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Federal Land Management, Freshwater Habitat, and Anadromous Fishes in the Interior Columbia River Basin

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Historical changes in the interior Columbia River Basin have influenced aquatic conditions and contributed to declines in fish populations and ecological integrity in ways that are readily apparent in the distributions and status of naturally reproducing anadromous salmonids (NPPC 1986, Nehlsen and others 1991, Lee and others 1996). The familiar list of contributing issues includes hydroelectric development, flood control, irrigated agriculture, hatcheries, ocean and in-river harvest, and degradation of freshwater spawning and juvenile rearing habitats. Issues that affect salmon in the Columbia basin often are grouped under four principal factors: Habitat, Hatcheries, Hydropower, and Harvest. While not all issues and problems facing anadromous fish fall nicely within these factors, this is a convenient taxonomy that we adopt for the current discussion. For clarity though, we separate habitat into two components: freshwater habitat where spawning and early rearing of juveniles occur, and estuarine and marine habitat that governs growth and survival beyond the Columbia River mouth.

While the relative contribution of each of these factors to historical declines and to currently depressed levels of production has been much discussed (e.g., NPPC 1986, Raymond 1988, Chapman and others 1991, Lichatowich and Mobrand 1995, Lee and others 1996, Lichatowich and others 1996), no one has been able to unequivocally assign proportionate responsibility to any single factor. This failure to allocate responsibility is not for lack of trying; rather it is an unavoidable consequence of the inherent interdependencies among factors and the complex life history displayed by these fish. As we discuss below, this problem is especially difficult to quantify in the case of freshwater habitat.

Even though we cannot quantify the contribution of each factor precisely, it is useful to discuss each factor qualitatively and to demonstrate their relative contribution with the use of models. To begin the qualitative discussion, some type of mental model or analogy of the relationship of the four factors is needed. One such model is the idea of limiting factors. Under this model, a single factor can limit the overall productivity of the system; until the limiting factor is mitigated, improvements in other areas will have no effect on overall system performance. In this regard, the limiting factor model is analogous to a circular bucket brigade in which the amount of water that can be cycled through the brigade at a single time is no larger than the smallest bucket (Figure 1.A).

Figure 1.A

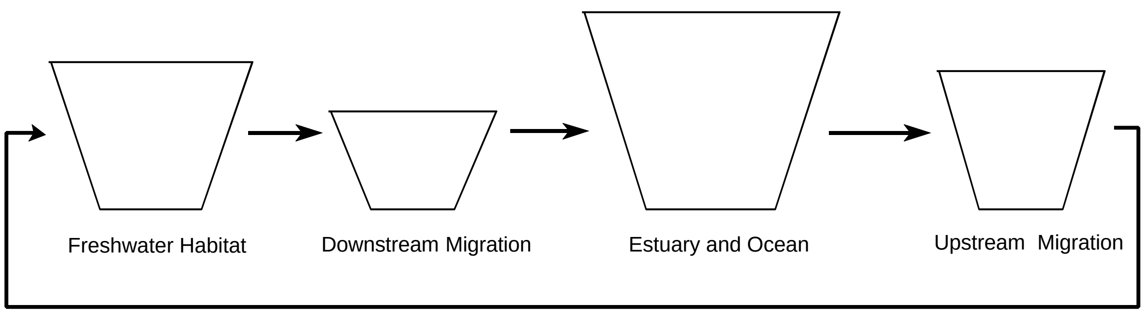

Figure 1.A. A conceptual view of salmon life history as a bucket brigade of limiting factors. The numbers of salmon that can circulate through the system is limited by the size of the smallest bucket.

Those who have critically evaluated the limiting factor model as a model for Pacific salmon have generally rejected it. The model is inadequate because it overly emphasizes capacity and ignores the multiplicative effect that increases in productivity in any phase of the life cycle can have on overall stock performance (Mobrand and others 1996). It also tends to derail efforts to simultaneously address all components of the life cycle, by focusing on a single issue.

