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CHAPTER 3. AN ALTERNATIVE CONCEPTUAL FOUNDATION FOR RESTORATION OF COLUMBIA RIVER SALMONIDS

> *"Conservation efforts must nurture the whole life history, not focus inordinate attention on elusive "bottlenecks" to production. I believe conservation efforts will fail if primary attention is not directed to providing the habitat opportunities that historically supported the stock in its natural state."*
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> M. C. Healey. 1994. Variation in the life history characteristics of chinook salmon and its relevance to conservation of the Sacramento winter run of chinook salmon. *Conservation Biology* 8:876-877.

This report is derived from a directive in the 1994 Fish and Wildlife Program in which the Northwest Power Planning Council directed the ISG to develop an explicit conceptual foundation for the fish and wildlife program. In 1992, the Council directed the Scientific Review Group (the precursor review body to the ISG) to examine critical uncertainties in the Fish and Wildlife Program. In our 1993 report to Council (Independent Scientific Group (ISG) 1993), we found fault with the Fish and Wildlife Program for its lack of an explicit scientific basis. As a result, in its 1994 program, the Council directed the ISG to develop an explicit conceptual foundation for the fish and wildlife program.

This book is a result of that directive. We have examined the scientific basis for present fish and wildlife recovery actions in the Columbia River (Chapter 2) and, in the light of continued declines of salmon and other species, have developed an alternative conceptual foundation (this chapter) that is grounded in contemporary thought (Independent Scientific Group 1999). Because the Council's Fish and Wildlife Program is developed from recommendations submitted by a variety of interested parties (especially the region's tribal, state, and federal fish and wildlife management agencies), it mirrors the themes of traditional fisheries management. Because of this, our review and the development of a conceptual foundation, while focused on the Columbia River and the Council's program, are applicable to a broad spectrum of natural resource management.

Fundamental Assumptions and Principles in the Alternative Conceptual Foundation

The critical elements of our conceptual foundation (Box 3.1) were derived from a synthesis of riverine ecological theory (Stanford et al. 1996) in the context of habitat diversity (Frissell et al. 1997), life history diversity (Thorpe 1994; Healey and Prince 1995), and declining trends in abundance of

Columbia River salmon (Nehlsen et al. 1991; National Research Council (NRC) 1996). The critical elements are given below and described in detail in sections that follow.

Box 3.1. An alternative conceptual foundation developed by the Independent Scientific Group

1. Restoration of Columbia River salmonids must address the entire natural and cultural ecosystem, which encompasses the continuum of freshwater, estuarine, and ocean habitats where salmonid fishes complete their life histories. This consideration includes human developments, as well as natural habitats.

2. Sustained salmonid productivity requires a network of complex and interconnected habitats, which are created, altered, and maintained by natural physical processes in freshwater, the estuary, and the ocean. These diverse and high-quality habitats, which have been extensively degraded by human activities, are crucial for salmonid spawning, rearing, migration, maintenance of food webs, and predator avoidance. Ocean conditions, which are variable, are important in determining the overall patterns of productivity of salmon populations.

3. Life history diversity, genetic diversity, and metapopulation organization are ways salmonids adapt to their complex and connected habitats. These factors are the basis of salmonid productivity and contribute to the ability of salmonids to cope with environmental variation that is typical of freshwater and marine environments.

The Conceptual Basis for Restoration

1. Restoration of Columbia River salmonids must address the entire natural and cultural ecosystem, which encompasses the continuum of freshwater, estuarine, and ocean habitats where salmonid fishes complete their life histories. This consideration includes human developments, as well as natural habitats.

A natural-cultural ecosystem encompasses all the ecological and social processes that link organisms, including humans, with their environments. The natural-cultural system supporting Columbia River salmonids extends from headwater tributaries into the northeast Pacific Ocean and includes upland regions and riparian corridors, as well as surface and subsurface flow pathways and processes. The salmon-bearing ecosystem is characterized by processes that create and maintain a wide array of habitats in which fishes grow and reproduce. Complex habitats with a high degree of spatial and temporal connectivity permit the development and expression of life history diversity, which is an essential component of salmonid productive capacity. In a life history context, salmonid restoration implies re-establishment of life history diversity, which requires reestablishment of habitat diversity and connectivity (Figure 3.1). Depleted populations of native salmonids cannot be expected to rebuild if any of the habitats required for successful completion of all life stages are seriously compromised by human activities.

The current approach to restoration in the Fish and Wildlife Program tends to focus on a small subset of habitats or life history types, abstracting them from the whole and neglecting the interaction among elements of the ecosystem and life histories. The search for a simple relation between river flows and survival of salmon is an example. Juvenile salmon are treated as physical objects moving passively with the current rather than as living organisms interacting with their habitat (reviewed in Chapter 5). Other examples include the effects of flow manipulation on the estuary and its capacity to support salmon are not considered.

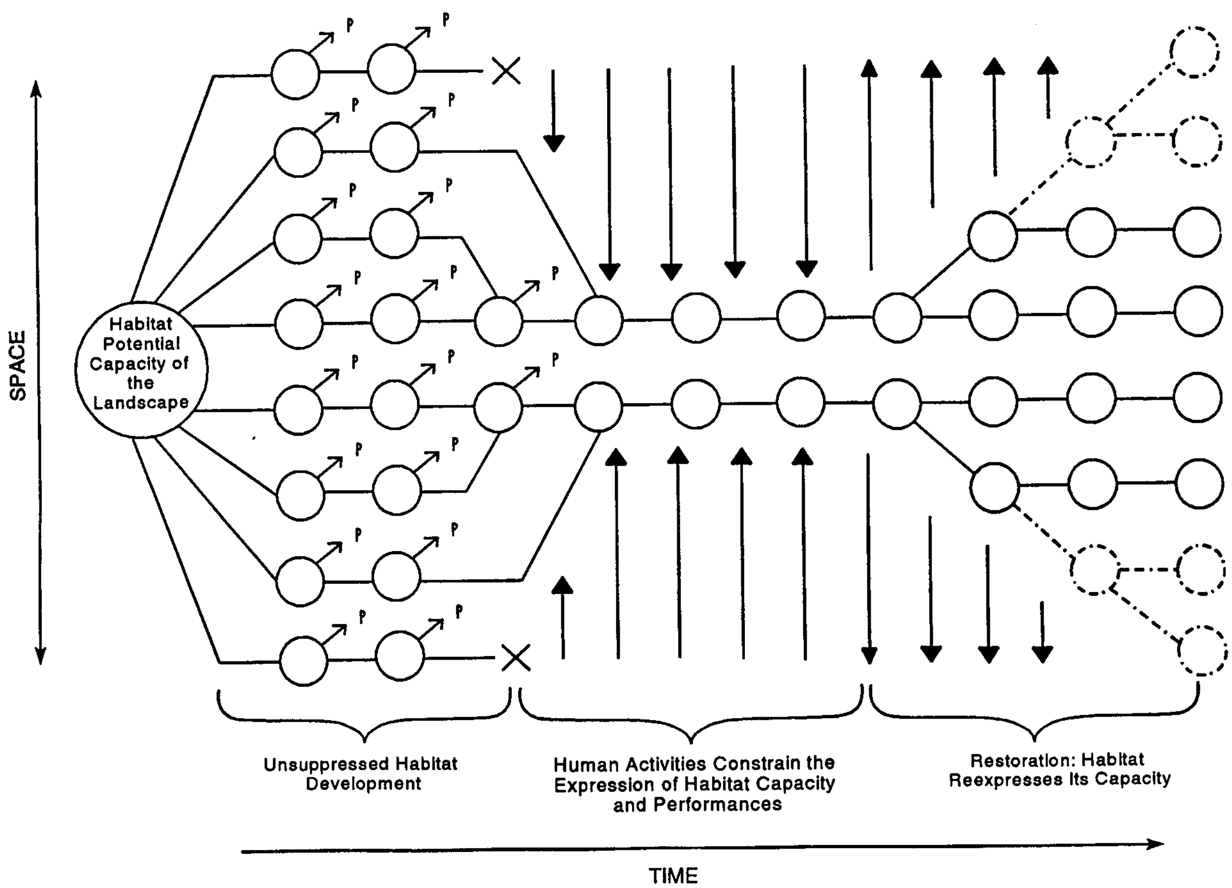

Figure 3.1. The expression of the potential capacity of a habitat system yields an array of developmental pathways and habitat performances (P).
Human activities can constrain habitat capacity expression by suppressing habitat diversification (inward arrows) or eliminating specific performances (X). Restoration occurs when habitat capacity is reexpressed following release of anthropogenic suppression (outward arrows). Alteration of potential capacity may preclude the reexpression of certain historic performances (dashed lines) (Ebersole et al. 1997).

The Normative Ecosystem

We believe an ecosystem with a mix of natural and cultural features that typifies modern society can still sustain all life stages of a diverse suite of salmonid populations if the essential ecological conditions and processes necessary to maintain diverse and productive salmonid populations exist within the ecosystem. We call this ecosystem, with its balanced mix of natural and cultural features, a “normative” ecosystem.

Normative refers to the functional norms of ecological functions and processes characteristic of salmon-bearing systems. These features can be identified and described, and when balanced with society’s needs and demands on the river and ecosystem, result in a an ecosystem, in which both natural and cultural elements exist in a balance that allows salmon to thrive and many of society’s present uses of the river to continue. We emphasize that our description of the normative ecosystem is necessarily general and focuses on biological and physical processes and conditions characterizing the normative ecosystem. The normative ecosystem is not a static target or a single unique state of the river, rather it is a continuum of conditions from slightly better than the current state of the river at one end of the continuum to relatively pristine at the other end (Figure 3.2).

