 1892 to 2009. Horizontal lines are the mean recruits for 1892–1940 and 1960–2009. (From Stout et al., 2012:29.)

Most salmon caught during the early 20th century were delivered to canneries. Mullen enhanced cannery records by adjusting for the percent of salmon canned, sold fresh, salted, and smoked. Data after 1922 come from statistics collected by the Oregon Fish Commission, and after 1975, its successor, the Oregon Department of Fish and Wildlife. Historical and current data were reviewed and adjusted by the Oregon Coastal Coho Salmon Evolutionarily Significant Unit Biological Review Team to produce Figure 3.

Figure 3 has another interesting pattern. Note the improvement in recruits from 1960 to 1977, but without an increase in spawners. This was a period of increasing hatchery production of coho salmon, which explains why the number of spawners remained low. The percentage of hatchery fish contributing to the harvest ranged between 69 and 90 percent during this period (Stout et al. 2012:40). High harvest rates became unsustainable as ocean conditions turned less favorable to salmon survival, particularly for hatchery fish, whose abundance dropped precipitously after 1977 (Nicholas and Hankin 1988, NRC 1996). Because of their diversity, the survival response of wild populations was less volatile than that of hatchery fish (Nickelson 1986, Lawson 1993). Buhle et al. (2009:2454) find adult coho "…reared in hatcheries experience reduced reproductive fitness due to genetic and environmental effects on size at maturation, run timing, behavior, and other traits, and the reproductive success of hatchery adult spawners can decline with increased spawner density."

The coastal coho salmon fishery was severely restricted in 1994 due to depressed returns and declining populations. *The Oregon Plan for Salmon and Watersheds* (OPSW 1998) was implemented to prevent listing of coho under the Endangered Species Act (ESA). Despite OPSW efforts to restore habitat, reduce harvest, and limit hatchery production, Stout et al. (2012:x) found "…little evidence for an overall improving trend." Coho have retained their threatened status because of the low level of spawners and continued concern about habitat conditions and water quality. Climate change is expected to exacerbate these conditions (Stout et al. 2012:111).

Coastal coho salmon runs collapsed due to excessive harvest pressure and too heavy reliance on hatchery stocks. Very high harvest rates could not be sustained when ocean conditions deteriorated for salmon, leaving those fishing for coho salmon in port for 1994. (Photo by Courtland L. Smith.)

Salmon Diversity

Concerns about salmon diversity were synthesized about 1990. Three of the region's leading fishery biologists published a classic article (Nehlsen et al. (1991) that called attention to loss of salmon populations. They pointed to the lost diversity that would be needed to respond to future environmental changes. The history leading to this article and the ESA listings of Columbia River salmon are described by Cone (1992), who detailed the process and its participants, the arguments and their proponents. Later, Cone and Ridlington (1996) identified the historic documents and the concerns that were the roots for reservations about the loss of salmon abundance and diversity creating the "Northwest salmon crisis." The 2008 collapse of Sacramento River fall Chinook salmon populations, so important to Oregon coastal trollers, is attributed, in part, to a loss of genetic and phenotypic diversity through habitat loss and aggregation of natural populations into a few hatchery stocks that limit life-history diversity (Lindley et al. 2009).

Human activities affecting salmon diversity are habitat, hydro, hatcheries, and harvest—often abbreviated as the "4-Hs." These activities affect the opportunities for salmon to create diverse life-history types. The cumulative effects of lost habitat, dam construction, hatchery production, and salmon harvest have reduced spawning opportunities, limited rearing possibilities, altered migration patterns, and eliminated many populations. Contemporary patterns of salmon migration and rearing appear much less diverse than the complex juvenile life-history patterns reported in the early 20th century.

A result of decreasing diversity is that populations become more vulnerable to environmental change and disturbance. Life history and genetic diversity provide the capacity to take advantage of habitat opportunities. Diverse habitats allow expression of a wide variety of rearing and migration behaviors to spread risks broadly in time and space. In this way, populations with diverse life histories reduce the risk of loss by ensuring that population members are not equally vulnerable to the same disturbances occurring at a particular time and place. As salmon lose diversity, their rearing and migration behaviors become more uniform and synchronous. Loss of diversity reduces the ability of populations to withstand environmental stress and change. Diverse salmon populations benefit ecosystems by bringing minerals and biomass back from the ocean to feed watershed flora and fauna much more effectively than human placement of hatchery salmon carcasses.