Rather than view the salmon life cycle as a bucket brigade, a more accurate analogy would be an unusual system comprised of a pump and a circular system of large-diameter, but leaky piping (Figure 1.B). The pump (freshwater habitat) requires a small, but steady stream of incoming water (adults) to prime the pump. Adults provide both eggs to produce the next generation, and nutrients to encourage their growth. The habitat pump produces a larger stream of outgoing water (smolts). As the water courses through the pipes, much of it is lost (mortality) due to inefficiencies or leaks in the system (e.g., hydropower losses) and some is purposefully removed for other uses (harvest). Rarely does the diameter of the pipes limit the flow rate. In this analogy, flow rate can be increased by increasing the efficiency (reducing the leakage) at any point in the cycle. For example, either reducing the losses from the hydrosystem or increasing the number of smolts produced per adult in the freshwater habitat stage will increase population numbers cycling through the system. Hatcheries reflect an engineered solution to increasing productivity per adult by shielding young fish from natural sources of mortality. Problems arise when the hatchery-reared fish are of substandard quality or of ill-adapted genetic composition relative to the naturally produced fish. Since so many factors influence survival, including the size and condition of fish, improvements in one portion of the life cycle may lead to unexpected efficiency gains in later life stages

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Figure 1.B

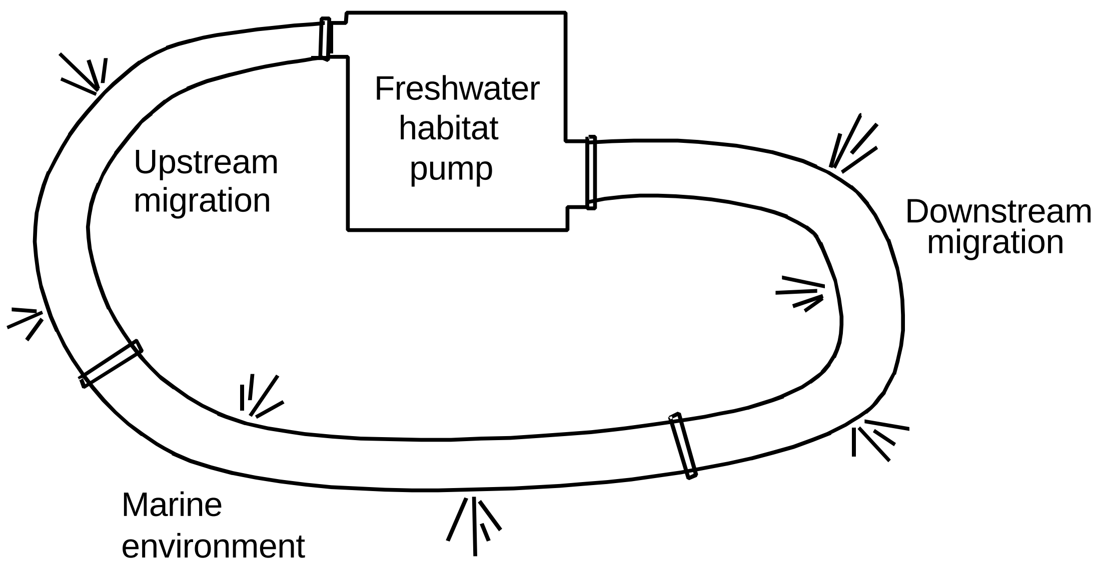

Figure 1.B. A conceptual view of the salmon life cycle as a pump and circular system of leaky pipes. Freshwater habitat (the pump) requires an inflow of adults from which it produces a flow of smolts into the river, on to the ocean, and return. Leakage in the system is analogous to mortality.