The region, through its policy representatives, will have to decide much it is willing to improve ecological conditions for salmon based on its economic, cultural, and ecological values (Miller 1997; Independent Scientific Group (ISG) 1998). Specific prescriptions, such as flow regimes, levels of stock and life history diversity, etc., will need to be developed to improve ecological conditions. We recognize that, because we are dealing with an ecosystem that has sustained extensive human development for over 150 years, numerous social and biophysical constraints exist for enhancing normative conditions (Blumm et al. 1998; Wood 1998). The challenge before the region is to reach consensus on the extent to which these constraints can be relaxed or removed to achieve Fish and Wildlife Program goals. Nevertheless, we believe strongly that improving natural ecological processes and functions is the only way in which Fish and Wildlife Program goals for recovery of salmonids and other fishes can be met. Progress toward the restoration goal requires moving the system from the current, degraded state to one that supports improved ecological conditions with regard to the most critical attributes for salmonids

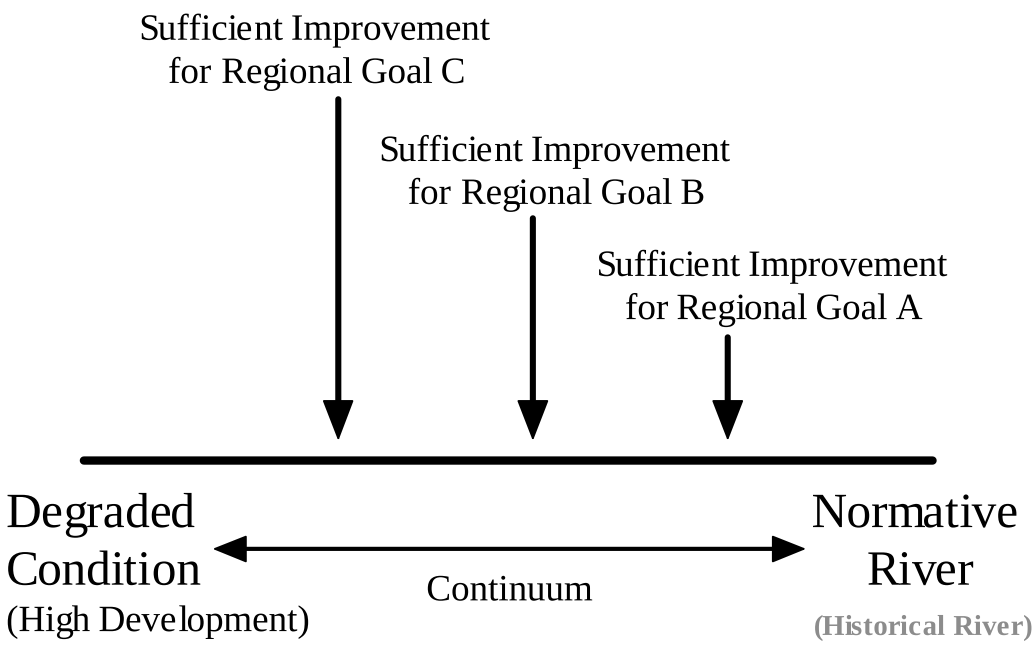

Figure 3.2. Diagrammatic representation of the relationship between three different regional goals for salmon production and improvement in ecosystem conditions.

The Normative River is defined in terms of the norms or standards that describe a set of conditions for a fully functional river ecosystem and are based on modern ecological science and measures. The pre-development river, which is poorly understood or described, is not attainable due to irreversible ecological changes, such as large-scale habitat changes and species introductions.

The three hypothetical regional salmon production goals are as follows: Goal A relies on a nearly pristine refuge area, which is very close to the normative ideal, that is managed for salmon spawning; Goal B relies on a rehabilitated major subbasin, such as the lower Yakima, where appropriate flows and temperatures exist for juvenile salmon outmigration in the spring. The subbasin would continue to have irrigation dams and return water, yet still provide migration conditions sufficient to pass large numbers of salmonid smolts and adults; Goal C relies on improving fish bypass facilities at existing dam structures to incorporate fish behavior, thus making fish passage sufficiently normative to achieve passage and production goals.

The River Continuum

> 2. Sustained salmonid productivity requires a network of complex and interconnected habitats, which are created, altered, and maintained by natural physical processes in freshwater, the estuary, and the ocean. These diverse and high-quality habitats, which have been extensively degraded by human activities, are crucial for salmonid spawning, rearing, migration, maintenance of food webs, and predator avoidance. Ocean conditions, which are variable, are important in determining the overall patterns of productivity of salmon populations.

The Columbia River, like all large gravel-bed rivers is a complex, dynamic gradient of habitat types from the headwaters to the estuary. Salmonids, and all other riverine flora and fauna, are distributed rather predictably along that gradient according to the requirements of each stage in their life cycle (Vannote et al. 1980). Each species or unique life history type will be present wherever there are enough resources to sustain growth and reproduction and thereby sustain the presence of the population in the river food web at that location (Hall et al. 1992). Some species can be maintained without much movement and suites of organisms appear to occur in zones along the river continuum. Other species must move long distances in search of resources needed for each life stage, sometimes involving migrations into lakes (e.g., adfluvial bull trout and cutthroat trout), the ocean (e.g., chinook salmon, coho salmon, chum salmon, and steelhead trout), or both (e.g., sockeye salmon).

Like all river ecosystems, the Columbia River has three important spatial dimensions (Figure 3.3) (Ward 1989): 1) <u>Riverine</u> - a longitudinal continuum of runs, riffles, and pools of varying geometry from headwaters to mouth; 2) <u>Riparian</u> - a lateral array of habitats from the middle of the main channel through various side and flood channels and wetlands to flood plains and the uplands of the valley wall, including streamside vegetation and associated faunal assemblages; and 3) <u>Hyporheic</u> - a latticework of underground (hypogean) habitats associated with the flow of river water through the alluvium (bed sediments) of the channel and flood plains. These three interconnected habitat dimensions are constantly being reconfigured by physical (e.g., flooding) and biological processes (e.g., salmon digging redds; beavers damming small streams and side channels on flood plains of larger rivers). Critical habitats for the various life stages of salmonids exist in all three dimensions.

Channel morphologies are determined by bedrock geometry and geology and by the legacy of flooding which mediates the process of cut and fill alluviation. Big floods fill channels with inorganic and organic materials eroded laterally and vertically from areas upstream, thereby producing a continuum of instream structures (pools, runs, riffles, gravel bars, avulsion channels, islands, debris jams) and lateral floodplain terraces in many sizes and shapes. Much of the Columbia River and its tributaries within the Columbia Plateau are constrained by ancient basalts (lava rock). Thus, flood plains are not expansive. In other areas of the basin, rivers have deeply bedded and expansive flood plains interspersed between canyon reaches. Channels with a greater sediment supply and frequent overbank flooding are constantly shifting, braiding, or meandering on the valley bottom from year to year as the channel fills with material in one place causing the flow pathway to erode new channels into the flood plain.

Flow of river water through interstitial pathways in gravel bars and floodplain alluvium and back to the surface is an especially important habitat forming process that may be overlooked with respect to salmonid ecology (Gibert et al. 1994). Salmonids select upwelling (water flowing upward through the gravel toward the gravel surface) and sometimes downwelling sites for spawning because their eggs are naturally aerated in those places. Nutrients increase along interstitial flow pathways and stimulate production of food for larvae and juvenile salmon in upwelling zones. The river temperatures are moderated by interstitial flow. Relative to surface temperatures, ground water from the hyporheic zone is cool in the summer and warm in the winter. Regional patterns of hyporheic flow appear to be critical to rivers of the high desert of the Columbia Plateau (e.g., Grande Ronde, John Day, Yakima), where late summer instream temperatures may be too high for salmonids (Li et al. 1995a; Li et al. 1995b). The upwelling zones provide cool refugia for salmonids on hot summer days and enhance winter growth by keeping the water warm and some habitats ice free. Upwelling ground water also mediates establishment of riparian plants. Leaves and wood debris eroded from the riparian zone into the channel energize the riverine food web, provide cover for fishes, and cause localized cut and fill alluviation that provides additional habitat complexity.

The importance of a complex and dynamic continuum of habitats in the Columbia River is a central tenet of our conceptual foundation. We believe that the floodplain reaches and gravel-cobble bedded mainstem segments (e.g., alluvial reaches such as the Hanford Reach in central Washington) are especially important because habitat diversity and complexity is greatest in those locations. Alluvial reaches are arrayed along the stream continuum between canyon segments like beads on a string and appear to function as centers of biophysical organization within the river continuum (Regier et al. 1989). They are likely to be nodes of production and biological diversity that are structurally and functionally linked by the river corridor (Copp 1989; Gregory et al. 1991; Zwick 1992; Stanford and Ward 1993; Ward and Stanford 1995b; Ward and Stanford 1995a). Worldwide, intermountain and piedmont valley floodplains like the Hanford Reach of the Columbia River are characterized by nutrient rich floodplain soils and diverse and productive backwater and mainstem fisheries (Welcomme 1979; Davies and Walker 1986; Lowe-McConnel 1987; Sparks et al. 1990; Junk and Piedade 1994; Welcomme 1995). Not surprisingly, these areas are frequently centers of human activities within a watershed (Amoros et al. 1987; Petts et al. 1989; Wissmar et al. 1994).

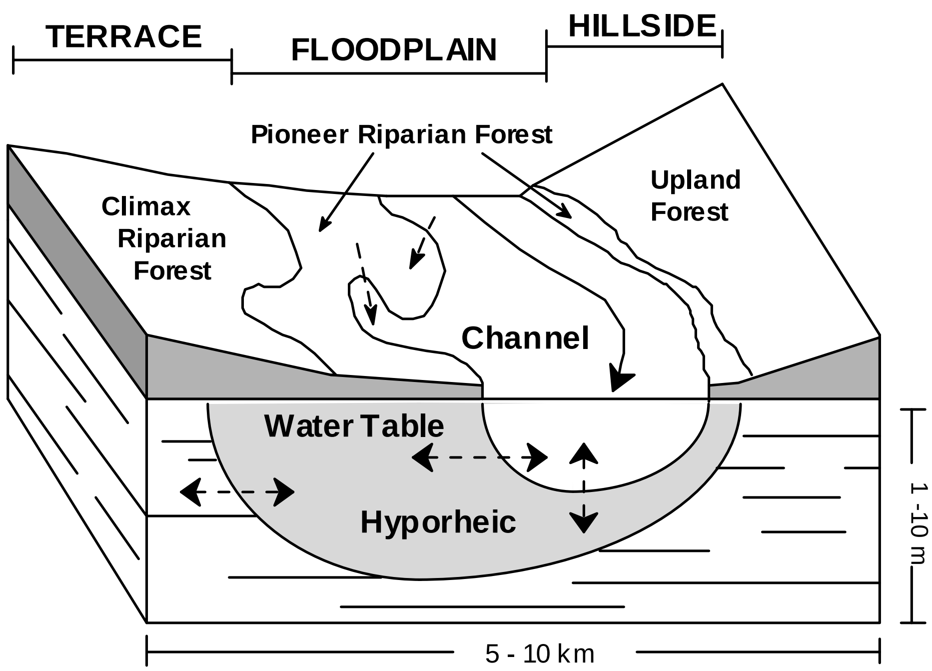

Figure 3.3. The three important spatial dimensions of the lotic ecosystem: 1) the riverine, or longitudinal habitats (A – C); 2) the riparian, or lateral habitats between terrace and hillslope; and 3) the hyporheic, or vertical habitats below the level of the water table where the river water flows through the bed sediments. Arrows show direction of water movement.

