CHAPTER 3. REVIEW OF THE SCIENCE UNDERLYING THE COUNCIL'S FISH AND WILDLIFE PROGRAM

VALIDITY OF ASSUMPTIONS AND STRATEGIES FOR SALMONID RESTORATION IN THE COLUMBIA RIVER ECOSYSTEM EMBODIED IN THE FISH AND WILDLIFE PROGRAM

We reviewed the science behind the Council's Fish and Wildlife Program from the perspective of the conceptual foundation described in the preceding chapter. Our conceptual foundation encompasses the salmon bearing ecosystem and provides a framework applicable to salmon restoration at large. The Council's Fish and Wildlife Program, however, was developed to "protect, mitigate and enhance" the fish and wildlife of the Columbia River as affected by development and operation of the Columbia River Basin hydroelectric system. Consequently, the Fish and Wildlife Program deals with a subset of the factors incorporated in our conceptual foundation. These actions can only be evaluated in the context of the overall salmonid ecosystem embraced by the conceptual foundation in Chapter 2. Given that context, our approach to review the science behind the Council's Fish and Wildlife Program was to list global principles (3) and specific assumptions (29) implied by the measures included in the program and then evaluate the validity of those assumptions. These were derived as part of our review based on the measures adopted by the Council and are not explicitly endorsed or contained in the Council's program.

Thus, our review did not evaluate individual program measures, but instead focused on the biological rationale for measures or groups of related measures. For example, the fact that the Program devotes a considerable number of measures to the idea of flow augmentation in the mainstem river presumably reflects a belief that flow rates as modified by operation and development of the hydroelectric system have contributed to the declines in salmonid populations. Once articulated, such a statement is amenable to scientific analysis whereas the individual measures themselves may not be.

However, as we discuss further below, consideration of the scientific basis for individual assumptions may lead us to a situation of focusing on the trees, while missing the forest. It is quite possible for each individual measure or strategy to be based on sound scientific principles, but for these measures collectively to be an inadequate response to the modification of the ecosystem that has occurred during this century. This could be a case of simply doing too little too late, or, as we contend is true of salmon restoration efforts in general, a case where an inadequate and poorly documented conceptual foundation has led to an inappropriate response to the problem.

In the review below, we begin with an examination of the program in general and how it is developed through the Council's process. This is followed by an evaluation of the set of assumptions and beliefs implied by the array of measures in the Fish and Wildlife Program.

Development of the Fish and Wildlife Program.

Strategically, the Fish and Wildlife Program (FWP) is a collection of individual measures proposed by regional parties without reference to an explicit, common scientific framework or conceptual foundation. The measures have been proposed by various interest groups in the Pacific Northwest, discussed in public forums, and adopted by the Council. Thus the FWP represents a political agreement which has not been evaluated with reference to a scientifically based standard for evaluation. Individual measures in the FWP have been grouped logically by topic and secondarily by entity or entities to be responsible for accomplishing each measure. The measures are diverse and span a broad spectrum of often traditional mitigation interests (e.g., hatchery development, habitat restoration, juvenile fish survival through the hydroelectric system). Some measures have been completed since the beginning of the FWP in the early 1980's, thus eliminating these measures from the list. As the program has undergone subsequent revisions, measures have been added. On the whole, revisions have been variations on the initial theme and have consisted of rearrangement of the program to provide an organizational structure, provide monitoring and evaluation, and deal with uncertainty.

A fundamental question is whether this is the best strategy for incorporating scientific knowledge into the restoration effort. We find three overall difficulties with this approach. First, the "list" definition of the FWP encourages a confrontational atmosphere in the proposal and selection of measures. Advocates argue for their suite of measures as most important (scientifically, politically, culturally, geographically, etc.). The list has no logical endpoint -- controversy can be accommodated by simply adding new items. The Council has limited legislated ability to reject measures, evaluate their scientific merit or incorporate them within an overall framework. Even if all parties can agree to a specific list at a specific point in time, new items can be added later. Because the Act mandates that the Council use an amendment process and revise the FWP periodically, the process can become a continuous process of reorganization and the addition of new items to the list. This leaves the Council and other resource managers of the region open to the criticism that they have not really established a comprehensive plan and defined a strategy.

Second, the FWP lacks a structure for selecting or prioritizing measures based on a framework of overall goals and objectives. While the Council has identified general goals and priorities for the FWP, their level of generality is such that they provide little guidance or rationale for subsequent selection or prioritization of measures. Each item (measure) on the list is given equal weight and acted upon before the FWP can be evaluated as a comprehensive solution. While there is some sequencing and scheduling built into the Program, there is little incentive for parties to follow the schedule or accountability if measures are not completed on time or at all. The 1994 program identifies important hypotheses and includes a process for testing and refinement of hypotheses, but sequencing of actions is not tied to this hypothesis testing. Prioritization of measures occurs outside the Council's public process in various forums and outside any logical structure that makes the collection of measures a program. Project ranking appears to depend greatly on the vigor with which proponents pursue their own agendas.

Third, focusing on the individual items encourages interest groups to become immersed in the endless fine details, thus losing sight of the big picture. Instead of focusing on the most biologically effective and socially acceptable means of achieving a specified biological condition, the Council has been diverted by efforts of various groups to protect or promote their own interests. The list structure of the FWP, although not precluding effective progress on specific items, tends to be unstructured and unfocused making evaluation and effective change difficult.

We recommend that the FWP incorporate an integrated approach to ecosystem management that is based on an overall, scientifically credible conceptual foundation such as we proposed in the previous chapter. This would lead to a rational structure of goals and objectives and provide a standard for evaluation of measures based on general properties of the salmon bearing ecosystem. It also would provide the Council with an objective, explicit structure around which to shape a scientifically based program. We suggest that the Council's approach should be to "protect, mitigate, and enhance" ecosystem properties that are consistent with the biological needs of salmon, steelhead and other native fish and wildlife species while providing for environmentally responsible energy production. While it would be naive to think that this would eliminate the traditional controversies that have divided the region's efforts for decades, we feel that this approach would place the FWP on firmer scientific ground and provide a rational structure for the region's efforts.

Additionally, credible scientific review is needed of projects proposed for funding. Projects needs to be reviewed for their scientific rigor and potential contribution to the purposes of salmon recovery. A credible review process would provide a means to assess projects and funding priorities, along with their potential contribution to salmon recovery goals. The Independent Scientific Group has developed guidelines for proposal preparation (ISG Report 90-3; "Guidelines for Research Proposals" and ISG Report 94-2; "Guide to Proposal Review") and has proposed a process for project review (ISG Report 94-1; "Guide to Peer Review of Projects") that could serve as a basis for design of an appropriate peer review process.

The Role of Adaptive Management in the Fish and Wildlife Program

Adaptive management uses management actions as part of an experimental design to refine understanding concerning scientific questions. As a result of these experiments, management should adapt, resulting in improved response to environmental problems (Holling, 1978; Walters, 1986). The appealing common sense of adaptive management belies the practical difficulties in actually implementing an adaptive approach. Although the concept has a rich literature spanning several decades, the number of cases of successful use of adaptive management are quite limited (McAllister and Peterson, 1992; Halbert, 1993; McConnaha and Pacquet, *in press*).

