

Executive Summary

Pacific salmon have disappeared from about 40% of their historical breeding ranges in Washington, Oregon, Idaho, and California over the last century, and many remaining populations are severely reduced. Most runs that appear plentiful today are largely composed of fish produced in hatcheries. Recreational and commercial fishing for several salmon species has been restricted or even prohibited from the coastal waters of the region to the headwaters of many streams, and tribal fishing has been much reduced. Petitions have been filed to list several populations as endangered or threatened under the Endangered Species Act; a few have been listed, and more could be soon.

Salmon have great cultural, economic, recreational, and symbolic importance in the Pacific Northwest. As a result, their declines—which have numerous interacting causes—have resulted in much concern. The often expensive efforts to reverse the declines have been controversial and unsuccessful in many cases. Faced with the possibility of dozens or perhaps even hundreds of listings of Pacific salmon under the Endangered Species Act, and faced with controversies over the effectiveness of proposed actions to slow, halt, or reverse the salmon declines, Congress requested advice from the National Research Council (NRC). In response, the NRC's Board on Environmental Studies and Toxicology assembled the expert Committee on Protection and Management of Pacific Northwest Anadromous Salmonids to review information concerning the seven species of anadromous salmonids¹ in the Pacific Northwest.

¹ This report deals with anadromous forms of the seven species of the genus *Oncorhynchus*. They are chinook, chum, coho, pink, and sockeye salmon and the anadromous forms of rainbow and cutthroat trout: steelhead and sea-run cutthroat. In this report, the general term *salmon* refers to all seven species.

The committee was asked to "evaluate options for improving the prospects for long-term sustainability of the stocks, and [to] consider economic and social implications of such changes" (statement of task; see Preface). It was asked to perform the following tasks:

- Assess the status of the salmon stocks.
- Analyze the causes of declines.
- Analyze options for intervention.

The committee was asked to consider all stages of salmon life histories, including the ocean phase, and to consider the appropriate roles of hatcheries. Congress did not request advice on whether society *should* make the investments needed to halted reverse salmon declines. However, the committee's analysis of options for intervention and their likely effectiveness should help to inform that policy decision.

STATUS OF SALMON POPULATIONS

The status of many specific salmon populations in the Pacific Northwest is uncertain, and there are exceptions to most generalizations with regard to overall status. Nevertheless, a general examination of the evidence of population declines over broad areas is helpful for understanding the current status of species with different life cycle characteristics and geographical distributions, and with some caution, the following generalizations are justified:

- *Pacific salmon have disappeared from about 40% of their historical breeding ranges in Washington, Oregon, Idaho, and California over the last century, and many remaining populations are severely depressed in areas where they were formerly abundant.* If the areas in which salmon are threatened or endangered are added to the areas where they are now extinct, the total area with losses is two-thirds of their previous range in the four states. Although the overall situation is not as serious in southwestern British Columbia, some populations there also are in a state of decline, and all populations have been completely cut off from access to the upper Columbia River in eastern British Columbia. Even if the estimate of population losses of about 40% is only a rough approximation, the status of naturally spawning salmon populations gives cause for pessimism.
- *Coastal populations tend to be somewhat better off than populations inhabiting interior drainages.* Species with populations that occurred in inland subbasins of large river systems (such as the Sacramento, Klamath, and Columbia rivers)—spring/summer chinook, summer steelhead, and sockeye—are extinct over a greater percentage of their range than species limited primarily to coastal rivers. Salmon whose populations are stable over the greatest percentages

of their range (fall chinook, chum, pink, and winter steelhead) chiefly inhabit rivers and streams in coastal zones.

- *Populations near the southern boundary of species' ranges tend to be at greater risk than northern populations.* In general, proportionately fewer healthy populations exist in California and Oregon than in Washington and British Columbia. The reasons for this trend are complex and appear to be related to both ocean conditions and human activities.
- *Species with extended freshwater rearing (up to a year)—such as spring/summer chinook, coho, sockeye, sea-run cutthroat, and steelhead—are generally extinct, endangered, or threatened over a greater percentage of their ranges than species with abbreviated freshwater residence, such as fall chinook, chum, and pink salmon.*
- *In many cases, populations that are not smaller than they used to be are now composed largely or entirely of hatchery fish.* An overall estimate of the proportion of hatchery fish is not available, but several regional estimates make clear that many runs depend mainly or entirely on hatcheries.