The Regulated River

At least three fundamental principles emerge from the large literature on the ecology of regulated rivers (Stanford et al. 1996; Poff et al. 1997). These principles are particularly germane to derivation of restoration strategies for Columbia River salmonids.

1. Habitat diversity is substantially reduced as a consequence of regulation

The dams of the Columbia River have inundated many of the piedmont and mountain valley floodplains, thereby severing the river continuum. Mass transport dynamics that create instream and floodplain habitats for riverine biota in remaining free flowing reaches have been drastically altered. Flood peaks have been eliminated, discharges are more variable, and temperature seasonality has been altered.

As a consequence of reservoir storage of peak flows for flood control, navigation, irrigation, and hydropower production, base flows have increased substantially and in many places fluctuate so erratically that aquatic biota cannot survive in shallow, near-shore habitats. Persistent shallow or slack water habitats are especially important for survival of early life history stages of fishes that cannot survive in the strong currents of the channel thalweg. Storage of bedload in the reservoir and constant clear-water flushing downstream artificially has depleted gravel and finer sediments in the tailwaters causing armoring of the bed with large cobble and boulder substratum. Channel constrictions and habitat simplification is nearly universal, except in headwater areas. Vegetation has clogged backwaters owing to loss of scouring flood flow. Riparian communities have been altered by deforestation and agricultural activities, which interact with effects of regulation to reduce habitat heterogeneity (all of these impacts are reviewed in detail in Chapter 5 of this report).

The general conclusion is that regulation has created a discontinuum of environmental conditions and severed the connectivity of channel, groundwater, floodplain, and upland components of the catchment ecosystem. Habitats for riverine biota have become spatially homogeneous, limited to the permanently wetted portion of the channel thalweg that is dominated by conditions dictated by operations of upstream storage reservoirs. Indeed, serial construction of low-head dams has converted virtually the entire mainstems of the lower Snake and Columbia Rivers into shallow reservoir habitat that is neither truly laucustrine, nor riverine.

2. Native biodiversity decreases and non-native species proliferate as a consequence of regulation

Native biodiversity has decreased substantially in the last 120 years (Behnke 1992; Huntington et al. 1996). Most salmon populations spawning in the mainstem Columbia and Snake Rivers have been extirpated (Nehlsen et al. l991). In the headwaters of tributaries, salmon populations have become increasingly isolated by flow regulation, diversion, and habitat degradation especially in the lower reaches. Moreover for anadromous species, mortality resulting from passage through dams and reservoirs in the mainstem may not affect all species and life histories equally, selecting against certain life history types, thereby reducing biodiversity, increasing habitat fragmentation, and increasing the vulnerability of populations to extinction.

Altered temperature patterns and continual export of very fine organic matter and dissolved nutrients, coupled with simplification of the channel, stabilization of bottom substratum, and loss of floodplain inundation, has promoted environmental conditions to which native species are maladapted (see Table 5.1 in Chapter 5 listing native and exotic fish species in the Columbia River Basin). This has created opportunities for nonnative plants and animals to establish robust populations. In some cases, one or a few native species are more abundant than they were before regulation (Poe et al. 1991). Non-native invertebrates, fishes, and plants are consistently more abundant in regulated river reaches compared to unregulated reaches (Li et al. 1987). Reasons for non-native proliferation vary, but in general non-native species are often better competitors in the homogeneous habitats of regulated river reaches. A wide array of non-natives have been introduced into the Columbia River system (see Table 5.3).

3. Normative conditions are re-expressed predictably as distance downstream from the dam increases and in relation to influences of tributaries

The Serial Discontinuity Concept (SDC) (Ward and Stanford 1983; Ward and Stanford 1995b) predicts that the conditions described above that are attributable to flow regulation will ameliorate in river reaches downstream of storage reservoirs, as a natural consequence of the biophysical energetics of rivers. The distance downstream of the dam needed to reset normative conditions is related to the limnological attributes (depth, volume, water retention time, trophic state) of the reservoir, the mechanics of water release (surface, bottom or depth-selective), the mode of dam operations, and the influence of tributaries entering downstream from the dam. If the tributaries are large and unregulated, they may substantially accelerate the reset (Stanford and Hauer 1992). In any case given enough distance, conditions at some point downstream from the dam will closely approximate original conditions.

Reset toward natural conditions has been demonstrated in Columbia River tributaries downstream of storage reservoirs, e.g., Flathead River (Hauer and Stanford 1982; Stanford et al. 1988); Kootenai River (Perry et al. 1986); and Clearwater River (Munn and Brusven 1991). For the lower Snake and Columbia Rivers, however, little reset of riverine conditions can be expected, because almost no river environment remains due to nearly continuous impoundment. The Hanford Reach, which contains a nearly 50 mile undammed free flowing stretch between Priest Rapids and McNary dams, is the single exception in the mainstem.

The Marine Environment

The Pacific Ocean and atmosphere do not move towards a steady state condition, but continually shift in response to changes in the global heat budget. Responses on the local scale to remote atmospheric and oceanic disturbances suggest that the Pacific basin is an interconnected oceanic ecosystem. Fluctuations in atmospheric and oceanic processes change the physical environment and the composition of assemblages of marine biota and act in effect to reset ecological conditions on local and regional scales. Local salmon populations may encounter a different set of conditions each year they enter the coastal ocean. The new conditions may be sufficient to qualitatively change the relationship between a species and regularly occurring environmental phenomena, such as coastal upwelling. For example, a reset in the ecological and physical processes might explain why production of coho salmon was positively correlated to upwelling in the 1960s and 1970s and negatively correlated to upwelling during the past decade (see Chapter 9 for a detailed discussion of ocean processes).

Historically, salmon managers treated the ocean as a constant in the development of management and restoration plans, as well as in the population models they used to set escapement and harvest levels. The models and programs assumed that oceanic habitats and biotic communities existed in stable equilibrium. Salmon managers ignored the ocean because it is impossible to control the climatic patterns and physical factors that influence ocean productivity. Although we cannot control oceanic processes, it is possible to control and regulate our behavior and adjust management practices in response to changes in the ocean. In that sense the ocean is not beyond our capacity to act, but appropriate action will require better understanding of the linkages between freshwater and oceanic environments and of the biophysical processes in the ocean that influence marine production of salmon.

Changes in the northeast Pacific ocean that dramatically alter both freshwater and marine conditions for salmon call into question management programs that emphasize constancy of the natural environment. Conservation programs designed under one climatic regime may not be appropriate under another. An ocean that is variable requires life history and genetic diversity in the anadromous species to successfully respond to a wide variety of potential environmental conditions. A highly controlled river and widespread use of artificial propagation has reduced diversity and the flexibility of salmon and steelhead and made them more vulnerable to collapse when ocean conditions change. The performance of salmon in the estuary and ocean is not independent of management programs in freshwater. Management programs that reduce variability in freshwater may unwittingly eliminate behaviors that buffer salmon production in unstable marine environments.

Salmonid Life Histories and Habitat

3. Life history diversity, genetic diversity, and metapopulation organization are ways salmonids adapt to their complex and connected habitats. These factors are the basis of salmoid productivity and contribute to the ability of salmonids to cope with environmental variation that is typical of freshwater and marine environments.

Availability of complex and connected habitat facilitates the expression of salmonid life history diversity and productivity in a watershed (Figure 3.1; Healey and Prince, 1995). Aquatic habitats change on daily, annual, or decadal cycles and in response to major disturbances such as record floods and droughts, volcanic eruptions, landslides, and other geomorphic processes. Variability is not limited to freshwater habitat. Ocean conditions favorable for salmon growth and survival vary on cycles that are both long (decades or more) and short (El Nino events of one to a few years) in duration. Salmonid populations increase or decrease in response to natural environmental changes, and during extreme changes, when constraints are strongest, individual populations in marginal habitats may be extirpated. However, the effects of natural disturbances moderate over time, habitat quantity and quality are gradually restored, and habitats where local extinction has occurred are recolonized by salmonids from neighboring populations.

W. F. Thompson (1959) visualized the salmon's habitat as "a chain of favorable environments connected within a definite season in time and place, in such a way as to provide maximum survival." Salmonids following some habitat chains exhibit high survival while other chains may lead to extinction from time to time, in response to the natural habitat changes. We interpret Thompson's chain of interconnected habitats as temporal and spatial "pathways" through the entire ecosystem (freshwater, estuarine, and marine). Salmonids following a particular chain of habitats --a particular pathway-- exhibit a unique life history pattern. A life history pattern is the salmonid's response to problems of survival and reproduction in that chain of habitats.

The complex, integrated set of phenotypic traits that comprise a salmonid's life history pattern result from interaction of an individual's genotype and its environment (Healey and Prince 1995). An important element of the environment is the "pathway" of habitats that the individual follows from birth to death. Life histories are comprised of demographic or phenotypic traits such as age at maturity, mortality schedules, size, and growth (Stearns 1976). Salmonid life history traits also include: a) the age and size that juveniles migrate within the river system, into lakes or to the sea; b) growth and maturity during riverine and lacustrine migrations; c) spawning habitat preferences; d) emigration patterns and; e) age and timing of spawning migration. All of these traits help salmonids survive and reproduce within the spatial and temporal boundaries of a chain of interconnected habitats.

Life history diversity, which is characteristic of salmonids in general (Groot and Margolis 1991; Rieman and McIntyre 1993; Ebersole et al. 1997), arises when individuals follow different habitat "pathways" and consequently manifest different sets of phenotypic traits. Healey and Prince (1995) summarize a fundamental premise of our normative ecosystem concept:

> *"Maintaining a rich diversity of Pacific salmon genotypes and phenotypes depends on maintaining habitat diversity and on maintaining the opportunity for the species to take advantage of that diversity."*

Thus, spatial and temporal habitat diversity are critical for expression of life history diversity (Figure 3.1). Multiple life histories have been observed in several populations of anadromous salmonids (Reimers 1973; Schluchter and Lichatowich 1977; Carl and Healey 1984; Gharrett and Smoker 1993; Lestelle and Gilbertson 1993). In the Columbia River ecosystem, life history diversity should be substantial owing to the ecosystem's large size, its complex riverine physiography and geomorphology, highly variable flow regime, and complex oceanic circulation pattern. Improving ecological conditions and increasing salmonid production requires restoration of habitat diversity, which will enable reexpression of life history diversity (Figure 3.1).

