Restoring Wild Salmon to the Pacific Northwest:

Chasing an Illusion?

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RESTORING WILD SALMON TO THE PACIFIC NORTHWEST: CHASING AN ILLUSION?[1]

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ABSTRACT

Throughout the Pacific Northwest (northern California, Oregon, Idaho, Washington, and the Columbia Basin portion of British Columbia), many wild salmon stocks (a group of interbreeding individuals that is roughly equivalent to a "population") have declined and some have disappeared. Substantial efforts have been made to restore some runs of wild salmon, but few have shown much success.

Society's failure to restore wild salmon is a policy conundrum characterized by:
(1) claims by a strong majority to be supportive of restoring wild salmon runs;
(2) competing societal priorities which are at least partially mutually exclusive;
(3) the region's rapidly growing human population and its pressure on all natural resources (including salmon and their habitats);
(4) entrenched policy stances in the salmon restoration debate, usually supported by established bureaucracies;
(5) society's expectation that experts should be able to solve the salmon problem by using a technological scheme and without massive cultural or economic sacrifices (*e.g.*, life style changes);
(6) use of experts and scientific "facts" by political proponents to bolster their policy positions;
(7) inability of salmon scientists to avoid being placed in particular policy or political camps; and
(8) confusion in discussing policy options caused by couching policy preferences in scientific terms or imperatives rather than value-based criteria.

Even with definitive scientific knowledge, which will never be complete or certain, restoring most wild salmon runs in the Pacific Northwest to historic levels will be arduous and will entail substantial economic costs and social disruption required. Ultimate success cannot be assured. Given the appreciable costs and social dislocation, coupled with the dubious probability of success, candid public dialog is warranted to decide whether restoration of wild salmon is an appropriate, much less feasible, public policy objective. Provided with a genuine assessment of the necessary economic costs

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and social implications required for restoration, it is questionable whether a majority of the public would opt for the pervasive measures that appear necessary for restoring many runs of wild salmon.

Through the 21st century, I conclude that there will continue to be appreciable annual variation in the size of salmon runs, accompanied by the decadal trends in run size caused by periodic changes in climatic and oceanic conditions, but many, perhaps most, stocks of wild salmon in the Pacific Northwest likely will remain at their current low levels or continue to decline in spite of heroic, expensive, and socially turbulent attempts at restoration. Thus, it is likely that society is chasing the illusion that wild salmon runs can be restored to the Pacific Northwest without massive changes in the number and lifestyle of its human occupants, changes that society shows little willingness to seriously consider, much less implement.

INTRODUCTION

Many populations of wild salmon in the Pacific Northwest (northern California, Oregon, Idaho, Washington, and the Columbia Basin portion of British Columbia) are declining (Netboy, 1980; Nehlsen *et al.*, 1991; Cone and Ridlington, 1996; National Research Council, 1996; Lackey 1999a; Lichatowich, 1999; Knudsen *et al.* 2000). Despite many costly efforts to protect and restore wild salmon, the total number of wild salmon in the region still declines (Huntington *et al.*, 1996; Lichatowich, 1999). Public institutions seem unable, or at least unwilling, to protect or restore wild salmon runs (Lee, 1993). Virtually no one is happy with the current situation, yet few 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).

Salmon restoration symbolizes a class of contentious, socially wrenching issues that are becoming increasingly common in the Pacific Northwest 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 (*e.g.*, 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).

The Pacific Northwest salmon restoration conundrum is characterized by a series of observations: (1) a strong majority claim to support maintaining or restoring wild salmon runs (Smith and Steel, 1997); (2) competing societal priorities exist, many of which are partially mutually exclusive (Michael, 1999); (3) the region's rapidly growing human population, coupled with increased consumption rates, creates increasing pressure on all natural resources (including salmon and their habitats) (National Research Council, 1996; Salonius, 1999); (4) policy stances in the salmon debate are solidly entrenched and supported by well established bureaucracies (McEvoy, 1986); (5) society expects salmon experts to help solve the salmon problem and often envision a relatively painless, but probably costly, technological solution (Lackey, 1999b); (6) each side of the political debate over the future of salmon employ salmon experts and scientific "facts" to bolster its arguments (Smith *et al.*, 1998); (7) it has proved to be nearly impossible for salmon scientists to avoid being categorized as supporting a particular policy position; and (8) many advocates couch their positions in scientific terms rather than value-based preferences (Lackey, 1999b). As is typical in science, fisheries scientists promulgate legitimate, but often different, interpretations of the same set of data. Also, the majority 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 migrating; now most scientists recommend putting wood debris into streams to provide habitat for juvenile salmon). Such scientific controversies may confuse policy discussions and create skepticism on the part of the public.

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 ("good" choices are defined as the desires or preferences of the majority being implemented without *unanticipated* consequences).

My purpose is to characterize the ecological, societal, and policy context for the current state of wild salmon populations in the Pacific Northwest and the options for their restoration. Most debate in salmon restoration is a clash between competing values and preferences. However, a certain amount of scientific information is required to appreciate the policy issues (Scarnecchia, 1988). It would be easy to concentrate on science because technical information is so abundant, but doing so would divert attention from the values and economic and lifestyle preferences society has adopted or may adopt. Therefore, I will constrain my treatment of scientific knowledge to that required to scrutinize salmon policy.

I use the term "salmon technocrat" to describe the collective, indistinct group of individuals who work professionally in salmon policy, science, economics, research, management, or regulation. They may be academically classified as biologists, economists, political scientists, food technologists, statisticians, sociologists, environmental scientists, toxicologists, lawyers, archeologists, or a number of other disciplines, but their common thread is involvement with some aspect of salmon. It is not a precisely delineated profession, but there are thousands of salmon technocrats in the Pacific Northwest. They may work for Federal, Provincial, State, or local Government fisheries, environmental, transportation, energy, military, agricultural, and forestry agencies. Indian, aboriginal, and first nations organizations employ many salmon technocrats, as do non governmental organizations representing other political interests (*e.g.*, environmental, fishing, nature conservation, logging, farming, economic development). Universities also employ many who are salmon technocrats. Most university-employed salmon technocrats focus on salmon research and policy, but some are active in advocacy of particular policy positions.

There are several definitions of what constitutes a "wild" salmon. 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 (*e.g.*, human assisted) spawning and 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? 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? I 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 a spawning channels (constructed by humans) to be wild.

Throughout this article, I attempt to be policy *relevant*, but not to advocate any particular policy option. Effective options to reverse the decline of wild salmon, and especially to restore *depleted* runs, would be socially disruptive, economically costly, and ecologically equivocal (Michael, 1999). The choice of whether to bear such "costs" in order to restore wild salmon runs is ultimately a societal choice.

SALMON BIOLOGY

Pacific salmon are one of the most studied group of fishes in the world (Scarce, 2000). The vast scientific knowledge available is a reflection of the economic, recreational, and cultural importance of salmon, both currently and historically. 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). 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 the Pacific Northwest have similar life cycles, are members of the genus *Oncorhynchus*, and are collectively part of the salmon restoration policy debate, I 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, but now widely distributed in North America).

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

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). 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 even found in Baja California and Nevada. Today, it is evident that the distribution of salmon is far from fixed (McLeod and O'Neil, 1983). It is possible, perhaps even likely, that there will be a range extension of Pacific salmon in the Arctic areas of North America (Salonius, 1973). If northern climates warm in the 21st century, such a range extension is probable. 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). Wild salmon usually return to their parental spawning ground, but 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 (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 chinook and sockeye, swim far out in the ocean, followed usually by a long ascension of a river to reach natal 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 Pacific Northwest 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 in the Pacific Northwest is unknown because of prior undocumented extinctions, incomplete biological data on the current condition, and ongoing 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 U.S. Endangered Species Act (Waples, 1995; Dodson *et al.*, 1998). Unfortunately, the Endangered Species Act 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 population"), the number of stocks in the Pacific Northwest is in the tens of thousands. Thus, if each stock was considered a "distinct" population, potentially subject to legal protection as a "species" under the Endangered Species 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). 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 there is no standard amount of significant "difference" among populations or stocks that is necessary 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 decisions 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 Endangered Species Act 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 Endangered Species Act 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.

