Salmon returns the season before publication of this book were higher than they had been in decades, but most of the fish came from hatcheries. We choose to forget these details in our rush to consume. If we want such numbers of wild fish, we're going to have to recognize that people are the problem, not fish. Specifically, our market-driven economy runs the risk of undermining the very ecological foundation on which it flourishes. What happens when we run out of cheap energy? How about clean water? And supposing we want wild salmon, how do we prioritize where to help them first?

Wild Salmon in the 21st Century: Energy, Triage, and Choices

Kenneth I. Ashley

Introduction

Making predictions 100 years into the future is risky business. For example, 2003 was the 100th anniversary of the Wright brothers' first flight, yet no one in 1903 could have predicted how aviation would change the course of human history. Making predictions about the status of wild salmon in California and the Pacific Northwest in 2100 is equally daunting, as this essentially involves predicting how society will function in 2100. What is different this time is that we know what the problems are and have many ideas on how to solve them. The primary uncertainty is whether society is willing to make the necessary changes to its collective behavior, particularly in the contentious areas of population growth, consumer lifestyle, and energy requirements. These three factors exert a powerful multiplier effect known as demophoric growth (Vallentyne 1974) that amplifies their effect and underlies most of the problems facing wild salmon in California and the Pacific Northwest.

I agree with the basic scenario outlined in Chapter 3 by Lackey et al. (2006, this volume) that society must implicitly respond to the four core drivers (rules of commerce, increasing scarcity of natural resources, regional human population levels, and individual and collective preferences) as part of any comprehensive plan to restore wild salmon abundance. I am unable to envision any strategy that could restore or maintain current wild salmon abundance throughout California and the Pacific Northwest without addressing these drivers. We know of sincere efforts at resolving important issues such as hatchery reform (Brannon et al. 2004), implementing selective harvest strategies, or initiating

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The views and opinions presented in this chapter are those of the author and do not necessarily represent those of any organization.

watershed-scale lake and stream enrichment programs (Ashley and Stockner 2003). While these efforts are important, I believe that they are inadequate for the situation facing wild salmon in California and the Pacific Northwest. Therefore, in this chapter, I will speculate how population growth, our consumer lifestyle, and societal energy demand could interact to determine the fate of wild salmon in California and the Pacific Northwest. I will start with a review of why salmon are inherently sensitive to human disturbance and conclude with a medical triage-type strategy for protecting and restoring wild salmon populations. This strategy explicitly acknowledges the population growth/consumer lifestyle/energy demand situation. As Walt Kelly stated in his comic strip Pogo, "We have met the enemy and he is us."

What Is the Problem?

At first glance, the early part of the 21st century may seem to be a strange time to be writing about concerns for wild salmon in the year 2100. Since 2001, the salmon populations in many coastal rivers in California have rebounded, and near record escapements of salmon have been recorded on the Columbia River. Recreational angling in Washington and the central and west coasts of British Columbia has been reasonably good for the past few years. So what is the concern?

An array of interacting factors feed the concern, as follows. A closer examination reveals that most of the recent escapements to the Columbia River and Sacramento–San Joaquin systems are of hatchery origin and mainly a result of favorable ocean conditions and several above-average water years prior to 2001. In 2001, a record drought year for the Columbia River basin, smolt passage protocols for Endangered Species Act (ESA)-listed stocks were cancelled at various Columbia River dams and were proposed again in 2004 to increase hydrosystem-generating capacity to supply a California market that had recently experienced rolling blackouts. Some farmers illegally diverted water from the Klamath River watershed that was, by order of the court, supposed to remain in the river for salmon, and massive salmon kills have since occurred there as the water allocation issue intensifies. Recent U.S. court decisions in Oregon, as well as federal government policies authored by the National Oceanic and Atmospheric Administration (NOAA-Fisheries), are considering delisting some ESA-listed stocks by combining hatchery and wild stocks within the listing unit (Myers et al. 2004). The 2004 NOAA-Fisheries draft biological opinion (BiOp; FCRPS BiOp 2004) salmon recovery plan states that the four lower Snake River main-stem dams are now part of the natural environment and beyond the present discretion of the government to remove them.

In 2004, the U.S. government proposed to roll back habitat protection in large areas from California to the Canadian border that was previously classified as critical salmon habitat. Many sockeye salmon *Oncorhynchus nerka* stocks are entering the Fraser River weeks early and experiencing mass die-offs or disappearing before reaching their spawning grounds. However, the Canadian federal government in 2004 rejected a scientific panel recommendation to provide Species at Risk Act (SARA) protection to two endangered coastal sockeye salmon stocks because of the economic impact to the remaining sockeye fishery. The climate seems to be getting warmer and drier with concerns being expressed about the rate of climate change. Crude oil and gasoline are at record highs in terms of current market price (i.e., not corrected for inflation), and the stability of oil rich areas in the Middle East, Africa, and South America often dominates the evening news.

As we will see in this chapter, all these issues are related and will interact with the policies adopted over the next few decades to deal with population growth, consumer lifestyle, and societal energy demand. What emerges from the interaction could determine the future of wild salmon in California and the Pacific Northwest. As history will eventually reveal, this is the right time to be writing about salmon in 2100.

Why Are Salmon so Sensitive?

Why are salmon so sensitive to human impacts compared with other species of fish? There are many factors, the most obvious being that salmon are highly valued for human consumption, are sought after by commercial and recreational anglers, and require clean, intact spawning and rearing habitat. A less obvious factor is their anadromous life history. Anadromy involves spawning in freshwater and adult rearing in the marine environment, with often long and arduous migration journeys in both directions. This life history strategy has evolved in all five species of true Pacific salmon and both species of sea-running trout (steelhead *O. mykiss* and cutthroat trout *O. clarkii*). By adopting an anadromous life history strategy, salmon that migrated to the ocean were able to exploit the differences in productivity between their freshwater and ocean environments, grow to larger sizes, and obtain higher fecundities than if they had remained in freshwater throughout their entire life. Since all true salmon are semelparous (i.e., they die after spawning), the selective advantage gained by adopting an anadromous history strategy likely increased the survival rates of their offspring by recycling marine-derived nutrients into their nursery habitats, thereby increasing habitat and stock productivity (Stockner and Ashley 2003; Murota 2003).

The interaction between human activities and anadromous salmons' complex life cycle increases the probability that they will be affected negatively by man-made deleterious habitat alterations, beyond the level faced by nonanadromous fish. Modern societal demands for land and water resources directly compete with and often conflict with salmon habitat requirements in these environments.

In their freshwater environment, adult and juvenile salmon habitat is altered by a variety of activities, including agriculture, ranching, forest harvesting, hydroelectric development, mining, and urbanization (see Chapter 2). Estuaries are focal sites for industrial activity (ship building/repair, transportation, forestry activities) and urban development. Given the propensity for urban development around estuaries, dyking often follows to protect property from flooding events, further disconnecting the estuarine habitat from side channels and marsh habitat. For example, in British Columbia, the Fraser River is the world's largest free-flowing salmon river, but the estuary is approximately 10% of historical size, despite strict federal regulations to protect critical estuarine salmon habitat.

In the marine environment, wild juvenile and adult salmon continue to be exposed to human impacts. The nearshore marine environment can be contaminated by industrial discharges and urban runoff. Concerns have been expressed about using Puget Sound salmon to restore stream productivity because of elevated tissue concentrations of several persistent organic pollutants (DDT, polychlorinated biphenyls) in the carcasses (Missildine 2005). Large releases of hatchery-origin salmon may compete with wild salmon, especially during periods of reduced ocean productivity (Levin et al. 2001). An emerging concern is the potential linkage between net-pen farmed salmon and the increased incidence of sea lice infestation and elevated mortality of juvenile pink salmon *O. gorbuscha* and chum salmon *O. keta* in the Broughton Archipelago of British Columbia (Watershed Watch 2001; Gallaugher et al. 2004; Morton et al. 2004). Similar sea lice infestations have been recorded near salmon farms in Scotland, Ireland,

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and Scandinavia; hence, the coastal BC migratory pathway of juvenile salmon may be at risk for sea lice infestation from concentrated areas of open net-pen aquaculture.

Another serious concern is the possible linkage between climate warming and the near surface productivity of the North Pacific. Large variations in productivity of the North Pacific have been a natural occurrence for millennia (Finney et al. 2002). However, the current concentration of atmospheric CO_2, as determined from Antarctic and Greenland ice core records, is significantly higher now than in the past 160,000 years (Lorius et al. 1988), which may lead to longer periods of thermal stratification, less nutrient upwelling, reduced phytoplankton production, and ultimately less food for subadult and adult salmon (Welch et al. 1998).