Salmonids following different chains of interconnected habitats may exhibit variation in important life history traits. For example in chinook salmon, phenotypic diversity is exhibited over a broad geographic scale in the stream and ocean life history types (Healey and Prince 1995). Stream type chinook salmon migrate to sea in the spring of their second year in freshwater, whereas ocean type chinook migrate to sea in their first year, usually within a few months after emerging from the gravel (Healey 1991). Stream and ocean type fish also differ in other aspects of their life histories, such as oceanic distribution and timing of adult migration (Healey 1991).

Stream and ocean life histories are major life history themes, but variation in juvenile migration patterns occurs within each theme. Continual downstream migration through the lower mainstem of rivers by ocean type chinook salmon throughout most of the spring, summer and fall (Rich 1920; Beauchamp et al. 1983; Nicholas and Hankin 1988) may represent several discrete migrations of juveniles from different locations in the watershed (Rich 1920). What appears to be a single continuous migration of ocean type juvenile chinook salmon may be a diverse assemblage of groups of salmon following somewhat different habitat pathways and thus having somewhat different life histories. Stream type juvenile chinook salmon that migrate to sea in their second year also exhibit variation in their migration pattern. Some stream type chinook salmon remain in headwater areas to rear, while others move into mainstem areas to rear in large pools over the winter (Healey 1991). In the Columbia Basin, this pattern has been observed in the Yakima River (Confederated Tribes Yakima Indian Nation (CTYIN) et al. 1990), Grande Ronde River**,** Deschutes River (Ratliff 1981; Lindsey and McPhail 1986), and the Lemhi River (Kiefer and Lockhart 1995). Steelhead juveniles become anadromous over a wide range of ages, from 2 to 7, depending upon temperature and productivity of the particular tributary where they were spawned (Mullan et al. 1992a). They appear to move downstream to more productive areas in the tributaries as they grow and require more sustenance. Eventually, they move into the ocean when they reach a suitable size.

Chinook salmon in the Columbia basin above Bonneville Dam prior to extensive human development likely consisted of a complex mosaic of spring, summer, and fall races of salmon distributed among mainstem and headwater spawning areas (Figure 3.4). Local populations of fall chinook whose juveniles migrated to the ocean as subyearlings spawned in several mainstem areas of the Columbia and Snake Rivers and lower mainstem segments of Columbia River tributaries (Fulton 1968; Howell et al. 1985; Mullan et al. 1992a). Spring and summer chinook that migrated as subyearlings reproduced in upper mainstem segments of major subbasins and lower reaches of tributaries to subbasin mainstems (Lichatowich and Mobrand 1995). Summer chinook probably spawned lower in the subbasin mainstems than spring chinook (French and Wahle 1959; Fulton 1968; Mullan et al. 1992a; Lichatowich and Mobrand 1995). Populations of spring chinook with yearling life histories reproduced in headwater streams of subbasin tributaries.

Habitat degradation and the loss of connectivity among habitats has constrained production and suppressed expression of life history diversity within the Columbia basin (Watson 1992; Lichatowich and Mobrand 1995, Figure 3.1). The decline of the ocean type life history has been an important contributor to the overall decline in production of chinook salmon within the Columbia River basin (Lichatowich and Mobrand 1995). In sampling conducted in the lower Columbia River from 1914 to 1916, Rich (1920) observed a migration of ocean type chinook salmon throughout most months of the year. He attributed this to the sequential migration of juvenile chinook salmon from tributaries progressively further upstream. Because the occurrence of the ocean type life history pattern is related to areas in the watershed where stream temperatures afford enhanced growth opportunity (Taylor 1991), the ocean type life history pattern likely would have originated from populations of fall chinook salmon that spawned in the mainstems of the Snake and Columbia Rivers and in the lower reaches of some subbasins, and from populations of summer and spring chinook salmon that spawned in the warmer middle reaches of the subbasins (Figure 3.4; Lichatowich and Mobrand, 1995). In Rich's (1920) sample, ocean type juveniles far outnumbered yearling stream type migrants (Lichatowich and Mobrand 1995).

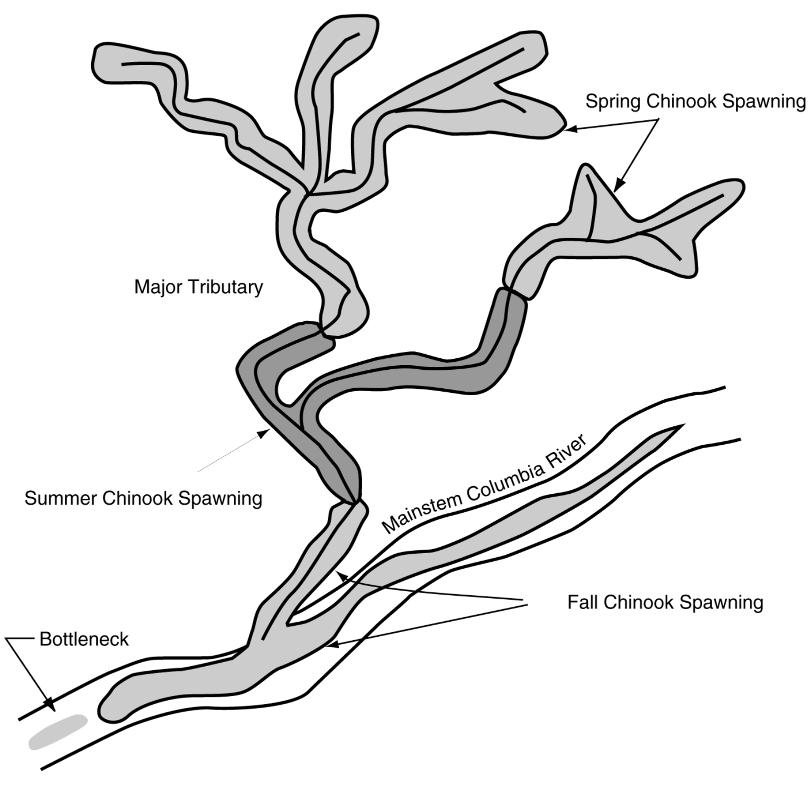

Figure 3.4. A concept of the geographic organization of chinook salmon in a mid-Columbia River subbasin prior to extensive human development. See text for explanation.

Salmon populations spawning in the mainstem Columbia and Snake Rivers and possessing ocean type life histories were depleted with the construction of the hydroelectric system. The Hanford Reach, small areas in the Snake River, and small areas in the tailraces of Columbia and lower Snake river dams support the last remaining populations of that life history type (Garcia et al. 1994). In the subbasins, loss of habitat connectivity, due in part to high summer water temperatures that likely were lethal to migrating salmon, was a major contributor to the loss of the ocean type life history (Lichatowich and Mobrand 1995). High temperatures in the lower sections of subbasins, resulting from a cumulative effect of watershed-wide habitat degradation, severed the connectivity of the chain of habitats linking the subbasins to the mainstem Columbia and Snake (Table 3.1), as happened in the Yakima River. In many subbasins alteration of habitat in the migration corridor through excessive temperatures or other barriers, (Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and Oregon Department of Fish and Wildlife (ODFW) 1990; Confederated Tribes Yakima Indian Nation (CTYIN) et al. 1990; Oregon Department of Fish and Wildlife et al. 1990; Oregon Department of Fish and Wildlife (ODFW) et al. 1990; Oregon Department of Fish and Wildlife (ODFW) and Confederated Tribes of the Warm Springs Reservation (CTWSR) 1990; Washington Department of Fisheries (WDF) et al. 1990)) eliminated life histories like the ocean type that were dependent on migration in the summer and fall months. Lethal temperatures in the lower mainstem also eliminated several life history pathways in spring chinook salmon in the Yakima River (Watson 1992). In contrast to Rich's findings early in this century, today, stream type juveniles are far more abundant than ocean type migrants, signaling a substantial loss of production of fall and summer chinook (Figure 3.5).

Table 3.1. Habitat suitability for juvenile chinook salmon in the lower reaches of the study subbasins (After Lichatowich and Mobrand 1995).

Subbasin	Comments on Habitat	Source
Yakima	Lower river below Prosser (RM 47.1) frequently exceeds 75°F and occasionally reaches 80°F in July and August rendering the lower river uninhabitable by salmonids.	CTYIN et al. 1990
Tucannon	Water temperatures in lower river at or above lethal levels.	WDF et al. 1990
Umatilla	Lower 32 miles subject to irrigation depleted flows and temperatures exceeding upper lethal limits for salmonids.	CTUIR and ODFW 1990
John Day	Juvenile chinook salmon generally not found in the river where temperatures reach 68°F. High stream temperature eliminates juvenile rearing habitat in the lower river.	Lindsay et al. 1981, ODFW et al. 1990
Deschutes	In the mainstem Deschutes River, summer temperatures are adequate for chinook salmon. However, there are temperature problems in the lower reaches of the tributaries where spring chinook salmon spawn. In addition *Ceratomyxa shasta* limit the survival of juvenile chinook salmon in the mainstem through the summer months.	Ratliff 1981, ODFW and CTWSR 1990

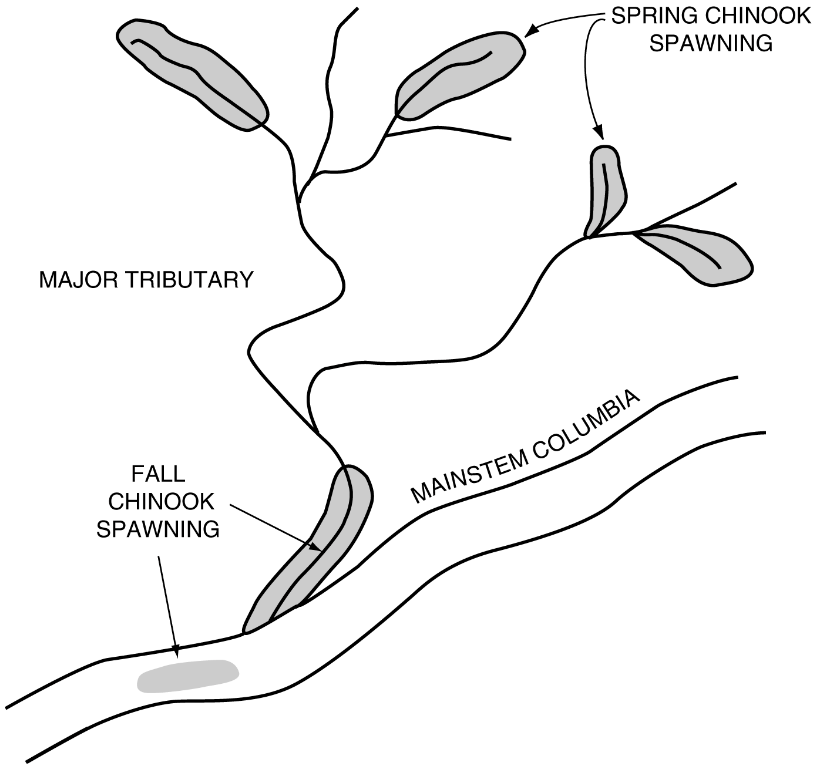

Figure 3.5. Diagrammatic concept of the present geographically fragmented organization of chinook salmon in the Columbia River basin.