Decisions on salmon restoration will never be based solely on biological information (Waples, 1995; Dodson *et al*, 1998). Ethical, moral, religious, 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). The decision as to what aggregate of salmon ESUs will constitute a single OCU is based on socio-economic trade-offs. In some cases ESUs might be synonymous with OCUs. 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 to watersheds (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 nutrients, especially in low-nutrient areas such as headwaters (Cederholm *et al.*, 1999). Because of the dramatic decline in the size of wild salmon runs in the Pacific Northwest, it is estimated that the amount of marine-derived nitrogen and phosphorous now delivered to the region's watersheds is less than 10% of its historical level (Gresh *et al.*, 2000).

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.

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 Pacific Northwest, 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 at risk and will possibly go extinct (Huntington *et al.*, 1996). Declines are widespread in the Pacific Northwest 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 southern-most 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). 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).

Area	Historic Run Size	Current Run Size	% of Historic 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 2. Estimated historic (*late 1800s*) and current (*late 1900s*) run sizes of wild salmon in western North America (modified from Gresh *et al.*, 2000). (All numbers are in millions of wild salmon and are rounded)

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 appears to be a small fraction of that a couple of centuries ago (Huntington *et al.*, 1996). Wild salmon stocks from the Columbia River watershed are mostly doing poorly; 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 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). 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 mid 1990s, surveys in southeastern Alaska showed salmon runs to be in mostly good condition (Baker, *et al.*, 1996) (Table 2). Catches in the 1990s 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 mid 1990s 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).

Alaska produced approximately 80% 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% in 1997 (Kruse, 1998). Catches in other major Alaska salmon fisheries also dropped appreciably in 1998 and 1999.

The size of salmon runs varies roughly 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*). The Pacific Decadal Oscillation appears to reverse every 20-30 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 (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 annually millions of salmon to supplement the number of wild, naturally produced salmon. 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" 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"). 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 the Pacific Northwest, Scandinavia, Scotland, and Chile and provide markets with a continuous supply of fresh salmon. There are biological risks of aquaculture (and hatcheries) for wild salmon and 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 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 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 Pacific Northwest 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

Estimating the size of past salmon runs in the Pacific Northwest 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). Such analyses show major declines in the aggregate size of wild salmon runs in California, Oregon, and Washington, a smaller percentage decline in British Columbia, and no obvious change in Alaska (Table 2).

Estimating the size of salmon runs in the Pacific Northwest 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 such anecdotal information to create benchmarks to 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). Apart from 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 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.

The level of salmon harvest by aboriginal fishermen in the Central Valley of California was roughly comparable to the peak commercial harvest of industrial fishermen of the mid to late 1800s (Yoshiyama 1999).

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 (that are 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 upward trend.

The 1500s marked the beginning of a dramatic change in the history of the salmon/human relationship in the Pacific Northwest. 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); 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 in the Pacific Northwest 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.

The level of fishing for salmon in the Pacific Northwest began changing markedly in the mid to late 1800s (Netboy, 1980; Mundy, 1997; McEvoy, 1986; Robbins, 1996; Lichatowich, 1999; Yoshiyama, 1999). By the early 1800s, the number of salmon harvested had been reduced due the drastic drop in Indian numbers, coupled with the breakdown in their social structure. Thus, salmon runs were being lightly harvested and were very large when substantial numbers of 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 was 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 in the Pacific Northwest) for many salmon stocks were massive and rapid, 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.

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 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 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 Pacific Northwest 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).

High harvest rates are not the only major cause of salmon decline. Dams were built on many rivers and streams in the Pacific Northwest for navigation, irrigation, power generation, log transport, and flood control (Reisner, 1993; Hartman *et al.*, 2000). Floods, for example, have been common and devastating (for humans); particularly devastating floods occurred in 1861, 1876, 1894, 1948, and 1964. Therefore, flood control, and associated dam, levee, and channel construction, has been a societal priority for over a century, even though salmon prosper in spite of periodic floods (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 over one-third of the habitat formerly occupied by salmon is now blocked by dams. Further, dams alter several key characteristics of water, especially temperature, dissolved gases, sediment transport, and the quantity and timing of flow (Power *et al.*, 1996). Each dam caused adverse consequences, some small, others huge, for salmon.

Salmon runs also dwindled as agricultural development took place in the Pacific Northwest (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 15-20%) 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).

Timber in the Pacific Northwest is of high commercial quality (especially 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) of timber 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).

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 are 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 (mainly responding to the adverse effects caused by dams, habitat deterioration, or overexploitation). Hatcheries were often successful in maintaining 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 inter-breeding, which affects the "fitness" of subsequent generations (Waples, 1999; (Noakes *et al.*, 2000).

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."

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, but often unrecognized, management difficulties for maintaining runs of wild salmon. 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 scheme 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"). Further, using selective fishing regulations in fisheries management is expensive because 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 and have any chance of protecting vulnerable stocks. It is theoretically possible to use "fish friendly" nets or other harvest gear that inflict 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.

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 an ongoing 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 works. Commercial fishermen often argue that they invested heavily in expensive gear with the implied commitment that salmon runs would be maintained.

Another troublesome development (from the perspective of proponents of salmon restoration) has been the introduction of 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) and the expansion in distribution of native species such as squawfish (also called northern pikeminnow) due to habitat alteration (*e.g.*, 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 the Pacific Northwest are vastly altered (generally changed from flowing water to impounded water, from forced into single channels from multiple channels, and 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.

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). 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 also 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).

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 Pacific Northwest 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 (*e.g.*, 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).

Predators, especially marine mammals, birds, mackerel, and squawfish are often identified as contributing to the decline of salmon in the Pacific Northwest (Smith *et al.*, 1998). 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.

Squawfish and birds, usually 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% 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).

THEORY OF FISHERIES MANAGEMENT

The decline of wild salmon in the Pacific Northwest occurred despite the fact that many salmon technocrats were aware of the situation (Taylor, 1999). Most of the negative consequences for salmon of intense fishing, water diversion, dam building and operation, logging, mining, road construction, land "reclamation" projects, and pollution were recognized by fisheries scientists by the late 1800s (Lichatowich, 1999). By the early 1900s the general limitations and shortcomings of salmon hatcheries, although less irrefutable, were documented in the fisheries literature (McEvoy, 1986).

As a formally organized profession, fisheries management has existed in North America for more than 125 years. The American Fisheries Society, for example, was incorporated in 1870 as the American Fish Cultural Society. Since the mid to late 1800s, although rarely stated explicitly or even debated, nearly all efforts to manage fisheries have followed a simple management paradigm, often called the "theory of fisheries management." The core assumption is that all benefits (loosely defined as things that have value) derived from aquatic resources are accruable to man (Lackey, 1998a). "Benefits" often has a very broad definition in fisheries management. For example, even though most people in eastern North America never see a wild Pacific salmon, the *existence* of wild salmon still has value to them. The actual catch of salmon (be it recreational, commercial, or subsistence) and economic return on investment (boat, gear, and labor) are commonly used measures of individual and societal benefits, but neither is sufficient to fully capture the benefits derived from fishing.

Society may choose to protect none, some, or all salmon species, maintain various stocks at high or low levels, permit some stocks to disappear, or manage for species other than salmon. These decisions produce benefits to people — not simply tangible, consumptive benefits. *Consumptive* use of salmon (*i.e.*, harvesting fish) is only one of the benefits derivable from fisheries management. Other, nontangible benefits (*e.g.*, the fishing "experience") may be of equal or greater importance in terms of societal benefits (Roedel, 1975).

From an analytical perspective, the theory of fisheries management is a example of "constrained optimization" and may be expressed as:

$$Q_{max} = f(X_1, X_2, \ldots, X_n \mid Y_1, Y_2, \ldots, Y_n)$$

where

Q = some measure of societal benefit
X = a management decision variable
Y = a societal or ecological constraint variable

The theory might look imposing, but it is not complicated conceptually. It reads "the greatest (maximum) societal benefit (*Q*) from a fishery can be realized by manipulating a series of decision variables (*Xs*), *given* a set of constraints (*Y*s)." Controlled or partially controlled decision variables (*X*s) are those regarded as fisheries management techniques (*e.g.*, selective fishing regulations, spawning ground improvement, predator control, dam alteration or removal, pollution abatement, etc.). Noncontrolled or constraint variables (*Y*s) include climate, ocean conditions, economic changes, societal attitudes, oil spills, *etc.* Recognizing constraint variables, the manager tries to select a series of decision variables that will maximize *Q*, the benefits accruable to humans. All elements of fisheries management, whether they are ecological constraints, economic preferences, or societal values, fit into this theory in at least an abstract manner.