The Consumer Society

Since the collapse of the Soviet Union in 1989, modern industrial capitalism has emerged as the unchallenged global economic system. At the heart of capitalism lies competition, which encourages continual technological innovation to maintain market share, increase labor productivity, and reduce unit costs. Capitalist societies are engaged in demand creation through innovation and competitive pricing and require that citizens consume goods and services (Homer-Dixon 2003). According to this macroeconomic view of the world, mass production, consumption, and constant growth are universally seen as positive and beneficial to society. There is much to be said for capitalism: it raises the standard of living for many and harnesses the imagination and innovation of its citizens better than other economic systems. Capitalism may also *eventually* foster interest in social justice, equality, and protecting what remains of the environment.

“The Achilles heel of capitalism is the risk that it may undermine the ecological foundation on which it flourishes because endless growth is not possible within a finite system.”

We know for certain that centrally hard planned economies ultimately fail, as exemplified by the collapse of the Soviet Union in 1989. Some Western European countries have adopted centrally “lite” planned economies, but their current effectiveness in protecting and restoring wild salmon habitat is debatable as the majority of their salmon populations and habitat was lost centuries ago in the heyday of the Industrial Revolution. The Achilles heel of capitalism is the risk that it may undermine the ecological foundation on which it flourishes because endless growth is not possible within a finite system. Consumerism, as it is currently practiced, is an unsustainable model. In California and the Pacific Northwest, population growth, consumer demand, and energy requirements have been on a collision course with wild salmon since the discovery of gold in California in 1848 (Lichatowich 1999).

Population Growth: The Taboo Subject

As noted in Chapter 3, population growth is a core policy driver, yet it is a taboo subject for discussion in modern society. Why? There are likely two reasons. The first is individual family desires to have children, which hitherto has been a private decision. Reproductive population growth remains a factor in California and the Pacific Northwest due to the younger population, despite an overall decline in reproductive rates of most Western societies in the latter part of the 20th century. However, as noted in Chapter 3, continued immigration is largely driving Pacific Northwest population growth, which may increase from the present 15 million to a projected 50–100 million by 2100.

The second reason that population growth is rarely discussed is because the concept of population stabilization conflicts with our current economic system, which encourages constant growth and consumption. Hence, any discussion of stabilizing or reducing population growth can be interpreted as being contrary to the nature of our consumer capitalist society. As noted in Chapter 3, by discussing population stabilization, "… you run the risk of being attacked as a racist, nativist, xenophobe, cultural imperialist, or, at the least, an economic elitist." No wonder this is not a popular topic at dinner parties.

Regional Planning: Management of Population Growth and Urban Sprawl

Some levels of government have attempted to *manag*e population growth though regional planning. One of the better known examples in the Pacific Northwest is land-use laws designed to contain urban sprawl and protect rural areas in Oregon. These came under attack in the 2004 Oregon general elections (passage of Measure 37), and it remains to be seen whether frustration with some of their tenets and a well-sold private property rights pitch will override the sense of social responsibility that initially put them in place in the 1970s.

In the Lower Mainland of British Columbia, the regional government (Greater Vancouver Regional District) adopted a core "Livable Region" strategy and created regional town centers to coincide with rapid transit stations. This strategy is designed to increase population density and concentrate growth (business and residential) in these town centers, thus sparing the surrounding countryside from Los Angeles or Seattle-style suburban, automobile-dependent sprawl. When used in combination with provincial agricultural land reserve policies, which permit only legitimate agricultural use with little option of subdivision, it has been reasonably effective at containing urban sprawl.

> "The concept of population stabilization conflicts with our current economic system, which encourages constant growth and consumption."

A comparison of the effects of various growth management policies of metropolitan Seattle and greater Vancouver reveals clear differences in urban sprawl and land use. Even though the population of greater Vancouver increased by nearly 50% from 1986 to 2001 (from 1.4 million to just over 2 million), and grew at an annual growth rate higher than many megacities in developing countries, it used 7,300 ha less land than had it sprawled like Seattle (Northwest Watch 2002). Greater Vancouver's livable region plans and

Table 1. Annual population growth rate of Vancouver, Portland, Seattle and selected Third World megacities. (Source: Northwest Watch 2002.)

City and country	Time period	Annual population growth (percent)
Karachi, Pakistan	1986–2001	2.6
Greater Vancouver, B.C.	1986–2001	2.6
Metropolitan Portland, OR	1990–2000	2.4
Jakarta, Indonesia	1986–2001	2.3
Cairo, Egypt	1986–2001	2.3
Rio de Janeiro, Brazil	1986–2001	1.9
Metropolitan Seattle, WA	1990–2000	1.7

Table 2. Neighborhood classification and population density. (Source: Northwest Watch 2002.)

Neighborhood classification	Density (people ha^{-1})
Rural and car-dependent	<2.47
Suburban, sprawling, and car-dependent	2.47–29.6
Urban, compact, transit-oriented	29.9–98.8
Urban, compact, pedestrian-oriented	>98.8

provincial agricultural land reserve regulations channeled growth inwards, consumed less land, and supported more transportation options than urban sprawl. Greater Seattle, on the other hand, has grown outward at the expense of farmland and transportation options because weaker, locally controlled zoning protections were less effective at containing sprawl and attendant losses of rural land on the fringe of the metropolitan area (Northwest Watch 2002).

A critical population density is approximately 30 people per hectare, at which point public transportation becomes cost-effective. Although land is used more intensively (i.e., higher density) in compact neighborhoods, less of the overall landscape is covered with impervious surfaces such as roads, rooftops, and parking lots, which tend to increase flooding, erosion, and sedimentation in streams and transport of pollutants to watercourses. The population of greater Vancouver's compact communities (>29.6 people per hectare) increased from 46% in 1986 to 62% in 2001, whereas greater Seattle only has about 25% of its residents currently living in compact communities (Northwest Watch 2002).

Densification does not guarantee better public transit, as a variety of complementary planning, transit funding strategies, and changed social values are required to facilitate the transition. However, it is a key first step to reducing automobile dependence and reducing the amount of impervious surfaces in the urban environment (Northwest Watch 2002). Unfortunately, the Greater Vancouver Regional District is under constant pressure from developers, who wish to circumvent the plan and perpetuate the inexpensive land/automobile/cheap fuel suburban growth model that has been at the heart of most North American development and population growth since the late 1940s (Kunstler 2005).

Ecological Footprint

An aspect of population growth that warrants additional explanation is the concept of ecological footprint, which is detailed in Box 1.

Energy and Society

In addition to rapid population growth, a key factor that will influence the abundance of salmon populations in California and the Pacific Northwest is the amount and sources of energy required by society in the decades leading up to 2100. The linkage to salmon is twofold: (1) the sustainability of the current hydrocarbon energy system that supports our technological society and its inflated ecological footprint, and (2) concerns about effects of fossil fuel combustion on climate change.

Our current societal dependence on fossil fuels has grown markedly in the past 100 years and spectacularly so since the early 1960s. North Americans currently have the highest energy footprint per person, *by world region*. The United States, with 5% of the world population, consumes nearly 25% of the world's oil (current world oil consumption is approximately 82 million barrels per day, of which the United States consumes approximately 20 million barrels; 1 barrel = 42 U.S. gallons = 159 L). This is

BOX 1: Humans and Their Ecological Footprint

Humans have basic metabolic and social requirements for food, water, and shelter. As society becomes increasingly technological, the basic requirements increase in order to support the underlying technology and increased consumer demand. For example, driving a large SUV creates a larger ecological footprint than driving a smaller fuel efficient vehicle or using public transit.

The total global ecological footprint of the world's 6.1×10^9-strong population was 13.5×10^9 global hectares in 2001 or 2.2 global hectares per person (WWF 2004). The earth's biocapacity based on its biologically productive area is 11.3 billion global hectares; hence, humanity's global footprint exceeds global biocapacity by 21% (WWF 2004). This global overshoot began in the 1980s and has been increasing ever since (Wackernagel et al. 2002). The average ecological footprint of North Americans is the highest by world region, nearly double that of Europeans and seven times that of the average Asian or African. In terms of individual countries, the United States is second highest overall (United Arab Emirates is first) with an ecological footprint of 9.9 ha per person, while Canada is eighth with 6.4 global hectares per person (WWF 2004).