For identifying viable salmon populations, McElhaney et al. (2000) list four criteria: abundance, productivity (survival), diversity, and stock spatial structure, particularly "metapopulations," or several distinct populations occupying a large area. In the Pacific Northwest, salmon are masters at creating temporal and spatial diversity. They divide by time into runs, such as early spring, spring, summer, early fall, and late fall Columbia River Chinook. They develop diverse life histories by dividing spatially and using combinations of ecologies in the ocean, estuaries, rivers, streams, stream reaches, and spawning sites.

One stream can have several salmon life-history types that represent alternative strategies for using a variety of freshwater, estuarine, and ocean habitats.

Salmon diversity is measured by fishery biologists and reported in NOAA status reviews of endangered species (Ford 2011, Stout et al. 2012). In the 1990s, the first ESA listings of salmon and steelhead occurred in the Columbia Basin. NOAA monitors 13 listed and 2 non-listed Evolutionarily Significant Units (ESUs) of Columbia and Snake River salmon and steelhead. An ESU is a distinct population segment that is substantially reproductively isolated from neighboring populations and represents an important component of the evolutionary legacy of the species. The diversity measures for salmon populations are more qualitative and relatively new, having been in existence for about a decade. Columbia Basin diversity data by population are presented in two figures by area (Figure 4) and listed species (Figure 5).

