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A Framework of Ecosystem Processes for Evaluating Effects of Dams on Endangered Species

Introduction

The motivation to develop the process-based framework described in this paper was the listing of several species of freshwater and anadromous fishes under the Endangered Species Act (ESA) in the Willamette Basin, western Oregon (Figure 1) during the 1990s by the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS). Unlike the Columbia River, the mainstem Willamette River is free of dams, nevertheless the construction and operation of large dams in the five major tributary subbasins (Figure 1) is one of the primary factors in the decline of the listed fish species (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2000, 2001). In the upper Willamette Basin, the

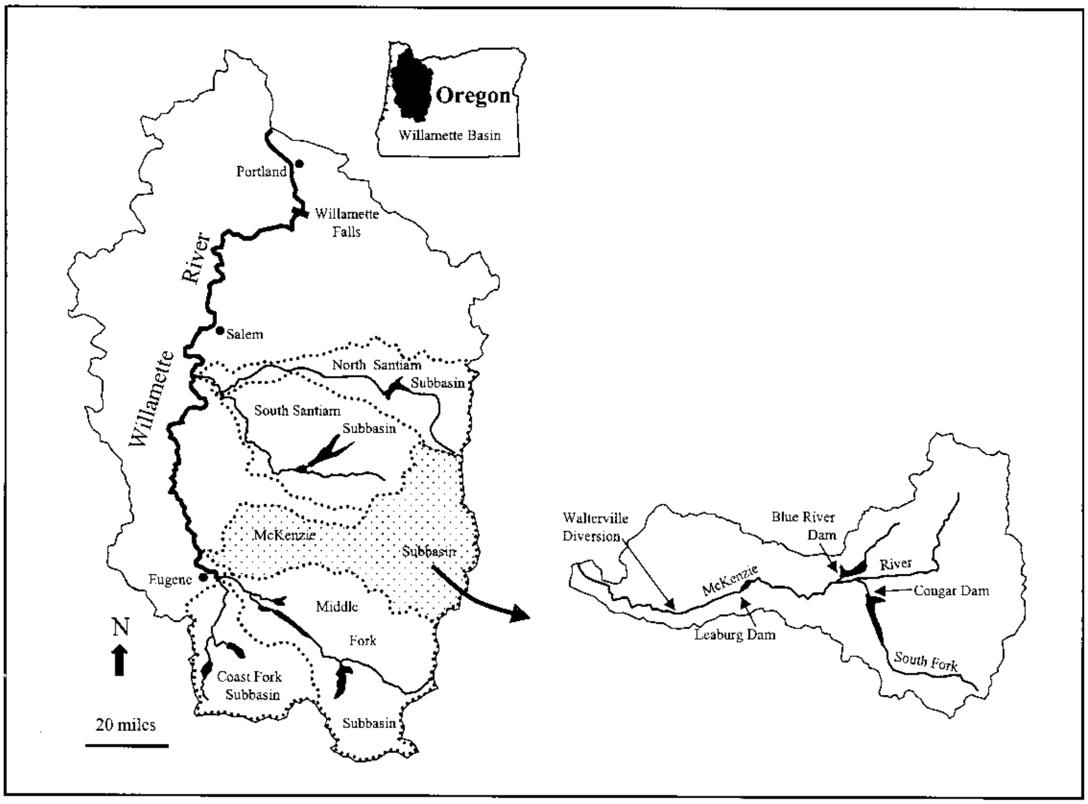

Figure 1. Map of the Willamette Basin and the four projects in the McKenzie subbasin.

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U.S. Army Corps of Engineers (USACE) owns and operates 13 large multipurpose dams, while the Federal Energy Regulatory Commission (FERC) regulates several other privately owned large dams and diversions that are operated for hydroelectricity.

Under the ESA, NMFS manages listed species that spend most or all of their life cycle in the marine environment (e.g. anadromous salmonids), while USFWS manages listed species that spend most or all of their life cycle in the freshwater or terrestrial environment. Thus both agencies are involved in implementing the ESA in the Willamette Basin. The ESA requires federal agencies such as USACE and FERC that own, operate, permit, or fund existing dams to provide biological assessments on how the dams affect ESA-listed species to either NMFS or USFWS, depending on the species. NMFS or USFWS reply with a biological opinion describing the likely effects of the dams on listed species, and possibly including guidance on modifications to the structure or operation of the dams to reduce impacts on the listed species (National Marine Fisheries Service and U.S. Fish and Wildlife Service 1998). This exchange of biological assessments and opinions is referred to as an ESA consultation.

