Wild Salmon in Western North America:
The Historical and Policy Context

Robert T. Lackey

National Health and Environmental Effects Research Laboratory
United States Environmental Protection Agency
200 SW 35th Street
Corvallis, Oregon 97333
Robert.Lackey@oregonstate.edu
(541) 737-0569

Denise H. Lach

Department of Sociology
Oregon State University
Corvallis, Oregon 97331
Denise.Lach@oregonstate.edu
(541) 737-5471

Sally L. Duncan

Center for Water and Environmental Sustainability
Oregon State University
Corvallis, Oregon 97331
Sally.Duncan@oregonstate.edu
(541) 754-8320

Citation: Lackey, Robert T., Denise H. Lach, and Sally L. Duncan. 2006. Wild salmon in western North America: the historical and policy context. pp. 13-55. In: *Salmon 2100: The Future of Wild Pacific Salmon*, Robert T. Lackey, Denise H. Lach, and Sally L. Duncan, editors, American Fisheries Society, Bethesda, Maryland, 629 pp.

The future of wild salmon in western North America remains uncertain. Opinion polls consistently demonstrate widespread support for salmon, but the long-term decline in wild salmon abundance from southern British Columbia southward apparently continues. Short-term (several decades) improvements have been common since the decline began following discovery of gold in California in 1848, but overall the trend has been downward.

Policy perspectives about salmon restoration are bounded by extremes. There are those who profess to be willing to bear any burden to protect and restore the remaining runs. Others assert that Pacific salmon are abundant worldwide and no species of salmon is in danger of extinction. Wild runs in California, Oregon, Washington, Idaho, and southern British Columbia are toward the end of their southern distribution, aquatic habitats have been changed dramatically, and now runs can be most efficiently maintained by supplemental stocking from hatcheries. Occupying a middle ground between the policy extremes, others acknowledge that salmon restoration may be an important policy priority to some in western North America, but it is only one of *many* competing, important policy priorities from which society must make some difficult choices. Still others question the soundness of expending substantial public resources to restore wild salmon because such efforts, they argue, have little chance of accomplishing their purpose.

In the scientific arena opinions are similarly diverse. Some credible scientists argue that restoration of wild runs is not only technically feasible, but is possible without significant disruptions to the functioning of individuals or society. Other scientists remain skeptical about the viability of wild salmon and recommend that *if* society wishes to maintain salmon, it must require technocratic intervention, such as hatcheries or spawning channels.

The question of whether wild salmon will continue to exist in western North America is not a new one. The decline began in earnest with the discovery of gold in California and the gold rush that followed the next year. By the 1850s, excessive harvest and the impacts of mining activities were decimating salmon in streams surrounding the California Central Valley. By the 1880s the Columbia River salmon runs were also in serious decline. In 1894 the head of the predecessor agency to the National Marine Fisheries Service proclaimed to Congress that the Columbia's runs were much reduced and still declining. By 1933, the year the first main-stem dam on the Columbia was completed, the total Columbia salmon run had already been reduced to a fifth or less of the pre-1850 level. One can argue that the most severe salmon decline took place in the 19th century — not the 20th century — though that is not to imply that the 20th century was a favorable one for salmon.

The decline of wild stocks was caused by a well-known but poorly understood combination of factors, including unfavorable ocean or climatic conditions; excessive commercial, recreational, and subsistence fishing; various farming and ranching practices; dams built for electricity generation, flood control, irrigation, and many other purposes; water diversions for agricultural, municipal, or commercial requirements; pollutants of many types; hatchery production used to supplement diminished runs or produce salmon for the retail market; degraded spawning and rearing habitat; predation by marine mammals, birds, and other fish species; competition, especially with exotic fish species; diseases and parasites; and many others (Augerot 2005).

The "future" can be considered according to many time frames. A few years or a decade is appealing in the political arena, but is biologically unrealistic because the subtle, but crucial, effects on salmon populations of ocean and climate cycles and various human-derived causes are impossible to assess over such short time frames. Also, salmon life cycles range from two to eight years and a decade is time enough for only one or a few generations to respond to a policy action. Conversely, forecasts several centuries ahead, while biologically appealing, are not credible because technological change and evolving societal priorities are highly uncertain. We argue that 2100 is a good compromise, a balance between scientific tractability and political relevance. We recognize that to some it may be too distant to be credible; to others it may not be sufficiently distant to comprehend the long-term consequences of salmon recovery policy.

Besides causing discomfort by forecasting a century ahead, serious discussions about the long-range future of salmon in western North America raise troublesome realities. There are realities that force us to accept that we cannot have it all. Other realities expose our personal battles between emotion and intellect. Still other realities force us to acknowledge mutually exclusive policy alternatives. Collectively, these are questions few of us relish. Nevertheless, they must be addressed head-on if policy options to restore wild salmon are to be rigorously assessed.

The Policy Conundrum

In the southern half of the range of western North American salmon (California, Oregon, Washington, Idaho, and southern British Columbia), salmon runs have declined markedly from the levels of the mid-1800s (Netboy 1980; Nehlsen et al. 1991; Cone and Ridlington 1996; National Research Council 1996; Lackey 1999a; Lichatowich 1999; Knudsen et al. 2000; Augerot 2005). Despite many costly efforts to protect and restore wild salmon, the total number of wild salmon in the region continues to decline over the long-term (Huntington et al. 1996; Lichatowich 1999).

Virtually no one is happy with the current situation, yet few in the general public recognize the connections between individual and societal choices and the current and future status of salmon. Thus, there is a policy conundrum: salmon ostensibly enjoy universal public support, but society collectively has been unwilling to arrest their decline, much less restore depleted runs (McGinnis 1994, 1995).

As a public policy issue, salmon restoration symbolizes a class of contentious, socially wrenching challenges that are becoming increasingly common in western North America as demands increase on limited ecological resources (Lackey 1997, 1999a). These issues share numerous characteristics: (1) *complexity* — there are innumerable options and trade-offs that can be presented to officials and the public (Taylor 1999); (2) *polarization* — these issues tend to be divisive because they represent a clash between competing values; (3) *winners and losers* — some individuals and groups will benefit from each policy choice and others will be harmed, and many of the trade-offs are well known; (4) *delayed consequences* — there is no immediate "fix" and the benefits, if any, of painful concessions will often not be evident for decades; (5) *decision distortion* — these are not the kinds of policy problems that democratic institutions address smoothly because it is easy for advocates to appeal to strongly held values; (6) *national vs. regional conflict* — the priorities of society at a national (or international) level often differ substantially from those of the local or regional society; and (7) *ambiguous role for science* — science is important but usually not pivotal in evaluating policy options because the selection by society of a policy option is inherently driven by values and preferences (including political judgments). Further constraining the role of scientific information is widespread public skepticism over its veracity because much of it is tendered by government agencies, industries, and myriad interest groups, each having a vested interest in the outcome of the debate and often promulgating "science" that supports its policy position (Scarce 2000).

As is typical in contentious ecological policy issues, various fisheries scientists promulgate legitimate, but often different, interpretations of the same set of data. Also, the dominant scientific view often changes over time (e.g., the consensus among scientists several decades ago was to remove trees and woody debris from streams to allow unimpeded access for adults during migration; now the consensus is to place or return woody debris into streams to provide habitat for juvenile salmon). Such scientific controversies confuse policy discussions and create skepticism on the part of the public and policy makers.

For those who place high value on maintaining runs of wild salmon, it is easy to conclude that conflicting societal priorities and technical limitations preclude a rational, positive resolution (Lang 1996). Regardless, choices are being made — even the "no action" option is a policy choice. From some political perspectives, society's policy choices may not be the correct or desirable ones, but the selected choices should definitely be "good" ones, with "good" choices defined as the desires or preferences of the majority being implemented, and preferably with no *unanticipated* consequences.

Even fundamental policy and science issues such as the question of what is a wild salmon are controversial (Brannon et al. 2004; Courter and Lackey, unpublished). There are several dramatically different definitions that lead to very different policy perspectives. Plainly, a "wild" salmon is one produced by natural spawning in fish habitat (e.g., streams, lakes, or estuaries) from parents that were spawned and reared in fish habitat. Conversely, a "hatchery" salmon is one produced by artificial (i.e., human-assisted) spawning which is usually accomplished in a hatchery. At the extremes, the difference between "wild" and "hatchery" is clear, but how are fish that use artificial spawning channels classified? What about first generation offspring from one or both parents of hatchery origin? How are the *additional* salmon produced by lake fertilization classified? What about salmon stocks which, over many generations, have been able to adapt and survive in highly altered aquatic environments? In this chapter we use the term "wild" salmon arbitrarily to include those individuals produced from natural spawning in natural or minimally altered habitat. Others consider salmon produced by wild parents spawning in spawning channels (constructed by humans) to be wild.

Technocrats continue to vigorously debate what proportion of the decline is attributable to which specific factor. Many affected agencies, organizations, and entities have developed, or funded the development of, sophisticated assessments or computer models of salmon populations that usually end up — probably not surprisingly — supporting their organization's favored policy position.

The most strident voices include a range of affected groups such as inland barge operators, marine shipping interests, highway users, industries that are dependent on high volumes of electricity, cattlemen's and farmers' associations, logging interests, recreational, commercial, Indian fishermen, and a spectrum of environmental advocacy organizations. In fact, no one, even the most astute salmon scientist, knows for sure the relative importance of the various factors that caused the decline of wild salmon, but we all make educated guesses.

We also have the recent incongruity of salmon abundance and concern about extinction. Two examples illustrate this point: First, in 1995, more *wild* Pacific salmon (summed over all regions) were harvested than in any other year in history. In such a situation, commercial fishermen typically assert that there is a salmon glut, hence the relatively low prices that they are able to command. Second, in the first few years of the 21st century, the *total* Columbia River salmon run, which are mostly hatchery fish, has been among the highest since at least 1938, the year the first Federal mainstem Columbia dam was completed.

There are explanations that attempt to untangle the seeming paradox of salmon abundance concurrent with concern about extinction (Nielsen 2004). Most of the wild fish now come from Alaska and northern British Columbia. They are abundant, but this plenty is due predominantly to favorable ocean conditions, spawning and rearing habitat in a relatively unaltered state, and vigorous regulations to control harvest. Also, large quantities of competitively priced "farm-raised" salmon are available year- round from many sources (e.g., Washington, British Colombia, Norway, Scotland, Chile, Australia, and New Zealand). And the recent "record" runs in the Columbia are but a shadow of their 1850 level of 10 to 15 million, as well as being predominantly fish of hatchery origin. Although there are explanations, for many there continues to be the seeming contradiction of salmon abundance occurring simultaneously with cries to confront risks of extinction.

The U.S. Endangered Species Act (ESA) and Canadian Species at Risk Act (SARA) are no less free of paradox and intellectual intrigue. Threatened or endangered salmon are the only listed animals for which governments routinely provide large numbers of licenses to kill. If society's concern about loss of salmon stocks in western North America is as great as many people assert, why don't we simply close fishing and hatcheries completely until salmon runs rebound? Recreational, commercial, and Indian fishermen would assuredly object, but most people would not be affected by a ban on fishing or supplementing runs with hatchery fish. Farm-raised salmon would remain abundant and could continue to supply the retail market, and taxpayers would save hundreds of millions of dollars by closing the hatchery system and eliminating the subsidies currently needed to maintain salmon runs.