From three different Columbia Basin areas, 174 populations are compared

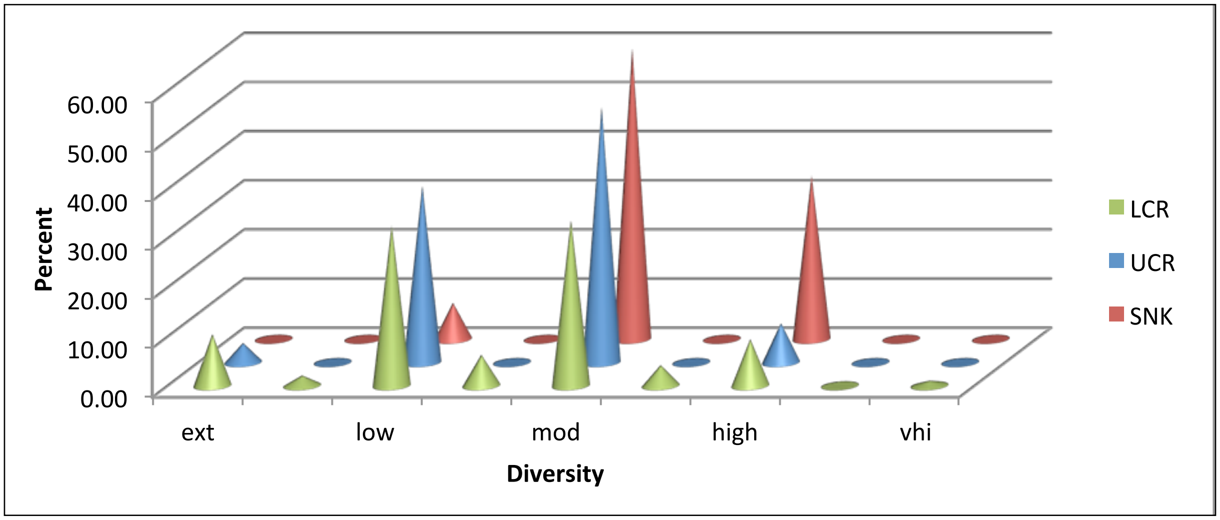


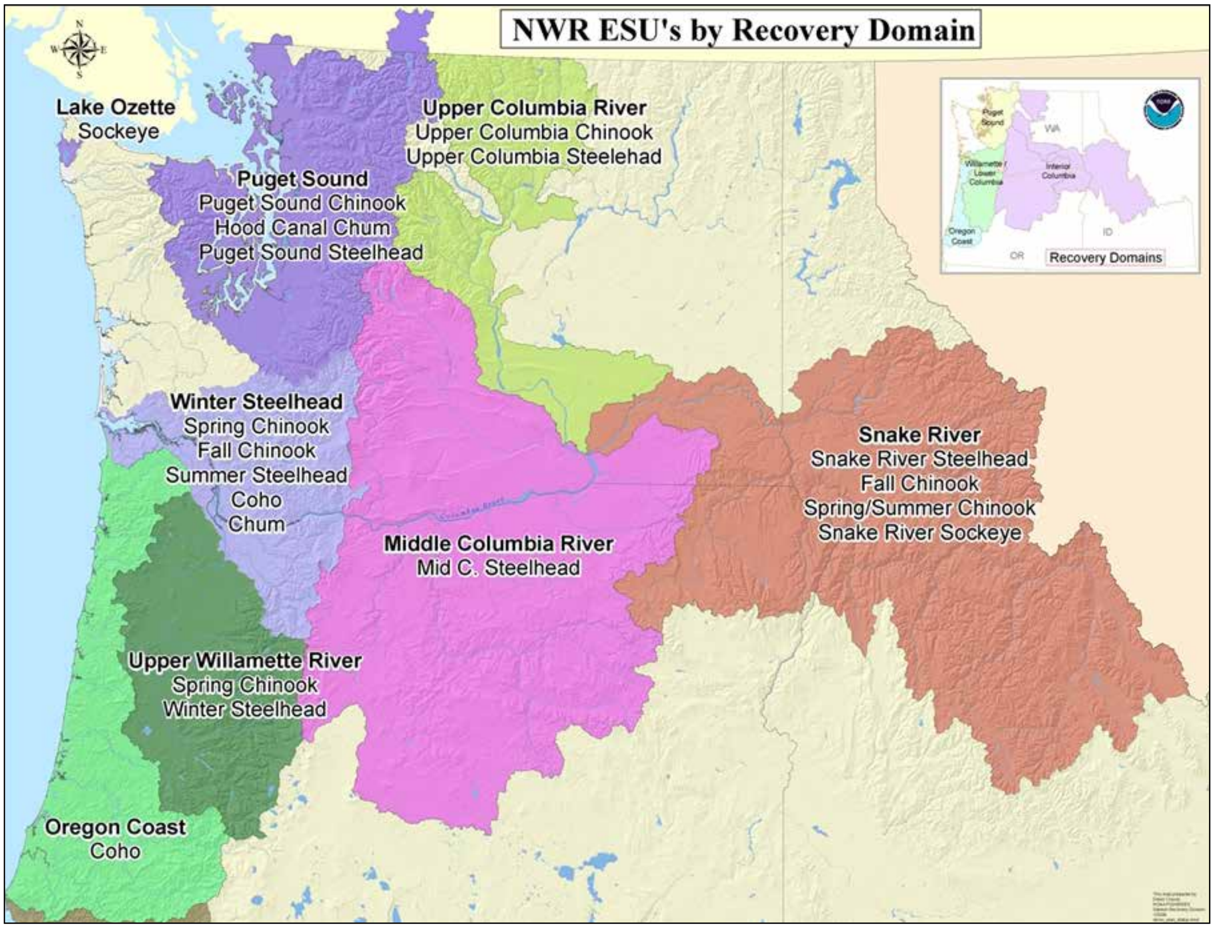
Figure 4. Diversity by area. Where there are colors with no cone, no populations were found in this category. Front row, green, is Lower Columbia and Willamette ESUs. Middle row, blue, is Middle and Upper Columbia River ESUs. Snake River ESU is red in the back. (Data from Ford 2011.)

for their diversity status. The species are: Chinook, with 75 populations; coho (25); and steelhead trout (74). The three areas are the Lower Columbia and Willamette (LCR), Middle and Upper Columbia (UCR), and Snake River (SNK) Basins. The Lower Columbia and Willamette had 95 populations, the Middle and Upper Columbia had 54, and the Snake River had 25. Figure 4 gives the percentage of populations in nine diversity levels, from the population being extirpated (ext) to diversity being very high (vhl). Diversity is based on the judgments of a panel of experts knowledgeable about each population.