Chapter 4 discusses some of the difficulties in evaluating the status of wild populations and how these difficulties have been addressed in recently published status reports. Regional trends are summarized, and the overall conditions of the species are presented.

THE SALMON PROBLEM

The salmon problem is the decline of wild salmon runs and the reductions in abundance of salmon even after massive investments in hatcheries. The declines—largely a result of human impacts on the environment caused by activities such as forestry, agriculture, grazing, industrial activities, urbanization, dams, hatcheries, and fishing—are widespread, although not universal. They have a variety of causes, and they are exacerbated by the unusual life cycle of Pacific anadromous salmon, which spawn in freshwater, migrate to sea to grow and mature, and return to their natal streams to reproduce. Salmon thus require high-quality environments from mountain streams, through major rivers, to the ocean. Economic development and population growth have created widespread declines in anadromous salmon abundance in the Pacific Northwest. Variations in ocean conditions—especially in water temperature and currents and the associated biological communities—also contribute to the rise and fall of salmon abundance, often thwarting the interpretation of events in freshwater and the surrounding terrestrial systems.

GENERAL CONCLUSION

To achieve long-term protection for a diversity and abundance of salmon in the Pacific Northwest, two general goals must be achieved:

- The long-term survival of salmon depends crucially on a diverse and rich store of genetic variation. Because of their homing behavior and the distribution of their populations and their riverine habitats, salmon populations are unusually susceptible to local extinctions and are dependent on diversity in their genetic makeup and population structure (Chapter 6). Therefore, management must recognize and protect the *genetic diversity* within each salmon species, and it must recognize and work with local breeding populations and their habitats. It is not enough to focus only on the abundance of salmon.
- The social structures and institutions that have been operating in the Pacific Northwest have proved incapable of ensuring a long-term future for salmon, in large part because they do not operate at the right time and space scales. As described in Chapter 13, differences among watersheds mean that different approaches are likely to be appropriate and effective in different watersheds, even where the goals are the same. This means that institutions must be able to operate at the scale of watersheds; in addition, a coordinating function is needed to make sure that larger perspectives are considered.

As a framework in which to approach its deliberations, the committee chose to focus on *rehabilitation*—a pragmatic approach that relies on natural regenerative processes in the long-term and the selected use of technology and human effort in the short-term—rather than on attempts to restore the landscape to some pristine former state and rather than on a primary reliance on substitution, i.e., the use of technologies and energy inputs, such as hatcheries, artificial transportation, and modification of stream channels. Rehabilitation would protect what remains in an ecosystem and encourage natural regenerative processes.

The solutions will not be easy or inexpensive to implement; even a holding action to prevent further declines will require large commitments of time and money from many people in many segments of society in the Pacific Northwest. Therefore, broad-based societal decisions are needed to successfully provide a long-term future for natural salmon populations.

ENVIRONMENTAL FACTORS

Natural and human-caused environmental changes affect all aspects of salmon life histories. Although humans can do little in the short-term to control or even predict large-scale changes in environmental conditions, salmon-management programs must expect such changes and take them into account. Managers must also recognize that the natural variability in environmental conditions

and people's desires for large and stable catches of salmon are often not compatible. Natural changes in environmental conditions in the ocean, in fresh water, and on land occur continually; sometimes they can lead to increased salmon productivity in an area; at other times they can lead to decreased productivity.

The emerging understanding of interdecadal changes in the ocean climate and the related mechanisms that affect salmon at sea have implications that are both exciting and disconcerting to scientists thinking about resources management. Humans are beginning to understand what happens to salmon during the majority of their lives—the portion spent at sea. Although we know little of the details, the new insights already demonstrate that variations in salmon abundance are linked to phenomena on spatial and temporal scales that humans and human institutions do not ordinarily take into account. Consider that the apparent effectiveness of hatcheries might have resulted from favorable ocean and climatic conditions in the era when the hatcheries were built; what looked like human manipulation of the total number of salmon might have been only a reapportionment among different populations. Or consider that the decline of some populations might be a direct result of introducing new hatchery populations into an ocean pasture of limited capacity.