Ultimately, listing wild salmon as endangered or threatened as defined by the ESA or SARA means that everyone, not just fishermen, is affected. Efforts required to restore wild salmon run headlong into many other individual and societal priorities. Two of the most obvious and visible recent examples are the periodic electricity shortages and decisions over how to balance Columbia River electricity generation vs. salmon survival, and the contentious law suits over how to divide up scarce Klamath Basin water supplies between farmers, refuge managers, threatened salmon, endangered suckers, and threatened bald eagles.

Do we need to bring some annoying reality to this discussion? Even though some predict a dramatic slowing of world population growth by the end of this century (Lutz et al. 2001), the human population of western North America continues to grow at an annual rate comparable to that of some Third World countries. For example, applying middle-of-the-road (from my perspective) annual growth rates of the current human population in Oregon, Washington, Idaho, and British Columbia (currently 15 million in total), there will be a population of 60-80 million people by 2100. Given such a probable human population level in the Pacific Northwest and the fact that California already is highly populated, you may ask whether society is being delusional about the chances of the ESA, SARA, or anything else, doing much to save wild salmon.

In western North America, we now expend considerable public and private resources in a frantic attempt to save salmon stocks that are down to a few individuals. Have we reached a point where society soon will conclude that sufficient resources already have been spent in an abortive bid to save *all* wild salmon stocks? Or are we at the stage of recognizing that society wishes to maintain salmon in the southern part of their North American range (mid-British Columbia southward), but prefers to do it using hatcheries and other technofixes that may be costly and not certain to succeed, but will avoid the major social dislocation of restoring *wild* fish? Alternatively, will society accept the creation of *salmon refuges*, analogous to National Parks, which preserve runs of a few stocks in a fully wild state? Or will society demand that protection and restoration of wild salmon trumps all other societal priorities, regardless of individual and collective costs?

Salmon Biology

Pacific salmon are one of the most studied groups of fishes in the world (Scarce 2000; Quinn 2005). The vast scientific knowledge available is a reflection of the economic, recreational, and cultural importance of salmon. Many gaps and uncertainties remain, however, in our understanding of the biology of Pacific salmon.

There are seven species of what are classically labeled “true” Pacific salmon (Groot and Margolis 1991; Quinn 2005). All are found on the Asian side of the Pacific Ocean, but only five (Chinook, coho, sockeye, chum, and pink) are found on the North American side (Lichatowich 1999). There are also two species of sea-running trout (rainbow or steelhead and cutthroat) that have similar life histories and are usually lumped in the genus *Oncorhynchus* with the five North American true salmon and treated as “Pacific salmon.” A major difference between true salmon and sea-running trout is that true salmon nearly always die shortly after spawning, but many sea running trout do not (Pearcy 1992). Because anadromous trout and salmon in western North America have similar life cycles, are members of the genus *Oncorhynchus*, and are collectively part of the salmon restoration policy debate, we will group all seven as *Pacific salmon* (Chinook, coho, sockeye, chum, pink, steelhead, and sea run cutthroat) (Table 1). Several species of

Pacific salmon have been introduced elsewhere (e.g., the North American Great Lakes, New Zealand, Chile, Argentina, and Norway) and have established prosperous populations; these are not considered here. Also not considered here are other anadromous salmonids such as Atlantic salmon (originally found only in the Atlantic and Arctic oceans and adjacent waters, but widely distributed, including in western North America) and brown trout (originally found only in Europe and small portions of Asia and Africa, but now widely distributed in North America).

Pacific salmon are native to California, Oregon, Washington, Idaho, Montana, British Columbia, Yukon, Northwest Territories, Alaska, the Russian Far East, Korea, China, and Japan (Groot and Margolis 1991; Augerot 2005). Their overall distribution has varied over the last several thousand years, with variations mostly due to climatic shifts, but the *approximate* distribution has been relatively constant (Chatters et al. 1995). Prior to 4,000 years ago, the distribution of Pacific salmon was considerably influenced by the residual effects of the last ice age. At certain periods in history, they were found in Baja California and Nevada, and even today remnant runs are found as far south as San Diego (Hovey 2004). Today, it is evident that the distribution of salmon is far from fixed (McLeod and O'Neil 1983). Pacific salmon are found in Asian and North American rivers emptying into the Arctic Ocean. If northern climates warm in the 21st century, it is possible, perhaps even likely, that there will be a range extension in this region (Salonius 1973; Babaluk et al. 2000). Since 1948, three of the five warmest Canadian winters have been 1997/98, 1998/99, and 1999/00 (Environment Canada, Climate Research Branch). In a parallel manner, there may be a range contraction in more southern locales where warming creates less hospitable salmon habitat.

Pacific salmon usually have an *anadromous* life cycle. They migrate from the ocean to freshwater, spawn, and, a few months to a few years after hatching, the young migrate to the ocean, where they spend from a few months to several years (Groot and Margolis 1991; Meehan and Bjornn 1991; Quinn 2005). Wild salmon usually return to their parental spawning ground, although a small percentage stray and spawn elsewhere (Cooper and Mangel 1999). Fidelity to the parental stream results in adaptation of the breeding population in a particular environment. Straying allows salmon to colonize new areas, or areas where salmon runs have been lost (Cooper and Mangel 1999). Because only a small *percentage* of salmon stray, the rate of expansion of the distribution is typically slow if the *number* of salmon is low, usually requiring from decades to centuries for salmon to occupy empty habitats or to re-occupy those habitats that have been restored. However, under other circumstances expansion can be very rapid. Pacific salmon, introduced into New Zealand, Chile, and Argentina, rapidly established self-sustaining populations and fairly quickly (over several decades) expanded their distribution.

Migrations of salmon vary among species (Groot and Margolis 1991; Pearcy 1992). They may spawn in very short coastal rivers, even in estuaries, or traverse thousands of kilometers to the headwaters of the Sacramento-San Joaquin, Columbia, Fraser, Skeena, Yukon, Mackenzie, and other large rivers. Salmon of some species, such as chum and sockeye, swim far out in the ocean, followed usually by a long ascension of a river to reach their home spawning grounds. Others, including anadromous cutthroat trout, stay close to the coast throughout the ocean portion of their lives.

Each salmon species is composed of many *stocks* — defined as self-perpetuating populations that spawn generation after generation in the same location (Nehlsen et al. 1991). Stocks are adapted to the specific “local” environment by inherited biological attributes, such as timing of migration and spawning, juvenile life history, and body size and shape. Local environmental or watershed conditions are often highly variable, so a stock must have the ability to respond to sometimes drastic environmental changes (Bisson et al. 1997). Debate over the “extinction” of wild salmon is usually focused on decline or loss of salmon *stocks*, not salmon *species* (Hyatt and Riddell 2000). Some *stocks* of salmon have been extirpated and a sizable part of the southern half of the range no longer supports runs of wild salmon, but it is unlikely that any *species* of salmon will entirely disappear from the region in the foreseeable future.

Even though the traditional unit of concern in salmon management is the *stock*, the number of salmon stocks is unknown because of prior undocumented extinctions, incomplete biological data on the current condition, and continuing scientific debates about the level of genetic distinctiveness appropriate to define a stock. Defining a stock is not just a scientific exercise because it has major policy ramifications (Hyatt and Riddell 2000). If a stock is considered a “distinct” population, it may be treated as a full “species” under government and court interpretations of the ESA (Waples 1995; Dodson et al. 1998). Unfortunately, the ESA does not specify how population “distinctiveness” shall be assessed, and that omission has fostered considerable confusion and debate in the Act’s application to salmon policy. For example, using a standard and fairly broad definition of a stock (“a group of interbreeding individuals that is roughly equivalent to a population”), the number of stocks in the southern half of the range is in the tens of thousands. By this definition, if each stock was considered a “distinct” population, potentially subject to legal protection as a “species” under the Act, the socioeconomic ramifications for society would be profound (Hyatt and Riddell 2000).

Genetic variation is important to maintaining the viability of a salmon species because it represents a species’ potential to survive in varying environments (Cooper and Mangel 1999; Levin and Schiewe 2001; Lynch and O’Hely 2001; Hilborn et al. 2003). Some scientists argue that protecting *every* stock may not be necessary to preserve sufficient genetic variation to sustain each species. For example, the concept of “evolutionarily significant unit” (ESU) was fashioned to describe a salmon population unit whose loss would be *significant* for the genetic or ecological diversity of salmon species (Waples 1995). Using ESUs as the unit of concern in salmon preservation has been criticized because no standard amount of significant “difference” among populations or stocks is required to identify ESUs (Dodson et al. 1998) and because ESUs deal with “evolutionary” time scales rather than shorter “ecological” time scales (Cooper and Mangel 1999).

Decisions about what constitutes “significance” and about the trade-offs implicit in protecting ESUs are largely societal choices that cannot be based on scientific grounds alone (National Research Council 1996). Some challenge even the premise that it is possible to judge the evolutionary significance of one spawning aggregate against that of another (Mundy et al. 1995). However, if the U.S. government agency responsible for implementing the ESA relative to salmon (U.S. National Marine Fisheries Service) chose to list an entire *species* as threatened or endangered, then the effect on society would be much greater than if some distinct population could be listed (Hyatt and Riddell 2000). Even though the listing process is ostensibly entirely based on "scientific" grounds, the political ramifications of each listing option (full species or a segment of a species) is apparent to those technocrats doing the listing. Hence the apparent restraint in listing any but the most at-risk segments of the population.

Decisions on salmon restoration will never be based solely on biological information (Waples 1995; Dodson et al. 1998; Wu et al. 2000). Ethical, moral, and religious values, combined with legal and economic factors, will also influence restoration decisions. Therefore, a biological unit of concern, the "operational conservation unit" (OCU) has been proposed (Dodson et al. 1998) as an explicit attempt to combine both scientific information and societal values and priorities in determining what aspect of a "species" will be considered for protection.

Beyond various concerns about the influence of declining salmon runs on their genetic diversity and long-term viability, there is the role salmon play in providing marine-derived nutrients (MDN), especially nitrogen, phosphorous, and carbon, to watersheds (Finney et al. 2000; Gresh et al. 2000). The death and decay of salmon after spawning results in the release of nutrients. Large runs of salmon provide an important source of MDN, especially in low-nutrient areas such as headwaters where their progeny spend their early lives (Cederholm et al. 1999; Bilby et al. 2001). Because of the dramatic decline in the size of wild salmon runs in the southern half of the range, it is estimated that the amount of marine-derived nitrogen and phosphorous now delivered to the region's watersheds is less than 10 percent of its historical level (Gresh et al. 2000). The implications of this decline in available nutrients for survival of juveniles are significant, but as yet are not fully understood.

Another important ecological role that salmon play is providing food to terrestrial and other freshwater animals (Willson et al. 1998). Many mammals, birds, and invertebrates prey on or scavenge salmon while they are in freshwater habitats. Predators and scavengers feed on salmon at every stage in their life cycle: egg, fry, smolt, immature adult, and returning spawners. When the sizes of salmon runs are dramatically reduced, there is an effect, although not yet fully quantified, on the dependent predator and scavenger populations, many of which are charismatic megafauna in their own right (e.g., grizzly bears, eagles, condors, orca, cougars, and wolves).