Figure 4 is a bird's-eye view that compares the three areas. The front row (LCR, green) has the most extinct populations and the fewest populations with moderate diversity. The back row (SNK, red) has the highest number of populations at the moderate diversity level and the fewest with low diversity. The Upper Columbia (UCR, blue) is between the outside rows. Most common are populations at low and moderate levels of diversity.

Figure 5 compares species. Added to this graph are populations in the Oregon Coastal Coho Salmon ESU. The OCCS ESU has had a complex history of coho being listed and not listed as threatened. The 2014 status is threatened based on the Stout et al. (2012) review. The Oregon Coast has few dams blocking passage, has had significant hatchery and harvest reductions, and, while having a legacy of extensive timber harvest, is in a restoration mode. Because Oregon coastal coho diversity data were on a 5-point scale, the Columbia River data were converted to the same scale. Diversity measurement is quite new. The graph makes a number of assumptions that need further testing. For example, the NOAA goal with diversity data is to analyze the risk of extinction, which was reversed for a measure of the level of diversity. With repeated and longer-term measures, greater reliance can be put on the diversity data.

In Figure 5, Columbia River coho (green) in the front row have the poorest diversity. None of the



Map of Columbia Basin and Oregon Coast Evolutionarily Significant Units. ESUs are the basis for evaluating whether salmon are recovering after being listed as threatened or endangered. (Courtesy of NOAA.)

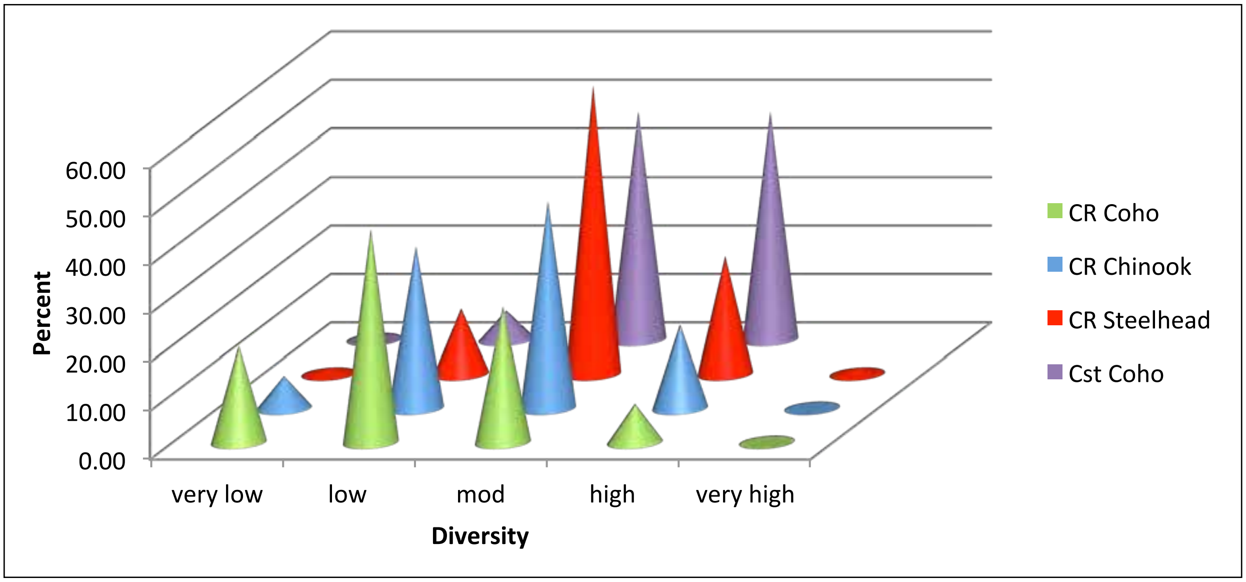


Figure 5. Diversity by species for listed Columbia and Snake River (CR), and Oregon coastal salmon populations (Cst). Where there are colors with no cone, no populations were found in this category. Front row, green, is Columbia River coho. Second row, blue, is Columbia and Snake River Chinook. Third row, red, is Columbia and Snake River steelhead. Oregon coastal coho, purple, is the back row. (Data from Ford 2011 and Stout et al. 2012.)