Fisheries management traditionally attempts to maximize (within constraints) some measure of "output" from fisheries resources (Stephenson and Lane, 1995). Analytically, management is simplest when the overall output or societal benefit is universally accepted by all elements of society and can be easily measured (*e.g.*, catch, angler days, income from fishing) within constraints (*e.g.*, which species may be harvested, which segments of society may fish and how, which ecological factors must be protected) that are few, well defined, and universally accepted. Lack of consensus on societal priorities for "benefits" and "constraints" are a vexing, but typical, problem for fisheries managers. Many of the controversies over sustainability, protecting biological diversity, and protecting certain species/stocks, for example, are predicated on how society ranks or balances constraint and decision variables. In practice, the aggregate benefit to society, Q, is a nebulous societal endpoint for which managers (and society) only have an array of surrogate measures such as number, weight, or size of fish caught, number of angler days provided, species or stocks preserved, ecosystems maintained in a desired state, cultural lifestyles maintained, or any of a number of economic or societal indices. Further hindering consensus on Q is the time dimension. Short-term time frames often lead to very different management strategies than longer-term ones. Gaining a consensus on defining Q is perhaps the pivotal challenge in fisheries management, as is amply demonstrated in salmon management.

Setting societally appropriate fisheries management objectives is not a simple task (Sylvia, 1992; Stephenson and Lane, 1995; Hartman *et. al*, 2000). Because of the divisiveness of setting objectives in natural resource management, establishing explicit objectives tends to be neglected. It is easy to criticize this oversight, but it often occurs for compelling reasons. Salmon managers may be reluctant to delineate explicit management objectives for fear that they will be violently opposed by some of the affected parties or, worse, they may be shown to be unattainable in the absence of an ecological miracle (Fitzsimmons, 1996; Hartman *et al.*, 2000).

Managers also may be unable or unwilling to formulate objectives because of a number of constraints such as incomplete awareness of problems (lack of biological data), incomplete knowledge of the intricacies of the problem (also lack of biological data), and inability to devote sufficient thought to the effort because of time, money, or workforce constraints. Further, in spite of a vast literature on the subject, objective-setting methods are not well defined nor are they straightforward to be of use for most management problems. Virtually everyone acknowledges the importance of management objectives, but the few sound techniques available are complex and laborious (Lackey, 1998a). The recent emergence of a suite of management decision support technologies offers some promise of providing objective setting tools useful to fisheries managers.

Who should set objectives — agency personnel, the directly affected parties (*i.e.*, fishermen), interested groups or individuals, the general public, or a combination of the these? Historically, fisheries managers have used consultation between professionals in institutional (usually governmental) roles to set objectives (Smith *et al.*, 1998). Critics term this an "elitist" planning process (Taylor, 1999), but it does have the advantage of allowing those who are trained and, presumably, best qualified and most knowledgeable to decree management objectives and make decisions to achieve those objectives. However, in a pluralistic society, most professionals now advocate, at least publicly, use of systematic public input in setting objectives (Smith *et al.*, 1998).

One of the most urgent social needs in natural resource management is determining public needs and preferences (Smith and Steel, 1997). Providing the public with understandable and credible assessments of the consequences of various choices is equally important and difficult. Many failures in salmon management are attributable to the inability of managers to understand the desires of influential segments of the public, and their failure to explain the impossibility of achieving some objectives (Stephenson and Lane, 1995; Hartman *et al.*, 2000). Once, North American society may have deferred to fisheries technocrats, but deference is not the case now, especially since they rarely appear to agree among themselves.

Historically, the most common management objective has been to maximize weight or numbers of fish on a sustained basis (Hyatt and Riddell, 2000). This is usually referred to as MSY (maximum sustained yield) or, sometimes, equilibrium sustained yield. Animal populations annually produce "excess" animals that may be harvested without adversely affecting the viability of the population. Salmon, like most fishes, have a high reproductive rate and generate substantial surpluses (often 30-70% of the total run size). In the past few decades this approach has come under various criticisms: (1) protein or biomass output from a fishery is no longer the dominant societal benefit; (2) the assumption of a constant external environment, typical with MSY, can no longer be justified; (3) "excess" spawning salmon provide an important ecological role in terrestrial ecosystems; and (4) the strong political pressure to continue past fishing levels even when fish populations are reduced (Roedel, 1975; Bottom, 1997; Malvestuto and Hudgins, 1996; Willson *et. al.*, 1998). There are many variants of the MSY approach; these usually revolve around maximizing either yield of certain species or stocks or maximizing catches of individuals of a certain size (Hyatt and Riddell, 2000).

Desirable properties of MSY are that it is a conceptually simple, objective-oriented approach to management and public policy. However, MSY has some inherent disadvantages, the main one being that catch is only one among the several measures of output (benefit) from a fishery. Catch is an important component of total benefit, but *fishing* itself is also an important component. Numerous surveys have shown that recreational anglers enjoy the fishing experience even though "fishing success" is less than what may be considered ideal (Hudgins, 1984). Other important aspects of recreational fishing are the perceived quality of the outdoor experience, the environment, and the sporting challenge. Elements of the benefits related to actual catch are species caught, fish size, and the angling method.

Even in commercial salmon management, it is important to recognize that economic return is only part of the benefit derivable to fishermen (and thus to society) (Larkin, 1977). For many commercial fishermen, psychological benefits (lifestyle preferences and personal satisfaction) are major factors in job satisfaction. Many regard commercial fishing as a rough, dangerous, demanding, undesirable vocation, but such types of work nourish strong, enduring bonds among participants who exhibit a collective will to assure that their life style continues. Thus, salmon fishermen often continue fishing when economic argument alone predicts they should stop.

Unfortunately for salmon managers, there is no functional pricing system to measure the importance of various recreational or commercial psychological factors, nor can such benefits be easily determined by market survey (Repetto and Dower, 1992). Aesthetics probably never can be accurately measured, but by identifying variables associated with the angling experience and anglers' perceptions of them, a reasonable approximation of aesthetic valuation might be obtained. Also, many societal benefits (*e.g.*, existence values, moral imperatives) from salmon management accrue to segments of society that do not fish. Even though such "non catch" benefits should be important in establishing salmon management objectives, their quantification is severely constrained.

An approach to managing recreational fisheries is to maximize the "experience," including the elements of aesthetics or environmental quality. Whereas this sounds laudable and desirable, it is difficult to apply in practice. Often referred to as optimum sustained yield (OSY), it has some of the characteristics of MSY but the meaning of OSY is ambiguous and it tends to be regarded as a philosophical rather than a pragmatic approach to fisheries management (Roedel, 1975; Hyatt and Riddell, 2000). Proponents of OSY typically argue for less emphasis on yield or catch, and more on benefits such as the recreational fishing experience, angling diversify, or total economic benefit. More recently, procedures have been developed to incorporate biological, economic, and social values into goal setting for fisheries management (Malvestuto and Hudgins, 1996).

A management goal in recreational fisheries, intermediate between MSY and OSY, is to maximize some measure of angler use or the quality of the angling experience. Fishing "quality" is a nebulous parameter, but certain factors that contribute to the fishing experience can be delineated and sometimes measured. The number of potential variables is great, but if the key ones could be identified, the analytical challenge would be reduced. Maximizing the diversity of angling opportunity, commonly used in agency management programs, is an example of this approach.

An unfortunate characteristic of fisheries management, true in the extreme for salmon management, is that orderly management does not start until a "problem" is apparent. The problem may be a precipitous decline in catch, the scarcity of preferred species or stocks, or the potential extirpation of species or stocks. Thus, salmon management tends to be reactive, not proactive. As Crutchfield and Pontecorvo (1969) conclude in evaluating the history of management of Pacific salmon fisheries:

There is no record of a major fishery management scheme that was not introduced in an atmosphere of desperation after the evidence of severe depletion had become too obvious for any explanation other than over-fishing.

Most ecosystems supporting salmon were already significantly altered and salmon runs adversely affected by the time fisheries managers became involved. The options open to managers (and society) were thus significantly truncated. Under such circumstances, the role of a fisheries manager is to be the bureaucrat responsible for allocating a scarce and often declining natural resource.