Technological societies have an ecological footprint that is greatly in excess of their population size. If abundant populations of wild salmon in California and the Pacific Northwest are to exist in 2100, when the population size of the Pacific Northwest is forecast to be 50–100 million, it will be necessary to reduce the regional ecological footprint or reduce the population size. It is unlikely that abundant salmon populations can coexist with 50–100 million humans exerting the per capita equivalent of today's ecological footprint.

due to the sheer size of the U.S. economy and because Americans have the third highest energy footprint per person, *by country*, which is higher than Canada and developed Western European nations (e.g., Germany, France, and the United Kingdom). Oil provides the majority of U.S. energy needs at 39%,

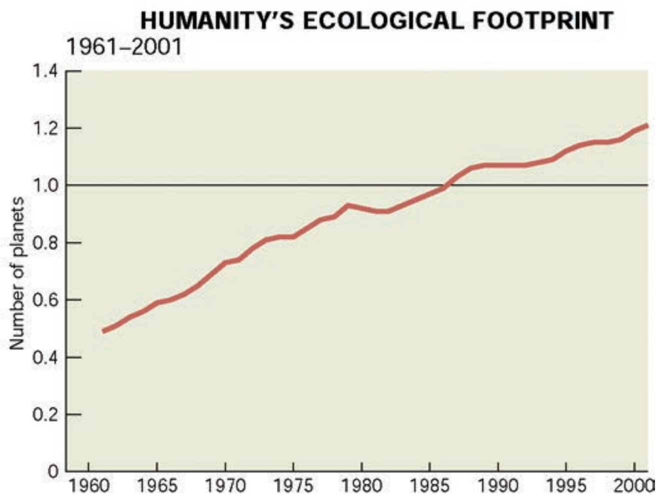

Figure 1. Humanity's ecological footprint, 1961–2001, showing how the human race's ecological footprint now exceeds the earth's biological capacity by about 20%. (Source: WWF 2004.)

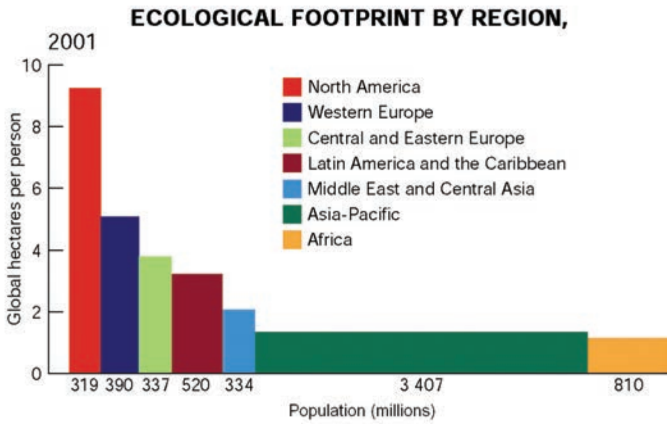

Figure 2. Ecological footprint by region in 2001 showing how North Americans have the highest average ecological footprint by world region. The height of each bar is proportional to each region's average ecological footprint. (Source: WWF 2004.)

followed by equal percentages of natural gas and coal at 23% each. The transportation sector is the largest consumer, using approximately two-thirds of the daily oil consumption. The United States has a fleet of about 210 million cars and light trucks (vans, pick-ups, and SUVs; Hirsch et al. 2005).

The availability of inexpensive energy has created a multiplier effect in terms of the size of our ecological footprint. The impact of this technological multiplier is significant. In lower income countries, the energy footprint remains relatively stable as many people cannot afford expensive, energy-dependent goods, and

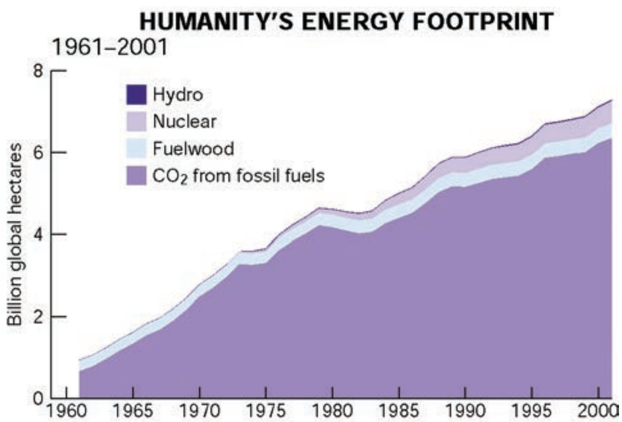

Figure 3. Humanity's energy footprint, dominated by fossil fuels, was the fastest growing component of the global ecological footprint, increasing nearly 700% between 1961 and 2001. (Source: WWF 2004.)

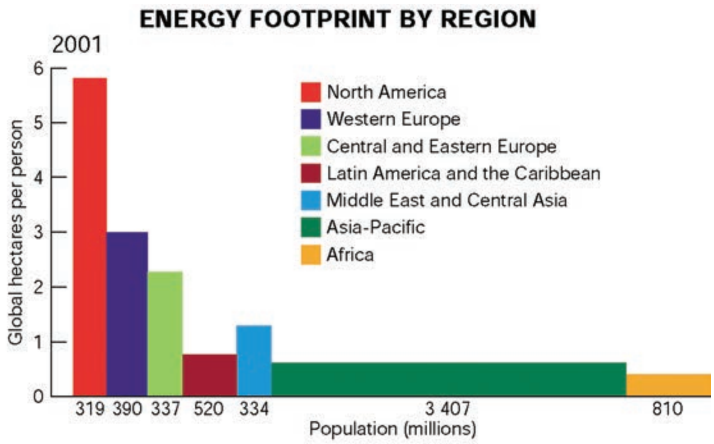

Figure 4. North Americans currently have the highest energy footprint per person, *by world region*. The height of each bar is proportional to each region's average energy footprint. (Source: WWF 2004.)

services. However, in highly industrialized countries, energy consumption is limited only by the consumers' ability to pay for energy and energy-related goods and services. This has created a demand for, and ability to pay for, the goods and services listed in Chapter 3 (e.g., tennis courts, football stadiums, and expressways) that conflict with wild salmon and their requirements for intact freshwater and estuarine habitat.

The Hydrocarbon Depletion Phase: Peak Oil

Several eminent independent petroleum geologists predict that a disruptive period will unfold in the next few decades due to the depletion and eventual exhaustion of conventional oil and gas reserves and the search for alternate sources of energy (Heinberg 2003). This rollover has only happened twice before in human history: in 16th century England, when the largely agrarian society converted from wood to coal, and throughout the first half of the 20th century, as industrialized nations converted from coal to oil. The conversion from wood to coal and coal to oil took place slowly over several decades and occurred mainly because of the technological superiority of the new energy source and strategic positioning rather than scarcity, although localized fuel wood shortages were becoming a major concern in several areas of medieval England (Freese 2004). The conversion from fossil fuels will occur for a variety of reasons, but with oil and natural gas, it will be mainly due to depletion of known conventional reserves, geopolitical concerns, and the environmental consequences of burning immense quantities of oil and gas.

The current direct and hidden subsidies distort the true cost of fossil fuel-based energy, encourage consumption, discourage conservation, discourage the development of price-competitiveness of alternate energy sources, and will ultimately cause immense environmental damage through climate change. For example, subsidized fuel costs have created the situation where the fossil fuel caloric energy input of some commercial fisheries in North America exceeds the nutritional caloric energy obtained in the catch by at least one order of magnitude (Tyedmers 2004). Estimates of the true cost of gasoline range between US$5.60 and US$15.14 per U.S. gallon (3.785 L), depending on the definition of subsidies and the quality of the data (Rees 2003).