Current Status of Pacific Salmon

Many efforts have attempted to quantify the extent of the wild salmon decline in western North America. For example, Nehlsen et al. (1991) concluded that over 200 salmon stocks in California, Oregon, Idaho, and Washington were then at moderate or high risk of extinction; that is, extirpation is likely unless something changes rapidly. An assessment (using somewhat different criteria) of British Columbia and Yukon stocks (Slaney et al. 1996) identified over 702 stocks at moderate or high risk. Across the southern half of the range, at least 100-200 stocks are already identified as extinct, but the actual number may be much higher. Even allowing for considerable scientific uncertainty over the past, current, and future status of wild salmon stocks, it is clear that some have become extinct, some are nearly certain to go extinct, and many more are at risk and will possibly go extinct (Huntington et al. 1996). Declines are widespread across the southern half of the range but are not universal, nor are they limited to large, highly altered watersheds such as the Sacramento and Columbia (Huntington et al. 1996). Declines are documented in many smaller rivers along the coast. Causes of the declines are numerous, vary by geography, species, and stock, and will be reviewed in detail in later sections.

In California — the southernmost extent of the current range of salmon in the northern hemisphere — virtually all salmon stocks have declined to record or near-record low numbers (Mills et al. 1997) (Table 2). Another survey concluded that most California salmon stocks are extinct or “unhealthy” (Huntington et al. 1996). Remnant runs of steelhead are found in a few streams in the San Diego area of California (Hovey 2004). A recent assessment of waters of the California Central Valley found that many of the principal streams and rivers that historically supported Chinook salmon runs still do, but nearly half of them had lost at least one stock, and several major streams had lost all their Chinook salmon stocks (Yoshiyama et al. 2000). Historical records document that for several major Central Valley streams and rivers, large salmon runs were severely reduced or extirpated in the 1870s and 1880s by hydraulic gold mining and blockage by dams (Yoshiyama et al. 1998). Hatchery-produced Chinook salmon constitute a substantial and increasing fraction of most runs in the Central Valley (Yoshiyama et al. 2000).

In Oregon, although there is considerable disagreement on the condition of specific stocks, the overall status of salmon stocks is mixed (Kostow 1997). Stocks from coastal rivers (e.g., those that are not part of the Columbia drainage) largely have stable to declining numbers, but some stocks are seriously threatened with extinction (Table 2). The absolute number of fish in most coastal wild salmon runs nonetheless appears to be a small fraction of that a couple of centuries ago (Huntington et al. 1996; Meengs and Lackey 2005). Wild salmon stocks from the Columbia River watershed are generally at low levels; an indeterminate number are extinct and many others are declining. Salmon are excluded from large portions of the watershed by impassible dams.

The status of wild salmon in Washington is also mixed. Of 435 wild stocks (salmon and steelhead), 187 were recently classified as healthy, 122 depressed, 12 critical, 1 extinct, and 113 of unknown status (Johnson et al. 1997). Coastal and Puget Sound stocks were generally in better condition than those occupying the Columbia watershed, although there are many stocks at risk (Table 2). One section of the Columbia River, the Hanford Reach, supports a healthy population of wild salmon. Another survey, however, found only 99 healthy (defined as at least one third of the run size that would be expected without human influence) stocks throughout the *entire* Pacific Northwest (Huntington et al. 1996).

Wild salmon have declined markedly in Idaho (Nemeth and Kiefer 1999). Idaho salmon travel as far as 1500 km downstream as smolts to reach the ocean, and eventually must return the same distance to reach natal spawning grounds to reproduce. Dam construction in the lower Columbia and Snake rivers has impeded salmon migrating to and from Idaho by converting a free-flowing river into a gauntlet of eight dams and reservoirs (Nemeth and Kiefer 1999; Kareiva et al. 2000). The decline has been especially sharp during the last three decades (Hassemer et al. 1997).

Assessments of British Columbia and Yukon salmon stocks show mixed results. Overall abundance of salmon in the Fraser River watershed decreased sharply since the late 1800s and early 1900s, although the most recent four decades (up to the early 1990s) have shown an apparent upward trend (Northcote and Atagi 1997). Similar patterns exist for much of British Columbia, although status varies by species. There appears to be a long-term decline, but there is considerable variation among species and over time (Table 2). Of the 9,662 identified salmon stocks in British Columbia and Yukon, 624 were at high risk of extirpation and at least 142 have disappeared in this century (Slaney et al. 1996). In 1998, the total Canadian salmon catch was at the historic low for the 20th century (Noakes et al. 2000).

Through the early 2000s, surveys in southeastern Alaska showed salmon runs to be in mostly good condition (Baker et al. 1996; Adkison and Finney 2003) (Table 2). Catches in the 1990s and 2000s were at record levels and the numbers of salmon reaching the spawning grounds were generally stable or increasing for all stocks for which there were adequate data (Baker et al. 1996). The condition of salmon runs elsewhere in Alaska through at least the present was also good: runs of wild salmon either showed no trend or increasing trends over time, indicating that the high catch levels are probably not due to over-exploitation (Wertheimer 1997). Some runs in western Alaska did, however, collapse in the late 1990s (Adkison and Finney 2003).

Alaska produced approximately 80 percent of the wild salmon harvested in North America in the 1980s and 1990s (Wertheimer 1997). Most Alaskan catches (and runs) increased since the late 1970s and reached or exceeded historical highs through the mid 1990s and even later (Kruse 1998). The highest worldwide catch of Pacific salmon ever recorded occurred in 1995 and was composed principally of the Alaska harvest (Beamish 1999). A recent sharp reversal of record high returns in some of the largest salmon runs in Alaska may signal the beginning of a general downward trend. The number of sockeye salmon returning to Bristol Bay, Alaska (the world's largest sockeye salmon fishery) declined 50 percent in 1997 (Kruse

1998). Catches in other major Alaska salmon fisheries also dropped appreciably in 1998 and 1999.

The size of salmon runs varies inversely between the northern and southern halves of the distribution. When stocks in the southern half (California, Oregon, Washington, Idaho, and southern British Columbia), have low run sizes, runs in the northern half of the geographic distribution (northern British Columbia, Yukon, and Alaska) tend to be high (Pearcy 1997; Hare et al. 1999). This reciprocal relationship in ocean conditions, the Pacific Decadal Oscillation, appears to be driven by climatic conditions; the resultant effect on ocean currents and upwelling determines the abundance of food for salmon (and predators), and thus has consequences for salmon during the ocean phase of their life cycles. As ocean conditions change, often abruptly, habitat that was ideal for salmon can rapidly become inferior (or *vice versa*) (Finney et al. 2000).

The Pacific Decadal Oscillation appears to reverse every 20 to 30 years (Downton and Miller 1998; Hare et al. 1999). Although still not well understood, the important role played by changing climatic and oceanic conditions in determining the size of wild salmon runs is amply documented (Finney et al. 2000; Noakes et al. 2000). For at least the short-term, there is little that society can do to influence climate or ocean conditions, but it is important to understand climate and ocean influences in order to assess their role in influencing the condition of salmon runs.

Many salmon found in the “wild” are not the result of natural spawning and thus not considered “wild” fish. Aquaculture — growing fish in captivity — is well developed for salmon. For over a century salmon hatcheries along the Pacific coast have produced millions of salmon annually to supplement the number of wild, naturally produced salmon (Levin et al. 2001; Brannon et al. 2004; Nielsen 2004). Further, because it is fairly easy to “farm” salmon and provide a steady, predictable supply to markets, salmon production for commercial purposes has dramatically increased in the past few decades. Atlantic salmon, a species not originally found in western North America, is the most popular species used in marine salmonid aquaculture (Noakes et al. 2000; Volpe et al. 2000). Some of the fish raised by the “pen rearing” aquaculture technique invariably escape. In other cases commercial hatcheries were built to supplement natural runs and produce a surplus returning to the hatchery which could be sold to the retail market (“ocean or salmon ranching”) (Adkison and Finney 2003; Nielsen 2004). Over the past decade, more than six billion artificially produced salmon have been released annually into rivers and streams surrounding the Pacific Rim (Nielsen 2004).

Because of the extensive commercial production of salmon through aquaculture, salmon are relatively inexpensive and are readily available to consumers. Commercial quantities of salmon are grown in captivity in British Colombia, Washington, Scandinavia, Scotland, and Chile and provide markets with a continuous supply of fresh salmon. Aquaculture and hatcheries carry biological risks for wild salmon; these risks will be summarized in a later section.

Salmon are not the only anadromous fishes that are significantly affected by human actions and natural climatic and oceanic oscillations. The Pacific coast lampreys, green and white sturgeons, and the eulachon (smelt), all native anadromous species, have also declined. Striped bass (an exotic anadromous species introduced into California in the late 1800s) are evidently declining in abundance. However, another exotic anadromous species, American shad, introduced into the Sacramento River in 1871, is thriving in many places along the Pacific coast, including the Columbia Basin.

In summary, no *species* of Pacific salmon is near extinction. For retail consumers, salmon are readily available and fairly inexpensive. Nonetheless, many wild *stocks* of salmon in the southern half of their North American range have been extirpated or are experiencing population decline. Overall, the 150-year trajectory of wild salmon numbers south of the Fraser River, British Columbia, is downward (Table 2).

Historical Ecological Context

Salmon runs vary greatly even in the absence of any human actions, but estimating the size of past salmon runs is useful because estimates provide benchmarks to measure the current state of wild salmon stocks and the effectiveness of restoration efforts. To assess changes in salmon runs during the past 150 years, it is possible to use cannery records, current field surveys, and harvest records (Gresh et al. 2000; Meengs and Lackey 2005). Such analyses show major declines in the aggregate size of wild salmon runs in California, Oregon, Washington, and Idaho, a smaller percentage decline in British Columbia, and no obvious change in Alaska (Table 2).

Estimating the size of salmon runs in California, Oregon, Washington, Idaho, and southern British Columbia prior to the late 1800s is more difficult. Explorers and settlers in the early to mid 1800s reported “massive” salmon runs, but it is difficult to interpret this descriptive information to create benchmarks and infer trends. A further complication is that relatively low rates of salmon harvest (as occurred in the early to mid-1800s) will often result in higher net reproduction, and thus *larger* subsequent runs than would occur in the absence of harvesting (Chapman 1986). In short, some level of harvest may actually increase overall population productivity. Even discounting human influence, the size of salmon runs has varied enormously over the past 10,000 years (Chatters et al. 1995).

Anthropological data are inexact and open to various interpretations, but it is certain that at the end of the last Ice Age, 10,000 - 15,000 years ago, humans and salmon expanded into the Pacific Northwest (Pielou 1991; Chatters et al. 1995). Until 7,000 to 10,000 years ago, many of the upper reaches of rivers were blocked by glacial ice. Eroding glacial deposits and low water flows limited the size of salmon runs for the next several thousand years. Ecological conditions improved for salmon approximately 4,000 years ago, probably from better oceanic conditions and more favorable freshwater environments (Chatters et al. 1995).