ENDANGERED SPECIES ISSUES

Salmon policy and management in the United States have recently become much more tangled with the application of the Endangered Species Act (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 Endangered Species Act 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 Endangered Species Act as an inflexible law based on a narrow set of societal preferences and predicated on a naive understanding of modern ecology.

Many ethical, political, and scientific issues envelope policies on threatened and endangered salmon. 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 fundamentally 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 *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. Society may conclude that preservation of salmon is important, but regulations to achieve this objective should not disproportionately burden particular members of society. The political argument is usually that no one should be required to *de facto* 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.*, Indian groups or other countries) who believe that their position is protected by treaties are likely to seek adjudication through the courts.

Debate over the Endangered Species Act and its implementation relative to salmon restoration is characterized by truculent adversaries who denigrate the motives of other combatants. The combatants 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 with mutually exclusive options possible? 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 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 explain the various political viewpoints that characterize the salmon policy debate.

In practice, the management consequences of the Act tend to be greatest on public, especially Federal lands. Supporters usually argue that, even if the consequences of the 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 Endangered Species Act as a tool 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 Endangered Species Act 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.

Others argue that historical perspective is required because species extinctions are not new in the Pacific Northwest. 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 — 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 Pacific Northwest, 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 the Pacific Northwest.

Is the Endangered Species Act the appropriate type of policy tool to reverse the salmon decline? Was it envisioned by its proponents as a legal tool to effectively address such a complex ecological and social problem? Jack Ward Thomas, 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." (Speech to the Columbia River Conference IV, March 16-17, 2000)

ECOSYSTEM HEALTH AND INTEGRITY

A common lament about invoking the Endangered Species Act to protect or restore wild salmon is that it focuses protection and restoration merely on species, stocks, evolutionarily significant units, or distinct population segments. In contrast, the concept of ecosystem health is often championed as superior to focusing on protecting remnant populations of declining species (*i.e.*, stocks of Pacific salmon) (Steedman, 1994; Gaudet *et al*, 1997). In most formulations of ecosystem health, the policy or management focus is the condition of the *entire* ecosystem, although individual species may be recognized as essential components of the ecosystem and important to society (Rapport, 1998; Lackey, 2000).

The notion of ecosystem health enjoys a wide following, especially among some of the popular press and some advocacy groups (Gaudet *et al.*, 1997). Part of the appeal is that it appears to be a simple, straightforward concept (Ryder, 1990; Lackey, 2000). Applying the human health metaphor to ecosystems, it proposes a model of how to view ecological policy questions (Callicott, 1995). In practice, however, it has proven difficult to implement (Lackey, 1998b).

Ecosystem health, especially in the 1970s and 1980s, was often defined in nebulous terms — definitely not as clearly articulated constructs (Steedman, 1994). It was typically depicted as a broad societal aspiration rather than a precise policy objective. Lacking precise definition, it was difficult to consider the concept as a practical public policy tool. As attempts were made to clarify the semantic ambiguity associated with the concept of ecosystem health, it became a serious topic for discussion and, predictably, a lightning rod for conflict (Rapport, 1998).

The most alluring feature of the human health metaphor is that people have an inherent sense of personal health (Ryder, 1990). By extension, proponents argue that people instinctively envision a "healthy" ecosystem (*e.g.*, a forest, lake, pastoral landscape, or river replete with migrating salmon) as pristine or having the appearance of minimal human alteration.

Most notions of *human* health focus on the *individual*, whereas ecosystem health considers the *ecosystem* as the unit of policy concern (Lackey, 2000). Concerns about *individual* animals — the typical focus of "animal rights" and "animal welfare" policy — are usually not the level at which *ecological* policy is debated.

Among proponents, there remains considerable variation in the meaning of "ecosystem health." Karr and Chu (1999), for example, reflect a common, but not universal, position that concepts of ecosystem *health* and *integrity* are fundamentally different. They define ecosystem *health* as the *preferred* state of ecosystems that have been modified by human activity (e.g., farm land, urban environments, airports, managed forests). In contrast, ecological *integrity* is defined as an *unimpaired* condition in which ecosystems show little or no influence from human actions. Ecosystems with a high degree of integrity are natural, pristine, and often labeled as the base line or benchmark condition.

Implementation of the ecosystem health concept has been surrounded by controversy (Jamieson, 1995; Wicklum and Davies, 1995; Callicott, 1995; Belaoussoff and Kevan, 1998). Addressing questions of ecosystem health might appear to be a fairly scholarly, perhaps even arcane, activity, free from the political intrigue that dominates much of the science and policy underlying environmental management, but such is not the case. Wicklum and Davies (1995) suggest that the word "health" elicits powerful, positive images even if its meaning is ambiguous. Therefore, a precise understanding of the concept is essential because it is likely to be used, and given a variety of meanings, by policy advocates, politicians, bureaucrats, and the general public. In practice, it may fall to salmon technocrats to provide operational clarity to such perplexing, value-laden, normative concepts that appeal intuitively to nearly everyone. Normative ecological concepts such as ecosystem health have become abstract perceptions, perhaps useful in general conversation, but impossible to quantify (Ryder, 1990).

Some (Shrader-Frechette, 1997; Kapustka and Landis, 1998) have counseled against using the concept of ecosystem health in communication to the public about environmental issues. Thoughtful discussions about ecosystem health and similar concepts are usually abstract, often contentious, and rarely lead to consensus, but is the use of the health metaphor, even as a heuristic tool, ill-advised? Kapustka and Landis (1998) posit that the metaphor is misleading and based on particular values and judgments, not an *independent* scientific reality. Lancaster (2000) concludes:

". . . definitions and measures of ecosystem health are open to so much abuse and misuse that they represent a threat to the environment."

"The notion that the ecological health of the environment can be assessed is a ridiculous notion in a scientific context because there can be no objective definition of 'health' or method for defining degrees of health. Ecological health is a value judgement."

Relative to salmon policy, most critics concede that, although the human health metaphor provides a simple heuristic framework for the decline of wild salmon and their possible restoration, it fails to capture the most contentious element of ecological policy — the decisive role played by competing individual and societal values and preferences. Further, it is prone to improper use by condoning, even encouraging, scientists and other technocrats to implicitly select which societal preferences will be sanctioned.

A derivation of the concept of ecosystem health that directly addresses options to restore salmon is that of the "normative river." Most of the efforts to manage and restore wild salmon in the Pacific Northwest have been based on the implicit and incorrect assumption that ecological processes that exist in a healthy salmonid ecosystem can, to a large degree at least, be replaced, circumvented, simplified, and controlled by humans while salmon runs are maintained or even enhanced (Independent Scientific Group, 1999; Lichatowich, 1999). Following the logic of the normative river approach, if society wishes to restore wild salmon runs to a semblance of their former size, then rivers such as the Columbia must be made more "natural." It remains for society to decide the degree to return altered watersheds to natural conditions, and thus increase the probability that wild salmon runs will increase.

Whether current notions of ecosystem health will evolve sufficiently to overcome their inherent deficiencies in addressing the general decline of wild salmon, or the disappearance of specific stocks, is uncertain. Notions of ecosystem health currently offer limited practical guidance in reconciling the most divisive elements of salmon policy.

ECOSYSTEM MANAGEMENT

To address the decline of wild salmon, management goals and approaches other than ecosystem health have been proposed, debated, and, in some cases, implemented. During the 1980s, a widespread concern surfaced that traditional approaches to managing renewable natural resources (including Pacific salmon) were not working (McLain and Lee, 1996). Concurrently, ecosystem management emerged, especially in the natural resource and land management agencies, as a popular, although philosophically imprecise, approach to managing natural resources (Grumbine, 1994; Stanley, 1995; Lackey, 1998b).

Ecological policy problems, for which ecosystem management is typically advocated, have several general characteristics: (1) fundamental public and private values and priorities are in dispute, resulting in at least partially mutually exclusive decision alternatives; (2) there is substantial and intense political pressure to make rapid and significant changes in public policy; (3) public and private stakes are high and there are substantial costs and substantial risks of adverse effects (some perhaps irreversible) to some groups regardless of which options are selected; (4) some ecological and sociological "facts," are highly uncertain; (5) the "ecosystem" and "policy problems" are meshed in a larger political framework such that decisions will have implications outside the scope of the narrow problem addressed (Lackey, 1998b). Reversing the decline of wild salmon stocks possesses all the above characteristics so it might be a good candidate for utilizing ecosystem management.