The Council introduced adaptive management to the region in its 1987 revision of the Fish and Wildlife Program. The initial efforts to craft a fish and wildlife program made the Council acutely aware of the deep divisions in the region that often revolved around technical questions of biology or hydrology. Adaptive management offered a way for the Council to take action in the face of significant scientific uncertainties (Lee and Lawrence, 1986).

With the Council's adoption of the concept, adaptive management became part of the standard lexicon of the Columbia Basin. Since its appearance in the FWP, adaptive management has been used to justify a variety of actions on the premise that something might be learned that could lead to improved management. Such a passive approach to learning is at odds with the rigorous application of the scientific method that is at the heart of adaptive management (Walters, 1986; Hilborn and Winton, 1993).

The use of adaptive management in the Council's program has been reviewed by Volkman and McConnaha (1993) and McConnaha and Paquet (*in press*). They noted that the Council's program is one of the first attempts to use adaptive management as part of an ecosystem scale restoration program. Previous applications focused on limited, if often complex, problems such as harvest management (McAllister and Peterson, 1992). Practical difficulties have resulted in only limited success in using adaptive management as part of the Council's Fish and Wildlife Program; there appears to be no instance where adaptive management, in the sense of Holling (1978) and Walters (1986), has been used to address major uncertainties (Volkman and McConnaha, 1993).

In the 1994 FWP, the Council laid out a strategy for using management actions to refine hypotheses concerning transportation and in-river passage (Section 5.0). This provided an explicit set of hypotheses on major scientific uncertainties and proposed a management experiment to address these hypotheses. The experiments were to be timed to coincide with identified regional decisions concerning drawdown, flow augmentation and transportation. However, the Council appears to have had little interest in following through on this experiment. The NMFS Biological Opinion on mainstem operations and the proposed recovery plan for endangered Snake River salmon contained many elements in common with the Council's proposed experiment, although the integration of the hypotheses, experimental actions and evaluation are less clear.

A major thrust of our review has been to provide an explicit conceptual foundation for the Council's efforts. Many features of our conceptual foundation can probably only be tested through experimental manipulation of management actions. Faced with the same need to take action in the face of scientific uncertainty that prompted the Council to originally incorporate adaptive management into the FWP, we find that adaptive management still offers the best solution to refining and testing ecosystem-scale hypotheses. In their review of the scientific basis for ecosystem management, the Ecological Society of America (Christensen et al., 1996) has recognized the key role of adaptive management in dealing with the complexities and dynamic behavior of ecosystems.

However, the weak links in an adaptive approach are a long term commitment to scientific evaluation and the political will for management to change or adapt to new information (Christensen et al., 1996). Adaptive management requires a long-term vision that can support scientific evaluation in the face of fixed or declining budgets. It also calls for a fundamental shift in the relationship between managers and the scientific community. Managers need to treat their actions as experiments, accept failure as part of the learning process and discard cherished paradigms that fail under scientific testing (Lee, 1993; Volkman and McConnaha, 1993). It is not clear that the Council or any other regional management entity is politically equipped to effectively utilize adaptive management.

We recommend that the use of the term adaptive management be confined to explicit management experiments and avoided as a general prescription. The tendency in the region has been for a vast array of actions, very few of which lead to meaningful learning or improved actions, to be justified under the banner of adaptive management. Like any good scientific experiment, management experiments should include description of hypotheses, test conditions (management actions), and an explicit experimental design. A critical feature of a management experiment, and perhaps the most difficult, is a process for coupling the results of the experiment to management decisions.

Assessment of the Fish and Wildlife Program.

Below we describe our assessment of the conceptual foundation implied in the array of measures contained in the FWP and summarize our evaluation of the scientific justification for the critical assumptions and beliefs. This assessment is based on the conceptual foundation described in Chapter 2 supported by the review of scientific information presented in chapters 4 through 10.

For each italicized assumption, we assigned a qualitative rating that summarizes our assessment of the scientific support for the assumption based on the analysis presented in Chapters 4-10 (Box 2.1). The rating system is necessarily subjective, and is intended to convey our judgment of the degree of scientific support available for each italicized assumption based on our review, rather than representing a rigorous quantitative score.

Each assumption is highlighted in italicized print and followed by the appropriate reference to the Council's Fish and Wildlife Program (FWP), by the chapter in this report that supplies documentation for the conclusions presented here (RETURN TO THE RIVER or RTR), and our qualitative assessment of level of proof for supporting evidence. This is followed by explanatory text, which summarizes details and conclusions from the referenced RTR section

Box 3.1. Levels of scientific support for implied assumptions in the Fish and Wildlife Program.

1- Thoroughly established, generally accepted, good peer-reviewed empirical evidence in its favor.
2 - Strong weight of evidence in support but not fully conclusive.
3 - Theoretical support with some evidence from experiments or observations.
4 - Speculative, little empirical support.
5 - Misleading or demonstrably wrong, based on good evidence to the contrary.

General Principles

Both the Northwest Power Act and the Council's program appear to be premised on the following general principles:

1. The salmon bearing ecosystem in the Pacific Northwest and Northeast Pacific Ocean has considerable excess carrying capacity.

Level of Proof: 4

The conceptual foundation in Chapter 2 describes a Columbia River salmon bearing ecosystem that includes the marine areas encompassed by the migrations of salmon and steelhead populations as well as the freshwater habitats. The implied assumption of the FWP, and indeed in most management of Pacific Salmon, is that improvement of the freshwater environment will have a positive impact on overall salmon production by increasing the number of juvenile fish surviving to reach the ocean. Validity of this assumption requires that there is presently excess capacity in the ocean to support the increased numbers of smolts.

However, there is evidence that the abundance and dominance of different marine fish species fluctuates in response to environmental fluctuations, as well as to the removal of dominant species by harvest or other factors. The consequences of this for salmon in the Columbia River is that increases in numbers of juvenile fish due to improvements in the freshwater environment may not result in an immediate, corresponding increase in adult returns. While removal of ecosystem constraints caused by human activities in freshwater is key to restoration of salmon, an appreciation of the dynamic nature of both the freshwater and marine portions of the salmon bearing ecosystem is necessary to avoid unrealistic expectations of simple cause and effect relationships between management actions and fish production. It also emphasized that actions to protect salmon in freshwater become more and more important as survivals of salmon in the marine environment decline (see Chapter 10).

The normative ecosystem concept described in Chapter 2 stresses that pristine or pre-development conditions in the Columbia River are unattainable because species composition and other key features of the ecosystem have irrevocably changed. Similarly, the estuary and ocean ecosystems may have fundamentally changed during this century as a consequence of harvest, other human-caused factors, and natural environmental change. Variation in the ocean environment further confounds the relation between the actions in freshwater and resulting returns. Relative abundance of sardines and anchovies in the Pacific Ocean, for example, has shifted over time, as has the abundance of tule and bright fall chinook in the Columbia River. These, and other species shifts, may reflect long term environmental cycles that can be expected to continue into the future and will affect the outcome of efforts to control negative human impacts in the freshwater environment.