A Framework of Ecosystem Processes

Biological assessments and opinions on dams are best conducted within an ecosystem context that recognizes the fundamental role of hydrology, geomorphology, and water quality (habitat processes) to create and maintain habitat for individual species within a fluvial ecosystem (Independent Science Group 1996). The typical purpose of biological assessments and opinions is to determine how the construction or continued operation of a dam will affect one or a suite of species. An ecosystem context is critical to provide the framework for these species-specific analyses because: (1) dams alter the habitat processes upon which aquatic ecosystems are based, thus dams can have complex ecosystem-wide effects that may be overlooked if individual species are the sole focus; (2) recognizing the underlying habitat processes that support all associated species reduces the likelihood of a multispecies biological assessment or opinion pitting the perceived needs of one species against another; and (3) fluvial species evolved in spatially and temporally diverse ecosystems, rather than under stable conditions that have often been considered optimal. Based on these principles, a framework of relevant habitat and biological processes (together referred to as ecosystem processes) for the stream channels, riparian areas, and floodplains above Willamette Falls (the upper Willamette fluvial ecosystem) was developed to organize and guide ESA consultations on the continued operation and maintenance of dams in this area.

The top panel of Figure 2 illustrates the framework of ecosystem processes (i.e., combination of habitat and biological processes) in general for aquatic species within the upper Willamette fluvial ecosystem. The interlocking ovals symbolize the connectivity of the habitat processes with one another, and of the organism-level biological processes with one another. For example, disturbance and flow regime are different aspects of hydrology, with disturbance representing extreme but infrequent high flows, and flow regime representing mean flow patterns throughout the year. The arrows symbolize how the different processes generally influence one another. While some biological processes exert influence over some habitat processes (e.g., decomposition of salmon carcasses affects water quality), habitat processes generally exert more influence over organism-level biological processes. Likewise, organism-level biological processes exert more influence over population-level biological processes than vice-versa, and so on (Spence et al. 1996). The bottom panel of Figure 2 illustrates some of the linkages between habitat processes and the biological processes for listed spring chinook salmon in the upper Willamette fluvial ecosystem. The collective effects of habitat processes on each of the organism-level biological processes influence the function of population-level and community-level biological processes.

Application of the Ecosystem Framework

The framework of ecosystem processes shown in the top panel of Figure 2 provides the organizational basis for biological assessments and opinions on the effects of dams that may be applied to a wide range of spatial scales, temporal scales, species, and types and numbers of dams. As described in the example below, the framework has been applied to ESA consultations jointly carried