Because salmonid populations occurred throughout the Columbia Basin across a mosaic of different landscapes, adaptation of individual populations to specific habitats (and life history pathways) created the abundant diversity that characterized salmonid fishes in the Columbia Basin (Taylor 1991). Complex and interconnected habitats were created and maintained in the Columbia Basin through natural riverine processes. The availability of these habitats facilitated the expression of life history diversity and contributed to maintenance of production of salmonids. The diversity that salmonids exhibit ecologically, behaviorally, and genetically is remarkable and well-recognized (Utter et al. 1974; Stearns 1976; Stearns 1977; Groot 1982; Hutchings and Morris 1985; Utter et al. 1989; Taylor 1990; Groot and Margolis 1991; Behnke 1992; Stearley 1992; Hutchings 1993), and arises out of an interaction between salmonids (comprised of genetically variable individuals) and the local conditions of their environments (i.e., local adaptation) (Taylor 1991; Allendorf and Waples 1996). Today, much of that diversity has been lost due to degradation of both mainstem and subbasin habitats.

Salmonid Metapopulations

In their review of the status of Pacific salmon, the National Research Council (1996) recommended that salmon be viewed as metapopulations, rather than isolated stocks. We define metapopulations in a broad sense as spatially-structured groups of local populations linked by dispersal (straying) of individuals (Hanski 1991; Hanski and Gilpin 1991). Metapopulation persistence is determined by the balance of local population extinction and re-establishment of extinct populations through recolonization.

The application of metapopulation concepts to conservation currently is being debated by scientists and managers, (Harrison 1994; Mann and Plummer 1995; Hanski and Gilpin 1997). Evaluation of the applicability of the concepts for understanding regional dynamics of fish populations, including metapopulation structure, the role and rates of dispersal of individuals among local populations, and population extinction rates, is in its early stages (Rieman and McIntyre 1993; Gresswell et al. 1994; Li et al. 1995a; Mundy et al. 1995b; Rieman and McIntyre 1995; Schlosser and Angermeier 1995; Rieman and McIntyre 1996). Consequently, data pertaining to salmonid metapopulation structure and dynamics are limited. In spite of this, Cooper and Mangel (1999) modeled salmonid metapopulations using a simple model focusing on source and sink populations and how conservation efforts may go awry if metapopulation structure exists, but is ignored.

However, metapopulation structure is likely in salmon because they display high fidelity of homing to their natal streams (Helle 1981), which allows them to establish local spawning populations. In addition, salmon have relatively low, but variable levels of straying (Quinn 1993) offering the opportunity for recolonization of habitats where local extinction has occurred. High natal fidelity favors adaptation of specific breeding demes, (i.e., local populations) to their environments via natural selection. In turn, this promotes population differentiation at the local level. However, because adjacent local populations are likely to occur in habitats that are similar (due simply to proximity), they may have very similar selection regimes. Therefore, differences or genetic divergence that accrue among them may be due largely to the effects of isolation and genetic drift. Straying (i.e., gene flow) between populations, even at very low levels, will tend to counteract the effects of isolation, thus retarding or even preventing genetic divergence among local populations.

A number of general classes of metapopulation structure have been identified (Harrison 1991; Stith et al. 1996). Although several studies on salmonid metapopulation structure are in progress, some recent work suggests that salmonid metapopulations resemble core-satellite metapopulations (Rieman and McIntyre 1993; Li et al. 1995a; Schlosser and Angermeier 1995). Core populations occupy high quality habitat and are generally large, productive populations that are less susceptible to extinction than smaller satellite populations (Hanski 1991; Harrison 1991; Schoener 1991; Harrison 1994). Core populations serve as important sources of colonists that could both reestablish satellite populations in habitats where extinctions have occurred (Harrison 1991; Schoener 1991; Rieman and McIntyre 1993; Harrison 1994; Schlosser and Angermeier 1995) and sustain populations whose abundance has been severely depleted, i.e., the "rescue effect" (Brown and Kodric-Brown 1977; Gotelli 1991). Thus, core populations can buffer metapopulations against environmental change and contribute to the resiliency of regional salmonid production.

Spawning populations that could have functioned as core-like populations likely occurred historically in alluvial segments with well-developed flood plains and gravel bars (Stanford et al. 1996). These areas provide a complex habitat mosaic highly suitable for spawning, egg incubation, and juvenile rearing and may have served as centers of habitat stability.

Most fall chinook populations spawning in the mainstem reaches of the Columbia and Snake Rivers have been driven extinct as a consequence of construction of mainstem dams. One of the remaining viable mainstem populations is the fall chinook population spawning in the Hanford Reach (Becker 1985), an alluvial river segment in the mid-Columbia region. The Hanford Reach is the last undammed section of the mainstem Columbia in the U.S., although flow through the Reach is regulated by dams upstream. Escapement to the Hanford Reach, where relatively high quality spawning and rearing habitat is still available, has ranged from 15,000 to 36,000 fish from 1968-1983 and peaked at over 88,000 spawners in 1987 (Figure 3.6). This population is the largest naturally spawning population of chinook salmon above Bonneville Dam and has persisted at relatively high densities through periods of variability in both freshwater and ocean conditions, when populations in other parts of the basin have undergone severe decline (Dauble and Watson 1997). The abundance of salmon spawning in the Hanford Reach could have been influenced by construction of Priest Rapids dam at the upper end of the Reach in 1960 and increases in smolt releases from Priest Rapids hatchery in the early 1980's (Dauble and Watson, 1997). Nevertheless, fall chinook in the Hanford Reach may presently function as a critical core population and could serve as a source for colonization of adjacent tributaries if ecological conditions were improved or restored in them. Young (1999), based on metapopulation theory and the general fecundity and adaptability of salmonids, proposed an ecological mitigation strategy of artificial recolonization programs aimed at hastening the return of natural demographic and evolutionary processes in populations. The metapopulation processes of dispersal and colonization are central to the proposal.

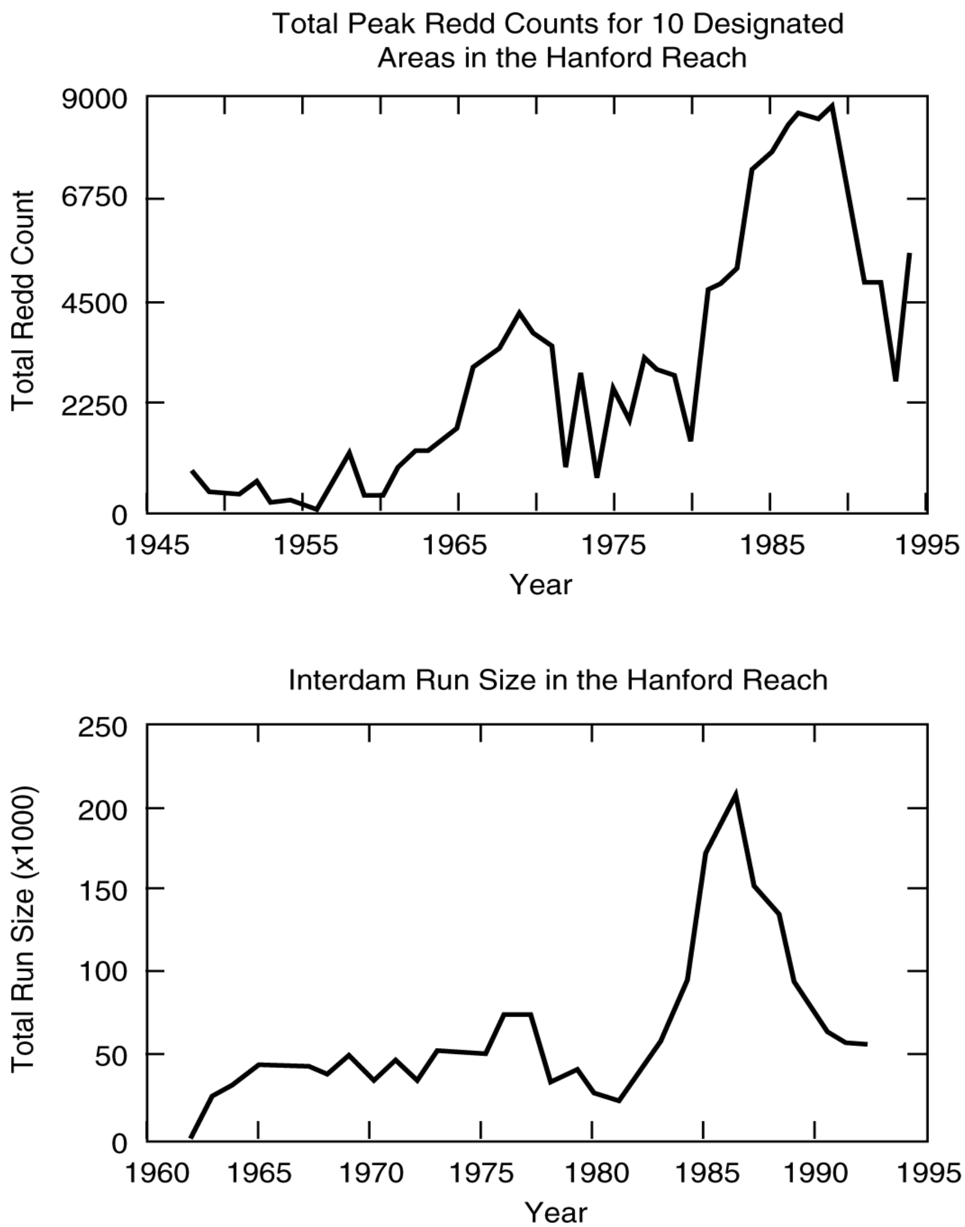

Figure 3.6. Spawning escapement of Hanford Reach fall chinook in the Columbia Basin. After Dauble and Watson (1997).