Columbia River coho populations are in the high level of diversity and above. In best condition are Oregon coastal coho, back row (purple). Coastal coho have nearly 50 percent in the high level of diversity. Columbia and Snake River steelhead (red), one row down from Oregon coastal coho, have one-quarter in the high level of diversity, and more than half the steelhead populations have a moderate level of diversity. Steelhead are quite diverse in natural settings. Columbia and Snake River Chinook (blue) is a little better in diversity than Columbia River coho.

In terms of average diversity, Columbia River coho are lowest, at 2.2. Columbia and Snake River Chinook are 2.7. Columbia and Snake River steelhead are 3.1. Coastal coho have the most diversity, at 3.4. Nearly all these populations are in listed ESUs. The average score for each species is at the moderate level or below. Scores of 4 and 5 would be more desirable. The ranking with Columbia River coho as least diverse and coastal coho as most diverse fits with general understanding for these different areas (Mrakovich 1998).

Nineteenth-century measures of diversity do not exist, but it is useful to think about the modifications Northwesterners have made to the environment. Fewer runs of wild salmon exist because of lost habitat, past methods of hatchery production, and reduced life-history diversity. At the time of contact with tribal peoples of the region, salmon and steelhead could travel up the Columbia River and into Canada. In the U.S., this is 745 stream miles. Downstream from the Bonneville Dam, built 146 miles up the Columbia River, and the area of the Hanford Reach, a 51-mile stretch near the Hanford Nuclear Reservation, are the only remaining undammed reaches of the Columbia in the U.S. Of the Columbia River's length in the U.S. above Bonneville, 8 percent is undammed. In the Snake River, salmon at one time traveled to Twin Falls, Idaho, more than 600 miles from the river's junction with the Columbia. The 100 miles from Lewiston, Idaho, to Hells Canyon Dam are still undammed, leaving 16 percent of the main river used by salmon and steelhead with riverine habitat.

A diverse landscape that at one time provided life-history diversity for salmon and many other species has been altered to meet human needs. Use of hatchery production to replace losses has fostered a public expectation that hatchery technology can provide abundant salmon for harvest, irrespective of habitat conditions. Heppell and Crowder (1998) conclude, "Unsuccessful hatchery programs often result from flawed assumptions about life-history characteristics…." Most discussion of the status of salmon populations focuses on the value of high abundance, but diversity is a much more complex topic, and its value has only begun to be discussed and measured by scientists. Increasing abundance may be enhanced with diversity (Bottom et al. 2009, Naiman et al. 2010, Jones et al. 2014). Ignoring the overall capacity of an ecosystem to support diversity for wild populations is ill advised because stability and resilience are compromised (Rieman et al. in press). Further, hatchery stocks, where needed, will contribute more successfully when diversity is considered.

Coinciding with the loss of abundance has been an even greater loss of diversity.

The concept behind hatcheries is that agricultural production techniques can provide greater abundance than nature. Hatcheries select life-history types that will produce the greatest abundance. The net result is to concentrate habitat use in time and space, the opposite strategy of natural populations. With the building of main-stem Columbia River dams, hatcheries had the role of replacing lost abundance. While most abundance in the Columbia has been maintained by hatcheries, the quantity is well below historic levels. Once juvenile salmon are released, the ability to control survival and growth is pretty much up to nature. Hatchery fish, like any wild or naturally spawning salmon, need rearing habitat, estuarine areas to adjust to saltwater, and ocean regions in which to grow to full size. Hatchery fish, too, can benefit from life-history diversity. Diversity enables the population to fill more habitat types. More recently, supplementation hatcheries are an innovation that begins looking at the need to replace lost salmon diversity. Life-history diversity, measured by area and species, is not at a desirable level for either hatchery or wild salmon. Having all populations above moderate diversity would be much more desirable than at the moderate level and below that was observed for the first decade of the 21st century. Perhaps more diversity will be realized in future status reviews. Work to improve and secure habitat is ongoing. Evaluation of hatchery programs (HSRG 2011) suggests promising modifications and gives a more comprehensive perspective for change. Hydro system fixes are improving passage. Harvest has been curtailed to protect critical salmon populations. Progress in thinking about and measuring diversity is being made.