A sampling of the definitions and descriptions of ecosystem management provide some indication of the amorphous nature of the concept. Some consider ecosystem management to be an evolution in the traditional approach to natural resource management:

"Ecosystem management . . . acknowledges the importance of human needs while at the same time confronting the reality that the capacity of our world to meet those needs in perpetuity has limits and depends on the function of ecosystems." (Christensen, et al., 1995)

". . . there is no a priori imperative to include management for biodiversity, ecosystem health and integrity, and commodity production in every ecosystem management effort, and therefore to specify them in a general definition." (Wagner, 1995)

"The application of ecological and social information, options, and constraints to achieve desired social benefits within a defined geographic area and over a specified period." (Lackey, 1998b)

Others, however, interpret ecosystem management as a substantial, even radical, departure from traditional natural resource management:

"The philosophy of ecosystem management requires asking ourselves what kind of a society, and correspondingly, what kind of relationship with nature we want. Patterns of politics suggested by ecosystem management include public deliberation of values toward the environment, cooperative solutions, and dispersion of power and authority. These are all avenues to lessen social hierarchy and domination. Through opening the value debate, fostering a sense of interdependence among humans, and renewing a sense of reason, the chains of social domination may be lessened." (Wallace et al., 1996)

"A human community in a sustainable relationship with a nonhuman community is based on the following precepts: first, equity between the human and nonhuman communities; second, moral consideration for both humans and other species; third, respect for both cultural diversity and biodiversity; fourth, inclusion of women, minorities, and nonhuman nature in the code of ethical accountability; and fifth, that ecologically sound management is consistent with the continued health of both the human and the nonhuman communities." (Merchant, 1997)

"Full implementation of a policy of federal management and protection of ecosystems would extend the reach of federal regulators to all private land . . , increase regulatory

burdens, and further restrict the economic use of public and private lands." (Fitzsimmons, 1998)

At least in North America, the ideas behind ecosystem management represent a predictable response to evolving societal values and priorities (Lackey, 1998b). Those values and priorities will continue to evolve, although their evolutionary direction is mostly unpredictable. Without major upheavals such as war, economic collapse, millennial earthquakes or volcanic eruptions, or the return of plagues, the movement of social preferences toward the values and priorities of "affluent" people will probably continue. While ecosystem management operates within the reality of intensive alteration and use of nearly all formerly natural areas, high value is given to the non-consumptive elements of ecosystems such as pristineness. Most people want the benefits and affluence of a "developed" economy, but few want its factories, foundries, and freeways in their back yards.

The future direction of ecosystem management is not transparent, but it could potentially play a very important, even principal role in how democratic institutions deal with ecological policy questions (Merchant, 1997; Lackey, 1999c). At a recent major international conference on ecosystem health and management, a statement from an audience member illustrates one such direction:

"It is time to change our [society's] charter with individuals. We have massive and critical problems with our ecosystems that cry out for immediate action because we have subordinated the collective good of society to the will of individuals. Personal freedom must be weighed against the harm it has caused to the whole of society, and more importantly to our ecosystems."

An immediate response to the statement from another member of the audience was equally instructive:

"Society and freedom are at greatest risk from those with the noblest of agendas."

Ecosystem management will continue to be place–based because ecological policy problems must be bounded explicitly to make them tractable and geographical boundaries are the most pragmatic (Lackey, 1998b). A practical problem in North America is that in many locations much of the "place" is owned by individuals, not by society in the form of "public lands." By being place–based, the application of ecosystem management will become a focus for debates over private versus societal "rights." How does society balance the right of individuals (or Indian tribes, private organizations, and nongovernmental organizations) to be free from property seizure without compensation against the right of society to achieve a collective goal? Perhaps the concept of privately owning ecosystems (places) must yield to other "rights" for the greater collective good by broadening the legal right of eminent domain for the public good?

Ecosystem management is often described in terms of ecosystem health, ecosystem integrity, biodiversity, and sustainability — scientific-sounding words that have frequently served as surrogates for specific personal values and policy preferences (Lackey, 2000). Unless these terms are precisely defined and clearly separated from values and priorities, their utility in science or policy analysis is severely diminished. There are a variety of meanings and nuances submerged in the concepts of "sustainability" and "sustainable development" that are not widely appreciated, but have important ramifications for ecological policy (Dovers and Handmer, 1993).

There appear to be two policy trajectories for resolving the operational meaning of ecosystem management (Lackey, 1999c). First, and most likely to happen, is that the expression "ecosystem management" might be defined as functionally equivalent to the classic, anthropocentric natural resource management paradigm and merely reflect another stage in the evolution of societal values and preferences. Second, "ecosystem management" will come to be the policy banner for an eco- or biocentric world-view that is closely tied to concepts of species egalitarianism, bioregionalism, democratization, and possibly local empowerment.

In summary, ecosystem management *may* be a revolutionary concept that results in a fundamental change in ecological policy and natural resource management, or it *may* end up as an evolution of existing, well-established approaches to natural resource management. Relative to its potential use in addressing salmon restoration, what distinguishes ecosystem management is its emphasis on the entire "ecosystem" occupied by salmon throughout their life cycle, as well as the recognition that humans are part of that ecosystem. Ecosystem management, unfortunately, offers no visionary path for salmon restoration, but rather serves to emphasize the interconnectedness of all the ecological and societal elements of the salmon decline/restoration issue (Lackey, 1999c).

SCIENCE AND 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. Technocrats do not *make* policy decisions, but because of their technical expertise 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 policy-relevant, but policy-neutral information is often more complicated than expected (Smith *et al.*, 1998; Lackey, 1999b; Mills and Clark, 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 range land users, electrical generators and users, natural resource management agencies, various segments of the environmental movement, endangered species and animal rights proponents, municipal and local governments, and a general public that is not aware of the implications and trade-offs of the various policy options, in part attributable to superficial reporting by much of the media. 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 and Clark, 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 while apparently uncomplicated, this principle is not as simple as it might appear. It is easy to avoid communicating the entire truth about the ecological consequences of various salmon policy decisions and thus 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. It is highly unlikely that *wild* salmon in substantial numbers (by historical standards) can be supported in such a highly modified environment. Society may well 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 extensive watershed alteration.

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. 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. Different predictions will result from 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.

In my experience, few salmon technocrats intentionally misinterpret data or lie, 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%) 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 2100 from its current 14 million to 85 million.

Perhaps the annual growth rate of the human population will decline, but the population in the Pacific Northwest will be much larger in 2100 than now (Hartman *et al.,* 2000). Current U.S. and Canadian policies *de facto* supports 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 were static, but habitat improvements will be increasingly more difficult to achieve if the human population increases several-fold by 2100.

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

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% and a "high" annual growth rate of 2.0%)

Salmon scientists should focus on "science" when they are providing scientific and technical information. The philosophical literature is replete with discussions of the differences between "is" and "ought" statements and whether the conduct of science is, or can ever be, value-free. The rudimentary philosophical dichotomy is that science deals with statements of fact, observation, or probability (the "is" statements), while policy advocacy deals with statements of preference (the "ought" or "should" statements). At the extreme in the salmon policy debate, the "is/ought" split is clear, but becomes much hazier when the explicit tasks performed by salmon technocrats are examined. Technocrats often subtly use "ought" statements under the appearance of "is" statements. For example, descriptors such as habitat *degradation* (or *improvement*) and stream channelization (or *improvement*) implicitly assume a desired condition for a particular species or ecosystem. Constructing a specific dam may be described as *degradation* of salmon habitat, while the same dam might also be characterized as *improving* habitat for walleye and northern pike. Similarly, harvesting an old growth forest and creating a meadow might *improve* habitat for black-tailed deer, but the same action would be *degrading* habitat for spotted owls and salmon.

Most technocrats accept the premise that science deals with "*is*" issues, but many also hold strong personal policy preferences that creep into what appear to be value-neutral science observations. Decision makers and the public need to insist that salmon technocrats remain focused on the *is* issues, the science aspects of policy.

Demanding that salmon technocrats focus on science does not constrain their activities to esoteric, policy-irrelevant science that has little influence on society's decisions on salmon policy. On the contrary, their work and professional judgments should be presented in brutally honest, direct, and understandable ways, but they should avoid advocating policy choices based on personal values or preferences (Mills and Clark, 2000).