One sees practically all combinations of pumps and pipes in the interior Columbia Basin, so it is very hard (and misleading) to generalize. Each major population must be evaluated on its own merits by looking at the relative strength of the population, the number of dams that must be negotiated, local watershed conditions, and historical indicators of potential population performance. In some Salmon River drainages, for example, there are very strong pumps with very leaky pipes. These stocks could benefit most from improvements in migration survival to stop the leaks. Conversely, habitat degradation could reduce pumping efficiency, leading to system failure. Lower in the Columbia system (e.g., the Deschutes River subbasin), the pipes are not so leaky but the pump is not as strong as it once was. Only in systems such as the John Day River subbasin and some portions of the mid-Columbia River (for ocean-type chinook) does one find the fortuitous combination of productive habitat and seemingly surmountable passage conditions.

With this conceptual model of the relationship among the four factors, we now look more closely at the specific influence of freshwater habitat.

Forest Service and BLM Contribution

Freshwater habitat is the one factor most prominently influenced by the Forest Service and Bureau of Land Management (BLM), which administer much of the remaining habitat used for spawning and juvenile rearing by anadromous fishes. How much responsibility the Forest Service and BLM have for contributing to the decline of anadromous fishes, and how far the agencies should go to correct perceived problems is an open debate that reaches beyond the arena of science. On one end of the spectrum are those who admit to no relationship among activities on federal lands, habitat degradation, and declines in anadromous fishes. To admit culpability is to implicitly acknowledge some responsibility for restoring population abundance. Since active restoration might constrain the activities of those with extractive interests in the National Forests and BLM-administered lands, there may be an economic motivation for some to disavow a connection between land management and anadromous fish declines. On the other end of the spectrum are those with a different agenda, who maintain that the Forest Service and BLM are responsible for deplorable habitat conditions that have single-handedly driven anadromous salmonids to the brink of extinction.

Both extremes of opinion are straightforward to debunk. Relative to the no-habitat-effect hypothesis, there are numerous published studies describing the effects of land-use activities on habitat conditions, and linking habitat conditions to survival and productivity of anadromous fishes. Nehlsen and others (1991) identify habitat loss as a major problem for 195 of 214 (91%)

anadromous salmonid populations in California and the Pacific Northwest. Meehan (1991) and Murphy (1995) provide excellent comprehensive overviews of the linkages between land management, habitat, and fish. The differences in fish survival between pristine and degraded habitats can be dramatic. Scully and others (1990) show that egg-to-parr survival for chinook salmon in degraded streams with high sand content is less than one eighth that exhibited in low-sand areas.

An equally large literature documents anthropogenic effects in other life stages, which argues against freshwater habitat degradation as the sole reason for decline. A collection of papers in Schwiebert (1977), for example, documents a litany of problems in the Columbia River Basin that still apply 20 years after publication. Hydroelectric development is generally regarded as a principal factor in the decline of anadromous populations, irrespective of changes in freshwater habitat (NPPC 1986, Raymond 1988). Explicit recognition of the role of hydroelectric development contributed to passage of the Northwest Power Planning and Conservation Act of 1980, and to development of the Northwest Power Planning Council's Fish and Wildlife Program, a regional effort to simultaneously address the four principal factors affecting anadromous fish (among other issues).

The information provided by the broad-scale assessment of aquatic habitats and species within the interior Columbia Basin by Lee and others (1996) lends further support to a scientifically credible view that is emphasized repeatedly in the literature: habitat change is pervasive and at times dramatic, but impacts are not evenly distributed across the landscape. High-quality areas remain that are capable of supporting anadromous fishes at near-historical levels. Furthermore, restoration of depressed populations cannot rely on habitat improvement alone, but requires a concerted effort to address causes of mortality in all life stages. These include freshwater spawning, rearing, juvenile migration, ocean survival, and adult migration.

The question is not whether Federal land management has an effect on anadromous salmonids; it does, though not to the extent that some suggest. Rather, the central issue is how important is spawning and rearing habitat, and will efforts to improve and/or protect this habitat aid in the recovery of depressed populations--given the litany of other factors affecting these fishes.