Spatial and temporal variability in the biological and physical aspects of the marine and freshwater phases of the ecosystem are fundamental features that have shaped the evolution of Columbia River salmonids. The biological solution to salmonid survival in a fluctuating environment has been for to develop a corresponding diversity of life histories. However, regional priorities in terms of effort and dollars have, for many years, stressed certain life histories and species over others. Fisheries restoration has focused on a subset of life histories and decreased overall life history diversity. For example, in the Columbia River, actions such as flow augmentation, spill, and smolt transportation have been managed to benefit primarily the central portion of the juvenile downstream migration composed predominantly of hatchery produced fish. This leaves the early and late migrating naturally produced populations unprotected, further driving the region to reliance on a very narrow range of solutions to a highly variable environment.

Restoration of life history diversity through improved management and the restoration of a diverse array of habitats, would increase the probability of achieving FWP goals. Increased life history diversity in fresh water environments should serve to buffer the effects of variability in the estuary and ocean environments.

2. Abundance of salmon and steelhead in the Columbia River Basin has, to a significant degree, declined due to, and is presently limited by, human actions.

Level of proof: 1

That human alteration of the salmon bearing ecosystem in the Columbia River has greatly contributed to the decline in salmon and steelhead in the basin is irrefutable. Even accounting for natural variation in the environment, decline of most species has closely paralleled the development of the basin and the degree of ecosystem alteration. Development and operation of the hydroelectric system has removed substantial portions of the basin from access by salmon and steelhead, altered the remaining mainstem and estuarine habitats, while logging, agriculture and urbanization have greatly changed tributary habitats. These continue to limit the abundance of anadromous and resident fish species and have decreased their ability to cope with natural environmental variation and alteration of the marine environment discussed above.

While the Northwest Power Act and the resulting Fish and Wildlife Program developed by the Council are premised on the importance of the alteration of the river by development and operation of the hydroelectric system, the narrow focus of the region on this single source of ecosystem alteration has hampered salmon restoration. This has also caused the region to focus much of its efforts on a single species and life history (Snake River stream-type spring chinook) thereby losing an appreciation of the diversity and abundance of salmon and steelhead encompassed by the entire basin. Without discounting the important role of alteration of mainstem habitat in the decline of salmonid species in the Columbia River, we feel that the ecosystem perspective of the conceptual foundation in Chapter 2 is key to the development of comprehensive solutions that address human imposed limitations on salmonid abundance throughout the basin at each stage of their lifecycle.

3. *Ecosystem functions lost as a result of development of the Columbia River can be replaced by technological solutions to individual problems.*

Level of proof: 4

During this century, the Columbia River Basin has been modified to provide for and protect human economic needs. Salmon restoration in response to that development has been based on the assumption that technological innovations could be devised that would substitute for ecosystem functions which would permit the continuation of abundant salmon populations. As dams were constructed, hatcheries were developed to substitute for lost habitat to permit the continuation of high harvest rates. The solution to alteration of mainstem habitat was to develop bypass systems, provide minor augmentation of flow for spring migrants, and to transport juvenile migrants around the developed river in barges and trucks. The extreme extension of this paradigm is evident in proposals to completely separate salmon from their ecosystem by construction of canals or pipelines to transport fish downriver leaving the river completely available to fulfill economic needs.

After decades of implementing these approaches, it is apparent they have failed. Despite innovative engineering and expenditures of billions of dollars over the course of this century, runs have declined inexorably to their present depressed condition (Figure 3.1). Efforts to develop technological solutions to individual human-imposed ecosystem changes have been based on the best of intentions and often on sound, if narrowly focused, science. In the review of the science behind each assumption in the present FWP that follows, it is apparent that, by and large, many individual assumptions are supported by the available scientific information. Yet, the fact remains that salmon have continued to decline despite actions based on these assumptions. It is our belief that this is the result of the guiding premise that for each identified source of mortality there is an individual technological solution. This piecemeal approach to ecosystem restoration presumes that we have sufficient knowledge to identify all direct, indirect, synergistic and cumulative impacts of our actions and that we can devise a technological solution for each impact. The recognized complexity and dynamic nature of ecosystems and the lack of success of this paradigm identifies this as an act of hubris. While technology will continue to be a part of any restoration effort in the Columbia River, we recommend that the region move from a strategy of "fixing" ecosystem damage to one that places greater reliance on re-expression of the natural biological and physical processes of the Columbia River salmon bearing ecosystem.

SPECIFIC ASSUMPTIONS

1. *Operation of the hydroelectric system is a major source of human-induced mortality limiting numbers and diversity of salmonid populations.*

FWP Chapters 1, 5 and 6; RTR Chapter 7. Level of proof: 1

Mortality induced by the development and operation of the hydropower system is well substantiated. Grand Coulee and Hells Canyon dams removed major portions of the basin from anadromous salmonid production, while dams below these produced reservoirs that destroyed most of the remaining mainstem fall chinook habitat. The series of hydroelectric dams induces both direct (such as in turbine passage) and indirect (such as flooding or blocking of spawning sites and increased predation) mortality. Modification of the salmon bearing ecosystem through development of the hydropower system is clearly one of the major factors limiting the numbers and diversity of upriver salmonid populations.

The negative impacts of habitat modification to the mainstem affect all populations above the dams regardless of local habitat conditions. With the exception of the Hanford Reach, the present river lacks many of the attributes of the normative river. Seasonal variation in flow has been reduced, while daily fluctuations have increased. Mainstem spawning and rearing habitat that may have historically supported vital core populations has been eliminated, species composition and diversity have changed, and food chains that formerly supported salmon and steelhead have been modified or eliminated. The magnitude of the mortality inflicted by the hydroelectric system relative to mortalities inflicted by other factors, such as habitat degradation in tributaries or ocean productivity cycles, is less clear. Efforts to minimize detrimental effects to salmon and their ecosystem from specific hydropower-related sources of mortality are desirable for preservation of salmon populations.

2. Operation and development of the hydroelectric system has altered the hydrologic profile of the river, which adversely affects survival of juvenile emigrants.

FWP Chapter 5 and 6; RTR Chapter 6 and 7. Level of proof: 1

The hydrologic profile has been altered by the hydrosystem in many ways that have important ramifications for the salmon bearing ecosystem that can adversely affect survival of juvenile salmonids. The spring flood that formerly assisted the juvenile outmigration have been reduced, increasing the metabolic costs of emigration. Fish that evolved to use water velocity to assist downstream migration must now expend metabolic resources to move downstream and to avoid predators. Salmon may reach the estuary late, exhausted of energy, or both. Flooding has been reduced or eliminated in both riverine reaches and in reservoirs thus reducing the production of aquatic insect food used by migrants and the biological and physical processes that maintain riverine food chains and habitats. Daily fluctuation in flow for power peaking along with rip-rap and other bank stabilization actions has simplified formerly complex habitats and created a barren shoreline zone less capable of supporting juvenile salmonids. Daily fluctuations also strand juvenile salmonids to die in peripheral slack waters or on shorelines. Annual temperature cycles that organisms use as developmental cues and that set rates of development have been altered by water storage and releases timed for hydropower purposes.