Some among the public have criticized scientists and policy makers for creating a *de facto* "priesthood of scientists" — those ordained to pass judgment on the rights and wrongs of ecological policy (Cooperrider, 1996). We live in a society that often venerates scholarly accomplishment, professional credentials, academic degrees, and professional titles. In fact, because politicians and appointed decision makers face difficult, controversial ecological policy choices, it is natural for them to use technocrats as a convenient political cover. It is inviting to shift the responsibility for an unpopular policy to salmon technocrats with their aura of credentialed respectability (Taylor, 1999). Salmon technocrats need to be constantly on guard to avoid being drawn into the role of providing political cover for decision makers. There is no *scientific* imperative for maintaining wild salmon in the Pacific Northwest even though proponents constantly offer up implicit support from science: "It is clear from the science what we need to do about the salmon problem." There would certainly be ethical, ecological, and social implications associated with driving wild salmon to extinction, perhaps severe ones, but there is nothing in *science* itself that says this should or should not be done (Scarce, 2000). It is possible, hypothetically, that even with a comprehensive and accurate assessment of the consequences of driving wild salmon to extinction, society might opt for this option given the perceived high costs and social disruption of maintaining or restoring runs.

No matter how much pressure there is from decision makers, salmon technocrats should not offer personal opinions about which option *should* be chosen. Decisions in salmon policy are largely based on differences in values, preferences, and priorities, not science. Scientific information has a role in decision analysis, but it is primarily to state clearly the consequences of various policy alternatives, not to lobby for any particular alternative (Stephenson and Lane, 1995).

All salmon technocrats should recognize that framing the policy question largely defines the analytical outcome (Mills and Clark, 2000). This article began with the implicit assumption that the decline of wild salmon was the primary policy issue of concern in the Pacific Northwest. It could have begun with a policy question focused on affordable housing, economic growth, "family wage" jobs, retirement security, social welfare, or education. Maintaining wild salmon is not *inherently* more important than alternative societal aspirations; it is but one of many competing societal aspirations. Competing societal aspirations are not necessarily mutually exclusive, but compromise is often difficult to achieve when policy positions are based on strongly held values.

Arguments over framing the policy question are typically the most divisive part of the policy debate because framing the policy question is a political exercise, not a scientific one. Defining policy questions is value-based, although scientific information has a role in identifying plausible options and in predicting the ecological consequences of different policy alternatives. From a ecological perspective, for example, Pacific lamprey have arguably declined as much or more than wild salmon, but there is little policy concern about their restoration.

Framing a policy question in *salmon* terms largely defines the result. In reality, the policy debate is not what should be done about wild salmon, as if it was the only policy question on the table, but rather, how important is salmon restoration compared to competing alternatives. For example, society, in addition to "demanding" maintenance of wild salmon, "demands" personal mobility. Personal mobility means having an effective road system. North American society implicitly "demands" economic growth which is fueled, in part, by an expanding human population. Increasing numbers of people require construction of additional roads, which means less quality habitat for salmon, and, eventually, fewer wild salmon. Thus, each of the small, piecemeal decisions that society makes about constructing roads has small but negative effects on wild salmon.
Salmon technocrats should avoid the allure of junk science and policy babble in providing information. "Pseudo-science" often disguises political advocacy. Concepts like ecological health, ecological integrity, sustainability, and biological diversity can be used

in scientifically valid ways, but they also can be used to beguile the public and politicians. Sustainability, for example, has an inherent appeal, but what does it mean? Traditionally, technocrats defined sustainability as "producing defined ecological benefits in perpetuity." Many different ecological elements are sustainable, so which are the most important? Sustainability is also possible at a variety of levels. What level of "ecological" yield is desired? Advocacy for "sustainability" does not really say much without a clear statement of policy preference. Further, it is tautological to argue that sustainability must *a priori* maintain ecosystems such that their capacity to produce goods and services in the future is not reduced. There is a multitude of possible goods and services, as well as a suite of sustainable levels of those goods and services, that can be provided by ecosystems.

Ecological integrity is sometimes offered as a concept that overcomes many of the limitations of ecosystem health, but it is likewise predicated on the assumption that there is some desired, preferred, or reference ecological condition or suite of conditions. Who is to say that a pristine ecological condition is any better or worse than an agricultural system or urban environment? Also, who decides which ecosystems are to be chosen as the reference or baseline state? Intended or not, the very idea of *reference* sites has a tendency to connote to the uninformed that ecological conditions in the reference sites are somehow better, and thus more desirable, than those in other sites.

Technocrats involved with salmon policy and management should concede that societal values and priorities evolve. It was not many years ago that many current wildlife icons, such as cougars, bears, wolves, eagles, seals, and sea lions were viewed as nuisances to be expunged from the land, water, and air. Much of society now has a different view — a conviction that, far from being earmarked for eradication, these species ought to be tolerated, even protected from humans by the force of law and, furthermore, reintroduced into their former ranges. For example, through the mid 20th century, even the revered bald eagle was subject to an aggressive predator control program in an attempt to protect salmon (Willson *et al.*, 1998). Neither the view that cougars, bears, wolves, eagles, seals, and sea lions are pests, nor the view that they are valued life forms to be protected, is "correct" scientifically, but they lead to dramatically different political positions. Salmon technocrats today work in a different "rights culture" than did their predecessors (McEvoy, 1986). Concepts of rights have changed, often dramatically. Human rights and property rights, at least in western North America, have meanings that are distinct from those a century ago. Clashes between the rights of individuals and those of the larger society are often resolved differently as society evolves.

A century from now salmon technocrats will deal with societal values and priorities as different from today's values and priorities as today's values and preferences are different from those of a century ago. None of the values in 1900, 2000, or 2100 is (or will be) more "legitimate" than the others, except within the societal and ecological context existing at the time.

Society weighs policy choices in the context of prevailing values, preferences, and understanding of "facts." Even with the same scientific information (facts) and the identical condition of stocks, a salmon policy position from the beginning of the twentieth century doubtless would be different from a current policy on salmon. Relative to wild salmon, societal values and preferences, as well as scientific understanding, have all changed over the past century. Over the long run, a search for the scientifically *optimal* salmon restoration solution will be futile because of the complexity of the policy (and science) problem, changing ecosystem conditions, and evolving societal values and preferences (McLain and Lee, 1996). The sooner that a salmon technocrat accepts this reality, the easier it will be to appreciate the ebb and flow of salmon policy debates. Salmon technocrats would do well to avoid technical and scientific hubris in providing information or offering policy recommendations. A critical look at history reveals little justification for an exalted notion of the effectiveness of technocrats in salmon management or policy. Salmon technocrats once exhorted employing hatcheries to supplement salmon runs as the preferred response to dwindling runs, but this approach is now widely discredited because of the adverse effect on wild stocks (Cooperrider, 1996). Some championed "scientific management" based on fish population dynamics models and the notion of maximum sustained yield (now acknowledged to be unsuccessful) which purported to be the solution to managing salmon and other natural resources sustainably (Ludwig *et al.*, 1993). Technocrats and others have also proposed such tools as computer simulation and modeling, benefit/cost analysis, risk assessment, habitat improvement, complicated harvest restrictions, adaptive management, and cooperative management. All have their positive features, but none has reversed the decline of wild salmon. Based on history, today's solutions to restore wild salmon runs will be held in disrepute by subsequent generations of salmon technocrats.

Although society expects salmon experts to solve, or at least identify practical options to solve the salmon problem, each side in the political debate attempts to manipulate salmon experts and scientific "facts" to bolster its policy argument (Volkman and McConnaha, 1993). Much of the manipulation is attempted by funding only that research that will "support" a particular policy position (Scarce, 2000). A veteran salmon research scientist who reviewed an early draft of this article offered a reality check:

"Lets face it — the scientist who doesn't choose sides goes hungry for lack of funding. Survival requires having a sponsor. Sponsors have agendas. The objective scientist is shot at from both sides — and dies in the process. Believe me — I live that precarious life without funding. Nobody will pay for objective research."