The scale of human endeavor often has been incommensurate with the scale of salmon ecology. Some of our current policies are based on deep ignorance: it is not reasonable to assume that ocean conditions vary in ways that are generally uniform and random in their impacts on populations of salmon. Interdecadal variations and the importance of the ocean phase should be incorporated into human thought, planning, and actions in response to the effects of and attempts to repair damage that occurred during the freshwater phases of the salmon lives. The possible overriding effects of interdecadal changes in ocean conditions on salmon, the results of freshwater salmon management, and the overwhelming focus of human attention on the more-visible freshwater phases of the salmon history combine to provide the key ingredients for surprises in future.

Recently, natural environmental conditions in the Pacific Northwest appear to have been unfavorable to salmon production. As changes continue to occur, environmental conditions will probably favor salmon and lead to larger runs in some areas for a time, even without human intervention. If such changes do occur, they should be regarded as providing time to develop better strategies for rehabilitation of salmon populations. They should *not* be used as reasons for abandoning efforts to rehabilitate salmon, for they will surely be followed by other natural changes. Inappropriate short-term responses to large-scale environmental changes at sea or on land should be avoided, because there can be long lags between causes and effects.

LIMITS ON SALMON PRODUCTION

The salmon production cycle has three principal components that determine

abundance: reproductive potential of adults returning from the sea to spawn, which is affected by their growth at sea; production of offspring from natural reproduction in streams and artificial propagation in hatcheries; and sources of mortality (including natural mortality, fishing mortality, dam-caused mortality, mortality from habitat alterations and changes in environmental conditions, and so on). All three components are affected by changes in environmental conditions as well as by human activities. Variation in the three components and their interactions ultimately determine the ability to sustain salmon populations and their production. These limitations cannot be easily overcome through technology. Although it has been widely assumed that a loss of natural salmon production can be compensated by enhancement (e.g., by increasing hatchery production), chapters 6, 11, and 12 show that such an assumption is untenable by explaining the need to conserve sufficient genetic variation in natural populations to support the evolutionary and ecological processes needed for sustained salmon production. Compensating for salmon loss from any source over the long-term therefore requires reducing other losses. Furthermore, an increasing appreciation of the marine environment and its effects on the above components is emerging as an essential consideration in salmon management.

VALUES

The salmon problem, like many other environmental issues, has been addressed through choices made within economic, political, and individual ethical frameworks. Values and ethical positions held by people involved in and affected by the salmon problem encompass a pluralistic, pragmatic, and evolutionary approach to natural resource management. Recognizing and articulating that pluralism is important because problems in managing and protecting fish populations are due in part to the failure to articulate divergent interests, goals, and values and to address them explicitly. Chapter 5 describes how the widely varied ways that humans intervene in salmon populations are linked to socially validated values.

From a policy perspective, the salmon problem is one of long-standing and serious conflict in fact, interest, and values. People often invoke widely held values to protect particular interests, but values are genuine sources of conflict in themselves. Value conflict stems from different assessments of the desirable goals of public action. From a scientific perspective, wild salmon populations are an example of an ecosystem's natural capital. Our greatest success has been in designing ways to use human-food benefits from wild salmon. Our corresponding failure has been in protecting indirect and nonhuman benefits.

One way to present the salmon problem is to say that the value of the Pacific Northwest's salmon-capital asset has depreciated over time as its productivity has declined. A major problem is that the market does not account for the full range of costs and benefits of salmon. That is called a market distortion. When

such market distortions exist, some resources are underpriced and overused, and others overpriced and underused. Many nonmarket values of salmon are under-represented and are not easy to measure or compare. Thus management decisions often do not adequately reflect the importance of salmon to society and decisions about resource use may not achieve societal goals. To correct the discrepancy between social values and resource use, attempts can be made to design policies that reflect the full range of resource values.

Full value is a public, not a private, question. Consequently, public choices are central to the salmon problem. Public choices have to take into account many owners with multiple preferences, attributes that are not fully observable and sometimes unknown, and prices that reflect only part of the resources' full value to society. The concept of full value points to the problem of "externalities"—the problem that some costs and benefits are beyond the accounting of the decision-making unit.

Environmental variability creates economic uncertainty, which causes people to discount the future more heavily, and this leads to pressures to increase rates of immediate, direct use. Environmental variability also creates scientific uncertainty about biological processes, which can be perceived to call for a cautious approach and lead to pressures to lower rates of immediate, direct use. The resulting tension between economic and scientific responses to uncertainty adds complexity to decisions about appropriate rates of resource use. That tension is widespread in decisions concerning the salmon problem.