Heuristic Examples

One way to examine the importance of freshwater habitat in the absence of empirical studies, is through the use of models which mimic the population dynamics of salmonids. Using this approach, previous authors have noted that declines in habitat productivity can have a disproportionate effect on population persistence and total population size. Thurow and Burns (1992), for example, demonstrate how a 20 percent loss in habitat productivity results in more than a 50 percent reduction in adult numbers, while a 50 percent reduction in habitat productivity causes extinction. Lawson (1993) uses a conceptual model of declining freshwater habitat quality and cyclic ocean conditions to show that freshwater habitat is most critical during periods of depressed ocean survival, and shows how improving ocean conditions can mask declines in habitat quality. In the following example, we used the stochastic life-cycle model of Lee and Hyman (1992) to compare the effects of simultaneously altering freshwater habitat quantity and quality, and downstream passage survival.

The Stochastic Life-cycle Model (SLCM) was developed by Lee and Hyman (1992) in order to simulate the life cycle of anadromous salmonids. It is designed to mimic the basic mechanisms regulating populations of Pacific salmon, while capturing some of the intra-annual and inter-annual variation inherent in these populations. The SLCM was designed for population viability assessments and has been used in recent years by the National Marine Fisheries Service and the Bonneville Power Administration.

Using the SLCM, we illustrate the relative effects of simultaneously varying incubation success, parr carrying capacity, and downstream passage survival on a hypothetical population of chinook salmon. Incubation success refers to the proportion of eggs produced that are successfully deposited in the redd and survive to emergence from the gravel. It can be viewed as an indicator of habitat conditions in terms of both spawning and incubation conditions (Bjornn and Reiser 1991). Parr capacity refers to the maximum number of parr or juvenile fish that an area can support. It reflects both habitat quality and quantity, but we use it here heuristically to measure habitat quantity only, assuming quality remains constant. Downstream passage survival refers to the proportion of the smolts that leave natal streams or rearing areas and survive migration to the estuary. Again, passage survival may reflect many things, but we use it here to index the effects of changes in the hydroelectric system.

We examined eleven levels of incubation success (15% to 65% in 5% increments) in combination with three levels each of parr capacity (50, 100, and 150 thousand) and downstream passage survival (35%, 45%, and 55%). All other parameters, such as fecundity, ocean survival, maturity rates, etc., were held constant at reasonable values for an upriver Columbia Basin stream-type chinook population. Since SLCM is a stochastic model that produces a unique result for each realization or trial, we simulated 500 trials for each parameter combination (49,500 trials total). Each trial started with an initial population of 250 female spawners and ran for 100 simulated brood years, or until the population declined to zero (simulated extinction). Results were summarized by plotting the proportion of the trials where the simulated population did not reach zero within the 100 year period (probability of persistence, Figure 2) and the average number of female spawners (mean run size, Figure 3) for each parameter combination.

The plots in figures 2 and 3 are instructive. Comparing figures 2A, 2B, and 2C, one sees that the probability of persistence responds to changes in incubation success and passage survival in a manner that is consistent across different levels of parr carrying capacity. As passage survival decreases, the level of incubation success required to ensure population persistence increases. Increasing parr capacity has no apparent effect on the relationship. Furthermore, the drop from certain persistence to certain extinction is fairly abrupt. Halving the incubation success (say from 50% to 25%) is sufficient to cause certain extinction of an apparently robust population, regardless of the passage survival or parr carrying capacity (remember the eight-fold difference observed by Scully and others [1990]). In practical terms, this suggest that increasing the amount of available habitat (parr capacity), without any increase in quality (incubation success), would have no discernable effect on the chances of the population persisting through time. Alternatively, more habitat of lower quality is less advantageous in terms of population persistence than less habitat of higher quality.

As evident in figure 3, all three factors can affect population numbers through time. Habitat quantity can have a measurable effect on mean run size, but only beyond a certain threshold combination of passage survival and incubation success. In this example, the response curves for the different parr capacities begin to diverge beyond the point where the product of passage survival and incubation success exceeds 16% (e.g., 35% passage survival and 45% incubation success, or vice versa). The asymptotic nature of carrying capacity limiting population numbers is observed only in the highest combinations of passage survival and incubation success (figure 2C).