The altered seasonal flow pattern has changed the dynamics of the freshwater plume in the estuary and nearshore ocean, thus affecting productivity cycles there. The pattern and nature of sediment and organic matter delivered to the estuary has been altered by changes in flow patterns and the creation of reservoirs that act as settling ponds to trap sediment and organic debris.

These results have been demonstrated in varying levels of detail, but the weight of evidence for an overall major effects is clear. Re-establishment of key riverine aspects of the normative ecosystem is desirable for salmonid production.

3. There is a limited period of time within which yearling juvenile emigrants must reach the estuary to successfully move from the freshwater to the marine phase of the life cycle.

FWP Chapter 5; RTR Chapter 6 and 7. Level of proof: 2-3

This is an assumption with multiple causes, each having a different degree of substantiation. There are two aspects to the assumption: (1) smoltification, which is the sum of physiological and morphological changes in a juvenile salmonid that make it ready to migrate to the sea and be capable of tolerating the change from fresh water to salt water, and (2) estuarine conditions including food availability and predator abundance. This second point is related to the synchrony of timing of smolt entry to the estuary and coastal waters to coincide with seasonal cycles of plant and animal production. Both aspects of this assumption are cued by seasonal aspects of day length, temperature, and river flow, and it is reasonable to assume that salmon are evolutionarily adapted to a limited range of these conditions. Migration that is not successfully coupled to these processes is assumed to be at high risk.

Smoltification is a well substantiated process with timing and attributes that vary with life history type and species (see Chapter 6 on juvenile salmon migration). There is a large scientific literature on the process from physiological and morphological perspectives. The relationships of smoltification to the survival of juvenile emigrants is less certain. Experimental tests of the assumption have been largely based on releases of hatchery fish at different times, in which survival is determined relative to when the fish are deemed "ready" to migrate. The length of time within which fish must reach the estuary to make the transition to the marine environment or how this window is related to stock or environmental variables is relatively unexplored. The conservative approach that entails ensuring outmigration timing that is reasonably close to "natural" in order to match presumed smoltification is founded on theory that needs more substantiation. Maintenance of stock diversity may have depended on the migrants not all passing at a similar time. At the same time, the estuarine environment encountered by juvenile salmonids is highly variable and subject to a complex set of biological and physical factors. Smoltification and its ecological consequences are a suite of processes occurring against a backdrop of a complex and variable estuarine environment and unlikely to be fully understood soon. Because of this, preservation or restoration of normal seasonal cycles of flow, temperature and physical habitat, and maintenance of a diversity of estuarine entry times and patterns is likely to aid the normal expression of smoltification.

4. Yearling chinook emigrants utilize the mainstem Snake and Columbia rivers primarily as an outmigration corridor linking tributary and marine areas.

FWP Chapter 5; RTR Chapter 6 and 7. Level of proof: 2

There is good evidence that yearling chinook salmon are primarily in a migration phase when they occupy the mainstem Snake and Columbia rivers. However, treatment of the mainstem as a simple conveyance for rapid flushing of outmigrant yearlings by high flows is an oversimplification that is not based on the full scope of scientific evidence. Juvenile salmonids use the mainstem Snake and Columbia rivers for rearing and migration to the ocean. The degree of use of the mainstem for either of these activities varies with different life histories. There is likely a continuum of variation in the relative use of the mainstem for rearing and migration ranging over the different chinook life histories. The range is set by the ocean type (subyearling) life history that uses the mainstem for most or all of the pre-smolt rearing in addition to emigration, to the stream type (yearling) life history that rears in tributary areas and uses the mainstem mainly for emigration.

Yearling chinook emigrants need to have flows in the main channel available when necessary to move downstream. Clearly, downstream migration is facilitated by downstream water movement and higher migration rates are associated with higher water velocities. However, this is an incomplete model of the relationship between habitat conditions in the mainstem and yearling chinook survival. Being incomplete, it has led to incomplete solutions to alteration of mainstem habitats that are based around the concept that yearling chinook (and steelhead and other spring migrants) simply need to be moved out of the river as quickly as possible. The relationship between chinook emigrants and their ecosystem is likely to be far more complex than is suggested by the conventional model.

Although yearling migrants pass through the mainstem corridor quickly as compared to subyearlings, a limited amount of scientific data suggests that resting and feeding habitats are needed during pauses in migration, particularly at lower flow levels. Smolts undergo a daily cycle of movement, with the majority of movement occurring at night or during hours of dusk and dawn (although this does not occur for all fish every day and patterns at different locations may vary). Thus, habitat space is needed that is suitable for periodic holding. The use of the term "corridor" implies a simple channel, which neglects the likely (but incompletely tested) relationships between fish movement and velocity structure (turbulence, unsteady flows).

5. Survival of yearling juvenile emigrants is inversely related to the amount of time they spend in the impounded sections of the mainstem Snake and Columbia rivers.

FWP Chapter 5; RTR Chapters 6 and 7. Level of proof: 3

The relationship between exposure time of emigrating smolts to mortality factors in the hydroelectric system and the overall survival of smolts is intuitively reasonable, but has not been demonstrated conclusively. Abundance of yearling chinook has clearly declined in concert with the expansion of the hydropower system. One of the effects of the damming of the Snake and Columbia rivers has been an extension of the migration time spent in impounded sections, which has been documented. Reasonable mechanisms have been proposed for relating survival to duration of time in the hydroelectric system, including among other factors, increased exposure time to predators, disease vectors, and the amount of energy needed to complete migration. As temperatures increase, predator activity and metabolic rates climb, increasing the probability of predation. Various disease organisms become pathological with the increased temperatures found in the reservoirs. Thus, other factors interact with time in migration through reservoirs. The relative importance of the interactions of passage time with these factors has not been well defined. The nature of relationship between flow and survival remains to be established.

6. The amount of time spent by yearling juvenile emigrants within the hydroelectric system is inversely related to the prevailing water velocity. Therefore, survival is positively related to the water velocity prevailing during the outmigration.

FWP Chapter 5; RTR Chapter 6. Level of proof: 3

Since juvenile salmon use water currents to move down river, it is both reasonable and well documented that the amount of time spent by yearling juvenile emigrants within the hydroelectric system is inversely proportional to water velocity. To date, water velocities have been analyzed to generally relate them to fish movement on a daily or seasonal basis over large reaches of the river. However, the flow and velocity environment within reservoirs is complex and it is likely that the relationship is a much more localized phenomenon in that fish react to water velocities encountered at particular places and times. However, because it has not been possible to separate the influence of flow from that of other variables on survival, the relation between flow and survival remains obscured.

Water flow and velocity are extremely important physical components of the normative ecosystem which shape the environment and link the series of habitats occupied during the life histories of anadromous salmonids. For juvenile salmon, sufficient water velocity during the down river migration likely reduces energy costs, saves time, and thereby increases the fitness of the emigrants. Survival during emigration depends on a multiplicity of factors which are related to flow and velocity, such as temperature, predation, food availability, and hydroelectric system operations.