Recent observations of radio-tagged fall chinook from the Hanford Reach reveal extensive movements throughout an area that includes the confluences of the Snake, Columbia, and Yakima rivers (Figure 3.7). Apparently fall chinook spawners also were abundant in the section of the mainstem Columbia presently inundated by the John Day Reservoir (Fulton 1968). This section of river could have formed another critical core area.

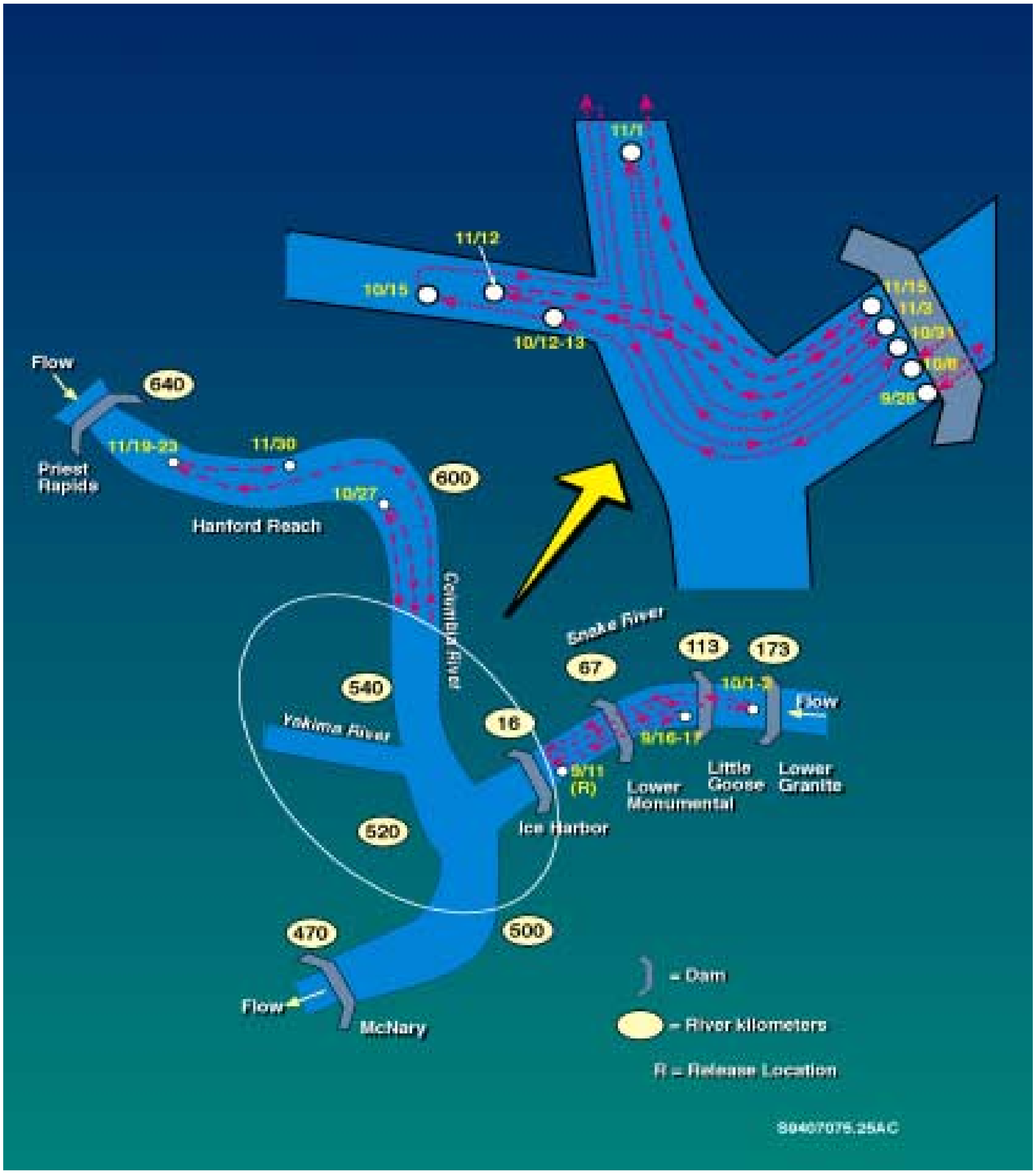

Figure 3.7. An example of the upstream movements of a female fall chinook salmon monitored during radio telemetry study conducted in 1993 by the Washington Department of Fish and Wildlife and Pacific Northwest National Laboratory (PNNL) (Mendel and Milks 1997).

After being tagged with a radio transmitter and released upstream of Ice Harbor Dam on September 11, 1993, biologists tracked this fish for 80 days as it moved between the Snake River, Yakima River, and the Hanford Reach. The fish (and tag) were finally recovered during spawner surveys on November 30, 1993, where it presumably spawned in the Hanford Reach in the vicinity of Vernita Bar (graphic supplied by David R. Geist, PNNL, Richland, Washington).

Potential Human Impacts on Metapopulation Organization

The extinction rate of local populations of chinook salmon has increased over the last century (Nehlsen et al. 1991; Williams et al. 1992; Frissell 1993b; National Research Council (NRC) 1996) and has altered the spatial structure and life history diversity of salmonid populations in the Columbia basin (Figures 3.5, 3.6, 3.8). Metapopulation theory suggests that fragmentation and destruction of habitat can disrupt metapopulation organization by extirpating vital core populations and isolating remaining populations. In turn, this can significantly reduce long-term metapopulation persistence and the stability of regional production (Rieman and McIntyre 1993; Harrison 1994; Li et al. 1995a; Schlosser and Angermeier 1995).

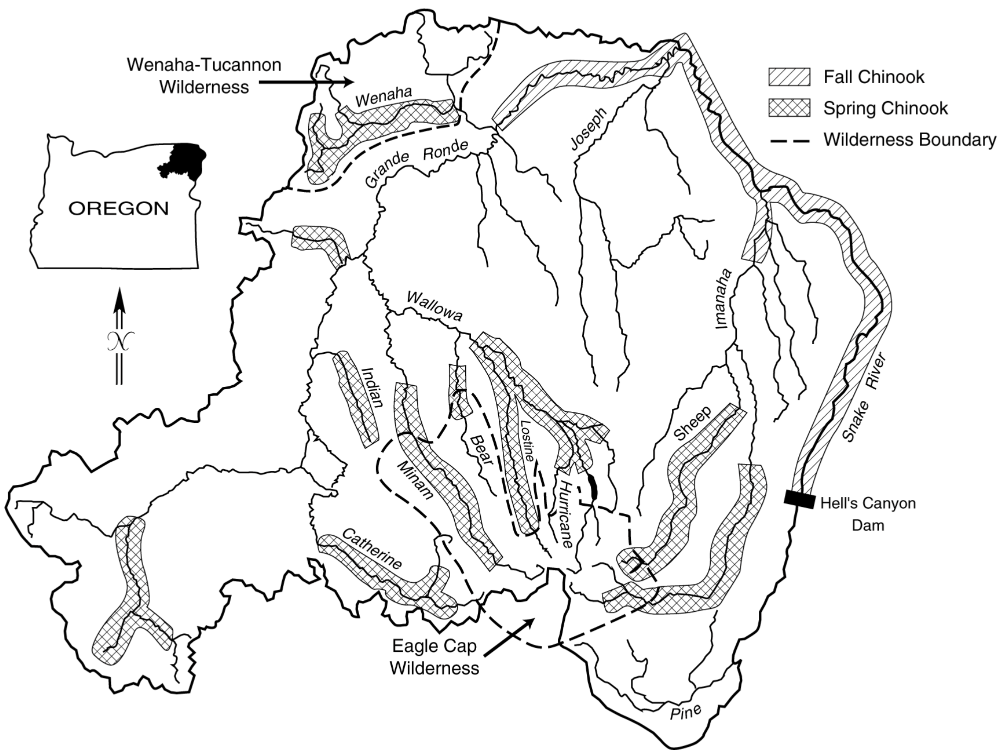

Figure 3.8. Spawning localities in northeastern Oregon of fall chinook salmon (stippled) in the undammed section of the Snake River below Hell’s Canyon dam, and for fall and spring chinook in two of its tributaries, the Grande Ronde and Imnaha. From Oregon Department of Fish and Wildlife, Oregon Watershed Health (1994).

Inundation of alluvial habitats in the mainstem Columbia and Snake rivers following construction of dams and degradation of mainstem habitats in major subbasins (see Chapter 6) have virtually eliminated productive mainstem spawning fall chinook stocks (except for the Hanford Reach stock). Remnant populations of fall chinook occur in the lower mainstems of most major subbasins, in the Snake River below Hell's Canyon dam (Figure 3.8), and in the tailraces of most Snake and Columbia river mainstem dams, but their abundance is much lower than in the past (Lavier 1976; Garcia et al. 1994). Most summer and spring chinook which spawned in upper mainstem segments of subbasins and lower reaches of tributaries to subbasin mainstems have been extirpated (Lichatowich and Mobrand 1995). Aside from the Hanford Reach, natural production of chinook salmon is largely confined to relatively small populations of spring and summer chinook in headwater streams where high quality habitat is still available (Figure 3.8). For example, spring chinook are confined largely to headwater areas of the Grande Ronde and Imnaha rivers and their tributaries that originate in wilderness areas where habitat is relatively pristine.

The probability of metapopulation extinction is enhanced if the dynamics of local populations and their individual probabilities of extinction become temporally correlated or synchronized (Harrison and Quinn 1989; Hanski 1991; Foley 1997). Regional stochasticity refers to the correlated or synchronized dynamics of local populations resulting from the operation of common environmental factors (Hanski and Gilpin 1991; Stacey and Taper 1992; Stacey et al. 1997). Asynchronous or relatively independent fluctuations in local population abundance, in which some populations are increasing while others are decreasing, reduces the probability of metapopulation extinction (den Boer 1968; Gilpin 1987; Goodman 1987; Hanski 1991) and probably stabilizes regional production. Natural populations in natural habitats are thought to function most often asynchronously. However, recent population data for spring chinook salmon in the Grande Ronde subbasin (Figure 3.9) show a synchronous decline in redd counts in most index streams. Similar synchronous declines were observed for spring and summer chinook from various Salmon River tributaries in the upper Snake River (Figure 3.10), but for wild spring chinook salmon not in the geographically distant John Day River (Nemeth and Kiefer 1999). The Salmon River chinook data are compelling, because they include an array of wild, natural and hatchery-influences populations in both wilderness and managed watersheds..