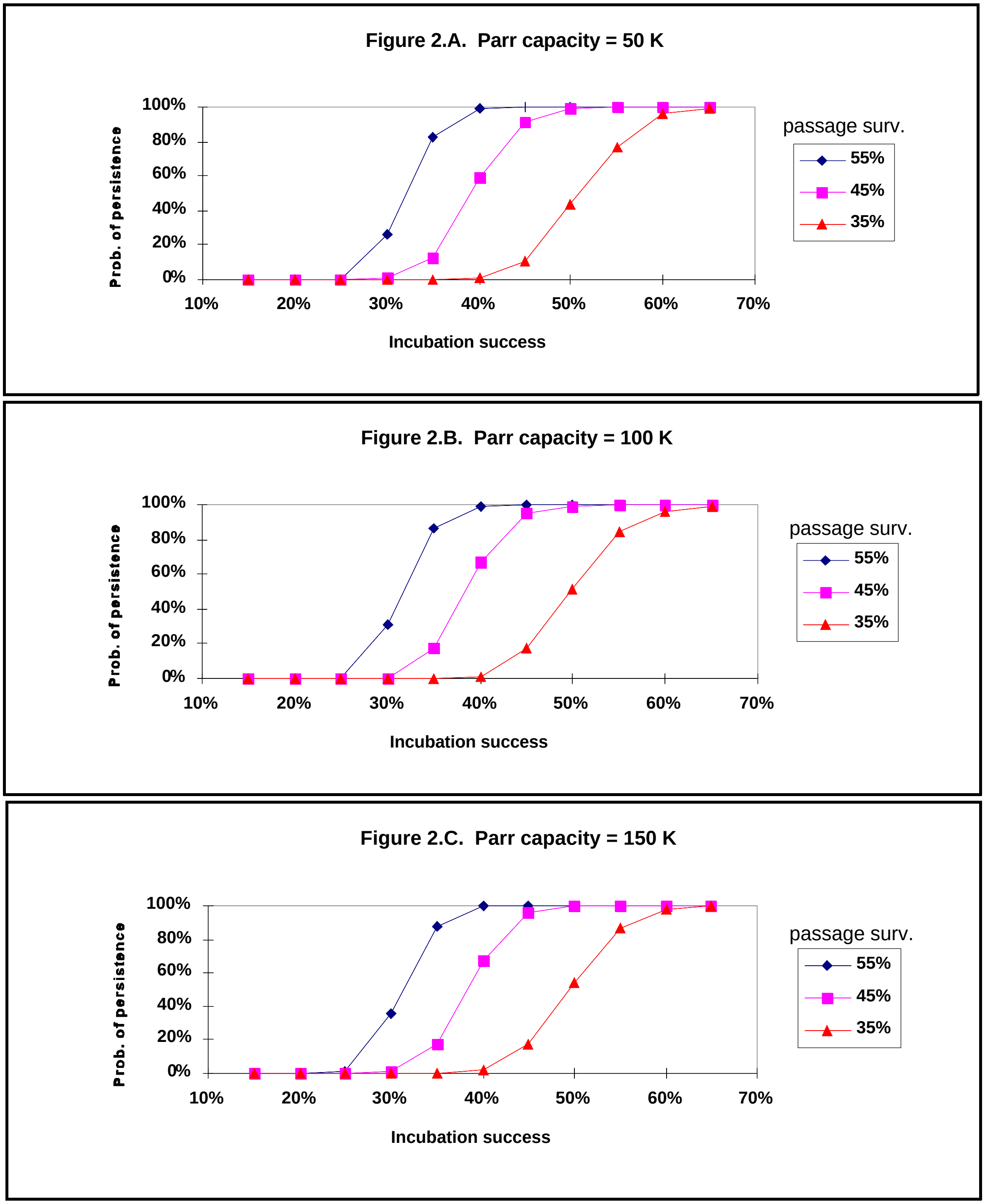

Figure 2. Probability of persistence versus incubation survival for three levels of downstream passage survival (55%, 45%, 35%) and 3 levels of parr capacity (50, 100, and 150 thousand).