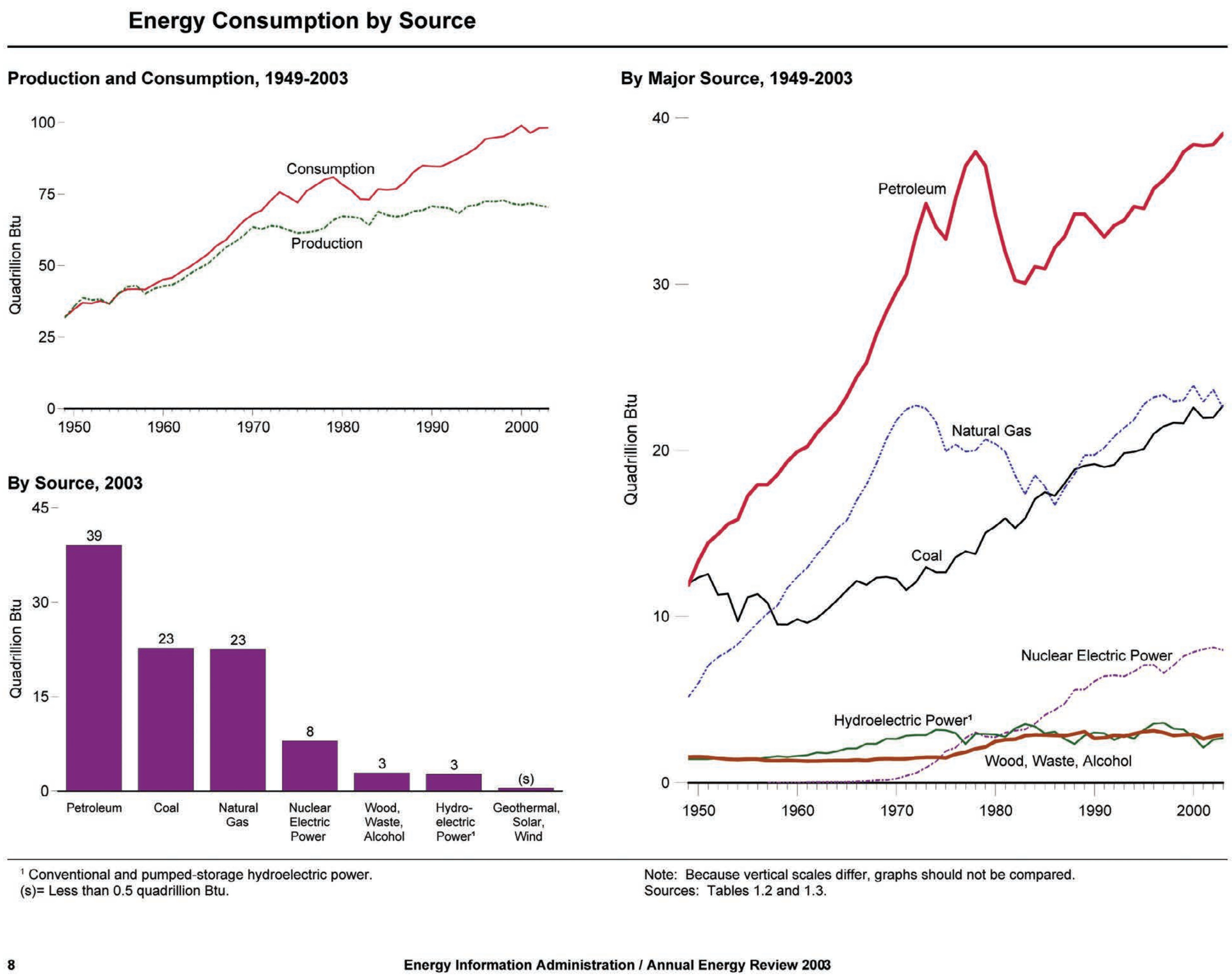

Figure 5. U.S. energy consumption by source in 2003 showing how oil provides the majority of U.S. energy needs at 39%, followed by nearly equal percentages of natural gas and coal at 23% each. (Source: Energy Information Administration 2003.)

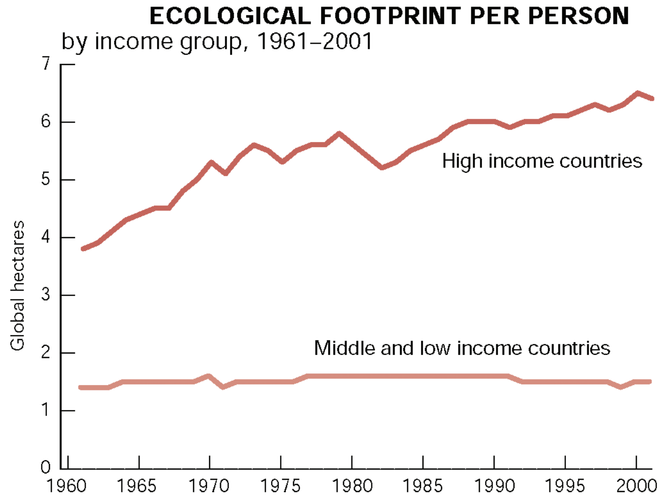

Figure 6. Ecological footprint per person by income group, 1961–2001, showing the multiplier effect of technological societies. (Source: WWF 2004.)

An important term in the oil industry is peak oil, which is a hydrocarbon reservoir's maximum oil production rate and typically occurs when 50% of the known conventional reserves have been recovered from an oil field. The term applies to a single well, collection of wells, or the planet as whole. After the peak, it becomes more difficult to maintain production and, eventually, production declines following the descending limb of a bell-shaped curve (Roberts 2004). Global demand for oil could then exceed the capacity to supply it for the first time in human history. Production of conventional oil in the United States peaked in 1970 and has been declining since (Deffeyes 2003). Estimates of the global peak oil year vary among experts, ranging from independent geologists' prediction of 2006 for the world outside of the Middle East and 2016 for the world, including the Middle East, to the optimistic U.S. Geological Survey prediction of 2023 for the word outside of the Middle East and 2040 for the world, including the Middle East (Appenzeller 2004).

Global supplies of natural gas fare somewhat better, although a familiar scenario emerges: most of the gas is located in distant, often politically unstable countries and must be shipped vast distances to reach the U.S. market. Russia, Iran, and Qatar contain 58% of the world's known gas reserves, while most of the remainder is in Saudi Arabia, United Arab Emirates, Algeria, Venezuela, Nigeria, and Iraq. Natural gas is vastly more expensive to transport than oil as it must be chilled to –176°C during transit and requires specialized liquefied natural gas ships and ports to ship and receive the gas (Heinberg 2003).

The connection between declining conventional oil and gas reserves and the future of salmon in California and the Pacific Northwest is straightforward: how will the government, energy suppliers, and society respond to the declining availability of conventional oil and gas, and how will these choices affect salmon? This is the fundamental question regardless of which oil depletion model is used, as most of the world's conventional recoverable oil will be exhausted before 2100.

In 2001, the response to the western North American energy shortage was clear: energy production had priority over salmon protection. Federally mandated smolt passage spill programs on the Columbia

River were curtailed to generate power for the California market. Since hydroelectric power is nearly greenhouse gas free and strategically secure, a plausible scenario for California and the Pacific Northwest is an expansion of existing facilities and construction of new generation stations and transmission lines in an attempt to compensate for declining, increasingly expensive, and geopolitically destabilizing supplies of foreign oil and gas. This would create additional upstream and downstream barriers for salmon in anadromous reaches, although with today's knowledge of juvenile and adult upstream and downstream fish passage requirements and advanced turbine designs (Coutant and Whitney 2000; Johnson et al. 2000), generation facilities could be designed, built, and operated in a salmon-friendly manner, albeit with additional costs. However, some species of salmon (e.g., steelhead) adapt poorly to reservoirs; hence, each component of a hydroelectric system must be designed and operated to benefit all species. Given the growing concerns about climate change exacerbated by fossil fuel combustion and requirements for alternate energy sources, hydroelectric power generation will not be going away soon, so it is unlikely that any large main-stem dams in the Columbia River basin would be dismantled to save endangered salmon stocks.

> "How will the government, energy suppliers, and society respond to the declining availability of conventional oil and gas, and how will these choices affect salmon?"

The initial responses to the hydrocarbon depletion phase occurred in 2004 when the U.S. government concluded that the hydroelectric dams on the Columbia and Snake rivers do not jeopardize salmon survival and that no dams, including the four lower Snake River dams, would be dismantled. The implicit assumption is that security of energy supply outweighs concerns about endangered salmon. Secretary of Energy Spencer Abraham corroborated this on March 19, 2001 when he stated, "America faces a major energy supply crisis over the next two decades…The failure to meet this challenge will threaten our nation's economic prosperity, compromise our security, and literally alter the way we live." It is likely that when foreign oil (and gas) supplies become limiting, too expensive, or strategically out of bounds for the United States in the years to come, national security interests could overrule existing state and federal laws protecting salmon, and California and Pacific Northwest rivers could be targeted for additional hydroelectric energy generation.

From an overall energy perspective, the Pacific Northwest is fortunate to have 71% of its aggregate 47,000 megawatts (MW) (i.e., 33,500 MW) of generating capacity supplied by existing Columbia River basin hydroelectric facilities and will be better positioned to cope with oil and gas depletion than many other regions in the United States and Canada that have little or no hydroelectric generation potential. A similar program of hydroelectric facility expansion and new construction is likely in British Columbia for domestic use and export to the western North American energy market. Future hydroelectric megaprojects in British Columbia (e.g., 900 MW Peace River Site C) are already on the drawing board, and three hydroelectric retrofit/expansion projects totaling 685 MW are nearing completion on the upper Columbia River (i.e., Arrow Lakes generating station, Brilliant expansion, and Waneta expansion projects). Additional generation capacity is available at Revelstoke and Mica generating stations on the upper Columbia River, and the BC government has formally requested applications for independent power projects. Even if the Hydrogen Age arrives as some envision (Rifkin 2003), vast amounts of energy will be required to produce hydrogen by electrolysis of water. The carbon dioxide enriched atmosphere of the mid- to late 21st century may have minimal tolerance for additional greenhouse gases; hence, hydroelectricity will likely assume increased importance in the California and Pacific Northwest energy sector.