A prominent feature of the debate in the region over fisheries restoration has been the shape and parameters of the relationships between flow, velocity, fish travel time, and survival. It seems unlikely that an incremental quantitative relationship between these variables would apply equally to all species and life history types or necessarily be constant over time and space. Hence, we suggest the abandonment of the search for the elusive “correct” or “optimum” flow and instead we advise focusing on the restoration of a riverine velocity structure as close as possible to the pre-impoundment hydrograph.

7. Water velocity can be enhanced either by augmenting flows from upstream reservoirs or by reducing the elevation of downstream reservoirs.

FWP Chapter 5; RTR Chapters 6 and 7. Level of proof: 1

Under normal circumstances, augmentation of flows from upstream reservoirs increases volume of flow in rivers (generally raising main-channel water velocities) and reduction of the water surface elevation of downstream (mainstem) reservoirs will increase water velocities in these reservoirs. This has been demonstrated empirically and it has a firm and well understood basis in hydraulic engineering. See Chapter 6 on juvenile migration, especially the portion on fluid dynamics. Each has additional side effects, such as enhancing the Columbia River plume (flow augmentation) and restoration of riverine habitat (reservoir drawdown). Water velocities may be increased locally for benefit of salmonids by other means, however (e.g., baffles), which may be preferable to the larger-scale options.

8. Subyearling emigrants utilize the mainstem Snake and Columbia rivers for both rearing and outmigration.

FWP Chapter 5; RTR Chapter 6. Level of proof: 1

This has been clearly established through many years of field studies. As is discussed in point 4, above, chinook with the ocean type (subyearling) life history use the mainstem river for both rearing and emigration. In contrast to the stream (yearling) life history, the demarcation between rearing and emigration phases of the life cycle is less distinct in the ocean type life history. At the present time, despite elimination of most of the historical mainstem habitat, the ocean type life history appears to be favored over the stream type as evidenced by the predominance of fall and summer run fish. While the subyearlings thus have somewhat different habitat requirements than yearlings, they are not mutually exclusive.

9. Subyearling chinook emigrants are less dependent on flow and water velocities as a physical aid to migration than yearling chinook emigrants, but are affected by high summer water temperatures.

FWP Chapter 5; RTR Chapter 6. Level of proof: 1

This has been clearly established through many years of field studies. Subyearlings (ocean-type, fall and spring run chinook) spend more time than do yearlings (stream type, spring run chinook) holding in the shallow-water, near-shore habitats where they feed and rear. They use channel velocities mainly at night, but move shorter distances than do yearlings. Their combined rearing and migration is protracted through spring and summer. The shallow habitats they occupy in the daytime are subjected to severe solar warming and temperatures increase above their preferred and physiologically optimum levels in the low-velocity reservoirs. Field studies in Snake River reservoirs have shown that high temperatures force the fish out into the channel where food resources are often insufficient for normal growth

10. Creation of reservoirs has enhanced native and exotic predator populations and increased the vulnerability of juvenile salmonids to predation.

FWP Chapter 5; RTR Chapter 6. Level of proof: 1

Non-indigenous (exotic) predator species of fish have been introduced into the Columbia River system and appear to be well adapted to the present reservoir system. While there is incomplete evidence regarding increased numbers of indigenous (native) predatory fish as a result of the alteration of the mainstem environment, there is ample evidence from the literature regarding changes in fish community structure following impoundment in other river systems to believe that present conditions have resulted in increased numbers of indigenous predators as well. It is also clear that the present reservoir system has produced conditions that increase the vulnerability of juvenile salmonids to both indigenous and non-indigenous fish predators.

Although predation rates are now high as shown by detailed field studies, direct evidence is lacking to compare the current predation rates with rates that prevailed in the unimpounded river. A related uncertainty is whether the predator control program has been effective in increasing smolt survival although it appears to have been effective in reducing the numbers predatory fish. Creation of reservoirs has likely increased vulnerability, even without the presence of additional predators. High temperatures, gas bubble disease, poor food production, and greater energy expenditure required to transit slowly moving reservoirs compared to a swift river, and disorientation in dam passage, are some factors affecting vulnerability of juvenile emigrants.

11. Impacts of alteration of the hydrologic cycle in the Columbia River on salmonid survival is not limited to the impounded section of the river, but extends to the conditions in the estuary and survival outside the impounded section.

FWP Chapter 5; RTR Chapters 6,7, and 10. Level of proof: 3.

This statement is logical, and can be demonstrated for physical habitat, but resulting changes in salmon survival are unsubstantiated. Estuarine ecosystems, including an extensive coastal plume in the case of the Columbia River, depend on the horizontal and vertical mixing dynamics of fresh and saline water for their essential characteristics. There is good evidence that the changes in flows of the Columbia River have altered the seasonal extent and characteristics of the brackish Columbia river estuary and plume. Diking and filling in the estuary have reduced emergent plant production which has reduced the macrodetritus available to shallow water benthic consumers. Creation of dams and reservoirs has blocked downstream movement of organic debris from upriver areas. Because estuarine organisms that utilize organic detritus are prominent prey of juvenile salmonids, it is reasonable to assume there is a linkage between that change in the food web and the status of salmon, although that linkage has not been demonstrated. The food web in the estuary is now composed of deep water, benthic, and pelagic consumers which are favored by fishes such as Pacific herring, smelts, and the non-native American shad. There is some evidence that the fresh or brackish water plume of the river extending into the ocean could protect juvenile life stages from marine predators. The decreased size of the plume during the spring as a result of riverine flow modifications could increase the vulnerability of salmon during their entry into the ocean. The river-estuary interactions can not be ignored.

12. In addition to alteration of the hydrologic cycle and creation of reservoirs, the dams themselves form a second major impact of development and operation of the hydroelectric system.

FWP Chapters 5 and 6; RTR Chapter 7. Level of proof: 1

It has been clearly demonstrated over several decades that the dams themselves are temporary barriers to upstream and downstream migration and a complex source of additional mortality to juveniles that pass through forebays, turbines, and tailwaters. Fish ladders for adults have been reasonably successful; however, even with highly engineered bypasses, juvenile mortalities remain high. Spill of water and fish over spillways has been demonstrated to provide lower mortalities than mechanical bypass systems, but spill can cause gas supersaturation, which can cause mortality to fish.

Fish bypass systems have been developed as afterthoughts to the construction of most hydroelectric dams. The dams were designed primarily to produce electricity, allow navigation and provide flood control, and secondarily to permit safe passage of fish. Existing designs require extraordinary fish behavior such as sounding to pass through turbine intakes and into bypass systems. As a result, juvenile fish are delayed in their migration and made more vulnerable to predation, independent of the success of the bypass system once it is located by the emigrating fish. Examination of fish bypass needs in the context of the normative salmon bearing ecosystem concept might suggest alternative bypass designs based on the natural behavior of downstream migrating fish. Not only might bypass design be approach differently, but the normative ecosystem concept might suggest that schedules and operations of bypass systems be extended to provide protection for less abundant, but potentially biologically important, populations arriving before or after the bulk of the migration.