The chronicle of attempts by salmon experts to help resolve the salmon policy conundrum is not encouraging (Meffe, 1992; Ludwig, *et al*, 1993; Cooperrider, 1996; Buchal, 1998). Even though the number of fisheries scientists (and total dollars spent) trying to reverse the decline of wild salmon has increased dramatically, wild salmon numbers continue to decline. Fisheries scientists dealing with salmon issues are largely limited to "situational science" — every ecological situation appears to be a specific case and few general rules or principles exist. Although important in understanding policy options, the few general scientific principles that do exist, even when embellished with complex jargon and detail, do not go much beyond common sense.

Fisheries scientists also operate in a world of conflicting societal mandates. As Scarnecchia (1988) observed about the state of salmon management:

". . . most Pacific Northwest salmon plans are themeless collages — surrealistic aggregations of incongruent management goals, objectives, and actions suggestive of many value systems but truly indicative of none. Such is the end result of broadly coordinated, painstaking efforts of hundreds of managers and user-groups representing diverse, often incompatible, value systems — some articulated, some not."

It is also apparent that salmon policy is serious business (Lackey, 1999b). Competent scientists, whether intentionally or not, routinely become embroiled in policy debates that fundamentally revolve around clashes in values and preferences, not science. We witness the spectacle of "dueling science" — each side in the policy debate parading scientists who articulate scientific opinions that *apparently* support the preferred political position (McLain and Lee, 1996; Buchal, 1998). If a group's position is to lobby for maintaining irrigated agriculture, for example, its advocates would do well to quote scientific findings showing that use of hatcheries, not irrigation, has done the most to reduce the number of wild salmon. If a group's political interest is in maintaining fishing and the tourist industry, its proponents will often quote scientists who attest that three-quarters of the salmon returning to the Columbia River system are hatchery-bred and, therefore, hatcheries are essential to maintaining fishing opportunities. Thus, even the same scientific "facts" can be used to "support" competing policy positions (Lackey, 1997; 1999b).

Most individuals interested in the fate of wild salmon are not salmon technocrats. From their perspective, a reasonable question is: "how should I deal with salmon technocrats in order to make best use of their expertise?" It is a reasonable query, but one not often asked outside the venue of adversarial legal proceedings. What should the public expect of salmon technocrats acting as responsible professionals?

First, the public should not tolerate unjustified optimism (or pessimism) from salmon technocrats. Few people like to be bearers of unpleasant news. Because the public longs for wild salmon restoration with minimum societal dislocation and economic cost, it is only natural that salmon technocrats search for the silver lining, the good news, in what otherwise would be a dismal message. My recommendation is to avoid such displacement behavior. Scientists should describe the consequences of current (and alternative) salmon policies as accurately as possible, succumbing to neither pessimism nor optimism. Also, those conditions that are not reversible (e.g., elimination of exotic fishes or depopulating the region) under any realistic policy option should also be clearly identified.

Second, the public should demand that salmon technocrats speak understandably. Most fundamental technical and scientific issues of crucial importance in salmon policy are not as difficult to understand as often asserted. Salmon technocrats should limit esoteric scientific discussions to scientific discourse, not extend them into public policy debates.

Third, the public should recognize that policy choices are tough and that honest salmon technocrats will not have easy, painless answers. The expectation of finding a magic solution to the declining runs of wild salmon is futile (Lichatowich, 1999).

Fourth, the public should be cautious with science being offered to "support" or "defend" an organization's preferred policy position. Many organizations (governmental and non governmental) have in-house or contract scientists that can be traipsed out to lend *apparent* support to the organization's preferred policy, management, or regulatory outcome. Scientific information and models can *appear* to favor certain promulgated policy choices, or undermine those of rivals (McLain and Lee, 1996). In reality, scientific information can be used to demonstrate that a particular policy option has little likelihood of success (*i.e.*, is not ecologically feasible), but scientific information, in and of itself, does not inherently support *any* policy option that *is* ecologically feasible.

Finally, the public should be wary of salmon technocrats offering policy positions under the guise of science. Many salmon technocrats have strong personal views on the desirability of restoring wild salmon to the Pacific Northwest, but such beliefs reflect personal values and preferences, not scientifically derived conclusions. Embellishing such personal views with the language of science adds a deceiving veneer of credibility.

ALTERNATIVE PNW ECOLOGICAL FUTURES

In the Pacific Northwest, the most vocal public concern over salmon policy is driven by the decline of *wild* salmon (Smith and Steel, 1997; Lichatowich, 1999). The precise extent of the decline is not accurately known, but the decline and public concern are real. Public concern is not limited to loss of a food or recreational resource because farm-raised (from many sources) and imported wild salmon (mainly from Alaska) are readily available for retail sale, and supplemental stocking could maintain at least some runs in perpetuity, albeit at high economic and ecological cost (Michael, 1999).

In the Pacific Northwest, many people view salmon as a cultural symbol, an indicator, however ethereal, of the region's quality of life (Lang, 1996; National Research Council, 1996). Such passion for the preservation of wild salmon does not mean that these individuals would *never* choose salmon restoration over competing priorities (*e.g.*, flood control, inexpensive electricity, personal mobility), but it does mean that maintenance of salmon is a pivotal policy priority; in fact, for some individuals, restoring wild salmon runs is a *central* public policy objective (Smith *et al.*, 1998).

The most important driver determining the ecological future of the Pacific Northwest is the size, character, and distribution of the region's human population (Northcote, 1996; Hartman *et al.*, 2000) which is growing — at a rate comparable to that in some Third World countries. From post Ice Age waves of aboriginal immigrants from the North ten millennia ago, to the influx of North Americans (and Europeans) from the East during the past two centuries, to the deluge from California and southward after the Second World War, the Pacific Northwest has been transformed in a few thousand years from a relatively sparsely populated region to one of the most urbanized in North America with nearly three-quarters of the population residing in urban communities (1990 US Census). The human population surely will continue to grow in the Pacific Northwest and will probably become even more urbanized (Hartman *et al.,* 2000).

It is debatable whether feasible public policy options for restoring wild salmon exist in the overlap between what is ecologically *possible,* and what is *desired* by society. For most individuals, the choices are difficult, unpleasant, and preferably avoided. For example, considerations in the salmon policy debate include: How expensive will energy be? Where will people be able to live? How will use of private and public property be prescribed? Will salmon be harvest at all and, if so, which individuals and groups will be granted the right to fish? Will human food, transportation, and energy continue to be subsidized? Will society be able to provide high paying jobs for the next generation? What personal freedoms will be sacrificed to restore wild salmon? Should society control the rate of human population growth in the Pacific Northwest which is driven almost entirely by immigration from outside the United States and Canada, as well as emigration to the Pacific Northwest from elsewhere in the United States and Canada? The answers to these and other questions will fundamentally determine the future of wild salmon runs. Scientists can obtain the necessary data and help evaluate the consequences of different policy options, but the salmon "problem" is an issue of *societal* choice (Smith and Steel, 1997; Lackey, 1999b).

The decline of wild salmon and other anadromous species is not confined to the Pacific Northwest (Parrish *et al.*, 1998). The demise of most salmon stocks in Europe, the Asian Far East, and the Northeastern United States is strikingly parallel to what is happening in the Pacific Northwest. Most wild salmon stocks in these other areas have vanished, yet, even in those locations, no *species* of salmon currently faces extinction even though their distribution is severely constricted.

RESTORATION — OPTIONS AND ILLUSIONS

"Restoration" connotes assorted expectations among salmon technocrats, decision officials, and policy advocacy groups (Hyatt and Riddell, 2000). At one extreme, restoration may mean nothing less than rebuilding Pacific Northwest *all* wild salmon runs to levels that existed prior to 1850 (*e.g.*, runs sufficiently large to support intense, but sustainable, fishing by commercial, recreational, and Indian fishermen). To others, salmon restoration efforts would be considered successful if the more modest goal of maintaining stocks at levels where extinction was unlikely was achieved (*e.g.*, endangered species recovery). Others, however, envision successful restoration as permitting sustainable commercial, recreational, and Indian fishing, but with the preservation of individual stocks being relevant, but not essential. Some people, arguing that most of salmon spawning and freshwater rearing habitat is altered beyond rehabilitation, condone a significant, even dominant, role for hatcheries to maintain runs at levels high enough to support past harvest levels. Others see no role for salmon hatcheries in salmon restoration except for the possible temporary and last ditch role of keeping a stock from disappearing. Some individuals and groups are willing to eliminate immediately all fishing for salmon, close all salmon hatcheries, and breach major dams. Conversely, others would be willing to forego some or all of the remaining wild salmon runs if the cost of their maintenance was too onerous.