If additional clean sources of energy become commercially available during the oil depletion era, then wild salmon *may* have a chance of surviving to 2100. Widespread replacement of oil by natural gas, renewed conservation efforts, and increased energy efficiency will likely be the initial responses to declining availability of conventional oil. Gas-fired combined cycle cogeneration plants are very efficient, can be built more quickly and paid off faster, and are less onerous to carry through the environmental approval process than nuclear or large-scale hydroelectric dams. Many energy experts believe that natural gas will be the bridge fuel after conventional oil is depleted, but global conventional gas reserves are predicted to peak around 2020 and decline very quickly thereafter (Campbell 2000; Darley 2004). Solar, wind, tidal, biofuels, geothermal, nuclear, and hydroelectricity are all energy options that could theoretically be used to replace declining conventional oil and gas supplies and could be designed as salmon-friendly, but a massive, decades-long coordinated effort would be required to achieve this goal. Nearly all energy experts agree that the most cost-effective strategy to deal with energy shortages is to consume less and extract more from what is consumed. For example, in the 1950s, the U.S. economy, as a whole, used 20,000 British thermal units (BTU) for every inflation-adjusted dollar of gross domestic product but, by 2000, required an amount closer to 12,000 BTU per dollar of gross domestic product due to improvements in energy efficiency (Heinberg 2003).

If, rather than developing clean sources of energy and pursuing conservation/efficiency, society decides to replace oil and gas with coal-burning power plants, or pursues massive oil shale projects, the environmental consequences for salmon will likely be considerably worse. The United States contains hundreds of years' supply of coal and oil shale, yet it is environmentally onerous to obtain because of the high cost of extraction and the subsequent emissions of mercury, sulfur, and greenhouse gases. The clean coal lobbyists indicate that all is well in the coal industry, but a perpetual waste management program of carbon sequestering, even if it is technologically feasible, would be required to keep carbon dioxide out of the atmosphere. A new process for burning coal, known as integrated gasification combined cycle (IGCC), refines coal into synthetic gas and then uses the gas in a standard gas-fired turbine. Carbon sequestering technology, still in its infancy, could theoretically be added to an IGCC system. However, it is estimated that this would require 20% more coal consumed to power the decarbonizing plant and would increase electric generation costs by 30–50% (Roberts 2004). Further, the question of how to dispose of huge amounts of sequestered carbon remains unresolved. Some energy experts believe that nuclear energy will provide the majority of energy for the Hydrogen Age in nonhydroelectric regions as the environmental and health costs of burning coal or shale oil is unacceptable (Ballard 2003).

There is also the question of energy returned on energy invested (ERoEI). It takes energy to develop energy resources, so an energy source that takes more energy to acquire than it yields is actually an energy sink. Subsurface coal in the United States is exhibiting a declining trend in ERoEI and may reach 0.5 by 2,040 (i.e., a net energy sink; Heinberg 2004). Alberta's vast oil sands, which are estimated to contain the equivalent of 870×10^9 to 1.3×10^{12} barrels of oil, require huge amounts of natural gas to extract the bitumen and add hydrogen to the synthetic crude oil molecules (Heinberg 2003). Hence, the satirical observation "Using natural gas to make synthetic fuel is like inventing a process that turns gold into lead" (Bolger and Issacs 2003). A crucial decision will be required in the not too distant future to decide whether northern Canadian natural gas should be consumed en masse at the oil sands or piped south to U.S. markets.

Climate Change

A very serious energy-related concern that could influence how many, and which, stocks of salmon in California and the Pacific Northwest survive to 2100 is the rate and magnitude of climate change, as outlined in Box 2.

How does climate change influence wild salmon in California and the Pacific Northwest? Conservative regional climate warming scenarios predict a 2–7°C temperature increase by 2100 and a 60% reduction in western snowpacks within 50 years (Service 2004). This in turn will reduce summertime streamflows by 20–50%, leading to widespread impacts as water becomes less available for everything from agriculture to streamflows for fish to increasingly valuable hydroelectric energy generation. The timing of the runoff will shift, with much of the expected precipitation occurring in winter and spring as rain, rather than the delayed snowmelt that the Pacific Northwest depends on for agriculture, reliable hydroelectric energy, and sustaining salmon habitat (Service 2004).

The warming, drying trend may affect forest health, which could influence salmon habitat. For example, the pine beetle infestation in British Columbia's interior is one of the biggest ecological disturbances ever observed in North America. Several days of –40°C weather are required to kill the beetle larvae, and severe winters have not occurred for several years. This massive loss of forest cover will likely influence runoff timing, increase summer stream temperatures, and alter the recruitment of large woody debris into streams and rivers. Climate warming is predicted to cause declines in ocean productivity, as stronger thermal stratification could result in less deep winter mixing and decreased nutrient regeneration availability. One model predicts that there could be no sockeye salmon south of the Aleutian Islands by the mid-21st century if

BOX 2: Atmospheric Carbon Dioxide

The concentration of atmospheric CO_2 has ranged from 190 to 280 ppm over the past 160,000 years (Lorius et al. 1988). Atmospheric CO_2 started increasing about 8,000 years ago due to humans in China, India, and Europe cutting and burning forests for early agriculture and has been increasing ever since, especially since 1850 and spectacularly so in the 20th century (Ruddiman 2005). The current concentration of atmospheric CO_2 is approximately 370 ppm, and it will continue to rise based on current and future estimates of fossil fuel combustion. Most global climate models predict that at our *current rates* of fossil fuel consumption, atmospheric CO_2 will rise approximately 1.5 ppm per year and reach 510 ppm by 2100. The same models predict concentrations of 450 ppm will produce a moderate climate change, but when CO_2 concentrations exceed 550 ppm, dangerous levels of warming and climate induced damage will occur (Roberts 2004).

The problem is that the current rate of 1.5 ppm annual increase in atmospheric CO_2 will continue only if we stay at our current fossil fuel consumption rates, which emit approximately 6.3×10^9 metric tons of CO_2 per year. By 2035, the global demand for oil is expected to increase from the current 82 million barrels per day to 140 million barrels. Natural gas consumption is predicted to expand by 120%, and coal consumption is predicted to increase by 60%. The Carbon Dioxide Information Analysis Center, a unit with the U.S. Department of Energy's Oak Ridge National Laboratory, has been monitoring atmospheric CO_2 at the summit of Mauna Loa, 3.5 km above sea level, and has detected atmospheric CO_2 rate increases of 2.08 ppm from 2001 to 2002 and 2.54 ppm from 2002 to 2003. Most climate models now predict annual atmospheric CO_2 rate increases greater than 1.5 ppm per year due to increasing world population growth and rapid industrialization of China, India, and Brazil, resulting in estimated CO_2 emissions of 12×10^9 metric tons per year by 2030. A climate wild card is the possibility of feedback loops that could cause runaway CO_2 and methane releases from thawing permafrost areas (Hassol 2004) and sea floor methane clathrates or a weakening of the gulf stream circulation in the North Atlantic and the resultant catastrophic cooling of Western Europe (Flannery 2005).