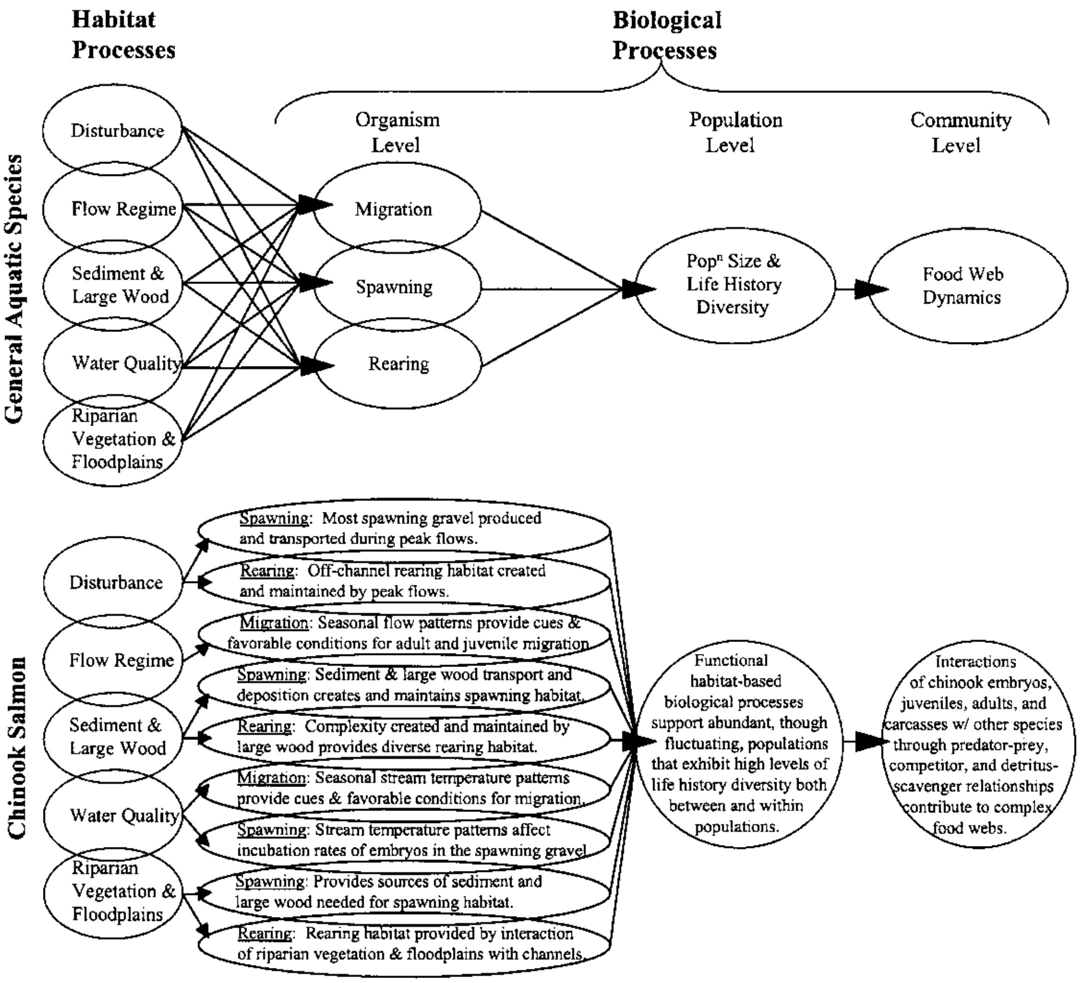

Figure 2. Framework of habitat and biological processes for aquatic species in general (top) and for chinook salmon (bottom).

out by NMFS and USFWS on the effects of dams in the McKenzie subbasin on the two listed fish species occurring there, spring chinook salmon and bull trout. The McKenzie subbasin contains two multipurpose dams owned and operated by USACE, located on the two largest tributaries of the Upper McKenzie River: Blue River Dam on Blue River and Cougar Dam on the South Fork McKenzie River (Figure 1). In addition, the Eugene Water and Electric Board (EWEB) owns and operates Leaburg Dam and Walterville Diverion on the lower mainstem of the McKenzie River, collectively called the Leaburg-Walterville Project, which is licensed by FERC. Leaburg Dam and the unscreened Walterville Diversion divert over half of summertime flows from the lower McKenzie River into the Leaburg-Walterville canal system. Collectively, these four projects have greatly altered fish habitat and fish passage in the McKenzie subbasin, contributing strongly to the decline of listed spring chinook salmon and bull trout (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2000, 2001).

NMFS and USFWS completed a draft joint biological opinion in late 2000 on the effects of the 13 USACE multipurpose dams in the upper Willamette, including Cougar and Blue River Dams, on listed species (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2000). NMFS and USFWS also completed a final joint biological opinion in September 2001 on the effects of the Leaburg-Walterville Project on spring chinook salmon and bull trout (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2001). Both joint biological opinions applied the framework of ecosystem processes to determine the likely effects of the four projects on the two species over the next 10-50 yr. This information was then used in the biological opinions as the basis for remedial measures for USACE and FERC/EWEB to implement, so that the projects would comply with the ESA.

An example is described below of how the ecosystem framework was applied in the two biological opinions to determine the effects of the projects on a listed species. For brevity, the example traces the effects of the four projects in the McKenzie subbasin on only two habitat processes (flow regime, and sediment and large wood) for one listed species, spring chinook salmon. After the appropriate spatial and temporal scales were set, the framework was implemented in the following three steps: (1) the likely effects of the projects on the two habitat processes were determined; (2) based on effects to the two habitat processes, the likely effects on each biological process for spring chinook salmon were determined; and (3) the direct effects on biological processes of spring chinook salmon unrelated to habitat processes were determined (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2000).

For Step 1, it was determined that the four projects likely will affect flow regime over the next several decades by collectively reducing peak flows during winter and spring throughout the lower McKenzie River, and increasing low flows during summer and fall in the river except for the 13 mile-long Leaburg-Walterville bypass reach where a substantial proportion of flow will be diverted. For sediment and large wood, it was determined that the two USACE dams likely will continue to trap in their reservoirs a large proportion of sediment and large wood produced by the upper McKenzie subbasin. In contrast, the Leaburg-Walterville project passes most medium to large sediment and nearly all large wood because Leaburg Dam is a run-of-river project and Walterville Diversion has no dam.

For Step 2, it was determined that the flow regime effects likely will impact the biological process of migration for spring chinook salmon by hindering downstream juvenile migration during late winter and early spring due to reduced flows. Upstream adult migration during early summer was not expected to be impacted by the flow regime effects because the increased flows by the USACE dams compensate for the reduced flows by the Leaburg-Walterville Project. The effects on sediment and large wood likely will impact the biological processes of spawning and rearing for spring chinook salmon by reducing spawning gravels, and by reducing the physical complexity of rearing habitat due to lack of large wood, respectively.