13. The primary source of mortality at dams occurs as juvenile fish pass through turbine generating units. This mortality occurs within the turbines and immediately downstream of the units.

FWP Chapter 5; RTR Chapter 7. Level of proof: 2-3

This is a generally valid assumption, although it varies among projects, salmon species, and life history types. Until recently, direct measurements of turbine-induced mortality were remarkably rare. The passage of fish through turbines includes delays at the forebay, descent to depths of turbine intakes, passage through the rotating blades, entrainment in the turbulence and pressure changes of the turbine draft tube, and ejection in a disoriented condition into the tailrace. Each step has potential for damage and mortalities. The assumption does not address losses in the forebay (e.g., predation, disease), which are caused mainly because descending to turbine intakes is contrary to the natural behavior of surface-oriented migrants. Because physical structure differs among the various hydropower projects, the relative impact of the many passage steps varies among projects. Although turbine passage is considered the primary source of mortality, it can be less damaging than poorly constructed bypasses or poorly located bypass discharges. Historically, gas supersaturation at dams may have induced more mortalities (latent and in-river) than turbine passage under some conditions.

14. Devices to collect juvenile fish before they pass into the turbines and deposit them downstream of the dam provide a benign means of passing the project.

FWP Chapter 5; RTR Chapter 7. Level of proof: 3

Substantiation of this assumption is mixed, depending on details of the bypass. The Council’s goal of 90% FGE for intake screens has been achieved at some projects for steelhead, coho, and yearling chinook, but not for subyearling chinook or sockeye. The Council’s goal of 98% survival in bypass systems has been achieved in a few hydropower projects, and is probably achievable in others with properly designed and maintained systems.

Bypasses in dams that use turbine-intake screens force migrants to alter their normal surface orientation, thus increasing delay in the forebay and associated mortality. Screens can also damage juvenile fish. Although bypass piping may be benign, release of fish downstream of the dam can increase predation. Some studies have documented overall bypass mortality in excess of that from turbine passage. Technology improvements to turbine-diversion bypasses have reduced overall mortalities, but the requirement of forcing fish to do something unnatural (dive to deep water and find passageways through gatewells and other dam structures) remains. Much more promising is the surface fish bypass, being tested at several dams, which uses the normal surface orientation of migrants and their tendency to follow surface currents as migration cues. This technology has promise of leading to benign passage. However, technology development is slow (bypasses have been developed over a period of over 30 years) and poorly responsive to rapidly declining fish stocks.

Finally, operation of bypass systems, like the operation of other bypass measures, is based on an implied cost per fish basis. Systems are operated when there are enough fish to justify the expense in the eyes of the operating entity. As is discussed elsewhere in this report, this results in less protection for early or late arriving migrants that may have important benefits to life history diversity. Over time, this could lead to selection of fish within a narrowing window of time and a further lessening of life history diversity.

15. Spill provides the route of hydroelectric project passage with the lowest mortality to juvenile emigrants.

FWP Chapter 5; RTR Chapter 7. Level of proof: 3.

Many uncertainties remain associated with this assumption. Managed spill using existing spillways to divert juvenile emigrants from turbine intakes is clearly less hazardous than turbine passage for those species and life history types for which measurements have been made. As levels of gas supersaturation which accompany spill increase, the benefits of spill may become less because prolonged exposure to gas supersaturated waters is a well substantiated mortality risk. Improperly managed spill or high levels of uncontrollable spill could decrease survival and negate any beneficial effect of spill passage.

Spill is known to disrupt feeding of predators on juvenile salmon in the areas immediately below dams. Hence the low mortalities observed for juvenile salmon passing hydroelectric projects via spill in the past may have depended in part on the effect of spill on rates of predation. Because of the cumulative effect of spill at successive dams, the desirability of spill as a means of maximizing survival of juvenile emigrants within the hydroelectric system as a whole, is less certain than the ability of spill to minimize mortalities of emigrants at individual hydroelectric projects. Field tests of critical assumptions regarding mechanisms and locations of reservoir mortalities, along with reach mortality estimates, are needed before spill can be relied upon as the most desirable means of passing the juvenile emigrants of all species and life history types through the hydroelectric system.

16. Transportation can mitigate, in some fashion, for the biological impact of operation and development of the hydroelectric system for some species and life history types of juvenile salmonids in the mainstem Snake and Columbia rivers, particularly in years of low runoff or other unusually bad conditions.

FWP Chapter 5; RTR Chapter 7. Level of proof: 3.

Transportation benefits are incompletely substantiated and assumptions of benefits are based on surprisingly few complete studies. Transportation involves the overt separation of salmon from their ecosystem and can provide no substitute for normative river conditions across the entire array of salmonid diversity in the river. However, in the absence of normative river conditions within the hydroelectric system, it may be able to delay the process of extinction for some species and life history types such as Snake River spring chinook.

The smolt transportation program in the Columbia River appears to have developed on the basis of the assumption that, because cumulative mortality on juvenile salmon passing through the mainstem rivers is high and occurs from a multitude of sources, a smolt transportation program would eliminate the need for both detailed scientific understanding of the ecological relationships that sustained salmon in the past and for technological solutions to each of the various sources of mortality brought on by development of the river. This logic has been supported by a series of studies that indicate better smolt-to-adult survival to the location where the tagged fish were released relative to the survival of fish migrating through the existing in-river conditions. These survival increases have been measured for only a few life history types and the increases are most substantial in years of very low flow. However, studies to date have not addressed the issue of whether transportation adequately mitigates for operation and development of the hydroelectric system or is simply better than the alternative for some life histories under some conditions. Abundance of most salmon and steelhead populations in the Snake-Columbia basin have plummeted during the period of mass transportation. This suggests that transportation is, by itself, insufficient to restore salmon species.

Under unfavorable migration conditions associated with low flows in the Snake River, transportation appears to offer a survival advantage for the stream type (yearling) chinook life history. The benefits of transportation to other life histories or species have not been tested in the Snake River. However, survivals of ocean type (subyearling) chinook transported from McNary Dam on the Columbia River indicate a positive benefit relative to migration over a broad range of lows under existing hydroelectric system configuration.

Restoration of normative river conditions may make transportation of juveniles unnecessary, if survivals of salmon were sufficiently high. Restoring the link between salmon and their ecosystem is a key feature of our proposed conceptual foundation. Normative conditions in the river would benefit feeding and rearing conditions for yearling and subyearling emigrants. Pending implementation of normative conditions, unfavorable circumstances associated with low flows may require transportation to be used in conjunction with, or in addition to, other mitigative measures.

The inability of transportation to protect all of the life history types of the listed species may require alternative mitigative measures and modification of transportation operations. Transportation is another mainstem juvenile fish passage measure that is conventionally managed to protect primarily the abundant central part of the migration with lesser or no protection for early or late migrants. Focusing on the central part of the migration is likely to contribute to reduced life history diversities and increase vulnerability to adverse fluctuations in natural conditions. Transportation also benefits only those fish susceptible to collection by bypass systems. If transportation is to be used, it should be applied across all dates of a migration, from beginning to end regardless of the number of fish migrating at any time. Because only collected fish can be transported, the benefit of transportation will also depend on the bypass factors discussed in points 12 through 14, above. The lower the fish guidance efficiency (FGE) for a species and life history type, and the greater its dependence on mainstem spawning and rearing habitat, the more important it is to provide conditions favorable within the river.