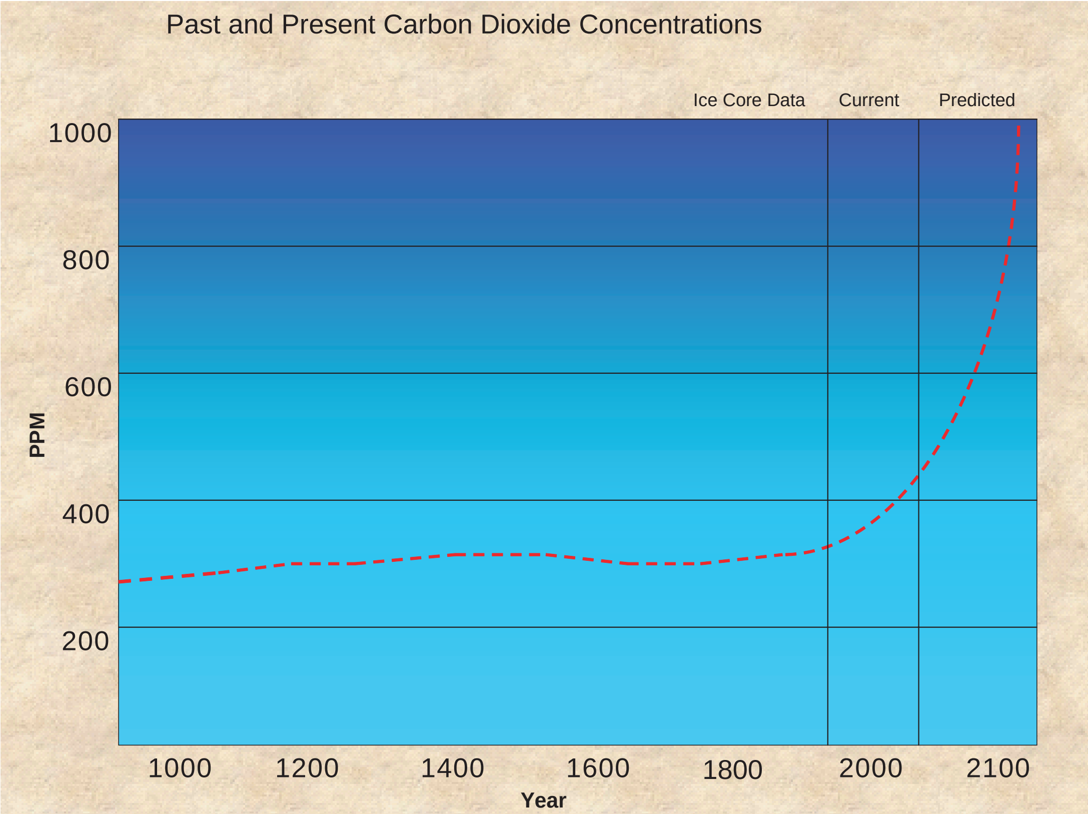

Figure 7. The concentration of atmospheric CO_2 was stable for millennia and has increased dramatically since the start of the Industrial Revolution. (Source: IPCC 1997.)

atmospheric CO_2 concentrations increase to 540 ppm by 2050 (Welch et al. 1998). In 2004, an oceanographic survey from the southern coast of British Columbia to Ocean Station Papa (50°N, 145°W) recorded the warmest surface waters ever observed since 1959, an especially shallow winter mixed layer, and a decrease in the ventilation of thermocline waters (Whitney 2005).

Policy Options: The Triage Approach

Given these potentially bleak predictions, is there any point in trying to ensure that healthy populations of wild salmon will exist in California and the Pacific Northwest in 2100? The key to answering this question lies in how society in California and the Pacific Northwest respond to the emerging linkages between population growth, consumer lifestyles, fossil fuel consumption, climate change, and the distribution and abundance of wild salmon.

Salmon Protection and Recovery Principles

The principal strategy for ensuring that significant populations of wild salmon will exist in California and Pacific Northwest in 2100 is the creation of an area-wide network of salmon sanctuaries for selected stocks

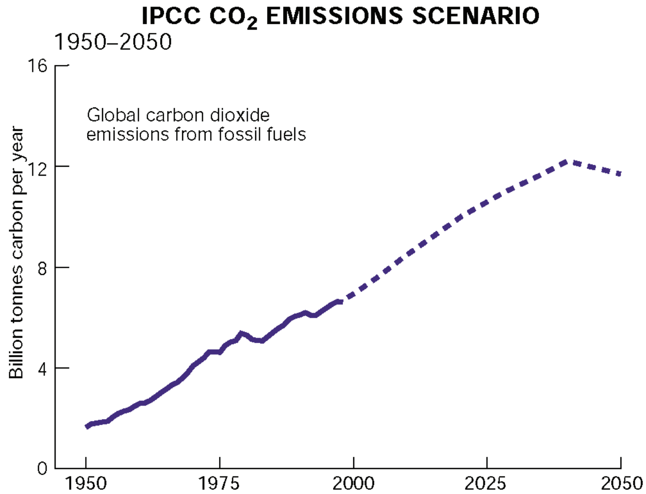

Figure 8. IPCC predicted annual global CO_2 emissions scenario, B1, 1950–2050, showing an increase to 12×10^9 metric tons by 2030. (Source: WWF 2004.)

and populations and transferring ownership of the land and associated water licenses to nonprofit salmon societies. I believe ownership by nonprofit, publicly accountable stewardship societies whose primary objective is the protection and restoration of wild salmon is the safest long-term strategy for the protection of salmon as it minimizes the risk of intervention by current or future individuals, industry, or governments, who may have different priorities. A variety of economic activities will be encouraged in these watersheds, with the objective of maximizing the economic return on investment, *with the proviso that salmon protection and conservation is the preeminent policy objective*.

The selection of which salmon stocks and habitats will be protected will be done on a triage-type basis, whereby various stocks will receive protection according to their stock status, genetic characteristics, and value as future donor populations. Medical emergency room triage classifies patients into three categories: (1) those that will die regardless of any treatment they receive, (2) those who will survive if they receive adequate treatment, and (3) those who will survive regardless of any treatment they receive. The selection of which salmon stocks receive sanctuary protection is analogous. Citizens, municipal, county, state, and federal governments will be asked to support this strategy on the premise that future social and energy supply/demand decisions will be complementary to these present-day investments. If not, then a sanctu-

“I believe ownership by nonprofit, publicly accountable stewardship societies whose primary objective is the protection and restoration of wild salmon is the safest long-term strategy for the protection of salmon as it minimizes the risk of intervention by future individuals, industry, or governments, who may have different priorities.”

ary-based strategy will ultimately be ineffective, and wild salmon will likely dwindle to isolated remnant populations by 2100 as per the predictions in Chapter 3. The rationale and policies for adopting this triage-style protection strategy are as follows.

1. Society may be incapable of undertaking or unwilling to undertake salmon protection and recovery projects when the major peak oil and gas energy shortages occur in the early decades of the 21st century. Most people, governments, and organizations will likely be preoccupied with obtaining sufficient energy to maintain their customary standard of living and geopolitical status (Heinberg 2004). Safe downstream passage for Columbia River ESA-listed salmon stocks was a low priority during the California and Pacific Northwest energy shortage of 2001, and future energy shortages may elicit similar responses. The chaos of the 1973–1974 OPEC oil embargo and the massive August 14, 2003 blackout across eastern North America when more than 50 million people were plunged into darkness when the electricity grid failed are examples of what could happen. It is reasonably certain that during a large-scale energy shortage or electrical grid failure, very few members of society will be overly concerned about the welfare of wild salmon in California and the Pacific Northwest, other than a few individuals operating emergency generators at hatcheries. Hence, habitat protection efforts should be undertaken in advance.
2. There is only so much money available for salmon recovery. Current General Accounting Office estimates of salmon protection recovery expenditures from 1982 to 2001 in the Columbia River basin are approaching US$3.3 billion (GAO 2002); yet, many stocks remain on the ESA's endangered or threatened lists. Rather than making heroic efforts and spending large amounts of money on small isolated stocks that may not survive to 2100 (e.g., Redfish Lake sockeye), it may be more

Figure 9. Estuaries often become focal sites for industrial activity and urban development. Diking usually follows to protect property from flooding events, further disconnecting estuarine salmon habitat from side channels and marsh habitat. (Source: U.S. Army Corps of Engineers.)

Figure 10. The transportation sector is the largest U.S. consumer of oil, using approximately two-thirds of the daily oil consumption. The United States has a fleet of about 210 million cars and light trucks (vans, pick-ups, and SUVs). (Source: Dain Hubley.)

strategic to focus efforts on protecting key conservation units via carefully selected habitat purchases, including estuaries and water licenses, to ensure that future donor populations are available for recolonizing salmon extirpated streams.

3. Decisions on which conservation units to protect will be made on the basis of stock status and which genotypic and phenotypic characteristics meet the requirements of a viable evolutionary significant units (ESU; ISAB 2005). The specifics of which stocks should be selected are beyond the scope of this essay, but it would be a defensible selection process by a panel of recognized salmon geneticists, biologists, and ecologists. Ruckelshaus et al. (2002) review the complexities of the conservation unit debate and how to identify relevant clusters of diversity. A recent report by the Independent Scientific Advisory Board recommends, " …given the high uncertainty in prediction of future environmental conditions, as well as the uncertainty in the interpretation of how genetic or other diversity metrics will be expressed in future environments, prudent management would hedge bets by avoiding loss of currently small, peripheral or in any way seeming less valuable ESU components." (ISAB 2005).

4. Populations at the extreme range of their distribution would receive priority protection only if they are truly unique populations, rather than simply being a population that exists in a single location in a state, county, or province, and a similar healthy stock exists nearby across a boundary or border.

5. Progressive tax penalties could be introduced by respective federal, state, provincial, county, regional, and tribal governments to encourage society to protect salmon and their habitat. These could include such options as an ecological footprint tax, deleterious land use tax, and consumptive water use taxes. Revenue from these taxes could be directed to non-profit salmon societies specifically created to purchase and secure salmon habitat and water licenses according to the selection principles previously mentioned. Tax incentives and credits would also be available to industries that exhibited significant reductions in their ecological foot- print and adopted more salmon-friendly business practices.