Aboriginal harvests of salmon increased gradually over the 4,000 years prior to European contact, and affected runs in at least some smaller rivers, especially toward the southern and eastern extent of the salmon distribution (Swezey and Heizer 1977; Taylor 1999; Yoshiyama 1999). It is often assumed that aboriginal fishing may be dismissed as an influence on historical run sizes. Taylor (1999), after reviewing the results of recent anthropological research, concludes:

> Taken as a whole, the aboriginal fishery represented a serious effort to exploit salmon runs to their fullest extent. Aboriginal techniques could be frighteningly efficient, and in many respects they compare favorably to modern practices. Weirs blocked all passage to spawning grounds; seines corralled large schools of salmon; and basket traps collected without discrimination. Indians in fact possessed the ability to catch many more salmon than they actually did.

Research indicates the level of salmon harvest by aboriginal fishermen in the Central Valley of California and along the coast of Oregon, for example, was roughly comparable to the peak commercial harvest of industrial fishermen of the mid to late 1800s (Yoshiyama 1999; Meengs and Lackey 2005).

Many Indian tribes possessed fishing gear that enabled them to catch salmon effectively in various settings and under a range of conditions. Their gear encompassed a spectrum comparable to that available to 19th century "industrial" fishermen who supplied salmon to canneries (Smith 1979). There was, however, a major difference between the two groups of fishermen. For Indian fishermen prior to 1500, a rough equilibrium existed between the size of the salmon catch and the region's human population because the number of salmon that could be consumed, sold, or traded was constrained (compared to modern standards) by technical limitations in fish preservation, storage, distribution, and, most importantly, a *relatively* low population of about a million people across the entire region.

Although aboriginal fishing may have affected individual stocks, especially those in smaller rivers and streams more vulnerable to the effects of fishing, the aggregate effect on salmon runs was less than that of the past 150 years (Schalk 1986). Further, except for using fire to clear vegetation, aboriginals lacked the capability to greatly affect salmon habitat. In summary, from roughly 4,000 years ago to approximately the 1500s, salmon runs probably fluctuated greatly, but with a long-term somewhat upward trend as continental habitat conditions improved from a salmon perspective.

The 1500s marked the beginning of a dramatic change in the history of the salmon/human relationship in western North America. From the early 1500s through the mid 1800s, a series of human disease epidemics (caused by Old World diseases, principally smallpox, measles, whooping cough, mumps, cholera, and gonorrhea) decimated aboriginal human populations (Denevan 1992; Harris 1997; McCann 1999), and this reduction in the human population caused a significant decline in fishing pressure (Taylor 1999). For example, to illustrate the extent of the decline, prior to 1800 the population of what is now British Columbia was greater, possibly much greater, than 200,000 (Harris 1997). By 1850, the total population of British Columbia was estimated to be only several tens of thousands. Thus, the large salmon runs observed in the early to mid-1800s were likely a reflection of the general, long-term trend of improving (from a salmon perspective) ecological conditions, coupled with a curtailment in harvest due to the diminished human population.

Causes of the Decline

It is unknown whether there have been other general declines of wild salmon over the past 10,000 years. There certainly were prodigious volcanic eruptions, forest fires, land slides, and tsunamis that may have had widespread influences on salmon, but research has not confirmed this.

Commercial Harvest

The level of fishing for salmon in western North America began changing markedly in the mid- to late 1800s (Netboy 1980; McEvoy 1986; Robbins 1996; Mundy 1997; Lichatowich 1999; Yoshiyama 1999). By the early 1800s, the number of salmon harvested had been reduced due to the drastic drop in the Indian population, coupled with the breakdown in their social structure. Thus, salmon runs were being lightly harvested and were very large when substantial numbers of Euro-American immigrants began arriving in the 1840s. Because of this immigration, the human population ceased declining and began growing slowly by mid-century.

The mid- to late 1800s also saw the refinement and widespread adoption of powerful fishing methods (traps, fish wheels, gill nets) and the development of techniques to efficiently process, preserve, and distribute the catch using steel cans (Smith 1979). In addition to their abundance, consumer appeal, relative ease of capture, and amenability to mechanization of processing and preservation, salmon offered the allure of reliability. The timing and approximate size of annual salmon runs were dependable, so fishermen, canners, and distributors could plan with confidence.

The consequences of the huge increase in fishing pressure in the mid- to late 1800s (coupled with other widespread human actions such as mining, grazing, and logging) were massive and rapid for many salmon stocks, even though salmon runs in the early to mid-1800s were probably at their historical highs (Chapman 1986). By 1900 many stocks were reduced below levels required to ensure reproductive success, let alone support fishing; some probably were extirpated during this period of accelerated pressure on the resource.

The well-documented history of the Columbia River "industrial" salmon fishery illustrates the dramatic effects of intense, minimally regulated fishing:

> . . . the Columbia River canned salmon industry, which began in 1866 [was] by the late 1880s . . . the biggest salmon-producing area on the Pacific Coast. During the early 1900s, the salmon industry was Oregon's third largest, but by 1975 the amount of salmon canned dropped to a level less than the pack of 1867, the second year of the industry. (Smith 1979).

Competition for salmon was severe throughout the 20th century; commercial, Indian, and recreational fishermen demanded a portion of dwindling runs and successfully pressured fisheries managers to sanction relatively high harvest levels (Smith 1979; McEvoy 1986; Taylor 1999). There was (and *is*) reluctance to reduce fishing pressure because the immediate economic and social consequences were and are real and often severe (McLain and Lee 1996). Further, U.S. and Canadian provincial fish and wildlife agencies, usually supported largely by the sale of fishing and hunting licenses and taxes on fishing equipment, have generally shown a distinct bias toward maintaining a high level of fishing (Volkman and McConnaha 1993).

The general pattern of rapidly increasing harvest and eventual over-exploitation seen with salmon is typical in renewable natural resource management (Hilborn et al. 1995). By the 1930s, and prior to completion of the Columbia River main-stem dams, salmon stocks were substantially reduced from the levels of the mid 1800s. For example, the significant drop in Columbia River salmon harvest around 1925 marked the beginning of a long salmon decline and coincided with a change in oceanic conditions for salmon from favorable to unfavorable (Anderson 2000).

Dam Construction

High harvest rates are not the only major cause of salmon decline. Dams were built on many rivers and streams for navigation, irrigation, power generation, log transport, and flood control, starting in the 1930s, and continuing through the 1970s (Netboy 1980; Hartman et al. 2000). Floods, for example, have been common and devastating (for humans); particularly devastating floods occurred in 1861, 1876, 1894, 1948, 1964, and 1996. Therefore, flood control, and associated dam, levee, and channel construction, has been a societal priority for over a century, even though salmon appear to have prospered before human disturbance in spite of periodic floods (Ligon et al. 1995; National Research Council 1996).

Dams impede passage of both returning spawners and outmigrating young fish. Moving salmon past dams has long been a challenge to fisheries managers and engineers. Some dams totally block salmon migration. In the Columbia Basin because of dams, access to over one-third of the habitat formerly occupied by salmon is now completely blocked to salmon migration. Further, dams alter key characteristics of water, especially temperature, dissolved gases, sediment transport, and the quantity and timing of flow (Ligon et al. 1995; Power et al. 1996). Each dam in its turn has caused adverse consequences, some small, others huge, for salmon.

Agriculture

Salmon runs also dwindled as agricultural development took place in the region (Cone and Ridlington 1996). Because most of the region is arid and irrigation has been necessary for economically viable farming, water diversions (and dams) for irrigation, coupled with wide-scale agricultural use of chemical fertilizers and pesticides, have indirectly contributed to reductions in salmon runs (Scholz et al. 2000). While a substantial portion (probably 15 to 20 percent) of the annual flow of the Columbia Basin is diverted for agricultural, commercial, and municipal uses, the extent of water withdrawals from individual streams varies markedly. Therefore, the true effect of water withdrawal on salmon runs must be assessed on a local basis. Also, cattle and sheep grazing (and many other agricultural practices) can adversely affect salmon by degrading water quality and physically altering spawning and nursery habitat. Agricultural practices can be especially harmful if the run size has already been reduced (Mundy 1997).

Pollutants can also cause adverse effects on salmon (Baldwin et al. 2003). Although highly visible fish-kills tend to be rare, sublethal effects of pollutants on salmon are well documented (Heintz et al. 2000).

Timber Harvest

Timber in the region is of high commercial quality (especially the forests in the Cascade and Coast Ranges) and there has been considerable economic incentive to use this natural resource. The harvest and transport of timber (initially by water released from splash dams and later by an extensive system of forest and rural roads) has also had adverse effects on salmon spawning and rearing. Logging and associated road construction (especially prior to governmental regulation and widespread adoption of improved management practices) caused increased water temperature and sediment load, and other changes that decrease the quality of salmon habitat (Meehan and Bjornn 1991). It is unclear to date how changes in road-building practices, selective reductions in harvesting, global shifts in timber markets, and new harvest technologies have cumulatively affected salmon habitat through the last several decades.

Fish Hatcheries

Use of fish hatcheries has been blamed for causing major problems for *wild* salmon (Hilborn 1992; Waples 1999), but the full extent of the effects is difficult to assess. Pacific salmon can be spawned and easily raised under artificial conditions. Historically, fisheries managers focused on hatcheries as a tool to maintain declining runs and harvest levels (mainly responding to the adverse effects caused by dams, habitat deterioration, or overexploitation) (Levin et al. 2001; Brannon et al. 2004). Hatcheries were often successful in maintaining a semblance of salmon runs that would not otherwise have survived, but hatchery programs have probably accelerated declines of *wild* salmon (National Research Council 1996; Noakes et al. 2000). Hatchery-produced fish may introduce diseases, compete with naturally spawned fish, and alter genetic diversity through interbreeding, which affects the "fitness" of subsequent generations (Waples 1999; Noakes et al. 2000; Levin and Schiewe 2001; Lynch and O'Hely 2001).

After evaluating the effectiveness of hatcheries, Hilborn (1992) concluded:

> Large-scale hatchery programs for salmonids in the Pacific Northwest have largely failed to provide the anticipated benefits; rather than benefiting the salmon population, these programs may pose the greatest single threat to the long-term maintenance of salmonids.

However, Michael (1999) acknowledged that, at least for many areas of the Pacific Northwest, society should:

> . . . recognize that habitat has been so altered that the cost of producing meaningful numbers of wild anadromous salmonids is too high and that wild salmonids may become essentially extinct. In these areas there will be extensive artificial-production programs designed to provide desired levels of harvest.

Brannon et al. (2004), after a careful review of the extensive literature on the subject, conclude that ". . . hatchery fish have an important role in recovery and supplementation of wild stocks."

From the late 1800s to the late 1900s, attitudes toward hatcheries, at least among fisheries scientists, evolved from near universal support to widespread skepticism as policy priorities shifted toward preserving *wild* salmon rather than maintaining runs using artificially spawned fish (Bottom 1997; Taylor 1999). Many individuals are now hostile to the use of hatcheries, contending that the more than 100 hatcheries releasing salmon into the Columbia River system actually worsen conditions for wild salmon. There are probably 500 salmon hatcheries in California, Oregon, Washington, Idaho, and British Columbia. The counter argument is that hatcheries *can* maintain salmon runs, even in rivers where there is no other practical option (Michael 1999).