We conclude 1) that any benefit of transport will not accrue to all migrants but only to those for which we have a high ability to collect for transport and which are less dependent on habitat conditions in the mainstem for spawning and rearing, 2) that existing knowledge of the benefits of transportation across species, life histories, biological and physical condition is limited and based on a small number of studies conducted under a restricted set of conditions, and 3) that the existing knowledge indicates a decrease in benefits of transport as conditions move toward the more normative condition. For these reasons transportation is unlikely to be an adequate response to modification of the mainstem Snake and Columbia rivers, and is inadequate, by itself, to rebuild Columbia River salmonid populations. Transportation should be considered an experimental, interim measure pending restoration of normative conditions sufficient to permit persistence of all types of salmon in the Columbia River ecosystem.

17. Operation and development of the hydroelectric system has been a major source of human-induced mortality to adult migrants, which has limited numbers and diversity of upriver salmonid populations.

FWP Chapter 6; RTR Chapter 7. Level of proof: 2

Inter-dam losses of immigrating adult salmon indicate that not enough has been done to provide in-river passage conditions suitable to fall chinook, as well as for other salmon species and steelhead. Requirements for successful passage are understood, if not satisfactorily implemented at all projects. For example, at some projects restraints to adult passage occur under certain operating conditions and river flows that can lead to failure to achieve escapement goals. Warm temperatures during migrations are a serious cause of concern, particularly for fall chinook, but also for summer chinook and sockeye salmon in the mid-Columbia. Substantial migration delays also occur in the Snake River and its major tributaries due to temperature blocks, which preclude movement of adult fall chinook and steelhead above Ice Harbor Dam until waters have cooled in autumn. Although the technology for adult passage at dams has been mature for several decades, dam operations and temperature regimes have not been carefully studied for their impact on adult survivals. Fall back of adult salmon and steelhead through the turbines occurs at some dam projects and may be a problem.

Interruption of migrations due to the prevalence of high temperatures in the mainstem Snake River in the fall is well established. Upstream impoundments have generally shifted annual temperature cycles toward later dates. Thus, peak summer temperatures that once occurred prior to arrival of fall migrants, now occur during the fall runs. Delayed movements into the Snake River have been documented. Because of well-known physiological responses, delays at elevated temperatures use energy reserves needed for migration and spawning activity, which may result in pre-spawning mortalities even after the fish have cleared the hydroelectric system alive. Studies now in progress need to be carefully evaluated and acted upon.

18. Present harvest rates are a significant factor limiting chinook populations in the Columbia basin.

FWP Chapter 8; RTR Chapter 8. Level of proof: spring chinook, 4; fall chinook, 1.

It is well documented that chinook of all races, including spring chinook, are available to conventional harvest methods in the Strait of Juan de Fuca, the Strait of Georgia, the west coast of Vancouver Island, and points north to Alaska. Tagging information indicates that most of the reported harvest of Columbia River chinook consists of fall chinook and summer chinook for the mid-Columbia area, while landings of spring chinook in ocean fisheries are small.

However, impact of ocean fisheries on spring chinook salmon is uncertain due to an almost complete lack of information on stock composition of undersized chinook or chinook incidentally killed in the Pacific Ocean fisheries. Because ocean fishers are required to release smaller salmon, and because some of these released salmon do not survive, very large numbers of chinook are killed, but not landed in Pacific Ocean hook and line fisheries. Until the very sharp harvest quota reductions implemented in 1995, Pacific Salmon fisheries killed, but did not land the equivalent of several hundred thousand adult chinook from a variety of west coast populations.

Because these incidentally killed chinook were not landed to be sampled, the locations of their spawning habitats are unknown. This does not include ocean trawl net fisheries, which also kill salmon incidentally during fishing operations. It is therefore not inconsistent with available data to postulate that substantial numbers of immature spring chinook salmon of Columbia basin origin could be killed each year in the Pacific Ocean fisheries.

Fisheries operating in the Columbia River impact fall chinook almost exclusively. A commercial harvest of upriver spring chinook has not occurred since 1977 and the last commercial catch of summer chinook took place in 1973. Sockeye have been commercially harvested irregularly and not at all since 1988. Treaty Indian Tribes in the Basin may land up to several thousand spring and summer chinook each year for ceremonial and subsistence use, with the actual numbers landed dependent upon conservation needs of the stocks.

19. Adult return to spawning areas can be limited to some degree by illegal harvest in the Columbia and Snake rivers.

FWP Chapter 8; RTR Chapter 8. Level of proof: 4

Loss of adult fish to illegal catch is, by its nature, usually undocumented. There is no evidence that illegal harvest is a significant, chronic factor contributing to low returns of fish to upriver areas. Law enforcement efforts make it highly unlikely that poaching is a significant factor causing decline, even though some poaching may occur in remote areas.

20. Management of fisheries should be based on the amount of information available to managers regarding stock composition and abundance. Managers should be most restrictive on harvest when information on stock composition and abundance is the most uncertain so that errors do not occur at the cost of biological needs of the populations.

FWP Chapter 8; RTR Chapter 8. Level of proof: 2.

It is a fundamental principle of modern salmon management that information on mortality schedules and stock composition for all stocks of concern needs to be in hand before sanctioning fishing mortalities due to harvest. Nevertheless, such information is difficult to obtain for many stocks. The least amount of information on stock abundance and composition is available for high seas fisheries, while information increases as fish move inshore and into their natal rivers. Where uncertainty or lack of information hampers harvest decisions for specific stocks, a conservative approach is warranted, which minimizes risk to the stock in spite of uncertainty.

The definition of stocks of concern for the purposes of management and the extent to which each stock of concern must be addressed, are policy matters. However, the wisdom of managing harvest conservatively until adequate information is available to determine the allowable impact to different populations is evident if not common.

21. Permanent loss of production capacity in the Columbia Basin as a result of operation and development of the hydroelectric system can be at least partially mitigated by improvements in habitat conditions in tributary areas.

FWP Chapter 7; RTR Chapters 5 and 8. Level of proof: 3.

Construction of Grand Coulee Dam on the Columbia and Hells Canyon Dam on the Snake permanently removed substantial portions of the basin from the production of salmon and steelhead. Dams below these points inundated most of the remaining fall chinook habitat with the exception of the Hanford Reach. Because of capacity limitations, major losses of production of mainstem spawning populations resulting from inundation of spawning habitat cannot be mitigated solely by enhancing tributary habitat. Loss of access to tributaries above impassable dams also cannot be mitigated in remaining tributaries accessible to salmon. Juveniles from tributary stocks still need food production capacity in the mainstem for successful migration. Restoration of tributary populations should consider metapopulation concepts that include the tributary "satellites" in the context of a broader and fluid mainstem "core" population structure. For example for fall chinook, metapopulation concepts suggest that restoration of historic production zones in several mainstem areas, coincident with enhancing normative conditions via habitat restoration in the lower reaches of adjacent major tributaries, would be the most promising way in which both overall and tributary production could be enhanced.