6. Under the triage system, a stock that is highly certain to become extinct regardless of massive intervention efforts because it has declined below a minimum viable population size or the habitat has

Figure 11. The average fuel efficiency of U.S. automobiles had been improving dramatically between 1980 and 1995, but the trend has now reversed itself as consumers, encouraged by low fuel prices, began buying light trucks and SUVs. (Source: Pam Roth.)

experienced irreparable damage would not receive *priority* attention. This is a difficult concept to accept and would require amendments to existing ESA and SARA legislation, which currently call for fixing the worst cases first, which may be the wrong approach to salmon restoration. The correct approach may be to ensure the survival of the most evolutionarily significant stocks first. The Canadian government, in its decision to not list Cultus Lake and Sakinaw Lake sockeye, and most recently Interior Fraser River coho, under the Species at Risk Act, is currently struggling with this dilemma. The triage approach would require careful monitoroing to prevent being manipulated by those scheming to avoid protecting endangered stocks.

7. If a hatchery is conclusively demonstrated to be weakening the long-term survival of a priority wild stock (e.g., genetic introgression, disease introduction) and the hatchery operations cannot be modified to protect the wild stock, then the hatchery should be closed and the operational funds reassigned to purchase sufficient land and water licenses within the watershed in order to ensure long-term survival of the priority salmon stock.
8. The maximum allowable harvest rate for any salmon stock will be conservatively set at less than 20%. Knudsen et al. (2003) explored various harvest rates via simulation modeling and identified a 20% harvest rate as the maximum long-term exploitation rate a stock could withstand and not experience an eventual decline in abundance and still maintain the positive benefits of returning salmon-derived nutrients on habitat and stock productivity.

Classification of Salmon Habitat

The following salmon habitat categories include examples of the types of protection that society may consider to resolve current patchwork attempts at protecting and restoring wild salmon in California and the Pacific Northwest. Note: these guidelines and revenue sources are not presumed to be exhaustive but are presented in point form to stimulate discussion as to which strategies may be compatible with the concept of wild salmon sanctuaries.

Category 1: Wild Salmon Refugia.—Salmon stocks in this category inhabit large, essentially intact habitat units in remote wilderness areas with minimal consumptive use, except those allowed under aboriginal treaty obligations or a community watershed fishing license (CWFL). The land base is likely government (federal, state, or provincial) with minimal private holdings. A maximum exploitation rate of 20% will be permitted by aboriginal or CWFL terminal fishery (i.e., located close to where salmon segregate to spawning streams) if the stock can sustain the harvest rate. This habitat would act as the primary refugia for identified salmon stocks. These stocks, under the worst case scenario, would become the remnant salmon populations in California and the Pacific Northwest, should current rates of human and industrial impacts continue. Since most of the land base is likely government-owned, transfer of these stock specific habitat areas into salmon refugia should be a straightforward land-property transfer process.

Guidelines for wild salmon refugia

- No hydroelectric development.
- No mixed-stock interception fisheries.
- 20% maximum exploitation rate by aboriginal or local community using terminal fisheries.
- No activities identified as being deleterious to salmon habitat.
- No hatcheries.
- Use revenue from salmon taxes to purchase the land if not on federal, state, or provincial government land.

- Limited residential dwellings permitted in watersheds.
- No water withdrawals except for approved residences in the watershed.

Revenue sources

- Consumptive-use salmon taxes and pollution taxes from category 4 watersheds.
- Ecotourism income and scientific use of the salmon watersheds.
- Royalty payments from selective harvest terminal fisheries.
- Watershed user fees for salmon-compatible industries (e.g., cottage industries, artists).
- Revenue from selective logging sales.
- Very limited residential development.
- Revenue from guided angling.

Habitat restoration/protection policies

No habitat restoration required because salmon habitat is mostly intact; main activity is to prevent introgression from potential hatchery strays (all hatchery fish must have adipose fins clipped); enhanced enforcement patrols to ensure habitat protection and harvest rate compliance.

Category 2: Wild Salmon Reserves.—Salmon stocks in this category inhabit large, partially fragmented habitat units in rural areas with a mixture of primary resource extraction (e.g., forest harvesting, gravel mining, agricultural, ranching, and sparse housing; <2.5 residents/ha). The land base is a mixture of federal, state, county, provincial, and municipal, with some private holdings. A maximum exploitation rate of 20% will be permitted by aboriginal or CWFL terminal fishery if the stock can sustain the harvest rate. These habitat units will receive the majority of salmon habitat restoration efforts as the rural land base and low housing density provides the highest probability of a positive return on investment for habitat restoration projects. Salmon populations in these watersheds function as an additional level of protection for the stocks identified by the selection procedure. These stocks would either stabilize or increase in population size due to the active habitat restoration efforts and add to the genetic mosaic of salmon stocks protected in sanctuaries throughout California and the Pacific Northwest. Since most of the land base likely has several owners, transfer of these watersheds into wild salmon reserves should be possible, with appropriate compensation for private land purchases or covenants.

Guidelines for wild salmon reserves

- Hydroelectric development permitted provided it is above any anadromous habitat, it is above any habitat inhabited by resident headwater donor populations of salmon and trout, and has no deleterious downstream effects.
- No mixed-stock interception fisheries.
- Twenty-percent maximum selective harvest exploitation rate per stock by aboriginal or local community using terminal fisheries.
- No activities identified as being deleterious to salmon habitat.
- No hatcheries.
- Use revenue from salmon taxes to purchase land and water licenses if not on federal, state, or provincial government land.
- Limited residential dwellings permitted in watersheds.
- Strictly regulated water withdrawals, including sustainable volumes for commercial bottled water sales.

Figure 12. Given the likelihood that hydroelectric energy generation facilities will remain the only large-scale sustainable energy source in the Pacific Northwest, greatly increased efforts must be directed at resolving upstream and downstream passage for juvenile and adult salmon. (Source: U.S. Army Corps of Engineers.)

Revenue sources

- Royalties from hydroelectric energy sales.
- Consumptive-use salmon taxes and pollution taxes from category 4 watersheds.
- Royalty payments from selective harvest terminal fisheries.
- Watershed user tax for salmon-compatible industries (e.g., cottage industries, artists).
- Revenue from selective logging sales.
- Limited residential development.
- Commercial sales of bottled water.
- Revenue from guided angling.

Habitat restoration/protection policies

Engage a full suite of active and passive habitat restoration to restore previously degraded salmon habitat (e.g., large woody debris placement, off-channel construction, reactivation of relict side-channels, and stream enrichment); prevent hatchery introgression from potential hatchery strays (all hatchery fish will have adipose fins clipped); enhanced enforcement patrols to ensure habitat protection and harvest rate compliance.

Category 3—Mixed-Use Salmon Watersheds.—Salmon stocks in this category inhabit medium-sized, fragmented habitat units in rural and suburban residential areas with a mixture of light to medium industrial, agriculture and housing densities (2.5–30 residents/ha). The land base is a mixture of county, regional government, and municipal ownership, with considerable private holdings. A maximum exploitation rate of 20% will be permitted by a CWFL terminal fishery if the stock can sustain the harvest rate. These watersheds will receive less salmon habitat restoration efforts than category 2 watersheds as the higher population density provides a lower probability of a positive return on investment for habitat restoration projects. Salmon populations in these watersheds act as a third level of protection for a limited number of identified stocks by species and region. These stocks will either stabilize or fluctuate slowly in population size due to climate change and human activities within the watersheds in the years leading up to 2100. Since most of these habitat units have hundreds of property owners, there is little possibility of conversion into category 2 reserves, other than selected purchases of identified critical parcels of land within the watershed.

Guidelines for mixed-use salmon watersheds

- Headwater and main-stem hydroelectric development permitted provided it allows upstream/downstream juvenile and adult passage using the best available technology.
- No mixed-stock interception fisheries.
- Twenty-percent maximum selective harvest exploitation rate per stock by aboriginal or local community using terminal fisheries.
- Any industry permitted in the watershed, subject to current laws regarding environmental stewardship.
- Full use of conservation hatcheries, all hatchery fish must have adipose fins clipped.
- Licensed water withdrawals for various user groups.

Revenue sources

- Royalties from hydroelectric energy sales.
- Royalty payments from selective harvest sales.
- Watershed user tax for salmon compatible industries (e.g., cottage industries, artists).
- Revenue from timber sales.
- Full residential development under current construction and residential guidelines.
- Revenue from volume-based water license fees.