Figure 3.A. Passage survival = 35%

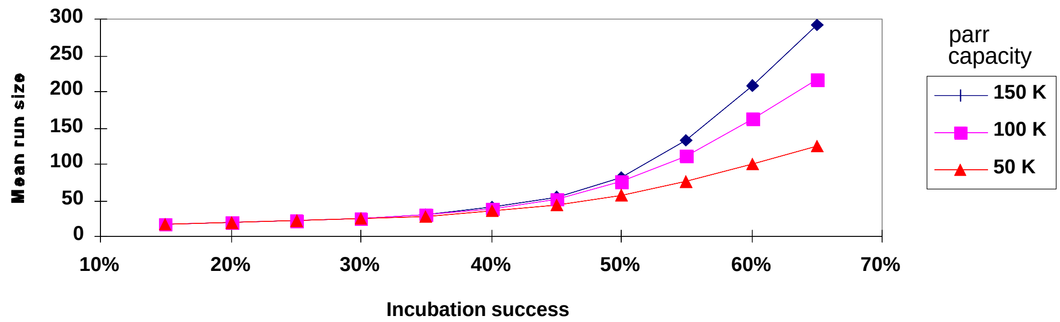

Figure 3.B. Passage survival = 45%

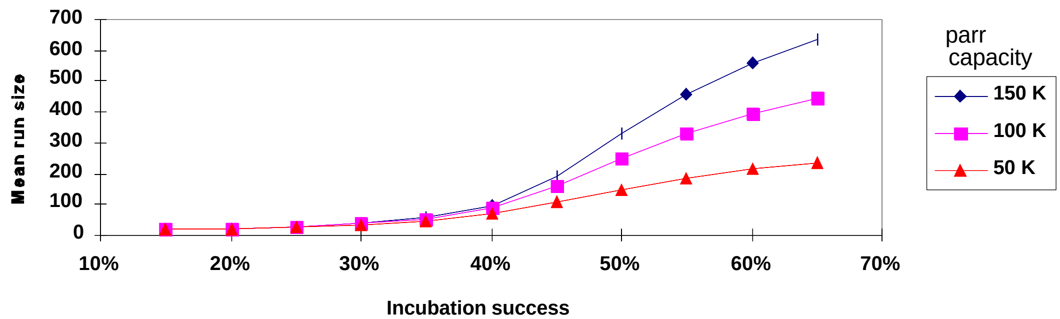

Figure 3.C. Passage survival = 55%

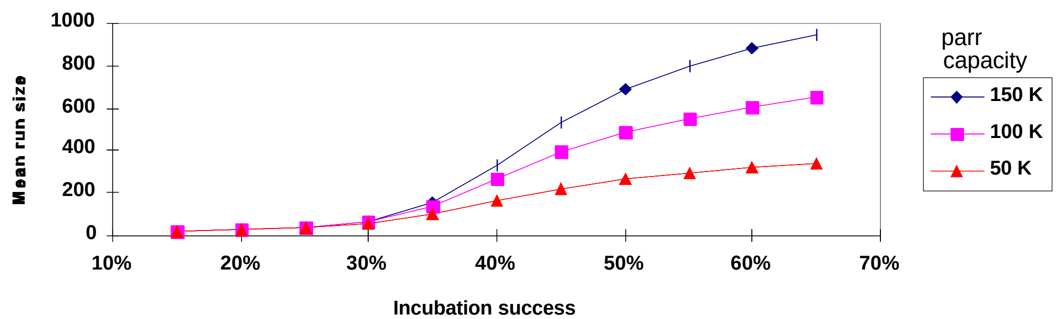

Figure 3. Mean run size versus incubation success for 3 levels of parr carrying capacity and 3 levels of

downstream passage survival. Note that run size is scaled differently in each plot.