22. The watershed is the appropriate physical unit around which to organize efforts to improve conditions in the tributaries.

FWP Chapter 7; RTR Chapter 5. Level of proof: 1

Rivers form a natural organizing feature of many ecosystems including the Columbia River Basin. For this reason, watersheds or catchments are natural structural elements and are appropriate units for organizing efforts to improve land use practices. However, a system of the extent and complexity of the Columbia River Basin is structured as a nested hierarchy such that efforts in individual subbasins or watersheds only make sense within the context of higher organizational levels such as ecoregions and the Columbia River Basin as a whole. Similarly, behavior of the ecosystem at these higher organizational levels can be understood only as the collective behavior of the lower organizational units. While subbasins or watersheds may be appropriate organizational units for biological, physical and social reasons, watershed planners should avoid undo introspection but instead should incorporate metapopulation structure and regional and basin-wide factors that form the context for their efforts.

23. Artificial production can be used to augment harvest without detrimental effects on naturally spawning populations.

FWP Chapter 7; RTR Chapter 8. Level of proof: 4

There is little empirical support for the proposition that harvest can be augmented by hatchery production without imposing detrimental effects on naturally spawning populations. There is increasing evidence that hatchery practices also have accelerated the decline of wild stocks. Harvest management programs focusing on harvesting hatchery production have chronically applied excessive harvest rates to naturally spawning populations.

Interactions between wild and hatchery fish have not been comprehensively examined, but the weight of evidence points to negative effects.

Because there has been a lack of comprehensive evaluation throughout the 120-year history of the implementation of the hatchery paradigm, it is not clear how to make the hatchery system more productive and more compatible with natural production in the basin.. Artificial propagation should be integrated into subbasin-specific watershed management, with a role and production objectives that are consistent with natural production goals for that subbasin. Artificial production must be viewed as an experiment, and should be implemented within an adaptive management framework. An important new objective of the experiment should be to reestablish metapopulation structure and function in the basin.

24. Natural populations are detrimentally affected by straying of returning hatchery fish.

FWP Chapter 7; RTR Chapter 8. Level of proof: 2.

Hatchery strays that interbreed with wild salmon are necessarily problematic if the hatchery has intentionally or inadvertently exerted selection pressure rendering the artificially propagated stock less fit in the natural habitat than the wild stock. Straying occurs naturally in salmon populations and is an important mechanism permitting recolonization of suitable habitat and the functioning of metapopulations. Salmon released from hatcheries also stray from their home stream into natural spawning areas and may successfully interbreed with wild salmon. The scale of hatchery production is often larger than the scale of natural production in streams, therefore, even if hatchery reared salmon stray at the same rate as wild salmon, the absolute number of hatchery strays can be greater. Consequently, large numbers of straying hatchery salmon can genetically swamp the naturally spawning population.

25. Overall survival of salmon and steelhead is decreased by exceeding the carrying capacity of the river, estuary, and/or ocean because of excessive releases of juvenile fish from production facilities.

FWP Chapter 7; RTR Chapter 6 and 8. Level of proof: 3.

The ecological, behavioral, and energetic interactions of hatchery fish with native species (including wild salmon) and fish assemblages of the Columbia River ecosystem have not been thoroughly studied and evaluated. However, the hydroelectric system has reduced the food production capability of the Columbia and Snake mainstems according to our analysis. An important component of this food base depended on seasonal flooding of riparian areas and rapid colonization and growth of aquatic insects (primarily chironomid midges). Regulated tributaries may have a similar reduction in food production important for rearing of migrants. Riverine food components have been replaced in lower Columbia River reservoirs by estuarine invertebrates that have lower nutritional value for juvenile salmonids. The Snake River mainstem has neither a riverine nor an effective replacement estuarine food base. The dominant reservoir plankton may be insufficient for the nutritional needs of juvenile salmonids. Additionally, it may be located in places that are inaccessible to subyearling migrants. Thus, the food production capability of the mainstem is deficient and may be made worse by infusion of an overabundance of hatchery fish.

26. Artificially reared fish can be used to augment the production of natural fish populations (i.e., in supplementation projects) in a manner that minimizes genetic change or reductions of fitness in the population.

FWP Chapter 7; RTR Chapter 8. Level of proof: 3

It remains to be shown whether natural and artificial production systems can be used in the same system to sustain long-term productivity. The conservation hatchery and captive broodstock technology are new concepts and roles for artificial propagation. Their purpose is to assist in the preservation of threatened or endangered stocks of salmon and to reestablish metapopulation structure. Their successful use is uncertain. Supplementation with a local stock depends on the ability of the habitat to support both naturally spawning and supplemented fish. Supplementation must be viewed as an experiment, and should be implemented within an adaptive management framework, confined to a limited and definite duration, using temporary facilities where possible. An important new objective of experimental supplementation should be to reestablish metapopulation structure and function in the basin.

27. Absence of fish screens or inadequate screens on agricultural and municipal water intakes leads to increased mortality of juvenile salmon and steelhead.

FWP Chapter 7; RTR Chapter 5. Level of proof: 1

Entrainment of juvenile migrants in agricultural and municipal water intakes is a well known source of mortality. Lack of screening may have been a factor in the extirpation of a number of salmonid populations including Snake River basin coho. Screening of water intakes is commonly employed in salmon restoration programs and has been shown to remedy this problem.

28. Productivity of naturally spawning populations is limited by habitat availability and habitat quality.

FWP Chapter 7; RTR Chapter 5. Level of proof: 1

Evidence exists to indicate that food production capability of the present mainstem habitat may be reduced relative to historic levels. A number of studies have documented the loss of pool and spawning habitats in tributaries due to siltation and inundation. Uncertainties about the lack of fertility in lakes, streams and headwater reaches resulting from the loss of nutrients contained in salmon carcasses has likely led to the disruption of the biogeochemical cycles. Disruption of this cycle leaves open the possibility of detrimental changes in food webs throughout the basin. Quantity of mainstem spawning habitat has undeniably been reduced by impoundments. Remaining spawning habitat in dam tail races is often of poor quality. Uncertainties about lack of fertility in headwater reaches remains

29. Biological diversity can be stabilized or increased through habitat conservation.

FWP Chapter 7; RTR Chapter 5. Level of proof: 2

Biological diversity arises as the interaction between the spatial and temporal diversity of the environment and the genetic and biological potential of the species. Diversity within the existing population of salmonids in the Columbia River is almost unquestionably less than occurred prior to development although comparative data are not available. While some diversity has been lost due to outright extirpation of populations, decline in diversity also has occurred in a more subtle manner through the elimination of habitat and the simplification of much remaining habitat. Management practices such as harvest, hatcheries and operation of mitigation measures such as transportation have also served to narrow the distribution of salmonid life histories. Conservation of the natural feature of the remaining habitat is essential to retaining the existing biological diversity, while re-expression of the natural diversity of tributary and mainstem habitats is essential to increasing biological diversity in the future.

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