Human activities have not only increased extinction rates of local salmonid populations (Nehlsen et al. 1991; Williams et al. 1992; Frissell 1993b; National Research Council (NRC) 1996) but they also could act to synchronize the dynamics of remaining populations and increase the probability of metapopulation extinction (Rieman and McIntyre 1993). For example, land use activities can have pervasive, region-wide effects on geographically diverse local populations (see Chapter 5). Synchrony can also be induced in common migratory pathways and the ocean as a result of mortality due to excessive harvest, construction of dams, and degradation or destruction of mainstem habitats.

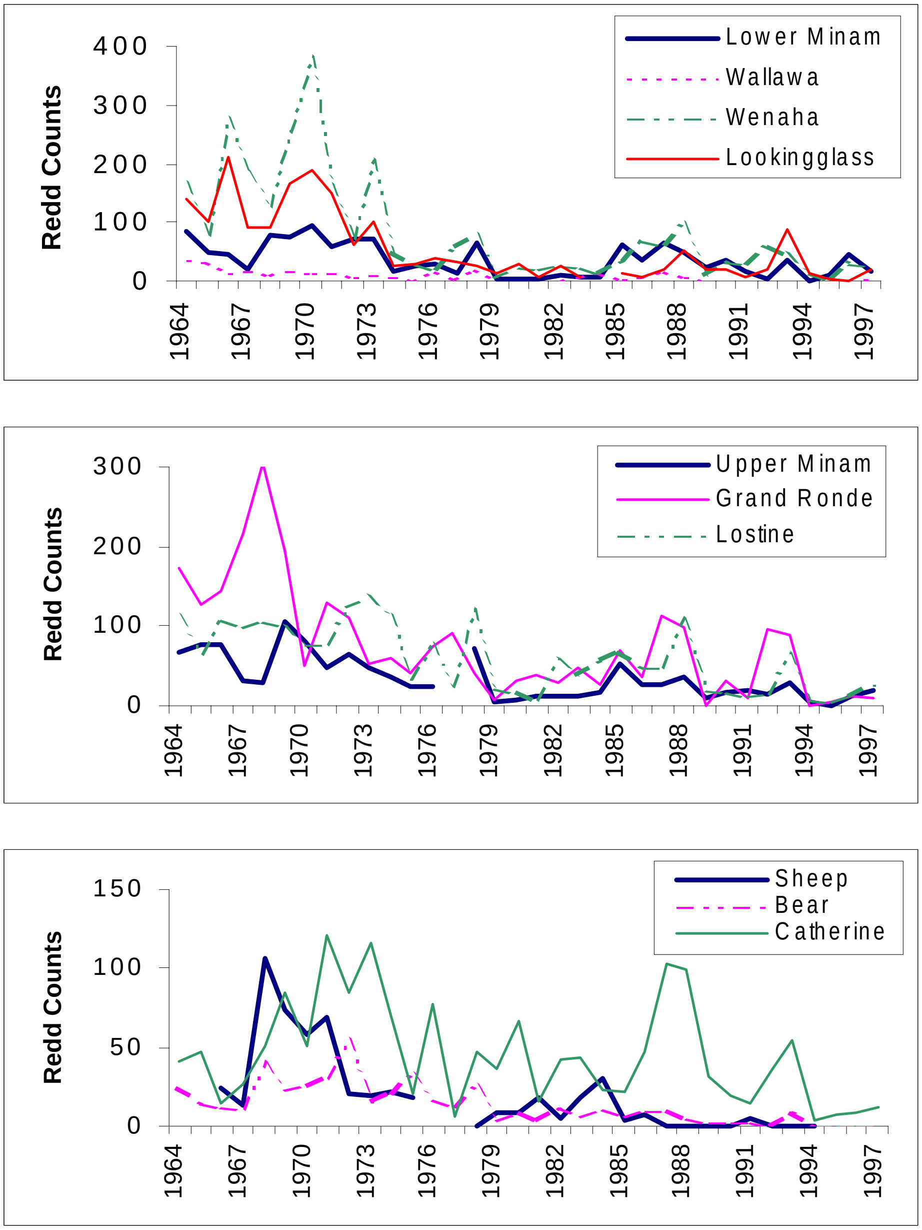

Figure 3.9. Spring chinook salmon redd (nest) counts in index areas of the Grande Ronde River and its tributaries demonstrating synchronous annual decline of spawners among sites. Data from StreamNet (www.StreamNet.org).

Synchrony may be more likely if migration timing of diverse populations is seasonally restricted. Moreover, during the last century, extinction rates have been elevated by human development of the basin, and local population and metapopulation sizes and dispersal rates have been reduced, possibly making salmon more susceptible to the effects of correlated natural environmental changes (Harrison and Quinn 1989).

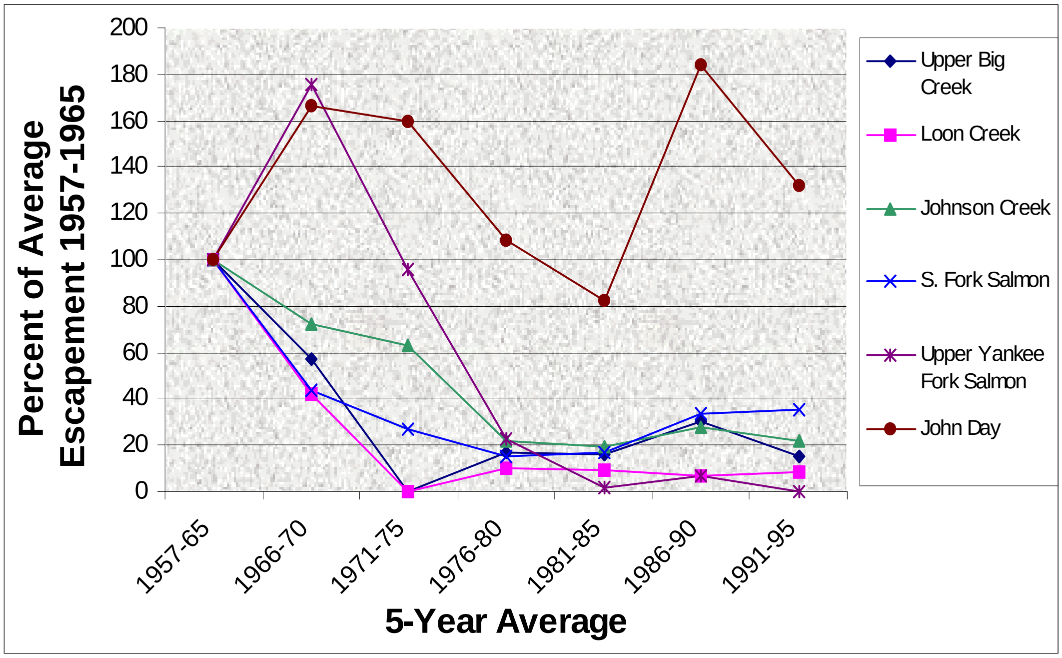

Figure 3.10. Escapement of spring and summer chinook salmon into index streams of the Salmon river basin and escapement of wild spring chinook salmon into the John Day River. Upper Big Creek (wild spring chinook, wilderness watershed); Loon Creek (wild summer chinook, wilderness watershed); Johnson Creek (natural summer chinook, managed watershed); South Fork Salmon River (hatchery-influenced summer chinook, managed watershed); Upper Yankee Fork Salmon River (hatchery-influenced spring chinook, managed watershed). Figure from Nemeth and Kiefer (1999).

Human impacts may have shifted metapopulation structure from core-satellite or some other structure to non-equilibrium metapopulations. In non-equilibrium metapopulations, extinction rates are consistently greater than recolonization rates and the metapopulations are undergoing regional decline (Harrison 1991). Many stabilizing core populations have been driven extinct, recolonization and re-establishment of extinct local populations is limited or does not occur, and only isolated satellite populations remain. Isolated populations have little chance of being refounded after a local extinction compared to a population that is close to other populations. As populations become isolated, local extinctions become permanent and the entire metapopulation moves incrementally toward extinction (Rieman and McIntyre 1993).

Other Ecosystem-Level Restoration Projects

The scale of the Columbia River basin salmon recovery and ecosystem restoration efforts are immense and represent one of the largest of such efforts in the world. Nevertheless, while the scale of the region's efforts and the annual expense are considerable, other large-scale and high cost ecological restoration programs are being implemented or contemplated elsewhere in the world. While some of these programs focus on salmon recovery, such as Atlantic salmon recovery efforts in New England and Europe, others are focused on large ecosystems (e.g., the Florida Everglades). What the programs share, regardless of their focal point, is instructive to our efforts here in the Columbia Basin. All of the programs have habitat and water quality as their primary implementation focus. This is followed in the salmon recovery programs, as needed, by concerns about passage and reintroductions.

The Fraser River, British Columbia,Canada

The current program to restore Columbia River salmon can trace its roots back to 1948 and the program developed by fishery agencies to mitigate for impacts on salmon created by federal hydroelectric development in the basin (Laythe 1948). A decade earlier another major restoration program on an important salmon producing river in the northwest was also initiated. On August 4, 1937 the United States and Canada ratified a convention for the protection, preservation and extension of the sockeye salmon fishery of the Fraser River system. The convention which created the International Pacific Salmon Commission (IPSFC) was the culmination of 45 years of negotiation and meetings between the United States and Canada (Roos 1991).

Fishermen from the United States and Canada harvested sockeye salmon returning to the Fraser River (Figure 3.11) so there was a need for an international convention to coordinate and rationalize the fishery and prevent over exploitation. In addition, the sockeye salmon runs to the Fraser River were rapidly depleted after 1913 by a dramatic change in their migratory habitat at Hell's Gate, a narrow gorge in the Fraser Canyon 130 miles from the sea. The velocity of flow through the narrow canyon at Hell's Gate was known to delay sockeye migration under natural conditions. However, in 1911 and 1912, during the construction of a railroad grade, a large landslide created very turbulent conditions which completely cut off salmon migration at certain flows. In 1913, fishermen took a record harvest of 32 million sockeye salmon bound for the Fraser River. Those fish that escaped the fishery massed below Hell's Gate unable to ascend the river to their natural spawning areas and most died without spawning. The average annual run of sockeye salmon to the Fraser River between 1894 and 1916 was 11.4 million fish compared to an average run of 3.31 million fish from 1917 to 1949 (Roos 1991). The last year of returns to the river from spawning prior to the Hell's Gate construction occurred in 1916. The last return to be unaffected by actions of the IPSFC was in 1949.