Hatcheries cause significant management challenges for maintaining runs of wild salmon (Levin et al. 2001). They can mask the decline of wild stocks by the presence of relatively abundant hatchery-bred salmon, a situation that takes place even in near-pristine habitat (Bottom 1997). Hatchery-produced fish mix with naturally spawned fish, resulting in simultaneous harvest ("mixed stock fisheries") of abundant hatchery fish and less common wild fish. It is difficult, impossible perhaps in practice, to harvest abundant hatchery salmon and concurrently protect scarce wild salmon. McGinnis (1994) concludes that:

> . . . hatchery production of salmon masks the decline of wild salmon, contributes to the genetic dilution and loss of wild salmon, and increases competition for limited freshwater and ocean resources on which wild salmon depend.

In an effort to permit continued fishing for relatively abundant hatchery salmon, while protecting depleted wild salmon runs, agencies sometimes permit "mixed stock selective fishing." The basic approach is to mark (by removing the adipose fin) each hatchery-raised salmon; thus if an unmarked salmon is caught, it is assumed to be wild and must be released. If selective fishing worked as intended, it would allow capture of abundant hatchery salmon, but would simultaneously safeguard less abundant wild fish.

Although conceptually appealing, the mixed stock selective fishing has the potential weaknesses of inflicting additional mortality on wild stocks that already may be at perilously low levels. The causes of additional mortality on wild salmon are: (1) selective fishing does not work in situations where the harvest method (i.e., gill netting and purse seining) results in the death of most captured salmon; (2) some fish die after being hooked, caught, and released (collectively called "hooking mortality"); (3) not all fishermen comply with the legal requirement to release unmarked fish ("non-compliance mortality"); and (4) illegal fishing is more difficult to police when some legal fishing is permitted ("poaching mortality").

Selective fishing regulations in fisheries management is expensive: hatchery-produced fish are costly to produce; marking *all* hatchery fish is labor-intensive and costly; monitoring the effects of fishing on wild stocks requires extensive field sampling; and law enforcement must be vigorous and continuous. For all of its risks, selective fishing currently may be the only way to permit fishing on mixed stocks with any chance of protecting vulnerable stocks. It is theoretically possible to use "fish friendly" nets or other harvest gear that inflict less capture and handling mortality on salmon. It might even be possible to modify the run timing of hatchery fish so they do not mix with wild fish and can therefore be harvested without concern for wild stocks (Brannon et al. 2004).

Atlantic Salmon

In the past 25 years Atlantic salmon (*Salmo salar*), a species not native to the Pacific Ocean and its tributaries, has become the dominant species used in salmonid aquaculture. There are major "pen rearing" operations in British Columbia and Washington (Noakes et al. 2000). One concern with these operations is that this exotic species might establish naturally reproducing populations and adversely affect wild native salmonids (Volpe et al. 2000). Among fisheries scientists there has been debate about the likelihood of anadromous runs of Atlantic salmon becoming established in western North America (Noakes et al. 2000). Gross (1998), after reviewing the experiences with farming Atlantic salmon in many different places throughout the world, concluded as to their likelihood of establishment in the Pacific:

> . . . the opportunity for invasion is unprecedented and success is probable at the current state of domestication of Atlantic salmon. Whether a new salmonid species in the Pacific drainage would result in a net decrease to all salmonid biodiversity through negative impacts, or instead increase total biodiversity through the addition of a new species, remains an open question."

There has been strong evidence of natural reproduction of aquaculture-escaped Atlantic salmon in British Columbia (Volpe et al. 2000)

In addition to those involved in commercial salmon aquaculture, there are other proponents of artificial propagation of salmon as an appropriate management tool. Some advocacy groups representing recreational, commercial, and Indian fishermen support use of hatcheries to supplement wild salmon runs. These proponents argue that there is no short term alternative if significant levels of harvest are to be maintained. Indian advocacy groups usually argue that treaty rights require the maintenance of salmon runs by whatever means is available (Scarce 2000). Commercial fishermen often argue that they invested heavily in expensive gear with the implied commitment that salmon runs would be maintained.

Other Non-native Species

From the perspective of proponents of salmon restoration, another troublesome development has been the intentional introduction of many non-native fishes (exotics) including walleye, striped bass, American shad, brown and brook trout, small- and largemouth bass, bluegill, northern pike, crappie, yellow perch, channel catfish, and carp (Fresh 1997; Levin et al. 2002) and the expansion in distribution of native species such as squawfish (also called northern pikeminnow) due to habitat alteration such as dam construction). Certain highly valued native species, such as rainbow trout and steelhead, were stocked widely outside their range. Often helped by habitats altered by human actions, some exotic and native fishes flourished. Once these fishes establish thriving populations in habitats no longer favorable for salmon, it is extremely difficult to reestablish viable salmon runs. Further, some agencies continue to manage in favor of popular, exotic game species and indirectly abet the decline of wild salmon (Taylor 1999). Conversely, because many aquatic environments in western North America are vastly altered (generally changed from flowing water to impounded water, from multiple channels to single channels, and from flood prone runoff to regulated runoff), there would now be very little fishing in much of the region if exotic species had not become established.

Ocean Conditions

Most salmon spend the majority of their lives in the ocean, not in freshwater environments, so the oceanic and coastal portion of their life cycle must also be considered in assessing the causes of the current declines (Pearcy 1997; Finney et al. 2000; Welch et al. 2000). Oceanic factors play an important role in salmon production on both sides of the North Pacific Ocean (Pulwarty and Redmond 1997). For example, the long-term pattern of the Aleutian low-pressure weather system appears to correlate with trends in salmon run size (Hare et al. 1999). On shorter time scales, and depending on the salmon species, stock, and where individuals in the stock spend the majority of their ocean life, El Niño and La Niña events may have detrimental or favorable effects. Although usually poorly quantified, it is undisputed that high quality freshwater habitat plays a critical role in the persistence of salmon stocks and especially during periods of unfavorable ocean conditions (Lawson 1993; Bisson et al. 1997). Welch et al. (2000) concluded that sudden and large changes in ocean conditions directly and significantly affected steelhead and coho stocks throughout much of their range on the west coast of North America.

Climate Change

Climatic variations also affect the condition of salmon stocks in freshwater (Pearcy 1997; Pulwarty and Redmond 1997), but as with oceanic variations, the type and extent of effects on salmon is rarely straightforward. Examples of climatic change in the region are the severe winters of the 1880s when many range cattle were killed, the extreme droughts of the 1910s and 1930s when many farmers were driven off their land, and the general drought of the 1970s and 1980s when water use conflicts were exacerbated. Over the last hundred years three major climatic and oceanic shifts have occurred (1925, 1947, and 1977) which significantly altered salmon survival in the Pacific Northwest (Anderson 2000). The past three decades in the Pacific Northwest have been among the warmest and driest for hundreds of years. If future climatic change (i.e., natural or human induced global warming) causes even more adverse conditions, then additional sections of the current range of Pacific salmon will likely be occupied by fishes better adapted to these altered habitats, exacerbating the competition faced by the remaining salmon (Lackey 1999a).

Predation

Predation on salmon (and all animals) is a natural phenomenon and would take place in the absence of humans. Some predators, especially marine mammals, birds, smallmouth bass, brook trout, mackerel, squawfish, and others are often identified as contributing to the decline of salmon (Smith et al. 1998; Levin et al. 2002; Fritts and Pearsons 2004). Since the early 1970s the number of Pacific harbor seals and California sea lions has increased to historical levels because harvest of these animals has been prohibited by U.S. and Canadian laws (Fresh 1997). These animals are especially efficient in capturing returning adult salmon congregated at river mouths and artificial constrictions in rivers (National Research Council 1996). Marine mammals do have significant effects on some salmon runs, but they are not believed to be one of the overriding causes of the general decline of wild salmon stocks (Fresh 1997). However, when a salmon run is threatened with extinction, any mortality is cause for concern and tends to prevent or retard recovery.

Squawfish, gulls, Caspian terns, and double-crested cormorants, tend to congregate around dam sites and in estuaries, and in some locations, can consume large numbers of juvenile salmon (National Research Council 1996). Squawfish populations in the Columbia and Snake rivers, for example, consume significant numbers of uninjured juvenile salmon (an estimated 16 million individuals or 8 percent of the population of juveniles) that would otherwise have survived migration (Beamesderfer et al. 1996). Caspian terns, a species that often congregates in large nesting colonies, have become well established on the lower Columbia (on islands created by deposition of dredge spoil) and are now a major local source of predation on young salmon migrating to the ocean. When considering all the causes of salmon decline, predation by marine mammals, birds, and squawfish may not be a dominant regional cause, but it can be a significant local factor, especially when salmon runs are low (National Research Council 1996).

Endangered Species Issues

Salmon policy and management in both the United States and Canada have recently become much more tangled with the application of the ESA and SARA (Rohlf 1991; Smith et al. 1998). A spirited debate over the policy-effectiveness of listing individual stocks or groups of stocks (e.g., evolutionarily significant units, metapopulations, or distinct population segments) as threatened or endangered has dominated salmon policy debate through the 1990s (Hyatt and Riddell 2000). Some people (e.g., McGinnis 1994) hail the ESA as the needed stimulus to provide " . . . a major incentive to develop a comprehensive watershed-by-watershed effort to restore wild salmon populations." Others reject the Act as an inflexible law based on a narrow set of societal preferences and predicated on a naive understanding of modern ecology. Yet others claim that ecology itself may not be up to the task (Carpenter 2002).

Many ethical, political, and scientific issues envelop policies on threatened and endangered salmon (Polasky and Doremus 1998). To some, the debate over declining salmon runs is simply a matter of choosing among options, similar to choices required for deciding energy, transportation, or international trade policies. Agreement on a plan to "save" wild salmon would be achieved by following the classic political process of compromise and trade-off.

Others view endangered salmon issues in the stark terms of right and wrong, moral and immoral, ethical and unethical. Indian advocates often base their arguments on a religious argument that is protected in law by court interpretations of treaties. If a participant in the policy debate perceives the salmon decline issue as principally a moral or ethical one, it is not realistic to expect a political compromise. Such strongly held policy positions mean the ultimate resolution will be perceived unconditionally as win-lose.

Still others hold strong moral and ethical views on endangered salmon concerns, but view such issues through the prism of competing rights — the rights of the public at large *vs.* the rights of individuals. An example is the ongoing debate over the legal adjudication of situations where a public action constitutes a "taking" of private property and requires financial compensation to the owner (Polasky and Doremus 1998). Society may conclude that preservation of salmon is important, but temper this position with the proviso that regulations to achieve this objective should not disproportionately burden particular members of society. The political argument is usually that no one should be required *de facto* to relinquish his private property without compensation caused by a "regulatory taking." The counter argument is that those individuals and segments of society that exacerbate the salmon decline or impede recovery ought to bear the cost of recovery. Those segments of society (e.g., Native American groups or other countries) who believe that their position is protected by treaties are likely to seek adjudication through the courts.