Problems with measuring effects

While modeling excersizes can suggest the importance of freshwater habitat, they do not measure the effects of habitat alteration directly. Estimates based on empirical data are the best means of quantifying specific effects. Unfortunately, the extent of the loss to anadromous fishes in the interior Columbia River Basin that is due to degradation of spawning and rearing habitats cannot be empirically measured with reasonable certainty. Similarly, although positive responses to habitat restoration are expected, no precise estimate of the expected benefit is possible. The data are neither in hand to answer these questions, nor are they expected.

In part, one cannot measure effects of habitat changes because myriad changes in the system have occurred simultaneously and the pre-treatment data to do a before-and-after comparison do not exist. For example, many of the factors that contribute to habitat degradation (e.g., timber harvest, mining, irrigation diversions) have been in play for a century or more. In contrast, reliable estimates of fish production are available for only the past few decades. This disconnect makes it impossible to test for changes in production that are due to historical changes in freshwater habitat. In their analysis of changes in freshwater spawning and rearing survival (FSR) since completion of the Federal Columbia River Power System (FCRPS), Petrosky and Schaller (in review) note, "A long time series, dating to before completion of the FCRPS, would be desirable to rigorously evaluate hypotheses about decreased FSR survival." Clearly, the post-1960 data used by Petrosky and Schaller do not meet this standard.

The complexity of interactions across life stages further confounds even the best of studies. For example, the raging debate over the efficacy of transporting smolts downstream focuses not so much on the survival through the transportation process per se, but rather on the latent effect that transportation has on post-release survival and adult returns. Similar questions could be raised regarding early rearing. For example, do juvenile fishes from degraded habitats exhibit the same migration and early marine survival as those from better habitats? Research in British Columbia suggests not (Hartman and Scrivener 1990).

Another reason why the effects of spawning and rearing habitat changes are difficult to precisely measure concerns the compensatory nature of fish-habitat relations. This compensation is also a reason why high-quality habitat is so vital to maintaining and rebuilding populations. When the number of spawning adults declines as it has in recent years, the adults can choose areas offering the best conditions. Similarly, juveniles from newly hatched fry through parr can spend their time in the better habitats with reduced competition for resources. The net result is that the number of smolts produced per adult can actually increase as the number of spawners decline. As long as the amount and distribution of high-quality habitat available remains proportional to the number of spawners and in locations used by the fishes, the apparent productivity of the population will remain fairly constant. Thus, it may be impossible to detect a historical decline in habitat conditions over a period when numbers of spawning adults are declining as well, if one looks only at the number of smolts produced per adult. This is the situation in the Snake River subbasins above Lower Granite Dam. During and after construction of the federal dams in the lower Snake River (post 1970), numbers of returning adult chinook salmon declined dramatically compared to run sizes in the 1950s and 1960s (Petrosky and Schaller 1992). The declining numbers of adult salmon do not permit an adequate test of the hypothesis that habitat conditions changed during the same time period. Such a test would require a return to historical levels of spawning adults that predate the dams.

Discussion

The information presented above reinforces the argument that existing high-quality habits must be maintained in order to prevent extinction of Snake River anadromous fishes and other at-risk stocks, and to maintain population resiliency until other causes of mortality are reduced. To ensure recovery, the amount of high-quality habitats available must remain proportional to the number of returning adults and in appropriate areas, so that there is no net loss in productivity as adult numbers increase. Because of current population losses associated with dams and other factors, only the most productive populations may retain the resilience to persist in the face of natural and human caused disturbance.   Simply put, with current conditions in migrant survival, many stocks are at serious risk. The differences between those that persist and those that are extirpated will include chance events and the survival and productivity of the stocks as they are largely influenced by freshwater habitats. Without substantial improvement in migrant survival, securing (where available) and restoring (where needed) high-quality freshwater habitats may make the critical difference in persistence for many populations. In the longer term, assuming mainstem conditions are resolved, it will be necessary to conserve and restore broader habitat networks to support the full expression of life histories and species (Lichatowich and Mobrand 1995; National Research Council 1995). To fully realize the benefits of improved migration and ocean survival, there must be a commensurate increase in the distribution of high-quality spawning and early rearing habitats. Federal land management is crucial to this task.