Problems like these emphasize the need to develop more appropriate interdisciplinary approaches. The idea of rebuilding the salmon runs of an industrialized ecosystem is heroically optimistic—a hope that might not have occurred to anyone except those who had rehabilitated the Willamette River Basin in Oregon or Lake Washington near Seattle. Those environmental successes came through the disciplined execution of the planning paradigm that has been fitfully applied to the much larger Columbia River Basin. The extension of those experiences to the multijurisdictional, multifunctional situations of the Pacific Northwest would require coordinated action and learning on a new, larger scale—a scale on which planning and action have been tried but have not been successful. A more explicit appreciation of the values, interests, and institutions involved in this undertaking is required. [Chapter 13](#) explores this further and urges constructive change in institutions that include cooperative management, bioregional governance, and adaptive management.

GENETICS AND CONSERVATION

Pacific salmon reproduce in freshwater streams. Their progeny migrate to the sea to grow and mature, and then return to freshwater streams to reproduce and (nearly always) die. This pattern of freshwater reproduction and growth at sea is called *anadromy*. Most of the adults actually return to the streams where

they hatched. This behavior—called *homing*—is an essential part of salmon biology and makes their genetics and conservation unusual. There is a great deal of environmental variation among the various streams and lakes where salmon spawn and in the rivers through which they migrate. Because of their anadromous life cycles and homing behaviors and the variety of environments they occupy, each salmon species tends to differentiate into local breeding populations—called *demes*—that are in general reproductively isolated from other populations and adapted to each stream. To sustain productive natural populations of salmon, it is crucially important to maintain this genetic variation and local adaptation. [Chapter 6](#) describes examples of such local adaptation.

However, more is involved than only local adaptation to various streams. Natural environmental fluctuations, including major disruptions caused by geological activity, can cause the extinction of local populations. Because homing is not perfect, fish that stray from nearby streams can replenish those populations. Strays are more likely to re-establish a population if the environment in the new stream is similar to that in the stream where they hatched. Thus, strays into tributaries in the same major river system or into nearby streams are more likely to succeed than those that stray into very different environments. This network of local populations (known as a *metapopulation*) provides a balance between local adaptation and the evolutionary flexibility that results from exchange of genetic material among local populations ([Chapter 6](#)). It likely also explains why artificial attempts to re-establish populations from a captive broodstock have often failed—too often, the gene pool of the broodstock has had reduced variation or has been derived from a population adapted to a different environment ([Chapter 12](#)). The metapopulation structure provides a balance between local adaptation and evolutionary flexibility; therefore, maintaining a metapopulation structure with good geographic distribution should be a top management priority to sustain salmon populations over the long-term. Many of the committee's recommendations are based on this crucial conclusion.

There is no "correct" answer to the question of precisely how much biological diversity and population structure should be maintained or can be lost to provide a long-term future for salmon. Scientific estimates—including uncertainties associated with them—are only part of the argument. Society must decide what degree of biological security would be desirable and affordable if it could be achieved, i.e., the desired probability of survival or extinction of natural populations, over what time and what area, and at what cost. Nonetheless, biological diversity and the structure of salmon populations are being lost at a substantial rate, and this loss threatens the sustainability of naturally reproducing salmon populations in the Pacific Northwest.

HABITAT LOSS AND REHABILITATION

The main habitat requirements of salmon in freshwater include a stream or

lake, the adjacent border of vegetation (riparian zone) that serves as the interface between aquatic and terrestrial ecosystems, and the quality and quantity of water (Chapter 7). The water must be clean enough and cool enough to support returning adults, for eggs to hatch, and for young to survive and grow until they migrate to sea. There must be enough water in the rivers at crucial times to make migration possible, to allow fish to escape predators, and to allow fish to find adequate food. Well-aerated streambed gravels are important for spawning. Streamside vegetation provides shade, which keeps the water cool; it provides a buffer against soil erosion, which maintains water quality; it provides living space for various animals that provide food and nutrients for streams; and it provides a source of large woody debris, which plays a key role in the formation of physical habitat and storage of sediment and organic matter and provides habitat complexity in stream channels, thus improving the stream environment for salmon. These requirements for environmental conditions in streams and adjacent riparian zones depend on the condition of the entire watershed in which they occur.

