DAMS, POLLUTION AND OTHER IMPEDIMENTS TO MIGRATION AND SPAWNING

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Summary

Most fish species must change habitats to reproduce, and man’s impediments to this strategy (e.g. dams and other forms of water flow management) may have a deleterious effect on fish population dynamics and conservation. The quantity and quality of the physical habitat available for spawning has also undergone strong modifications (through flow regulation, channelization, land-use, etc.) and these changes have affected fish spawning behavior and success. Impediment management must focus on the means to improve spawning habitat quality. In many areas this could be accomplished through restoration of flow heterogeneity (spatial and temporal). Efforts must also be taken to

re-establish the connectivity between growth habitats and spawning habitats with a special awareness of the outstanding importance of temporal factors.

1. Introduction

The "world of water," including open oceans, coastal areas, and inland lakes and waterways, is heavily exploited and harvested by man. Most aspects related to Marine Ecosystems have been addressed by others' contributions in the EOLSS Theme entitled "Fisheries and Aquaculture: Fish and Other Marine and Freshwater Products". Thus, this article will deal exclusively with the Freshwater Ecosystem. Freshwater is used for human and animal consumption, irrigation, industry, energy production, and recreation. Sediments are dredged for construction. It has recently been estimated that dams have fragmented almost 60% of the world's rivers. In addition, many recent catchment studies have revealed the influences of terrestrial ecosystems on water chemistry and stream biota. These multiple uses have numerous effects on aquatic ecosystems and the fishes that utilize them. Many fishes with high fishery value are diadromous and, as such, must travel throughout the "world of water" to reproduce at sea (catadromous species, e.g. eels) or in freshwater (anadromous species, e.g. salmon). However, holobiotic species also undergo spawning migrations since the environmental conditions of feeding habitats do not necessarily comply with incubation and rearing habitat conditions. Hence, at a given season (usually spring and early summer) many fish move into spawning areas. This usually implies lateral (often towards backwaters or seasonally flooded vegetation, e.g. carp, pike, perch) or longitudinal displacements (often towards tributaries, e.g. trout, grayling). Water quality experienced during maturation and spawning migrations, availability of spawning habitat and quality of connections (distance, presence of obstacles, etc.) between spawning and feeding habitats represent important environmental components for the maintenance of fish populations.

2. Impediments to Migration: River Obstacle Construction, Fishing, and Water Quality

2.1. Physical Obstacles

Bridges, sills, dams, etc. may cut off longitudinal connectivity needed by most fishes to carry out reproduction. The magnitude of an obstruction to migration not only depends upon the obstruction's height, but also upon the specific hydrodynamic conditions associated with the obstacle at the time of passing (e.g. velocities, water depths, turbulence) and upon the swim speed and endurance of the fish utilizing the waterway. Location of dams in the river course is also important: estuarine dams have catastrophic consequences for diadromous species because they usually prevent all fish passage, thus sterilizing the entire watercourse. Dam construction began about a thousand years ago, with most construction occurring during the last two centuries, mainly for inland navigation, flood and flow regulation, and energy production. Most big dams were constructed during the last century with more than 200 major dams completed between 1962 and 1968 in North America. Nowadays the proportion of flow stabilized by dams exceeds 20% in Africa and North America, 15% in Europe and Asia, and 5% in South America.

Because most dams represent an obstacle to migration, many have been equipped with passing devices of one sort or another, such as fish ladders, Denil passes, fish elevators, etc. (see Figure 1) and with behavioral (light, sound, electricity) or mechanical screens to prevent entry into turbine draft-tubes (see Figures 2 and 3). A major problem is that efficiency of fish passing varies with river flow, which affects both the attractivity and the passability of the obstacle. While fish-passing technology has proven efficient for salmonids moving upstream, most devices cannot be negotiated by other anadromous species such as shad or sturgeons. The valuable Acipenseridae have been particularly threatened by hydroelectric obstacles in most of their distribution areas. In addition, fish may lose time waiting for favorable flow and/or temperature conditions before passing. When obstacles are numerous, delays may decrease the physical conditions of fish and impact spawning success because fish may spawn in unfavorable areas or because ovocytes may over-mature.

Figure 1. An example of a fish pass (successive pools), EDF hydro-electric power plant (Loire River, Brives-Charensac, France). *(Photo: H. Carmié – Photothèque CSP).*

Figure 2. Turbine, Pelton Wheel, Bazacle hydro-electric power plant (Toulouse, France).
(Photo: J-M. Gougis – Photothèque CSP).

Figure 3. Trouts injured after passing through the turbines at the EDF power dam on the Allier River. *(Photo: H. Carmié – Photothèque CSP)*
a: Salmons injured after passing through the turbines at Langeac (Loire River). *(Photo: B.M.S. – Photothèque CSP)*
b: Eels injured after passing through turbines of an hydro electric power plant.

Fish-pass technology has mainly been developed with regard to upstream movement of salmon, but this is not enough to maintain populations since at a certain stage of the life cycle (such as smolt) they must travel downstream. Difficulties associated with downstream dam passing have not been resolved and specific guiding devices to prevent fish entering turbines are still being studied. Catadromous species, (e.g. eels) or iteroparous upstream moving spawners returning to their original habitat (e.g. trout) may suffer lethal injury when passing through turbines (mortality will depend on the size of the fish and type of turbine).

In large hydroelectric plants, mortality rates may be high (e.g. 40-50% reported in spent shad). However, fish damage appears rare in small hydropower stations. Passing spillways cause less mortality. However, indirect mortality can occur when passing dams during heavy spillweir discharges due to gas supersaturation (primarily nitrogen and oxygen). Unlike juveniles, adults do not recover after exposure and customarily die. In addition, the risk of mortality exists by predation at the bottom of the obstacle.