Debate over the ESA and SARA, especially their implementation relative to salmon restoration, is characterized by truculent adversaries who denigrate the motives of other combatants. The opposing sides have different motives and each policy choice involves winners and losers.

Some skeptics question how democratic institutions are to choose among salmon restoration options when the losers cede so much and there is little societal consensus except at the most general, abstract level. Others assert that we have *de facto* accepted the philosophy of those who hold it morally improper to extirpate a species or subspecies under any circumstances. Is compromise possible when options are mutually exclusive? Can public policy be implemented when a "choice" can end up in court for years? And what is so important to society about individual stocks, much less the emerging but contentious concept of evolutionarily significant units? Are critics correct in asserting that the Act is pre-ordained to failure because compliance costs sometimes fall heavily on private landowners, who lose land, pay fines, face restriction on use of their property, or watch their investments and business ventures collapse? Or are these simply groundless charges playing on people's skepticism of government? Each of these questions, of course, has many answers, and the answers help explain the various political viewpoints that characterize the salmon policy debate.

In practice, the management consequences of the ESA tend to be greatest on public lands, especially Federal lands. Supporters usually argue that, even if the consequences of either Act are painful, the pain is a necessary part of a last ditch effort to save listed species. But such "pain," whether current or anticipated, evokes political backlash to using the Acts as tools to protect and restore salmon:

> This is as much a human crisis as a salmon crisis. We must commit ourselves to restoring a balance between the interests of humans and of salmon, and must do so soon. We used to ask how we could save salmon without hurting people, but that compromised nature too often. The Endangered Species Act reversed the equation by blocking all development that threatened salmon, but that raised protests because the law ignored important human interests. Neither way has worked. (Taylor 1999)

Arguments in support of the ESA and SARA (and similar legislation) are often moral assertions not amenable to easy compromise. There may be references to the importance of protecting species because of their commodity value or their use as surrogates for environmental quality, but the issue is inherently whether humans have (or should have) a right to drive a species, stock, evolutionarily significant unit, or metapopulation to extinction, or hasten their extirpation from a particular region.

Others argue that historical perspective is required because species extinctions are not new. People have been moving to the region for the past 15,000 years and causing “problems” from the start (McCann 1999). As recently as 10,000 years ago, the region supported mastodons, mammoths, giant sloths, giant armadillos, giant beavers, American camels, American horses, the American tiger, and the giant wolf — all of which are now extinct, probably due to a combination of hunting, climate change, and introduced diseases (Pielou 1991; McCann 1999).

While species (and stock) extinctions are not new in the region, it is the rate and scale that are the issue today, and that the causes chiefly reflect human actions (Hartman et al. 2000). Salmon gene pools (stocks) that survived perhaps 10 millennia were eradicated within a few human generations. Only mighty events such as cataclysmic volcanic eruptions, colossal earthquakes, and severe climatic episodes such as droughts have previously caused salmon stock extinctions at the scale observed today in California and the Pacific Northwest.

Is the ESA or SARA the appropriate type of policy tool to reverse the salmon decline? Was it envisioned by its proponents as a legal tool to address effectively such a complex ecological and social problem? Jack Ward Thomas (2000), former chief of the U.S. Forest Service and veteran of endangered species conflicts in the Pacific Northwest, concluded:

> It does not seem possible that the Endangered Species Act was written, debated, and passed with any inkling that an issue of the magnitude of the Columbia salmon issue would arise. Magnified by the collateral issue of tribal fishing rights, this set of circumstances makes the spotted owl/old growth issue pale into relative simplicity and insignificance.

Salmon Policy

Even more than a new policy or management paradigm, any credible effort to restore wild salmon will require the active involvement of salmon technocrats (salmon scientists working within bureaucracies of various kinds). Technocrats do not *make* policy decisions, but because of their expertise they provide information to those who do, or implement policy decisions made by others. The appropriate role of salmon technocrats, however, is not often appreciated by the public nor by policy officials because providing information that is both policy-relevant and policy-neutral is often quite complicated (Smith et al. 1998; Lackey 1999b; Mills 2000).

For the salmon technocrat, providing useful scientific information to assist decision-makers takes place on a battlefield of intractable policy alternatives, complex and contentious scientific challenges, and confused roles (Scarce 2000). There are forceful advocacy groups representing commercial, recreational, and Indian fishermen; agricultural activities; various elements of the transportation sector; forest and rangeland users; electrical generators and users; natural resource management agencies; various segments of the environmental movement; endangered species and animal rights proponents; and municipal and local governments. Further, the general public is only marginally aware of the implications and trade-offs of the various policy options, in part attributable to superficial reporting by much of the media (Black 1995). Technocrats themselves often have strong personal policy preferences and end up arguing for "salmon friendly" policy positions.

What role salmon technocrats should play in salmon policy is a time-honored discussion topic among technocrats and policy advocates (Cooperrider 1996; Lackey 1999b; Salonius 1999; Mills 2000). Some advise staying out of the policy arena; others bluntly encourage all technocrats to argue for those public policies they prefer. In their conferences and publications, members of the American Fisheries Society regularly squabble over the proper role of members and the Society relative to advocacy.

The public and policy makers have a right to expect salmon technocrats to be honest in providing scientific information, but though that may seem uncomplicated, such honesty is not necessarily a given. It is easy to avoid communicating the entire truth about the ecological consequences of various salmon policy decisions and partial truths can unintentionally mislead people:

> . . . water managers have been asking fishery biologists to determine how to maintain salmon runs while damming rivers. Biologists dutifully proceeded to experiment with fish hatcheries, minimal flows, and so on, many of them knowing that such mitigations are virtually hopeless. In retrospect scientists should not have played this role." (Cooperrider 1996)

However, organizations typically direct their fisheries technocrats to work with their counterparts in other organizations to attempt to minimize the effect of human actions on salmon runs.

Policy debates often focus on narrow, relatively insignificant technical or scientific issues (Smith et al. 1998). For example, there are over 250 major dams in the Columbia Basin. Arguments over removal of a few dams, or the options for transporting smolts around dams, are interesting and controversial technical debates, but aquatic and terrestrial habitats *have* drastically changed in the Columbia Basin over the past 150 years (Ligon et al. 1995; Kareiva et al. 2000). It is highly unlikely that *wild* salmon in substantial numbers (by historical standards) can be supported in such a highly modified environment. Society may choose to make the trade-offs necessary to maintain a *relatively* small number of wild salmon (current levels, perhaps), but technocrats should be bluntly realistic about the actual number of wild salmon that can be expected in the face of continuing watershed alteration that adversely affects salmon.

Being honest in providing scientific information also extends to full disclosure about scientific uncertainty and unknowns (Stephenson and Lane 1995). Presenting traditional statistical expressions of uncertainty is imperative, but so is acknowledging the boundaries of scientific knowledge, and explaining them in clear language. Predicting the ecological consequences of policy options is often little more than enlightened conjecture based on professional judgment, and that reality should be clearly conveyed to decision makers and the public (Scarce 2000).

Further, it is important for salmon technocrats to be honest and forthright about the assumptions used in developing and presenting scientifically based predictions (Mills 2000). Different predictions will emerge from the work of different scientists, depending on which, arguably valid, assumptions (e.g., anticipated human population growth or evolving life styles) are used in the technical analysis. Reasonable people differ on what are the most realistic assumptions, but the assumptions used will substantially determine the likelihood of success of most salmon policy options. It is wrong to hide these important assumptions from the users of the scientific information.

Few salmon technocrats intentionally misinterpret data, but what does the public *hear*? Much of the current salmon policy debate is over the extent to which freshwater habitat improvement and/or changes in oceanic conditions will stimulate a rejuvenation of wild salmon runs. Absent from the debate is the trajectory of human population growth in the United States in general, and the Pacific Northwest in particular (Table 3). If the average annual growth rate for the past half century (1.9 percent) continues, the current population of approximately 10 million (Oregon, Washington, and Idaho) will swell to 65 million by 2100 (National Research Council 1996). Using the same growth rate for British Columbia’s human population, we might arguably anticipate the human population of the Pacific Northwest to expand by the year 2100 from its current 14 million to 85 million. California, of course, supports a large (compared with the Pacific Northwest) human population that will be much larger by 2100.

On a worldwide scale, human population growth rates appear to be decreasing (Lutz et al. 2001), but the human population in western North America will be much larger in 2100 than now (Hartman et al. 2000). Current U.S. and Canadian policies in fact support human population increase through relatively open immigration, even as the current reproductive rate of the American- and Canadian-born segment of the human population is below the population replacement level (Salonius 1999). To overlook the near certain reality of a much larger human population, and the corresponding implications for the future of salmon, is misleading the public (Salonius 1999; Hartman et al. 2000). Some overall improvement in salmon spawning habitat *may* be possible *if* the number of humans in the Pacific Northwest remained static, but habitat improvements will be increasingly more difficult to achieve if the human population increases several-fold by 2100.

References

Adkison, Milo D., and Bruce P. Finney. 2003. The long-term outlook for salmon returns in Alaska. Alaska Fishery Research Bulletin 10(2):83-94.

Anderson, James J. 2000. Decadal climate cycles and declining Columbia River salmon. Pages 467-484 *in* E. Eric Knudsen, Cleveland R. Steward, Donald D. MacDonald, Jack E. Williams, and Dudley W. Reiser, editors. Sustainable fisheries management: Pacific salmon. Lewis Publishers, Boca Raton, Florida.

Augerot, Xanthippe. 2005. Atlas of Pacific salmon. University of California Press, Berkeley.

Babaluk, John A., James D. Reist, James D. Johnson, and Lionel Johnson. 2000. First records of sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) from Banks Island and other records of Pacific salmon in Northwest Territories, Canada. Arctic 53(2):161-164.

Baker, Timothy T., Alex C. Wertheimer, Robert D. Burkett, Ronald Dunlap, Douglas M. Eggers, Ellen I. Fritts, Anthony J. Gharrett, Rolland A. Holmes, and Richard L. Wilmot. 1996. Status of Pacific salmon and steelhead escapements in southeastern Alaska. Fisheries 21(10):6-18.

Baldwin, David H., Jason F. Sandahl, Jana S. Labenia, and Nathaniel L. Scholz. 2003. Sublethal effects of copper on coho salmon: impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. Environmental Toxicology and Chemistry 22:2266-2274.

Beamesderfer, Raymond C. P., David L. Ward, and Anthony A. Nigro. 1996. Evaluation of the biological basis for a predator control program on northern squawfish (*Ptychocheilus oregonensis*) in the Columbia and Snake rivers. Canadian Journal of Fisheries and Aquatic Sciences 53:2898-2908.

Beamish, Richard J. 1999. Shifting regimes in fisheries science and salmon management. International Journal of Salmon Conservation 5(1):12-16.

Bilby, Robert E., Brian R. Fransen, Jason K. Walter, C. Jeff Cederholm, and Warren J. Scarlett. 2001. Preliminary evaluation of the use of nitrogen stable isotope ratios to establish escapement levels for Pacific salmon. Fisheries 26(1):6-14.

