

**THE EFFECTS OF A BARRAGE ON THE MIGRATION  
OF ATLANTIC SALMON SMOLTS AND ADULTS**

M.J. Ives  
CEFAS, Lowestoft Laboratory, Pakefield Road,  
Lowestoft, Suffolk, NR33 0HT, UK  
Telephone: +44 (0) 1502 524356 Fax: +44 (0) 1502 513865  
e-mail: m.j.ives@cefass.co.uk

A. Moore and I. C. Russell  
CEFAS, Lowestoft Laboratory, Pakefield Road,  
Lowestoft, Suffolk, NR33 0HT, UK  
Telephone: +44 (0) 1502 524212 or 524330 Fax: +44 (0) 1502 513865  
e-mail: a.moore@cefass.co.uk or i.c.russell@cefass.co.uk

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**Introduction**

In recent years there has been increasing interest in the UK in the construction of estuarine barrages for urban regeneration, hydroelectric power generation and flood defence purposes. However, there has been wide concern that these constructions may have a significant impact on the estuarine environment and the species that inhabit these ecosystems. Of particular concern are the possible effects an estuarine barrage may have on diadromous fish species, which move between fresh and salt water environments. The construction of a tidal barrage across the lower sections of an estuary may affect the behaviour of migratory species, such as Atlantic salmon and sea trout, in a number of ways. Firstly, by modifying the tidal regime within the estuary it may significantly reduce the ebb and flood tidal cues which are used by salmonids to orientate (Moore *et al.*, 1995). Secondly, by reducing saline intrusion and “flushing” during the ebb tide cycle, both the aquatic environment and water quality will be modified.

Thirdly, the barrage may form a physical barrier to the passage of both juvenile and adult salmonids.

Between 1993 and 1995 an acoustic telemetry study of the migratory behaviour of both juvenile and adult salmonids (Atlantic salmon, *Salmo salar* and sea trout, *Salmo trutta*) was carried out in the vicinity of a barrage on the River Tawe in South Wales (Russell *et al.*, 1998). The barrage consists of a primary and secondary weir, a navigation lock, and a 'pool and traverse' fish pass. The Tawe estuary experiences a large tidal range and approximately 71 % of tides overtop the barrage and allow the influx of salt water into the impoundment for about 16 % of the total time. During overtopping there is limited mixing of fresh water and salt water in the impoundment, and some saline stratification may extend up to 5 km upstream of the barrage. The surface area of water within the impoundment is about 22 ha.

The localised upstream movements of 76 kHz acoustically tagged returning adult salmonids (n = 28) were investigated in the immediate vicinity of the barrage and associated fish pass using a High Resolution (HiRes) tracking system (Russell *et al.*, 1998). The behaviour of salmonid smolts (n = 52), tagged with 300 kHz miniature acoustic transmitters, was also monitored during their spring seaward emigration within the impounded estuary using an array of 300kHz acoustic sonar buoys (Moore *et al.*, 1996).

#### Movements of adult salmonids

The majority of adult salmonids (73 %) which approached the barrage were found to hold station for relatively long periods of time, often fairly close (<10 m) to the barrage structure. Many of these fish holding station (~50 %) were clearly attracted by the plume of water discharging from the fish pass and spent continuous periods of sometimes some hours within a radius of a few metres adjacent to or in the plume. Other fish adopted a rotational pattern of movement or moved along the length of the barrage, occasionally holding station in shallower water at the margins of the estuary. Many of the fish recorded approaching the barrage (68 %) were not subsequently recorded within the impoundment, immediately upstream of the barrage, within the period of acoustic life of the tag.

Passage over the barrage itself commonly occurred around high water on over-topping tides, with fish mostly migrating over the primary or secondary weirs (78 % of those recorded passing the barrage). Fish appeared to either hold station below the weirs before moving upstream when conditions were suitable or approached and crossed the barrage more rapidly on a flooding tide. However, two fish were also recorded moving through the fish pass when the barrage was not over-topped by the tide. Two of the fish which were recorded crossing the secondary weir briefly dropped below the barrage before immediately re-entering the impoundment, again over the secondary weir. The movement of fish over the barrage was significantly unimodal with respect to the tidal cycle (Rayleigh Test  $r = 0.64$ ,  $p < 0.05$ ,  $n = 9$ ), with a mean passage time of 4 minutes after high water.

On crossing the barrage into the impoundment, the movements of most fish appeared to become fairly random with quite long periods (an hour or two to several days) of residency relatively close to the barrage (<100 m). Three fish (43 % of those tracked into the impoundment) subsequently dropped back over the barrage for varying periods, some momentarily, others for periods of a few hours to a few days, before either moving out to sea (1 fish) or re-entering the impoundment (2 fish). One fish traversed the barrage three times in this way before moving further up the impoundment.

#### *The movements of salmonid smolts*

The movement of salmonid smolts through the impounded estuary and into the lower estuary, downstream of the barrage, was not continuous. On reaching the barrage the fish ceased their downstream emigration. The mean residence time of fish immediately above the barrage was  $54.76 \pm 23.1$  hours (mean  $\pm$  S.E.M.). The time spent by individual smolts in the vicinity of the barrage ranged from 0.2 to 389.53 hours. This represented between 0.28 and 99.0% of the total time spent by the smolts within the tidal and impounded sections of the estuary. The movement of smolts upstream of the barrage was predominantly random and there was no consistent pattern of movement of smolts during the period that they were in the vicinity of the Tawe Barrage. A number of smolts demonstrated exploratory movements within the study area. Individuals were monitored moving back and forth along the length of the barrage, and in a circular pattern within the impoundment. It was also observed that in a number of instances smolts within the study area moved in the direction of the

navigation lock during its filling. This suggests that the localised increase in flow within the impoundment as a result of filling the lock basin acted as a stimulus for the smolts to continue downstream emigration. Fish that successfully negotiated the barrage did so by migrating through the ship lock or over the weir during an over-topping flood tide.

The construction of the barrage, which resulted in the formation of a largely freshwater lake, the length of the original estuary, modified the tidal cycle and removed the strong ebb tide currents that the smolts used to emigrate rapidly seawards. The significant reduction in the tidal cycle also resulted in poor water quality above the barrage and the concentration of contaminants within the impoundment. The exposure of salmon smolts to sub-lethal levels of pesticides, and oestrogenic compounds (Madsen *et al.*, 1996) have been shown to significantly effect the hypo-osmoregulatory capabilities of the fish and result in high mortality once the fish migrate into the marine environment. In addition to the delay to migration caused by estuarine barrages, toxic mechanisms that interfere with smoltification and the adaptation of the smolts to the marine environment may also be a factor in the decline of some salmon stocks.

## References

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