Reservoirs (see Figure 4) may result in longer residence times and altered food resources. Reservoir morphology may contribute to poor feeding success and could lead to reduced smolt survival. Yet when fish passes have been properly constructed, migrations can be deferred by the absence of navigational cues, such as strong currents. This stresses energy stores of the fish, as anadromous fish like salmon do not eat during migration.

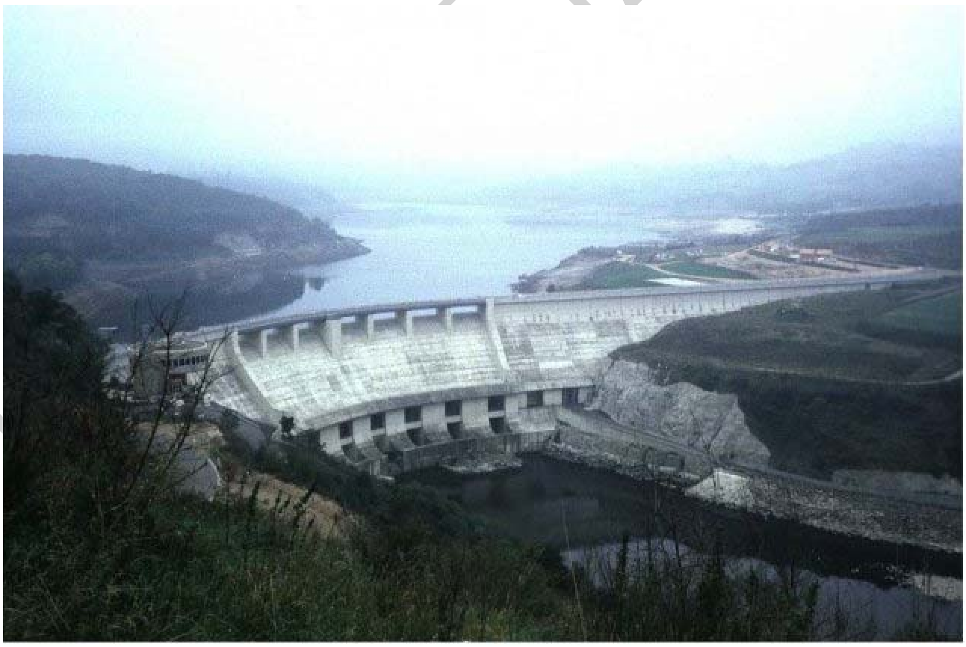

Figure 4. Villerest Dam on the River Loire. In addition to the impediment to fish movement note the impact on the river morphodynamics upstream and downstream of the dam.
(photo: B.M.I.- Photothèque CSP)

The reservoir itself may represent an obstacle to downstream fish migration because overflowing periods are limited in time and travel time is directly related to water velocity. Substantial delays have been observed for juvenile salmonids. The migration rates of juvenile Pacific salmon, *Oncorhynchus* spp., through the impounded sections of the Snake and Columbia Rivers were reduced by half at low flow and one-third at moderate and low flows. Sockeye salmon arrival dates have been positively correlated with water flow and negatively with water temperature. Experiments on individually marked eels in a small-impounded basin indicated that only 20% of silver eels (future spawners) migrated the following year.

Whether the delay in migration of several months imposed by the reservoir overflowing period was responsible for that low proportion remains unknown. In addition, travelling through some reservoirs may represent a major risk as they concentrate organic and toxic waste. Thermal stratification associated with oxygen-depletion may also induce mortality by creating unfavorable conditions for fish in the water column (high temperatures in the upper layer, oxygen deficit in certain layers).

Fish passes or ladders have been presented as a mitigation measure to reduce the impact of damming projects on fish. However, a close look at the 2000 report of the world commission on dams shows fish pass construction not to be the case. For example, of the over 450 large dams in South Africa only 16 have available fish passes. Of the almost two thousand large dams in USA only around 10% have upstream fish pass facilities.

Yet, having a fish pass or ladder does not mitigate the impact of a dam when they are installed. Of the 34 fish passes on 40 dams in one area in Norway, only 26% work with ‘good efficiency,’ and as many as 32% do not work at all. In general, the efficiency of fish passes and ladders is thought to be low, and fish migrations are almost always severely affected by a dam. In addition, fish passes engineered for Salmon are not applicable for other species.

At Pak Mun Dam in Thailand, fish passes were found to be inappropriate for the large migratory species of the Mekong that can be up to two meters long and cannot fit through salmon sized slots. Fish passes require modification to meet the requirements of each species and the circumstances at each dam. It is not an easily interchangeable technology, as shown by the Pak Mun dam which used a fish pass design suitable for leaping trout and salmon in mountain streams, but was not appropriate for species living in the slower-flowing Mekong River.

Freshwater discharges from continental areas help nurture marine fish production since many marine fish spawn in estuaries or delta regions. Dam construction decreases freshwater input and its associated nutrients and affects nursery grounds by increasing salinity, allowing invasion by predatory marine fish and reducing available food supplies. An excellent example is the effect of the Aswan High Dam on the associated Mediterranean coastal waters, where a reduction in river transported nutrients has lowered production in all trophic levels, with a resultant decline in sardine catches and other fish.

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Biographical Sketches

Agnès Bardonnet graduated from Lyon University, France, with PhD in Freshwater Ecology. After a post-doctorate in S.O.A.F.D. Freshwater Laboratory, Pitlochry, Scotland, UK, she entered the National Institute for Agronomical Research (INRA), in the Department of Hydobiology and Wildlife. Her research topics mainly focus on the behavioural ecology of amphibiotic fishes, with special concern to habitat conservation.

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