Many human activities—such as forestry; agriculture; grazing; industrial uses; commercial, residential, and recreational development; and flood control—have a variety of adverse effects on salmon habitats. For example, they can increase soil erosion, reduce the amount of woody debris in streams, raise the water temperature, add contaminants to the water, affect water flow, and reduce the amount of water available, with resultant loss or degradation of riverine and adjacent riparian and near-river habitat. Therefore, protection and rehabilitation of riverine and riparian habitats and associated watershed processes will be an integral part of rehabilitating salmon populations, although it is a major and difficult undertaking (Chapter 8). In the past few years, genuine improvements in protecting forested streams have been initiated. Nonetheless, for real progress to occur, habitat protection must be coordinated at landscape scales appropriate to salmon life histories, and they must be more consistent across different types of land use (chapters 8 and 13).

DAMS

Hundreds of dams have been built on rivers of the Pacific Northwest. They range from small irrigation dams with a hydraulic head of only a few feet to massive dams at Grand Coulee, Dworshak, and Hells Canyon on the Columbia and Snake rivers that are several hundred feet high and completely block upstream and downstream passage of anadromous fish. Dams on various rivers—some of them impassable—have greatly reduced wild runs. Even smaller dams (e.g., those associated with many hatchery operations and irrigation-diversion dams) can block salmon runs. In addition to their effects on migration, large storage dams affect the quantity and timing of water flow in the river as well as flow velocities, water chemistry, and water temperatures. Reservoirs behind

dams can also inundate extensive areas of spawning and rearing habitat, although in some cases the reservoirs provide new (but different) rearing habitat. Many water diversions for irrigation lack protective fish screens of modern design; installing such screens would reduce mortality of smolts as they migrate down-stream.

Even when fish ladders provide passage for adult salmon, many young salmon (smolts) migrating downriver die at dams. Although as many as 90% of young salmon might survive passage over, around, and through any single major project on the Columbia-Snake mainstem, the cumulative reduction in survival caused by passing many projects has adversely affected salmon populations. To counteract these effects, it is essential to improve the survival of smolts migrating through hydropower projects, especially in the Columbia and Snake rivers. Serious consideration needs to be given to all available alternatives for doing so; even a small improvement in survival would be helpful if it were repeated at several dams.

Controversy surrounds the effects of dams and how best to mitigate them. Alternatives include removal of dams, modification of turbines and other structural aspects of dams to improve fish survival during passage, drawdown of the water during the seaward migration of smolts to restore the river's profile to its pre-dam (river-grade) configuration to increase the flow rate and diminish the smolts' travel time, drawdown of the river to some level above river grade, augmentation of water flows during smolt migration to speed their passage downriver, transportation of smolts around dams by truck or by barge, control of predators in reservoirs and below dams, and spilling of water over dams instead of through the turbines. However, there is a dearth of good scientific information on which to base evaluations of the alternatives, some of which would be very expensive and would cause large losses of hydropower revenues.

Dam removal and drawdown of those rivers to river grade would be enormously expensive, would take many years, and probably would have long-term adverse impacts on the rivers. However, because the many dams on the Columbia River and its tributaries cumulatively have large effects on salmon survival, the addition of any new major dams in undammed reaches in the system (e.g., the Hanford Reach of the Columbia River) would make the situation worse; existing dams should have adequate fish-passage facilities where feasible and appropriate before being relicensed. The committee is unaware of any scientific data that unequivocally support drawdown to a level above river grade as the best available dam-mitigation option for the Columbia River or the Snake River. Based on limited information, transportation appears to be the most biologically effective and cost-effective approach for moving smolts downstream. It should be continued on an adaptive basis (i.e., in such a way that additional information can be obtained about its effectiveness). Additional information is needed on effects of transportation on survival to the adult return stage, on homing, on success of natural spawning, and on genetic diversity of returning adults. Because any

action that could jeopardize all of the fish in a stream must be avoided, not all the fish in any stream should be transported.

Research is needed on the effects of various options on the survival of both smolt and adult migration through dam and reservoir systems. Any management option should be applied on an adaptive (experimental) basis. The committee is not recommending that the salmon be "studied to death," a criticism often leveled at those who urge further studies. Indeed, enough is known now to take some actions. In recommending "adaptive" actions, the committee is recommending that any mitigative actions be taken in a way that allows their effects and effectiveness to be measured and assessed objectively. For example, if some fish in a stream are transported downstream, the action should be designed so its effectiveness can be assessed and compared with other alternatives. Despite the paucity of information, it is clear that no single approach would eliminate the adverse effects of dams on salmon.