The modeling examples also demonstrate the difficulty of trying to extrapolate conclusions about the relative influence of habitat (or any other principal factor) in one area of the basin to a separate area with a different management history and natural features. Each of the 99 points which compose figures 2 and 3 can be viewed as a different combinations of habitat quantity and quality and passage conditions. To say that a marginal improvement in habitat quality would have the same relative effect everywhere is obviously untrue. The nonlinear shape of the response functions in figures 2 and 3 suggest that in some places the effect might be dramatic, while in others there would be little visible impact. Thus, there can be no single answer for the entire interior Columbia Basin. As stated above, each population must be examined on its own merits. Such site-specific responses suggest that viability judgements on local populations are best performed using higher resolution data than are generally available.

Conclusions

We state our conclusions as answers to four basic questions that have been asked by Forest Service and BLM leadership.

1. *What are the relative contributions of habitat, hydropower, hatcheries, and harvest on the current state of populations within the interior Columbia Basin?*

This question cannot be answered precisely. Simultaneous changes in a variety of factors, combined with the lack of historical data, prevents estimation of the proportionate influence of each factor. The relative contribution of each factor also varies across the entire basin. We expect the contribution of freshwater habitat changes to be least in the less-disturbed areas of central Idaho and in the northern Cascades, but greater in the lower Snkae and mid-Columbia drainages. Similarly, the contribution of hydropower declines downriver where there are fewer dams between the freshwater spawning and rearing areas and the ocean. Hatcheries are an important element throughout the basin, but their effects on native stocks is quite variable. Harvest, which has been much curtailed in recent years, has less of an effect today than it did historically. In some subbasins such as the Umatilla, irrigation withdrawals may be the major contributor to declines in naturally reproducing populations.

2. *If all other factors were held constant, would a further degradation of habitat increase the risks of extirpation or extinction?*

Yes. Regardless of the contribution of other factors, spawning and juvenile rearing habitat remains an important component in the viability equation. As demonstrated above, freshwater habitat can be most important in ensuring viability of stocks that are depressed through a combination of other factors.

3. If all other factors were held constant, would an improvement in freshwater habitat conditions increase fish abundance and reduce the risks of extirpation or extinction?

Yes, though the magnitude of the effect would vary greatly from subbasin to subbasin. In areas where present habitat is degraded and hydropower effects are smaller, such as the Deschutes River, habitat improvements could result in immediate increases in numbers of fish. In areas where habiat is degraded and hydropower effects are large, such as in the Grande Ronde River and some tributaries of the Salmon River, increases in population numbers due to habitat restoration would be more modest and gradual. In other areas where there is abundant high-quality habitat but few adult spawners, such as the Middle Fork Salmon River, immediate increases in fish abundance would not be expected. One aspect of habitat improvement that could have long-term repercussions, if not immediate benefits, is that increased availability of high-quality habitats reduces the chances that a random, catastrophic event such as a large fire followed by flooding would wipe out all of the best available habitat. A wider distribution of high-quality habitats also improves the likelihood of increased genetic diversity--an additional benefit over the longer term.

4. *If nothing is done to restore habitat, and mitigation of major factors such as the dams is successful, would there be sufficient habitat available to accommodate increasing fish numbers?*

The answer varies across the basin. Population numbers in much of the interior Columbia Basin are far below what current habitat conditions could likely support under a scenario of increased downriver survival. Some remote areas potentially could support hundred-fold increases or better in the number of adult numbers. But this is not the case everywhere. There are more disturbed areas where increased adult numbers would lead to compensatory declines in freshwater survival rates, thus reducing the per capita productivity of the population and limiting the effectiveness of downstream improvement efforts. To fully realize the benefits of downstream improvements, commensurate increases in the availability and idstribution of high-quality habitat will be necessary.

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