Habitat restoration/protection policies

Active habitat restoration to restore previous degraded habitat (e.g., large woody debris placement, off-channel construction); all hatchery have adipose fins clipped; enhanced enforcement patrols to ensure habitat protection and harvest rate compliance.

Category 4: Urban Salmon Watersheds.—Salmon stocks in this category inhabit small, fragmented watersheds in suburban and urban residential areas with a mixture of medium to heavy industry and housing densities (30–100 residents/ha). The land base is mainly municipal and private. No exploitation is permitted as the stocks are unable to sustain any harvest rate. These watersheds will receive minimal salmon habitat restoration efforts as the amount of industrial and residential development provides a low return on investment for habitat restoration projects. Some salmon populations in these watersheds are not restorable and mainly function as educational and demonstration watersheds and for case studies for innovative salmon protection and restoration trials. Some stocks may become extirpated because of conflicts over water, habitat loss and/or destruction, and episodic point and non-point source pollution events within the watersheds. These watersheds have thousands of property owners; hence, there is little possibility of these watersheds being converted into category 3 mixed-use salmon watersheds.

Guidelines for urban salmon watersheds

- Headwater and main-stem hydroelectric development permitted with best available upstream and downstream juvenile and adult fish passage technology.
- All industries permitted in the watershed, subject to current laws regarding environmental protection and stewardship.
- No mixed-stock interception fisheries.
- All hatchery fish have adipose fins clipped.

Revenue sources

- Consumptive-use salmon taxes and pollution taxes, to be used to purchase habitat and water licenses for categories 1 and 2 above.
- Residential development under current industrial and residential guidelines.
- Revenue from licensed water withdrawals for domestic, agriculture, and industrial use.

Habitat restoration/protection policies

Habitat restoration for demonstration and individual stewardship group projects; habitat protection as per current laws.

Figure 13. Given the potential threat that open net-pen aquaculture poses to wild salmon through amplification of sea lice, these operations should be fallowed during spring smolt migrations, moved to land-based systems, or converted to closed-pen aquaculture until the sea lice threat to wild salmon can be unequivocally resolved. (Source: Alexandra Morton.)

Discussion

So we have met the enemy and he is us. Now what? Some obvious consequences emerge from this type of salmon triage and sanctuary strategy:

1. *Complete a California and Pacific Northwest genetic relatedness map for all salmon stocks.*—Much of this work has already been done by various government agencies in preparation for biological opinions, ESA, and SARA listings. The data gaps should be addressed and public dialogue initiated to determine which conservation units should be used to determine the stocks for each category.
2. *Produce detailed geographic information system (GIS) maps of all salmon watersheds, and overlay these maps with the salmon conservation units database.* Again, much of the GIS work has likely already been done by various levels of government, tribes, and nongovernmental organizations. This information must be combined into a single database to avoid duplication; then, public dialogue should be initiated to classify the salmon watersheds into categories 1 through 4.
3. *Write and pass legislation to enact the salmon user fees, tax incentives, and the various land-use regulations that have been determined for each of the four categories*.
4. *Begin the transfer of federal, state, and provincially owned land and the purchase of critical private land and water licenses* to establish sufficient refugia, reserves, and mixed-use watersheds before any societal disruptions occur due to decreasing availability and increasing costs of conventional oil and gas. The highest overall priority of this plan is conservation and restoration of wild salmon. If a harvestable surplus is identified, a negotiated portion is initially allocated to treaty-entitled aboriginal tribes for food and ceremonial purposes, as per current Canadian and U.S. federal and state law. The remaining allocation of harvestable surplus remains the responsibility of the watershed group charged with protecting and managing the salmon. Professional angling guides living within the community could be allowed a certain percentage of fish to support small, family-based guiding businesses. It is likely that many charitable organizations and wealthy individuals would contribute to this approach due to the certainty of protection it provides, absence of government involvement, plus the opportunity to live in salmon refugia or salmon reserves. Some proactive organizations in the Pacific Northwest have already adopted this strategy. For example, in Washington State, the Salmon Recovery Funding Board recently awarded a US$1 million grant to the Whatcom Land Trust to purchase 1,012 ha of salmon spawning habitat on both sides of the south fork of the Nooksack River. This is in addition to the 1,615 ha of upstream habitat already purchased and protected by Seattle City Light. Whatcom County is providing $400,000 in matching funds, and the Lummi Indian Business Council will contribute an additional $22,000.

In addition to the aforementioned actions, some key societal changes must be made within the next few decades to protect future returns on present investments in various categories of salmon sanctuaries. First, North American society should *begin* paying the true cost of fossil fuels (gasoline, diesel fuel, heating oil, and natural gas) through a series of orderly price increases and initiate an intensive conservation and energy efficiency program. Orderly price increase will stimulate interest in conservation and energy efficiency, which is the most cost-effective response to increasing energy costs. For example, the average fuel efficiency of U.S. automobiles had been improving dramatically between 1980 and 1995, but the trend has now reversed itself as consumers, encouraged by low fuel prices, began buying light trucks and SUVs (Heinberg 2003).

Second, given the potential threat that open net-pen aquaculture poses to wild salmon through amplification of sea lice (Morton et al. 2004), these operations should be fallowed during spring smolt migrations, moved to land-based systems, or converted to closed-pen aquaculture until the sea lice threat to wild salmon can be unequivocally resolved. Open net-pen salmon aquaculture, using high protein fish-based meal from the southern oceans, produces less salmon biomass than the biomass used as feed (Naylor et al. 2000). Hence, it is illogical to encourage unsustainable industries that are "…the aquatic equivalent of robbing Peter to pay Paul" (Pauly et al. 2003).

Third, given the likelihood that existing and future hydroelectric energy generation facilities will remain the only large-scale sustainable energy source in the Pacific Northwest, greatly increased efforts must be directed at resolving upstream and downstream passage for juvenile and adult salmon. Ironically, with peak oil and peak gas on the horizon, salmon-friendly hydroelectricity may be the best energy source for supporting sustainable populations of *both* humans and wild salmon in the Pacific Northwest. Investigations into safe downstream passage of adult steelhead kelts must receive special attention as these fish have demonstrated that they are the most fit to survive (Evans et al. 2004). In addition, salmon-friendly scenarios for operating the entire California and Pacific Northwest integrated energy system (generation facilities and impoundments) must be developed to ensure societal energy demands (e.g., peak loads, load shaping), especially in drought years, are compatible, and not detrimental, with various life history stages and anadromous behavior of juvenile and adult salmon.

"Salmon are the canaries in the coal mine for our entire society."

Finally, two very important issues that few politicians are willing to tackle, population growth and consumer lifestyle, will likely be resolved during the hydrocarbon depletion phase. Our entire 20th century industrial economy and Western lifestyles have been built on a foundation of inexpensive fossil fuel energy, and as the direct and indirect costs of fossil fuels begin to accumulate, many current societal practices and activities will be increasingly recognized as unsustainable. Most societal activities from 2010 onwards will be viewed through the lens of energy cost, energy efficiency, and environmental effects as society enters the downward phase of the hydrocarbon age. The availability and cost of energy may ultimately dictate how many people live in California and the Pacific Northwest and determine the size of their ecological footprint, thus by default making the difficult decisions that society was unwilling or unable to make.

Conclusion

To end where we started, humans learned to fly in 1903 and walked on the moon in 1969. In 2003, a mere 100 years after the Wright Brothers' first flight, *Homo sapiens* could watch live images from the surface of Mars. Will a civilization that is capable of these achievements fail to heed the obvious warnings and continue down an unsustainable path that could lead to the widespread loss of wild salmon throughout California and the Pacific Northwest? Salmon are the canaries in the coal mine for our entire society. Where go the salmon, there follows an intricate self-supporting ecosystem that has persisted for millennia. Yet, we now face the distinct possibility that we may extinguish it in less than two centuries.

I close with a comment by Ronald Wright, noted essayist, historian, and archaeologist and winner of the 2004 Massey Lecture Series in Canada: "Things are moving so fast that inaction itself is one of the biggest mistakes. The 10,000-year old experiment of settled life will stand or fall by what we do and don't do, now. The reform that is needed is not anti-capitalist, anti-American, or even deep environmentalist; it is simply the transition from short-term to long-term thinking. From recklessness and excess to moderation and the precautionary principle. ….We have the tools and the means to share resources, clean up pollution, dispense basic health care and birth-control, set economic limits in line with natural ones. If we don't do these things now, while we prosper, we'll never be able to do them when times get hard. Our fate will twist out of our hands. And this new century will not grow very old before we enter an age of chaos and collapse that will dwarf all the dark ages in our past. Now is our last chance to get the future right." (Wright 2004).

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