HATCHERIES

Hatcheries have been used for more than 100 years in attempts to mitigate the effects of human activities on salmon and to replace declining and lost natural populations. As a result, a major proportion of salmon populations in the Pacific Northwest now consist largely of hatchery fish. These hatchery fish appear to have had substantial adverse effects on native fish populations.

For many years, people did not recognize the potential for hatchery fish to affect wild fish and did not believe that there was any limit to the ocean's capacity to provide food for growing salmon. It therefore seemed that producing more juveniles would result in more returning adults. The difficulties and shortcomings of hatchery production did not become apparent until fishing pressure and habitat-related mortality increased and marking technologies became available. As a result, hatcheries were not part of an adaptive-management program; that is, they were not considered as scientific experiments—they were not even adequately monitored—so many of their effects were not well known.

It is now clear from synthesis of experience and from consideration of well-established biological knowledge that hatcheries have had demographic, ecological, and genetic impacts on wild salmon populations and have caused problems related to the behavior, health, and physiology of hatchery fish. They have resulted (among other effects) in reduced genetic diversity within and between salmon populations, increased the effects of mixed-population fisheries on depleted natural populations, altered behavior of fish, caused ecological problems by eliminating the nutritive contributions of carcasses of spawning salmon from streams, and probably displaced the remnants of wild runs (Chapter 12). Hatchery fish have at times exceeded the capacity of streams and are increasingly being associated with reduced marine growth and survival in wild salmon populations (Chapter 12).

Many of the problems stem from purposes to which hatcheries have been put—mainly to provide substitutes for natural populations lost or displaced because of human development activities. Because of their deleterious impacts, however, hatcheries should no longer be viewed solely as factories for producing fish. Hatcheries should also be thought of as laboratories that can provide controlled environments for studying juvenile fish and for testing treatments to improve our understanding of what happens to juveniles after they leave spawning areas. Seen in that light, hatcheries can be a powerful tool for learning about salmon.

Hatchery planning, management, and operations should be changed so that their goals are to assist recovery of wild populations and to increase knowledge about salmon. As described above and in many parts of this report, especially chapters 6, 11, and 12, precautions must be taken to protect the genetic diversity and ecological productivity of naturally spawning populations of salmon. Those precautions will include an overall decrease in hatchery-fish production and—over the short-term—in fishing opportunities. The basic guideline is to ensure that any hatchery production for fishing is not detrimental to natural populations. Because adaptive-management experiments should be tailored to the circumstances in different watersheds of the Pacific Northwest, decisions about use of hatcheries will differ across these watersheds. Therefore, decisions about uses of hatcheries should include a focus on the whole watershed and its linkage to the region and the ocean pasture, rather than only on the fish.

FISHING

Fishing for salmon is important in the Pacific Northwest. It includes commercial, recreational, and treaty fishing at sea and in rivers and is an important source of mortality, especially for adults returning to spawn. Salmon mortality caused by other human activities and structures such as dams, habitat loss or degradation, pollution, and water diversion and by natural factors such as predators, disease, and environmental variability together usually exceed fishing mortality. Those causes of mortality have a major effect on the production of adult fish and thus influence the rate of fishing that can be sustained. However, fishing is the easiest mortality factor to control. Control of fishing has rehabilitated marine and anadromous fish populations in various parts of the United States.

Managing salmon fisheries is more difficult than managing many other fisheries because of the geographic distribution of salmon, their metapopulation structure, and the fact that most adult fish spawn only once and then die. In the jargon of Pacific salmon fisheries, managers refer to groups of salmon populations that are identifiable for management as *stocks*. Frequently, *stock* refers to a geographic aggregate of populations that includes many local breeding populations of varied size and productivity; this is too large a unit for conservation of genetic diversity and rehabilitation of salmon production. Managing at the stock

level obscures critical biological complexity. But even managing such large units is difficult because of the complex relationships, responsibilities, and obligations among a large number of institutional entities in the region (including nations, states, provinces, federal agencies, tribes, interest groups, and other organizations), the mandates of the Endangered Species Act and other laws, and the diverse array of interests and values in the region.