Bisson, Peter A., Gordon H. Reeves, Robert E. Bilby, and Robert J. Naiman. 1997. Watershed management and Pacific salmon: desired future conditions. Pages 447-474 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Black, Michael. 1995. Tragic remedies: a century of failed fishery policy on California's Sacramento River. Pacific Historical Review 64:37-70.

Bottom, Daniel L. 1997. To till the water — a history of ideas in fisheries conservation. Pages

569-597 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Brannon, Ernest L., Donald F. Amend, Matthew A. Cronin, James E. Lannan, Scott LaPatra, William J. McNeil, Richard E. Noble, Charles E. Smith, Andre J. Talbot, Gary A. Wedemeyer, and Harry Western. 2004. The controversy about salmon hatcheries. Fisheries 29(9):12-31.

Carpenter, S. 2002. Ecological futures: building an ecology of the Long Now. Ecology 83:2069-2083.

Cederholm, C. Jeffrey, Matt D. Kunze, Takeshi Murota, and Atuhiro Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24(10):6-15.

Chapman, Don W. 1986. Salmon and steelhead abundance in the Columbia River in the nineteenth century. Transactions of the American Fisheries Society 115:662-670.

Chatters, James C., Virginia L. Butler, Michael J. Scott, David M. Anderson, and Duane A. Neitzel. 1995. A paleoscience approach to estimating the effects of climatic warming on salmonid fisheries of the Columbia River Basin. Pages 489-496 *in* Richard J. Beamish, editor. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121. National Research Council of Canada, Ottawa.

Cone, Joseph, and Sandy Ridlington, editors. 1996. The Northwest salmon crisis: a documented history. Oregon State University Press, Corvallis.

Cooper, Andrew B., and Marc Mangel. 1999. The dangers of ignoring metapopulation structure for the conservation of salmonids. Fishery Bulletin 97:213-226.

Cooperrider, Allen Y. 1996. Science as a model for ecosystem management — panacea or problem. Ecological Applications 6:736-737.

Denevan, William M. 1992. The pristine myth: the landscape of the Americas in 1492. Annals of the Association of American Geographers 82:369-385.

Dodson, Julian J., R. John Gibson, Richard A. Cuneal, Kevin D. Friedland, Carlos Garcia de Leaniz, Mart R. Gross, Robert Newbury, Jennifer L. Nielsen, Mary E. Power, and Steven Roy. 1998. Elements in the development of conservation plans for Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 55(Supplement 1):312-323.

Downton, Mary W., and Kathleen A. Miller. 1998. Relationships between Alaskan salmon catch and North Pacific climate on interannual and interdecadal time scales. Canadian Journal of Fisheries and Aquatic Sciences 55:2255-2265.

Finney, Bruce P., Irene Gregory-Eaves, Jon Sweetman, Marianne S. V. Douglas, and John P. Smol. 2000. Impacts of climatic change and fishing on Pacific salmon abundance over the past 300 years. Science 290:795-799.

Fresh, Kurt L. 1997. The role of competition and predation in the decline of Pacific salmon and steelhead. Pages 245-275 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Fritts, Anthony L., and Todd N. Pearsons. 2004. Smallmouth bass predation on hatchery and wild salmonids in the Yakima River, Washington. Transactions of the American Fisheries Society 133:880-895.

Gresh, Ted, James A. Lichatowich, and Peter Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. Fisheries 25(1):15-21.

Groot, Cornelis, and Leo Margolis, editors. 1991. Pacific salmon life histories. University of British Columbia Press, Vancouver.

Gross, Mart R. 1998. One species with two biologies: Atlantic salmon (*Salmo salar*) in the wild and in aquaculture. Canadian Journal of Fisheries and Aquatic Sciences 55(Supplement 1):131-144.

Hare, Steven R., Nathan J. Mantua, and Robert C. Francis. 1999. Inverse production regimes: Alaska and west coast Pacific salmon. Fisheries 24(1):6-14.

Harris, Cole. 1997. The resettlement of British Columbia: essays on colonialism and geographical change. University of British Columbia Press, Vancouver.

Hartman, Gordon F., Cornelis Groot, and Thomas G. Northcote. 2000. Science and management in sustainable fisheries: the ball is not in our court. Pages 31-50 *in* E. Eric Knudsen, Cleveland R. Steward, Donald D. MacDonald, Jack E. Williams, and Dudley W. Reiser, editors. Sustainable fisheries management: Pacific salmon. Lewis Publishers, Boca Raton, Florida.

Hassemer, Peter F., Sharon W. Kiefer, and Charles E. Petrosky. 1997. Idaho’s salmon: can we count every last one? Pages 113-125 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Heintz, Ron A., Stanley D. Rice, Alex C. Wertheimer, Robert F. Bradshaw, Frank P. Thrower, John E. Joyce, and Jeffrey W. Short. 2000. Delayed effects on growth and marine survival of pink salmon (*Oncorhynchus gorbuscha*) after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208:205-216.

Hilborn, Ray W. 1992. Hatcheries and the future of salmon in the Northwest. Fisheries 17(1):5-8.

Hilborn, Ray W., Thomas P. Quinn, Daniel E. Schindler, and Donald E. Rodgers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences 100:6564-6568.

Hilborn, Ray W., Carl J. Walters, and Donald Ludwig. 1995. Sustainable exploitation of renewable resources. Annual Review of Ecology and Systematics 26:45-67.

Hovey, Tim E. 2004. Current status of southern steelhead/rainbow trout in San Mateo Creek, California. California Fish and Game 90:140-154.

Huntington, Charles W., Willa Nehlsen, and Jon K. Bowers. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. Fisheries 21(3):6-14.

Hyatt, Kim D., and Brian E. Riddell. 2000. The importance of “stock” conservation definitions to the concept of sustainable fisheries. Pages 51-62 *in* E. Eric Knudsen, Cleveland R. Steward, Donald D. MacDonald, Jack E. Williams, and Dudley W. Reiser, editors. Sustainable fisheries management: Pacific salmon. Lewis Publishers, Boca Raton, Florida.

Johnson, Thom H., Rich Lincoln, Gary R. Graves, and Robert G. Gibbons. 1997. Status of wild salmon and steelhead stocks in Washington State. Pages 127-144 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Kareiva, Peter, Michelle Marvier, and Michelle McClure. 2000. Recovery and management options for spring/summer Chinook salmon in the Columbia River Basin. Science 290:977-979.

Knudsen, E. Eric, Cleveland R. Steward, Donald D. MacDonald, Jack E. Williams, and Dudley W. Reiser. 2000. Sustainable fisheries management: Pacific salmon. Lewis Publishers, Boca Raton, Florida.

Kostow, Kathryn E. 1997. The status of salmon and steelhead in Oregon. Pages 145-178 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Kruse, Gordon H. 1998. Salmon run failures in 1997-1998: a link to anomalous ocean conditions? Alaska Fishery Research Bulletin 5:55-63.

Lackey, Robert T. 1997. Restoration of Pacific salmon: the role of science and scientists. Pages 35-40 *in* Sari Sommarstrom, editor. What is watershed stability? Water Resources Center Report 92. Centers for Water and Wildland Resources, University of California, Davis.

Lackey, Robert T. 1999a. Salmon policy: science, society, restoration, and reality. Renewable Resources Journal 17(2):6-16.

Lackey, Robert T. 1999b. The savvy salmon technocrat: life's little rules. Environmental Practice 1:156-161.

Lang, William L. 1996. River of change: salmon, time, and crisis on the Columbia River. Pages 348-363 *in* Joseph Cone and Sandy Ridlington, editors. The Northwest salmon crisis: a documentary history. Oregon State University Press, Corvallis.

Lawson, Peter W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries 18(8):6-10.

Levin, Phillip S., and Michael H. Schiewe. 2001. Preserving salmon biodiversity. American Scientist 89(3):220-227.

Levin, Phillip S., Stephen Achord, Blake E. Feist, and Richard W. Zabel. 2002. Non-indigenous brook trout and the demise of Pacific salmon: a forgotten threat? Proceedings of the Royal Society of London: Biological Sciences 269:1663-1670.

Levin, Phillip S., Richard W. Zabel, and John G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proceedings of the Royal Society of London: Biological Sciences 268:1153-1158.

Lichatowich, James A. 1999. Salmon without rivers: a history of the Pacific salmon crisis. Island Press, Washington, D.C.

Ligon, Franklin K., William E. Dietrich, and William J. Trush. 1995. Downstream ecological effects of dams. BioScience 45:183-192.

Lutz, Wolfgang, Warren Sanderson, and Sergei Scherbov. 2001. The end of world population growth. Nature 412:543-545.

Lynch, Michael, and Martin O'Hely. 2001. Captive breeding and the genetic fitness of natural populations. Conservation Genetics 2:363-378.

McCann, Joseph M. 1999. Before 1492: the making of the pre-Columbian landscape: part I: the environment. Ecological Restoration 17(1-2):15-30.

McEvoy, Arthur F. 1986. The fisherman's problem: ecology and law in the California fisheries, 1850-1980. Cambridge University Press, Cambridge, UK.

McGinnis, Michael V. 1994. The politics of restoring versus restocking in the Columbia River. Restoration Ecology 2:149-155.

McGinnis, Michael V. 1995. On the verge of collapse: the Columbia River system, wild salmon, and the Northwest Power Planning Council. Natural Resources Journal 35(1):63-92.

McLain, Rebecca J., and Robert G. Lee. 1996. Adaptive management: promises and pitfalls. Environmental Management 20:437-448.

McLeod, C. L., and J. P. O'Neil. 1983. Major range extensions of anadromous salmonids and first record of Chinook salmon in the Mackenzie River drainage. Canadian Journal of Zoology 61:2183-2184.

Meehan, William R., and Ted C. Bjornn. 1991. Salmonid distributions and life histories. Pages 47-82 *in* William R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.

Meengs, Chad C., and Robert T. Lackey. 2005. Estimating the size of historical Oregon coastal salmon runs. Reviews in Fisheries Science 13:51-66.

Michael, John H. 1999. The future of Washington salmon: extinction is not an option but may be the preferred alternative. Northwest Science 73(3):235-239.

Mills, Terry J., Dennis R. McEwan, and Mark R. Jennings. 1997. California salmon and steelhead: beyond the crossroads. Pages 91-111 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Mills, Thomas J. 2000. Position advocacy by scientists risks science credibility and may be unethical. Northwest Science 74(2):165-168.

Mundy, Phillip R. 1997. The role of harvest management in the future of Pacific salmon populations: shaping human behavior to enable the persistence of salmon. Pages 315-329 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Mundy, Phillip R., Thomas W. H. Backman, and Jim M. Berkson. 1995. Selection of conservation units for Pacific salmon: lessons from the Columbia River. Pages 28-38 *in* Jennifer L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society, Symposium 17, Bethesda, Maryland.

National Research Council. 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.

Nehlsen, Willa, Jack E. Williams, and James A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Nielsen, Jennifer L. 2004. History and effects of hatchery salmon in the Pacific. Pages 153-167 *in* Patricia Gallaugher and Laurie Wood, editors. Proceedings of the World Summit on Salmon. Simon Fraser University, Burnaby, British Columbia.

Nemeth, Douglas, and Russell B. Kiefer. 1999. Snake River spring and summer Chinook salmon — the choice for recovery. Fisheries 24(10):16-23.

