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Management and Ecological Note

Conserving iteroparous fish stocks in regulated rivers: the need for a broader perspective!

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Hydroelectric dams and weirs often represent barriers for a wide range of migratory fish species and may cause population fragmentation (Jungwirth 1998; Lucas & Baras 2001; Heggenes & Roed 2006). In general, the migratory system of diadromous fishes requires both up- and downstream migrations during the life cycle. Anadromous and potamodromous fish, such as Atlantic salmon, *Salmo salar* L., brown trout, *Salmo trutta* L., steelhead, *Oncorhynchus mykiss* (Walbaum) and grayling, *Thymallus thymallus* L., exhibit a varying degree of iteroparity and perform repeat migrations between habitats (Fleming 1996; Klemetsen, Amundsen, Dempson, Jonsson, Jonsson, O'Connell & Mortensen 2003; Keefer, Wertheimer, Evans, Boggs & Peery 2008). Catadromous eels (*Anguilla* spp.) and most Pacific salmon (*Oncorhynchus* spp.) are semelparous, but are still vulnerable to migration problems (Jansen, Winter, Bruijs & Polman 2007; Ferguson 2008). When human encroachment creates obstacles for migratory individuals, the benefits gained from migration may be reduced or even eliminated. Increased mortality may occur from contact with turbine blades, pressure changes in powerhouses and traumas caused by other artificial migration routes (e.g. Cada 2001; Ferguson 2008). As a consequence, the expression of iteroparity among migrating fish species may decrease or even disappear. Thus, residency may replace migratory life history strategies in some species (Bohlin, Pettersson & Degerman 2001).

Maintaining or restoring migratory fish populations in regulated rivers depend on implementing measures at the right scale. Establishing fishways are obvious measures to mitigate the negative impact caused by dams and weirs, but numerous studies document migratory problems and selectivity in fishways (Laine, Jokivirta & Katapodis 2002; Carlsson, Aarestrup, Nordwall, Näslund, Eriksson & Carlsson 2004; Antonio, Agostinho, Pelicice, Bailly, Okada & Dias 2007). However, on a broad spatial as well as a temporal scale, fishways and other efforts to aid upstream migration represent only one element in the overall problem complex encountered by migrants after hydropower development. In this paper, temporal and spatial challenges regarding iteroparous fish migrations in regulated rivers are examined.

Traditionally, measures to mitigate barriers to fish migration focused on a very narrow time-window: the migration towards spawning grounds. Maintaining the spawning run in regulated rivers by constructing suitable fishways at migration barriers is of major importance for reproduction. However, iteroparous species need to pass the same barriers in a downstream direction after spawning. This may be a problem, particularly for autumn spawners (e.g. the genera

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Salmo and *Salvelinus*). These species initiate the return migration in late autumn or early winter during unfavourable environmental conditions, such as low water flow and low water temperatures (Kraabøl, Arnekleiv & Museth 2008). The energetically costly spawning activity and low water temperatures lead to a poor physiological state among post-spawners (Jonsson, Jonsson & Hansen 1991). Energetically costly migration delays, accumulated physiological stress and loss of optimal synchrony between the timing of migration and physiological adaptations for entering sea water may reduce the success of the return migrators (Venditti, Rondorf & Kraut 2000; Budy, Thiede, Bouwes, Petrosky & Schaller 2002; Schaller & Petrosky 2007). Aspects related to return migration of spent adult autumn spawning fish call for a broadened perspective regarding conservation and management of iteroparous species in regulated rivers, especially concerning fish passages. Spring spawning fish species in European rivers (e.g. the genera *Thymallus*, *Hucho* and *Acipenser*) are less vulnerable because spring floods often provide excellent migratory cues.

Several migration barriers along previously interconnected river stretches may increase the overall mortality on migrating fish populations as a result of turbine strikes and aborted migrations, even where functional fishways are present. Further, fish moving downstream encounter migration barriers from the opposite direction and may pass through alternative and potentially dangerous routes such as turbines (Cada, Loar, Garrison, Fisher & Neitzel 2006). Migration problems associated with downstream migration must be added to the familiar problems encountered during upstream migration. The return of post-spawners covers a similar distance as the pre-spawning migration. However, the fish encounter a very different structural landscape and different migration routes during downstream movement. Downstream migrants do not use fishways to any extent, probably because they are attracted to the main waterways into turbines or spillways (Boggs, Keefer, Peery, Bjornn & Stuehrenberg 2004; Arnekleiv, Kraabøl & Museth 2007; Schilt 2007; Wertheimer 2007; Wertheimer & Evans 2007). Turbine water intakes are often submerged waterways, and turbine passages are likely to cause increased mortality both in juvenile and in particular adult fish (Coutant & Whitney 2000; Cada 2001; Cada *et al.* 2006; Östergren & Rivinoja 2008). Spillways releasing water from the reservoir surface mimic the natural situation and offer the most desirable migration routes (Arnekleiv *et al.* 2007; Kraabøl *et al.* 2008). Bypass and transportation systems have mainly been constructed for juvenile fish (Schilt 2007). Migratory problems associated with the establishment of large reservoirs are also a spatial scale issue. Converting river stretches into lake basins may change the fish community from stream-dwelling salmonids to lake-dwelling predator species. Such structural changes in the river system may increase predation on several life stages of migrating fish (Jepsen, Pedersen & Thorstad 2000; Olsson, Greenberg & Eklöv 2001).

Conservation strategies for migratory fish in general, and iteroparous species in particular, require a broader perspective at adequate temporal and spatial scales. First, maintaining or restoring connectivity among the various habitats used by the population requires facilitation of free transit of individuals both upstream and downstream through artificial barriers at all relevant times of the year. The passage technology should allow for non-selective and non-delaying dam negotiation through fishways and spillways, and avoid turbine passage. Although considerable research and management efforts have focused on maintaining the downstream smolt migration of Atlantic and Pacific salmon, less attention has been paid to the important return migration of iteroparous post-spawners (but see recent literature concerning iteroparous neotropic; Agostinho, Marques, Agostinho, Almeida, Oliveira & Melo 2007) and northern fish fauna (Arnekleiv *et al.* 2007; Wertheimer 2007; Keefer *et al.* 2008; Östergren & Rivinoja 2008).

These perspectives present challenges to both management and research. Faunal diversity as well as design of dams and waterways in regulated watercourses calls for improved empirical knowledge regarding iteroparous fish migrations. Research exploring the relationship between introduced migratory problems and maintenance of iteroparity among migrating fish population is imperative to assess full-scale ecological effects on migratory systems. To gain this knowledge, the migration cycle should be addressed at a wider temporal and spatial scale, incorporating the timing of return migration and development of technical devices and designs to aid adult fish passing hydroelectric dams. Large scale strategies to increase iteroparity by eliminating mortality factors associated with hydroelectric power plants, may also involve kelt transportation programmes (Evans, Wertheimer, Keefer, Boggs, Peery & Collins 2008). This strategy has been applied to smolts (Ruckelhaus, Levin, Johnson & Kareiva 2002; Buchanan, Skalski & Smith 2006), and represents an applied approach useful for both management and research tasks.

Fish migrations in the northern hemisphere are normally bound to seasonal cycles. Research programmes designed to pinpoint critical time-windows for all major migration events during the migratory cycle, and defining dam-specific threshold values for maintaining ecological functionality are needed from more developed rivers, especially in Europe. Hopefully, dam design solutions necessary to maintain ecological functionality in impounded rivers might arise from this applied ecological approach.

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