For rehabilitation of salmon populations, the aim for fishery management—as for other management efforts—should be to achieve long-term sustainability based on maintaining diversity of gene pools and population structures. Therefore, a successful fishery-management component for protecting natural salmon runs in the Pacific Northwest should explicitly recognize the need to maintain and rehabilitate the genetic diversity of salmon and recognize the interdependence of genetic diversity, habitat, and salmon production. It must also account for the uncertainty in scientific predictions and the inherent variability of biotic and abiotic environmental factors.

In general, the aim should be to assure adequate escapements for depleted populations. To achieve long-term sustainability, which requires sufficient genetic diversity, fishing should occur only where the identity (i.e., the originating population) of the salmon is known, when total fishing mortality is consistent with productivity of the fish, and when the catching technology ensures minimal mortality in depleted demes. This will require fishing methods that allow different degrees of fishing effort on various salmon populations and that allow identification of fish taken from depleted demes so that they can be avoided or released alive. Two methods of achieving these goals (but not the only ones) are terminal fisheries and live-catch fisheries.

In general, the serious declines of wild salmon populations show that not enough fish are being allowed to return to spawn. The number of fish returning to spawn (escapements) must be substantially increased to conserve genetic diversity within and between demes, use available habitats, rehabilitate ecological processes (including the return of nutrients to aquatic ecosystems), and increase the sustainable production of salmon. Increasing escapements will disrupt fisheries, industry, and communities, but it is necessary for restoring production. As salmon abundance increases and fisheries begin operating at lower, but sustainable, catch rates, actual catches will gradually increase, although probably not to the sizes of some historical catches, because those were based on excessive catch rates. Implementing this recommendation will initially require low fishing effort in many areas, especially in the ocean, and it will require cooperation from British Columbia and Alaska, because many salmon that originate in the Pacific Northwest are caught at sea off British Columbia and southeastern Alaska (chapters 10 and 11).

A more holistic management approach must recognize the connections between the genetic resource base, habitat, and the resulting salmon production; it must also account for the uncertainty in our scientific advice and for inherent

environmental variability. The committee has outlined a process intended to improve the potential sustainability of salmon in the Pacific Northwest. Furthermore, the committee does not believe that the sustainability of Pacific Northwest salmon can be achieved without limiting the interceptions of U.S. salmon in Canada and obtaining the cooperation of Alaska. An effective and cooperative Pacific Salmon Treaty is necessary. The committee does not provide specific recommendations about altering specific fisheries, because there are numerous options and interactions between fisheries. Achieving agreement on changes in fisheries will be difficult and necessitates an effective institutional process.

INSTITUTIONAL CHANGE

The long and serious decline of salmon in the Pacific Northwest has been promoted—often unwittingly—by human institutions; effective remedies, if they are to be found, will have to involve change in those institutions. Growth in human populations and economic activity threatens the continued existence of salmon in the Pacific Northwest. Institutions developed in different times for diverse purposes have been asked to do things foreign to their original objectives and capabilities. Political changes have hindered attempts to take a long-term perspective. There has been fragmentation of effort and responsibility.

Changing institutional structures is notoriously difficult, but it is possible. Because the problems facing salmon have many aspects, a multidisciplinary approach to their solution is essential. Indeed, if the money that has been spent to date on salmon research had been spent with a more unified, regional vision, greater progress would have been made in maintaining viable salmon populations ([Chapter 14](#)). Unless agencies cooperate more effectively, salmon populations are unlikely to recover.

One problem is that current institutions and the boundaries of their jurisdictions usually do not match the spatial, temporal, or functional scales of the salmon problem. In addition, current institutional structures lack both a fine-grained aspect to respond to local concerns and variations and a coarse-grained aspect to integrate across small regions and to make sure that the interests of a few small areas do not jeopardize larger regional interests.

Because we often do not know what the effects of a management option will be, management must be undertaken with an experimental, adaptive point of view. Flexibility must be built into institutional structures to allow for changes in management practices based on experience. Institutions must allow and encourage refocusing the energies of salmon management to recognize the importance of demes in maintaining genetic processes and to maintain and expand their diversity. The goal of management should be to achieve a biologically sound escapement (instead of focusing on a "sustainable" or permissible catch) for each metapopulation and an explicit adoption of time scales for management and planning that are commensurate with the multiyear scale of salmon life cycles.