Netboy, Anthony. 1980. The Columbia River salmon and steelhead trout: their fight for survival. University of Washington Press, Seattle.

Noakes, Donald J., Richard J. Beamish, and Michael L. Kent. 2000. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia. Aquaculture 183:363-386.

Northcote, Thomas G., and Dana Y. Atagi. 1997. Pacific salmon abundance trends in the Fraser River Watershed compared with other British Columbia systems. Pages 199-219 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Pearcy, William G. 1992. Ocean ecology and North Pacific salmonids. University of Washington Press, Seattle.

Pearcy, William G. 1997. Salmon production in changing ocean domains. Pages 331-352 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Pielou, E. C. 1991. After the Ice Age: the return of life to glaciated North America. University of Chicago Press, Chicago, Illinois.

Polasky, Stephen, and Holly Doremus. 1998. When the truth hurts: endangered species policy on private land with imperfect information. Journal of Environmental Economics and Management 35:22-47.

Power, Mary E., William E. Dietrich, and Jacques C. Finlay. 1996. Dams and downstream aquatic biodiversity: potential food web consequences of hydrologic and geomorphic change. Environmental Management 20:887-895.

Pulwarty, Roger S., and Kelly T. Redmond. 1997. Climate and salmon restoration in the Columbia River Basin: the role and usability of seasonal forecasts. Bulletin of the American Meteorological Society 78:381-397.

Quinn, Thomas P. 2005. The behavior and ecology of Pacific salmon and trout. American Fisheries Society, Bethesda, Maryland.

Robbins, William G. 1996. The world of Columbia River salmon: nature, culture, and the great river of the west. Pages 2-24 *in* Joseph Cone and Sandy Ridlington, editors. The Northwest salmon crisis: a documentary history. Oregon State University Press, Corvallis.

Rohlf, Daniel J. 1991. Six biological reasons why the Endangered Species Act doesn't work — and what to do about it. Conservation Biology 5:273-282.

Salonius, Peter O. 1973. Barriers to range extension of Atlantic and Pacific salmon in arctic North America. Arctic 26:112-122.

Salonius, Peter O. 1999. Population growth in the United States and Canada: a role for scientists. Conservation Biology 13:1518-1519.

Scarce, Rik. 2000. Fishy business: salmon, biology, and the social construction of nature. Temple University Press, Philadelphia, Pennsylvania.

Schalk, Randall F. 1986. Estimating salmon and steelhead usage in the Columbia Basin before 1850: an anthropological perspective. Northwest Environmental Journal 2(2):1-29.

Scholz, Nathaniel L., Nathan K. Truelove, Barbara L. French, Barry A. Berejikian, Thomas P. Quinn, Edmundo Casillas, and Tracy K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 57:1911-1918.

Slaney, Tim L., Kim D. Hyatt, Thomas G. Northcote, and Robert J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21(10):20-35.

Smith, Courtland L. 1979. Salmon fishers of the Columbia. Oregon State University Press, Corvallis.

Smith, Courtland L., Jennifer Gilden, Brent S. Steel, and Karina Mrakovcich. 1998. Sailing the shoals of adaptive management: the case of salmon in the Pacific Northwest. Environmental Management 22:671-681.

Stephenson, Robert L., and Daniel E. Lane. 1995. Fisheries management science: a plea for conceptual change. Canadian Journal of Fisheries and Aquatic Sciences 52:2051-2056.

Swezey, Sean L., and Robert F. Heizer. 1977. Ritual management of salmonid fish resources in California. Journal of California Anthropology 4(1):6-29.

Taylor, Joseph E. 1999. Making salmon: an environmental history of the Northwest fisheries crisis. University of Washington Press, Seattle.

Thomas, Jack W. 2000. Watching the Columbia River salmon dwindle toward extinction — elephants in the room. Northwest Science 74(3):248-253.

Volkman, John M., and Willis E. McConnaha. 1993. Through a glass, darkly: Columbia River salmon, the Endangered Species Act, and adaptive management. Environmental Law 23:1249-1272.

Volpe, John P., Eric B. Taylor, David W. Rimmer, and Barry W. Glickman. 2000. Evidence of natural reproduction of aquaculture-escaped Atlantic salmon in a coastal British Columbia river. Conservation Biology 14:899-903.

Waples, Robin S. 1995. Evolutionarily significant units and the conservation of biological diversity under the Endangered Species Act. Pages 8-27 *in* Jennifer L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society, Symposium 17, Bethesda, Maryland.

Waples, Robin S. 1999. Dispelling some myths about hatcheries. Fisheries 24(2):12-21.

Welch, David W., Bruce R. Ward, Barry D. Smith, and J. P. Eveson. 2000. Temporal and spatial responses of British Columbia steelhead (*Oncorhynchus mykiss*) populations to ocean climate shifts. Fisheries Oceanography 9:17-32.

Wertheimer, Alex C. 1997. Status of Alaska salmon. Pages 179-197 *in* Deanna J. Stouder, Peter A. Bisson, and Robert J. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York.

Willson, Mary F., Scott M. Gende, and Brian H. Marston. 1998. Fishes and the forest. BioScience 48:455-462.

Wu, JunJie, Richard M. Adams, and William G. Boggess. 2000. Cumulative effects and optimal targeting of conservation efforts: steelhead trout habitat enhancement in Oregon. American Journal of Agricultural Economics 82:400-413.

Yoshiyama, Ronald M. 1999. A history of salmon and people in the Central Valley region of California. Reviews in Fisheries Science 7(3-4):197-239.

Yoshiyama, Ronald M., Frank W. Fisher, and Peter B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter B. Moyle. 2000. Chinook salmon in the California Central Valley: an assessment. Fisheries 25(2):6-20.

Photo Captions:

Figure 1: Starting with the discovery of gold in California in 1848, mining spread to many areas of western North America. Salmon runs were decimated by the effects of these early mining operations and never recovered. (Source: www.historichwy49.com.)

Figure 2: Many runs of wild salmon in California, Oregon, Washington, Idaho, and southern British Columbia are either extinct or at risk of going extinct. (Source: The Wild Salmon Center.)

Figure 3: One of the great ironies in salmon policy is that salmon are the only species listed as threatened or endangered for which people regularly buy licenses to hunt and kill. (Source: Curtis Miller.)

Figure 4: Dams come in all sizes and, along with many other human activities, caused the decline of wild salmon runs starting in the mid 1800s. (Source: Oregon Sea Grant.)

Figure 5: Various engineering structures have been developed to reduce the adverse effects of dams and their operation on salmon. Fishways, as shown here, have been incorporated as part of many dams across the region. (Source: U.S. Army Corps of Engineers.)

Figure 6: Massive stocking of salmon from hatcheries has had major effects on wild salmon runs. The long-term effects of these hatcheries are hotly debated by scientists. (Source: U.S. Department of Fish and Wildlife.)

Figure 7: Aquaculture – growing fish and shellfish in captivity – is now highly developed for salmon. Salmon hatcheries annually stock hundreds of millions of young salmon throughout the Pacific Rim. (Source: Oregon Sea Grant.)

Figure 8: Salmon harvest by aboriginal inhabitants of western North America was large, possibly on a similar level to that of the commercial fishing harvest of the late 1800s. (Source: U.S. Department of Agriculture Forest Service.)

Figure 9: Commercial fishing in the late 1800s, aided by the development of commercially viable canning technology and better fishing gear, had a large effect on salmon abundance. (Source: Oregon Sea Grant.)

Figure 10: In many sections of western North America, floods continue to be common occurrences. The political pressure to eliminate or at least reduce the frequency of floods is significant, and constructing flood control dams was often the option of choice. (Source: Oregon Historical Society.)

Figure 11: Many runs of salmon, especially in the southern half of the distribution, are supported by release from hundreds of hatcheries. (Source: The Wild Salmon Center.)

Figure 12: Many animals prey on salmon. Marine mammals prey efficiently on adult salmon and have generally increased in abundance over the past several decades. Notice the large bite missing from this salmon, most likely due to a marine mammal. (Source: Oregon Sea Grant.)

Figure 13: During the 1800s many coastal rivers were cleared of navigation obstructions, which decreased the quality of salmon habitat. (Source: U.S. Department of Agriculture Forest Service.)

Figure 14: Altering streams to recreate habitat that more closely resembles the pristine environment is a commonly used salmon recovery tactic. (Source: Washington Department of Fish and Wildlife.)

Figure 15: Timber harvest along stream banks can cause erosion and other problems that are detrimental to salmon. (Source: Oregon Sea Grant.)

Figure 16: Many natural streams such as this one have been permanently altered, to the point where salmon recovery would be all but impossible. Others still could be transformed back at least to a state to support some level of salmon run. (Source: Oregon Sea Grant)

Figure 17: Wild salmon runs are declining and large wild salmon such as these are becoming harder and harder to find and observe in their natural habitat. (Source: Oregon Sea Grant.)

Figure 18: The six species of focus for the Salmon 2100 Project. (Source: Augerot 2005.)

Figure 19: Original distribution of genus *Oncorhynchus*. (Source: Augerot 2005.)

Table Captions:

Table 1: Common and scientific names of Pacific salmon. All species are of the genus *Oncorhynchus*.

Table 2: Estimated historical (*late 1800s*) and current (*late 1900s*) run sizes of wild salmon in western North America. (Adapted from Gresh et al. 2000 and Meengs and Lackey 2005). (All numbers are in millions of wild salmon and are rounded).

Table 3. Estimated past (*1900* and *1950*), current (*2000*), and future (*2050* and *2100*) number of humans living in the Pacific Northwest. (All numbers are millions of humans and are rounded; numbers for 2050 and 2100 are extrapolated from the 2000 population level using a “low” annual growth rate of 0.5 percent and a “high” annual growth rate of 2.0 percent).

Table 1.

Common Names	Scientific Name
Chinook salmon, king salmon, tyee salmon, spring salmon	*O. tshawytscha*
Coho salmon, silver salmon	*O. kisutch*
Sockeye salmon, red salmon, blueback salmon	*O. nerka*
Chum salmon, dog salmon, calico salmon	*O. keta*
Pink salmon, humpback salmon	*O. gorbuscha*
Steelhead	*O. mykiss*
Coastal cutthroat trout, sea run cutthroat trout	*O. clarkii*

Table 2.

Area	Historical Run Size	Current Run Size	Percent of Historical Run Size
Alaska	150-200	115-259	106.7
British Columbia (non Columbia River)	44-93	24.8	36.2
Puget Sound	13-27	1.6	8.0
Washington Coast	2-6	0.07	1.8
Columbia Basin	11-15	0.11-0.33	1.7
Oregon Coast	2-4	0.10-.032	7.0
California	5-6	0.28	5.1
California, Oregon, Washington, Idaho	33-58	2.16-2.60	5.2

Table 3.

Area	1900	1950	2000	2050	2100
Oregon	0.4	1.5	3.3	4-8	5-24
Washington	0.5	2.4	5.8	7-15	9-41
Idaho	0.2	0.6	1.2	1.5-3.3	2-9
British Columbia	0.2	1.1	4.0	5-11	6-29
TOTAL PNW	1.3	5.6	14.3	18-39	23-103

****