Farmed Salmon and Diversity

An alternate approach to abundance is farmed salmon technologies. Figure 6 shows farmed salmon production worldwide, which has risen to more than 3 million tonnes. Farming of fish, like industrialized agriculture, raises the same questions as growing beef, chicken, and pork. There are significant issues surrounding waste products and the use of antibiotics and other chemicals to increase productivity. The biggest concern, however, is loss of diversity. Any kind of agricultural process involves selection for certain varieties, physical traits, behaviors, and life-history characteristics.

Farmed salmon have shown the ability to provide abundance for consumers, but they do not support fishing lifestyles nor sustain salmon-centered cultural practices (Smith 2012). By 1996, the amount of farmed salmon produced worldwide equaled the total harvest of naturally spawned and wild-caught hatchery salmon (Figure 6). From 1970 to 2012, farmed salmon production increased from 13 to 77 percent of the total quantity of salmon produced worldwide (FAO 2009) from all species and areas. Salmon harvests of wild-caught salmon produced

The Bonneville Hatchery was built in 1909. This picture shows the hatchery in the 1920s. With the building of Bonneville Dam in the 1930s and John Day Dam in the 1960s, the hatchery was expanded to make up for abundance lost as a result of dam construction. The hatchery serves fisheries in the river below Bonneville and in the ocean. It does not contribute to abundance above Bonneville Dam. (Photo courtesy of Oregon Department of Fish and Wildlife.)

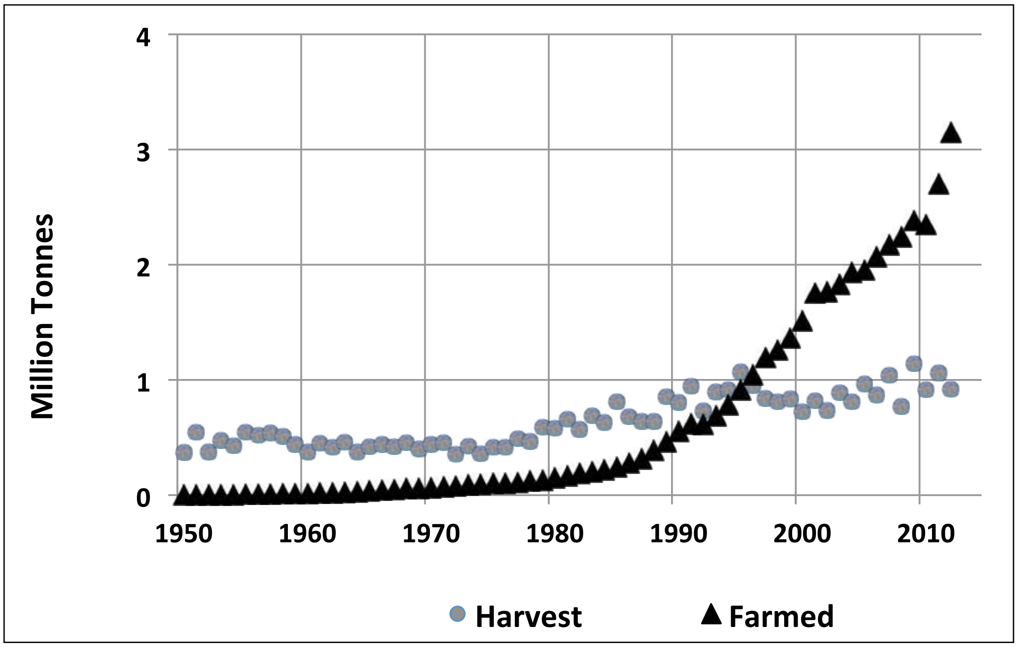


Figure 6. The United Nations Food and Agricultural Organization's estimate of world production of salmon from harvests of wild and hatchery salmon and salmon produced by farming since 1950. Includes all salmon and rainbow trout (steelhead) species. (FAO 2014.)