Step 3 was done after the effects on all habitat processes, and subsequent effects on biological processes, were considered. For spring chinook salmon, the direct effects of the four projects on fish passage (i.e., the physical blocking of passage by the dams) are not related to habitat effects. The USACE dams lack passage facilities, and thus block spring chinook salmon from a large proportion of historic habitat, especially above Cougar Dam. Leaburg Dam and Walterville Diversion both kill 10-15% of outmigrating spring chinook fry, while Leaburg Dam delays adults. Based on the expected effects outlined in Steps 2 and 3, proposed remedial measures included increasing water releases from the USACE dams in the spring, a hydrogeomorphic study to better determine effects of the four projects on sediment and large wood, passing some large wood around the USACE dams, designing fish passage facilities for Cougar Dam, improving fish passage facilities at Leaburg Dam, and installing a fish screen at the Walterville Diversion (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2000, 2001).

Institutional Barriers

Four institutional barriers within NMFS and USFWS hinder the implementation of an ecosystem framework for evaluating the effects of dams. First, NMFS and USFWS share jurisdiction under the ESA, depending on whether the listed species is marine, freshwater, or terrestrial. The development of the joint Endangered Species Consultation Handbook (USFWS and NMFS 1998) helped to unify the efforts of the two agencies, but joint ESA consultations are still uncommon on projects affecting species under the jurisdiction of both agencies. Second, physical processes such as geomorphology and hydrology are not given due consideration by NMFS and USFWS in the conservation of aquatic species. For example, as of April 2002, NMFS employed over 100 biologists in Oregon, Washington, and Idaho to conduct ESA consultations and other environmental regulatory work on in-channel activities such as dams, roads, bridges, and dredging. However, NMFS only employs one physical scientist (a hydrologist) in the entire region to assist the biologists in interpreting the effects of such activities on physical processes.

Third, NMFS and USFWS staff have poor information resources at their disposal. Agency managers are pressured by litigation and politicians to complete biological opinions quickly, but staff lack the information they need to do the job accurately within the desired time frame. For example, neither of the largest NMFS and USFWS offices in the Pacific Northwest (both in Portland, Oregon) has a library or information management staff. Fourth, NMFS and USFWS have focused on the effects of single, small-scale human activities on individual organisms, while often ignoring the effects of multiple activities at large scales on populations and species. Several factors are involved in this phenomenon, including the complexity of cumulative effects at large scales, and the desire of staff to work on projects they can most easily understand and control. The resulting institutional myopia hampers an ecosystem approach to implementing the ESA.

Recommendations

The following recommendations help implement an ecosystem framework for biological assessments and opinions on the effects of dams or other in-channel activities on vertebrate, invertebrate, and plant species. Inherent in the recommendations is an interdisciplinary approach that may require environmental regulators to integrate unfamiliar subject matter into their areas of expertise.

1. Define the area of interest hydrologically, such as a watershed or basin, plus downstream streams, channels, and floodplains.
2. If there is more than one dam within the area of interest, synthesize evaluations of the effects of each dam into a comprehensive evaluation so that combined effects are not overlooked.
3. Work with sister agencies that have jurisdiction within the area of interest to produce joint evaluations of the effects of dams on a suite of species.
4. Identify spatial and temporal scales for the evaluation, based on the estimated geographic and temporal extent of the effects of the dams, the range of protected species or populations, and policy, legal, and management considerations.
5. Establish a framework of ecosystem processes relevant to the watershed (habitat processes) and species (biological processes) of interest to guide the evaluation effort.
6. Determine the status of the ecosystem processes for the watershed and species of interest. Obtaining the best available information requires patiently contacting agency staff and sifting through the gray literature, and the more straightforward review of the scientific literature.
7. Predict the likely effects of the dams on the habitat processes at the specified spatial and temporal scales. This interdisciplinary exercise requires staff to integrate hydrology, geomorphology, riparian function, floodplain ecology, and water quality to form a complete picture of the effects of the dams on the underpinnings of the fluvial ecosystem.
8. Based on the likely effects of the dams on the habitat processes, predict the likely effects on the biological processes of each species considered in the biological evaluation. In addition, consider the effects of the dams on biological processes not related to effects on habitat processes (e.g., direct effects of dams on fish passage may be unrelated to the effects of dams on habitat processes).

In conclusion, it is an impossible task to predict the *actual* biological effects of a complex human activity (operation of dams) in a complex ecosystem (the fluvial ecosystem) with a high level of certainty, especially if the biological evaluation is on a little-studied species. However, by first establishing a context of how the dams affect habitat processes, and then considering the biological processes of each species in question within this habitat context, the *likely* biological effects can be determined. The integration of habitat processes and biological processes at the appropriate spatial and temporal scales establishes a meaningful framework of ecosystem processes for evaluating the likely effects of dams.

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