Beyond those facilitating changes, the formal institutions that manage salmon need to be restructured or refocused to reflect three important institutional principles. First, decision-making authority should be shared among all legitimate interests (cooperative management); legitimate interests that are excluded from decision-making are likely to block desirable changes. Second, the organizational structures and decision-making processes should allow for local conditions and variations and the management strategies should vary accordingly. Third, systematic learning using appropriate experimental designs (adaptive management) should be an essential goal.

As a first step, the relevant agencies in the Pacific Northwest, including the National Marine Fisheries Service, should agree on a process to permit the formulation of salmon recovery plans *in advance* of listings under the Endangered Species Act, and the Pacific Northwest states, acting individually and through the Northwest Power Planning Council, should provide technical and financial assistance to watershed-level organizations to prepare and implement these preemptive recovery plans.

A SCIENTIFIC ADVISORY BOARD TO ADDRESS SALMON PROBLEMS

A great deal is known about salmon and their difficulties, but a great deal remains unknown or controversial despite the expenditure of large amounts of money and time on research. Part of the reason for the lack of knowledge is that people have not agreed on what information is needed, have duplicated each other's work, and have been unwilling to fund needed research. An independent, multidisciplinary, standing scientific advisory board should be established to ensure that the limited money available for research is spent most productively to answer the most critical questions in a timely manner. A standing scientific advisory board would also help to ensure that when urgently needed actions are taken, they are designed so that their effects and effectiveness can be properly assessed. The board's reports should be public.

AN APPROACH TO SOLVING THE SALMON PROBLEM

The salmon problem took many years to develop, and its solution will require the commitment of considerable time, money, and effort. The committee's analyses of the problems and potential solutions lead to the conclusion that there is no "magic bullet." Therefore, like the problem itself, solutions will be complex and often hard to agree on; to be successful, they will need to be based on scientific information, including information provided by social and economic sciences. In addition, to be successful, consensus will be needed about the size of the investments to be made in solving the problem and how the costs should be

allocated. This means that solutions will have to be regionally based, just as the salmon problem has regional variations (see [Chapter 13](#)).

The committee recommends the following general approach. *For each major watershed or river basin*, the following should be assessed:

- All causes of salmon mortality, including their estimated magnitude and the uncertainties associated with the estimates. Factors known to decrease natural production should also be listed.
- Ways of reducing those sources of mortality or compensating for them, their probable effectiveness, and their drawbacks.
- The probable costs of each method of reducing mortality. To be most useful, the estimates should include both market and nonmarket costs. To the degree possible, it is important to identify what societal groups would bear the major portion of the costs of each method and significant uncertainties in the estimates. (For example, reductions in catch rates would primarily affect fishers and tourists; changes in water use could affect agricultural interests or ratepayers; changes in riparian management could affect forest-products industries or private landowners.)

All the estimates would include substantial uncertainties, due both to lack of knowledge and to fundamental environmental, socioeconomic, and biological uncertainties. Nonetheless, such a process of assessment and evaluation is essential for rational decision making. They will provide a basis for evaluating options—for weighing benefits and costs—and for identifying areas where research is critical. *All the recommendations in this report should be viewed in this context: they need to be considered on a regional basis (i.e., major watersheds) and in a comprehensive framework that includes an analysis of their costs, probable effectiveness, and the ability and willingness of various sectors to bear the costs.*

This will be challenging for several reasons. First, in many cases, the desired information has not been collated or does not exist. Second, considerable time and resources will be needed to perform such analyses even for one watershed. But the most important reason is that estimates of costs and how they might be distributed will require intimate knowledge of each watershed and of people's preferences and habits. These essential estimates should be made with input from the people involved. The committee believes this approach will lead to improved effectiveness and—if not reduced costs—at least increased cost-effectiveness and reduced controversy.

THE FUTURE

The best approach to establishing a sustainable future for salmon in the Pacific Northwest is to use currently available information to develop workable,

comprehensive programs rather than reacting to crises. This report has analyzed many parts of the salmon problem and assessed many options for intervention. However, if current trends continue, the Pacific Northwest will continue to see the effects of more people, more resource consumption, changing economic demands and technologies, and changing societal values. Because the success of programs to improve the long-term prospects for salmon in the Pacific Northwest will depend on the societal and environmental contexts, it is important to develop ways for improving our ability to identify changing contexts and to respond to them. As long as human populations and economic activities continue to increase, so will the challenge of successfully solving the salmon problem.