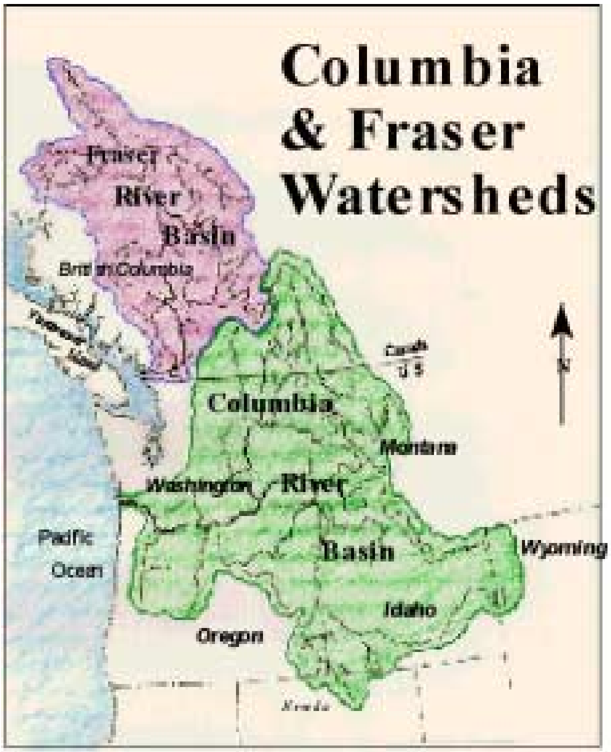

Figure 3.11. Map of the Columbia and Fraser River basins.

The IPSFC's initial program had four key elements:

1) *Correct the problem at Hell's gate*. The blockage at Hell's gate was an obvious bottleneck that had to be corrected. The problem at Hell's Gate was corrected by construction of fish ladders, as well as judicious use of explosives.
2) *Protect the watershed*. One of the early policy statements of the IPSFC put the Canadian Government on notice of its intent to protect salmon habitat in the watershed. Subsequent policy decisions were made that protected the watershed form development of mainstem dams.
3) *Protect the different sockeye stocks.* Each had specific spawning and rearing areas, run timing and environmental requirements. Stocks were protected by a vigorous research program that identified the sources (lakes of origin) of individual stocks that could be identified by their time of return to the mouth of the Fraser and environs. Population estimates and escapement goals were established for each stock or appropriate groups of stocks. This was coupled with close regulation of harvest targeted on each stock separately.
4) *Hatcheries were given a low priority* (Roos 1991). Early work on hatchery success for sockeye salmon in British Columbia (Foerster 1931; Foerster 1936) showed little success. This reinforced the decision to focus on wild stocks, natural production, and watershed health

as the keystones for salmon management in the Fraser River, rather than relying on artificial production to offset natural production losses due to habitat degradation or hydrosystem development.

The question of artificial propagation came up again in 1960, in response to proposals to build major hydroelectric and flood control dams in the Fraser River, many of them downstream from juvenile rearing areas in the basin. The IPSFC reviewed the prospects of mitigation through hatchery propagation of sockeye salmon and concluded that hatcheries were not a safe and proven method of maintaining even small localized stocks of Fraser River sockeye and pink salmon (Andrew and Geen 1960).

The IPSFC's program was successful. From 1950 to 1978 the total annual run averaged 5.55 million fish compared to 3.31 million fish form 1918 to 1946 (after Hell's Gate but before IPSFC actions took effect). Recent run sizes have been 12 million fish in 1991, 13 million in 1985, 15 million in 1986, and 22 million in 1990 (Pacific Salmon Commission 1991; Roos 1991; Pacific Salmon Commission 1994). The total budget for the 48 year life of the IPSFC was 42.7 million dollars including about 4.5 million for construction. The IPSFC ceased to exist in December 1985. It was replaced by the Pacific Salmon Commission (Roos 1991).

The Chesepeake Bay Striped Bass

Atlantic striped bass *Morone saxatilis* have been important component in the fisheries off the East Coast since colonial times (Richards and Rago 1999). Commercial landings reached an all time high in 1973 of nearly 7000 metric tons, then declined abruptly by almost 90% over the next decade due in part to problems in juvenile recruitment. Overfishing appears to have been the major factor in the decline as it negatively affected recruitment. Secondarily, episodic water quality problems also appeared to affect juveniles in early life stages.

Restoration strategies for striped bass focused first on reducing harvest mortalities, and second on water quality/habitat issues. Some stocking of hatchery-reared striped bass also occurred, although their role in the subsequent recovery has been questioned. Stringent management actions were implemented in 1985 including severely limited harvest on females. Abundance of females on spawning grounds doubled between 1985 and 1989 and recruitment began to improve in 1989. Recreational catches improved coastwide more than 40% between 1985 and 1989. Regulations were relaxed in 1990 and an adaptive management plan was implemented allowing limited harvest during the recovery phase. In 1995, ten years after the stringent management controls were implemented, the stock was declared fully recovered.

The Everglades, Southern Florida

The entire southern portion of Florida is ecologically interrelated, linked by water, weather, and rainfall. Early conservation efforts focused on the southernmost region, now lying within the boundaries of the Everglades National Park, without understanding the linkages between that area and Lake Okeechobee and the Big Cypress Swamp to the north. Draining and dredging in the northern areas severely impacted historic water flow patterns throughout the ecosystem and continues to threaten the integrity and stability of the southern Florida "River of Grass" ecosystem.

The initial steps in the conservation of this ecosystem came in 1947, when the Everglades National Park was opened. As awareness increased about the size of the southern Florida ecosystem and the small fraction of it that was protected by the Everglades National Park, other ecologically important areas were also given protection. Big Cypress National Preserve was created in 1974 to protect the Big Cypress watershed. Similarly southern Biscayne Bay was protected as a national monument in 1968, a designation that changed to a national park in 1980. Curent major threats to the southern Florida ecosystem come from decreased water supply, interrupted hydrology, nutrient pollution (nitrate contamination from agriculture), exotic plants and mercury contamination.

Ecosystem-level restoration activities started in 1983 and by the late 1980s, had spawned the Kissimmee River Restoration Project, encompassing the Kissimmee River, Lake Okeechobee, the Everglades, Big Cypress swamp, and the estuaries of Florida Bay, Biscayne Bay, and the Ten Thousand Islands. Restoration efforts focus on reestablishing natural water flow patterns (while still sustaining Southern Florida communities and the economy), reducing nutrient input from agricultural practices and controlling exotic plants.

Europe's Rhine River and Atlantic Salmon

Another ecosystem-level restoration effort is currently underway in central Europe on the Rhine River. The Rhine is Europe's most important inland waterway, a navigable system that runs north 820 miles from Basel, Switzerland to the North Sea. More than half its length and 80% of its ship-carrying waters flow through or along the borders of Germany.

A century ago, commercial fishermen netted more than 250,000 Atlantic salmon annually from the Rhine; however, by the late 1950s, Atlantic salmon had disappeared from the Rhine. By the 1970s, 40% of the native fish species in the Rhine were extirpated as compared to 1880, when approximately 50 species were present (Drozdiak 1996; Chichester 1997). At this same time, the river's highly polluted state gained international attention. Germany, France, Luxembourg, Switzerland, and the Netherlands enacted and enforce major water quality reforms through the ICPR (International Commission for Protection of the Rhine). The Atlantic salmon, because of its need for high quality water and habitat, was chosen as the focal species for ecosystem restoration efforts.

Restoration efforts through the 1980s and early 1990s have focused on the Sieg River, a minor tributary in Germany that is estimated to contain nearly a third of the Rhine's remaining potential salmon spawning areas once obstructions such as dams are removed. Results include improvements in water quality in the Sieg and the removal or alteration of several dams and obstacles providing an additional 50 miles of spawning habitat. Juvenile Atlantic salmon have been stocked into the Sieg since 1988 and in 1990, the first adult return was documented. By 1997, more than 50 adult salmon had returned to the Sieg. Restoration goals for the Rhine system are 10,000 to 20,000 adult salmon, about 2-4% of historic abundance (Chichester 1997). Lessons learned from the Rhine are being applied to other historic Atlantic salmon rivers in Europe, including the Elbe (between Germany and the Czech Republic) and the Oder River (between Germany and Poland).

Summary

Habitat conditions for salmonids vary greatly among watersheds within the Columbia River basin as a consequence of geographic variation in physiographic factors such as climate and geology. Even within a watershed, conditions vary from headwater areas to the lower mainstem reaches. As salmonids complete their life cycles, they encounter a wide array of habitat conditions to which they must adapt to successfully survive and reproduce. Biodiversity in salmonid species is manifested as phenotypic, life history, stock, and genetic diversity and, at least in part, it represents adaptation to variation in habitat conditions both in space (i.e., from location to location) and in time. A fundamental premise of the conceptual foundation presented in this chapter is that biodiversity is sustained by complex, high quality habitats with conditions suitable for completion of diverse life cycles.

In general, human actions, including hydroelectric development and habitat degradation, can constrain or reduce the expression of habitat diversity within and among watersheds which, in turn, can constrain the expression of salmonid biodiversity, disrupt the integrity of metapopulations, and lower regional salmonid productivity and stability. Other human perturbations such as excessive harvest and introduction of non-native species, can act in concert with habitat loss to reduce salmonid biodiversity. As a consequence of human development of the basin, major spawning populations in the mainstem Columbia and Snake and the lower mainstems of major subbasins have been eliminated and, with the exception of the Hanford Reach fall chinook, salmonid production in the basin largely has become confined to hatcheries and to headwater areas where high quality habitat remains.

In this context, restoration of salmonids involves removing or reducing influences constraining the expression of biodiversity across the landscape. A critical aspect of biodiversity restoration is restoration of the diversity and connectivity of habitats necessary for successful completion of an array of life histories. Full re-expression of diversity may not be possible, either because society may not be willing or able to sufficiently reduce some constraints due to economic and other social reasons, or because some other human activities (e.g., greenhouse effects; regulation of the flow of entire river systems by hydropower operations, non-native species, deforestation) may have fundamentally altered the ability or capacity of the ecosystem to re-express diversity.

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