There is little agreement on what constitutes "successful" salmon restoration, so it is important to define expressly how success should (or will) be determined when a particular restoration strategy is proposed. Even among the organizations that champion salmon restoration, there is a jumble of divergent, often contradictory, goals for restoration. At the poles are groups that view "restoration" as restoring fishing to past, high levels and, at the opposite end, others who view "restoration" largely as a biological or genetic diversity concern and would close all fishing immediately. Many see hatcheries as an appropriate tool, while others would immediately close all salmon hatcheries. The following publicly-stated restoration goals and objectives are examples extracted from documents developed by government agencies, Indian groups, and private organizations:

". . . halt declines . . . and rebuild populations . . . to a level that will support commercial and sport harvest . . ." [U.S. Government hydroelectric organization]

"The opportunity to catch and keep salmon in reasonable numbers for sport fishermen is the general goal of salmon fisheries management . . . hatchery raised fish can be substituted in any instance where natural reproduction cannot be sustained." [Recreational fishing advocacy organization]

"Our goal is to restore wild salmon and steelhead populations to harvestable, self-sustaining levels . . . hatcheries may be used for various purposes including to provide fisheries and in attempts to preserve or restore naturally reproducing populations." [U.S. State Government fisheries agency]

". . . to ensure the long-term viability of Pacific salmon populations in natural surroundings and the maintenance of fish habitat for all life stages for the sustainable benefit of the people. . ." [Canadian Government fisheries agency]

"Salmon restoration should ultimately aim toward the production of wild adult salmon runs comparable in size to historic numbers . . . anything short of production of large harvestable runs makes little economic sense." [Commercial fishing advocacy organization]

". . . abundant harvestable wild salmon and steelhead populations in our rivers and streams, region-wide." [Environmentalist and preservationist advocacy organization]

". . . there is a fundamental conflict between the goal of recovering endangered wild salmon and the goal of providing fish for commercial harvest through hatchery operations . . . ensure that policymakers are aware of the costs associated with efforts to

recover salmon . . . Federal, state, and tribal fishery agencies tend to be insensitive to the significant cost of the measures they propose . . ." [Organization representing interests of industries that are major users of electricity]

"Restore anadromous fishes to historical abundance in perpetuity." [Organization advocating the interests of certain Indian tribes]

Regardless of which restoration goal is endorsed, is society chasing an illusion in attempting to restore wild salmon to the Pacific Northwest? Two pervasive realities limit the feasibility of widespread restoration: (1) the dramatically different habitat of the Pacific Northwest compared to what existed even a century ago (Northcote, 1996); and (2) the certain ongoing increase in the region's human population (Hartman *et al.*, 2000).

Many Pacific Northwest environments have been permanently altered in ways that do not favor salmon. The Columbia Basin, for example, is now dominated by a series of mainstem and tributary reservoirs. Land use in much of the watershed has also changed in ways that no longer favor salmon (Bisson *et al.*, 1997; Michael, 1999). As dramatic as the environmental changes are, some fishes, especially exotics, are thriving (*e.g.*, walleye, American shad, smallmouth bass, northern pike, and brook trout). These exotic species are well adapted to the new environment. It would be difficult to re-create the Pacific Northwest habitats that once existed and were ideal for wild salmon. Some argue that it is impossible. A simpler, cheaper policy option would be to manage for those fishes, typically exotics, best suited to *current* habitat. Such an approach, while relatively easy and cheap to accomplish, would be an explicit decision to terminate many stocks of wild salmon.

There have been serious efforts to systematically prioritize salmon stocks to allocate society's efforts to restore runs (Allendorf *et al.*, 1997). A similar option is to preserve stocks in locations, such as "coastal" rivers, where some reasonably healthy wild stocks often still exist and where the chances of restoration are greater (Michael 1999). Also, some stocks (*e.g.*, chinook using Hanford Reach on the mainstem of the Columbia River) are better adapted to the highly altered environment of the Pacific Northwest because they spawning at times of the year when water flows are more "natural" and in locations relatively less altered. Others argue that perhaps we should stop focusing on *stocks* and accept that no *species* of salmon is in danger of extinction. This acceptance of the "inevitable" is countered as merely admitting defeat in the face of difficult, expensive, and divisive policy choices.

People of the United States and Canada now devote considerable resources toward earnest, and often futile, attempts to restore wild salmon stocks (Independent Scientific Group, 1999). Will society conclude that the *economic* costs of maintaining wild salmon in ecologically suboptimal environments of the Pacific Northwest are too high? More fundamentally, will society question and reverse, as some suggest, the economic expansionist ideology that has long been the hallmark of western society (Lichatowich, 1999; Salonius, 1999)? Michael (1999), in one of the few cases of someone trying to

answer such questions, concluded that:
" . . . society has already decided that anadromous salmonids in the Pacific Northwest will exist in low numbers and less diversity than historically."

Current and past attempts to deal with the inexorable increase in human population of the Pacific Northwest (primarily land use planning and zoning) have met with limited success (Northcote, 1996; Kline and Alig, 1999). Growth management, including the various permutations of "land use zoning," "balanced growth," "sustainable growth," "smart growth," or "environmentally sensitive growth" have merely attempted to accommodate human population growth in the least disruptive way. Without a change in the "standard of living," it is a delusion to expect that wild salmon runs can be maintained, much less restored, with a doubling, tripling, or more of the region's human population (Hartman *et al.,* 2000). Most people would assuredly find the prerequisite changes in policies on human population growth rate and associated economic reorientation to be draconian; there is little evidence of the willingness of most people to consider such choices.

CONCLUSION

Restoring runs of wild salmon to the Pacific Northwest to levels that will support substantial fishing will not happen if current trajectories continue. Dramatic changes in salmon trends would have to occur if restoration had any chance of success. Society has yet to make the changes necessary for the restoration of wild salmon in appreciable numbers.

Through the 21st century there will likely continue to be appreciable year-to-year variation in the size of wild salmon runs, accompanied by the decadal trends caused by cyclic climatic and oceanic changes, but most stocks of wild salmon in the Pacific Northwest likely will remain at their current low levels or continue to decline in spite of costly restoration efforts. Based on historical patterns, another cyclic climatic and oceanic change likely will occur early in the 21st century, last several decades, and stimulate modest increases in the size of wild salmon runs, but the long-term trend is likely to remain downward (Hare *et al.*, 1999).

It may appear that political institutions are unable to act, but, in fact, decisions are made daily by institutions (and individuals) on the relative importance of maintaining or restoring *wild* salmon compared to competing societal priorities. Although few people appear to be happy with the present situation and a strong majority publicly professes support for maintaining wild salmon, there is little indication that society is inclined to confront the fundamental agents of the decline. Those causes deal with both individual life style and sheer numbers of people. Thus, it is likely that society will continue to chase the illusion that *wild* salmon runs can be restored without massive changes in the number, lifestyle, and philosophy of the human occupants of the western United States and Canada.

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About the Author:

Dr. Bob Lackey is professor of fisheries science and adjunct professor of political science at Oregon State University. In 2008 he retired from the Environmental Protection Agency's research laboratory in Corvallis where, over a 27 year career, he served in various senior science and leadership jobs. Since his very first fisheries job, mucking out raceways in a California trout hatchery, he has worked on an array of natural resource issues from various positions in government and academia. His professional assignments involved diverse aspects of natural resource management, but mostly you would find him working at the interface between science and policy. He has published over 100 articles in scientific journals and authored or edited 5 books. Dr. Lackey has long been an educator, having taught at 5 North American universities. He continues to teach a graduate course in ecological policy at Oregon State University. A U.S./Canada dual citizen, he was a Fulbright Scholar at the University of Northern British Columbia during the 1999-2000 academic year. Dr. Lackey holds a Doctor of Philosophy degree in Fisheries and Wildlife Science from Colorado State University and was selected as the 2001 Honored Alumnus by their College of Natural Resources. He is a Certified Fisheries Scientist and a Fellow in the American Institute of Fishery Research Biologists. In 2008 he was awarded the U.S. Environmental Protection Agency's highest honor — the Gold Medal — for exceptional contributions in strengthening the role of science in ecological policy.

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