naturally and from hatcheries leveled off. Opportunities for catching wild and hatchery-produced salmon in the Pacific Northwest declined after the late 1970s, while fishing conditions in Alaska improved (Augerot and Smith 2010). FAO data are aggregated from many sources and protocols. Figure 6 illustrates the general pattern of change toward greater amounts of farmed salmon in the marketplace.

Oregon does not allow salmon farming to use waterways, estuaries, or the nearshore ocean. Oregonians favor avoiding the farmed salmon path to pursue a restoration strategy embodied in *The Oregon Plan for Salmon and Watersheds* (OSPW 1998). In 2010, Measure 76, which provides major financial support for *The Oregon Plan*, passed in every county of the state and had a 2–1 statewide margin. Success for *The Oregon Plan* would be the restoration of diversity and "returning the river" to salmon, as recommended by the Independent Scientific Review Panel of the Northwest Power and Conservation Council (Williams 2006).

From 1997 to 2014, $1 billion in inflation-adjusted state, federal, and other funds were spent in Oregon to buy habitat, restore streams and wetlands, improve fish passage, and stabilize forest roads (OWEB 2011). In addition to improved conditions for salmon, Oregonians get better water quality, more habitat for flora and fauna important to people, more preserved farm and forest lands, and a more natural setting in which to live.

A Future with Salmon Diversity

Taking this look at abundance and diversity over the span of more than a century shows that, in Oregon, diversity is being achieved in a very incremental way—stream-by-stream and habitat-by-habitat. The intention to replace lost runs and augment stocks to historic levels with hatcheries has maintained levels of salmon abundance well below what they once were. In addition, land-use change has resulted in considerable loss of habitat diversity.

Three production strategies—wild, hatchery bred, and farmed—produce salmon for many different biotic, nutritional, recreational, aesthetic, and cultural uses. In one sense, these are diverse sources of production. Wild salmon have the potential to maintain the greatest diversity and support many of the goals of Oregonians. Farmed salmon support consumers whenever they want salmon to eat. Because of low diversity, the greatest risk is with farmed salmon. Chile was second in farmed salmon production until its farmers encountered disease problems that cut yields and increased costs (Asche et al. 2009). Hatcheries have offered great promise since being introduced in Oregon in the 19th century. They produce a large share of salmon for those wanting to harvest salmon, fish recreationally, and pursue salmon-centered cultural practices, but at lower overall abundance and diversity levels.

The pursuit of hatchery-enhanced abundance obscures important aspects of diversity that may actually improve the status of salmon. Diversity in wild populations addresses a larger web of cultural and ecological relationships linked to naturally producing salmon and the habitats that sustain them. Hatchery and farming strategies depend on the continued existence of diverse wild populations, and the practice of farming and hatchery techniques can undermine the diversity needed for the future survival of salmon.

Hatcheries and farming homogenize populations, reduce the spatial and temporal distribution enjoyed by harvesters and others, and increase the risk of extinction of important populations that may better adapt to future environmental conditions. Wild salmon contribute to maintaining natural places, add nutrients to the watersheds they inhabit, and provide for spiritual practice and aesthetic enjoyment.

More salmon diversity means less risk of their extinction and more benefits to society.

Salmon have stayed on the front page for more than two decades. They continue to occupy a significant place in the cultures of Native Americans and Oregonians. Scientists are learning more and more about the life-history behavior that produces diverse salmon populations. This scientific knowledge helps sustain salmon. In general, a future with more salmon diversity means less risk of their extinction and more benefits to society and aquatic ecosystems.

Tours sponsored by Oregon's watershed councils help people understand how habitats can be improved and deliver multiple benefits to citizens and landowners. (Photo by Courtland L. Smith.)

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