Possible Effects of Tidal Power Development in the Upper Bay of Fundy On Anadromous Fish Passage

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ABSTRACT

This report summarizes some of the probable negative effects of a tidal power barrage in the upper Bay of Fundy on the passage and hence maintenance of anadromous fish in freshwater streams embraced by the development. The predicted negative impacts are based mainly on supporting research conducted in freshwater and estuarine situations, since studies of fish passage at marine obstructions are lacking. Probable negative impacts on anadromous fishes include: delayed or failed passage, straying from native rivers, mortality of large adults in turbines (particularly if recycling is high), decreased passage time at tidal aboiteaux, and loss of spawning and rearing habitat through inundation if peripheral pumped storage facilities are constructed. It is speculated that the overall success of maintaining passage of anadromous fishes into the tidal headpond and its freshwater tributaries will likely be determined by the ultimate placement and relationship of the sluice (both in plan and elevation) and hydroelectric turbines.

Key words: Atlantic salmon, alosids, striped bass, sturgeon, smelt, STAFLO turbine, mortality, cavitation, sluices, Cobequid Bay, Cumberland Basin.

RÉSUMÉ

Comme il est question d'aménager un barrage de centrale marémotrice au fond de la baie de Fundy (rentrant nord), l'auteur s'interroge au sujet de certains des effets négatifs prévisibles sur le passage et, par conséquent, le renouvellement des poissons anadromes dans les cours d'eau (non salés) affectés par l'aménagement. La prévision de ces effets négatifs s'appuie surtout sur des recherches effectuées dans les milieux d'eau douce et les zones estuariennes, puisqu'il n'y a à peu près pas d'études portant sur le franchissement des obstacles marins par les poissons. Au nombre des effets négatifs probables sur les poissons anadromes, on peut mentionner les suivants: passage retardé ou empêché, abandon forcé des cours d'eau d'origine, mortalité des adultes de grande taille dans les turbines (particulièrement si le recyclage est élevé), diminution du temps de passage aux aboiteaux et, finalement, perte de l'aire de frai et d'accroissement du saumon, de l'alose et du bar rayé par des inondations sur les lieux des

installations possibles de stockage pompé à la périphérie. L'auteur estime que les succès général résultant du maintien du passage des poissons anadromes dans l'échancrure tidale et ses ramifications d'eau douce dépendra vraisemblablement de l'emplacement ultime et de la dispostion relative des vannes registres (tant en plan qu'en altitude) et des turbines hydroélectriques.

INTRODUCTION

There are seven commercially or recreationally important anadromous fish species that could be affected by a tidal power barrage in the upper Bay of Fundy: Atlantic salmon (Salmo salar), alewive (Alosa pseudoharengus), blueback herring (Alosa aestivalis), American shad (A. sapidissima), striped bass (Morone saxatilis), Atlantic sturgeon (Acipenser oxyrhynchus), and rainbow smelt (Osmerus mordax). All of these species spend most of their adult lives in the ocean but migrate to freshwater habitat to spawn.

The fisheries resources of the Bay of Fundy and some of the possible impacts of tidal power development have recently been reviewed by Scarratt (1977). Kerswill (1960) has broadly recorded the possible effects of a tidal power project in the Passamaquoddy Bay area on anadromous fishes and Martin (1960) has done the same for groundfishes. The present report emphasizes some of the possible effects of tidal power development on the passage and migration of anadromous fishes between the tidal barrage and the freshwater streams that it embraces.

Two tidal power sites are presently considered as economically attractive, the mouth of Cobequid Bay (B9) and the mouth of Cumberland Basin (A8). Feasibility designs are for a single effect operation mode whereby power would be generated in only one direction when the head difference between the headpond and the sea is 0.6 m or greater.

FISH PASSAGE AT EXISTING TIDAL STRUCTURES

In the upper Bay of Fundy tidal barrages are present near the mouths of several rivers. In 1968 a causeway was built across the Petitcodiac River at Moncton and a vertical slot fishway was incorporated into the tidal structure to pass anadromous fishes. Despite the provision of a fishway, anadromous fish passage at the causeway was impeded (Dominey 1970a). This finding has been substained by ultrasonic tagging of Atlantic salmon, fishway counts and significant reductions in angling catch and commercial landings of anadromous fishes in statistical reporting areas associated with the Petitcodiac River (Semple 1979).

Tidal barrages are also present near the mouths of the Tantramar, Missaguash and Nappan Rivers at the head of Cumberland Basin and at the Great Village and Chiganois Rivers near the head of Cobequid Bay. All of these barrages were constructed to reclaim marshlands for farming or to prevent flooding. The water control structures at all of these sites, except Tantramar River, are aboiteau flap gates. The flap gates are mounted and hinged on the seaward side of conduits which pass through the barrage. At low tide, the pressure of impounded water automatically forces the gates to open allowing fish passage and conversely closes the gates on the rising tide preventing fish passage.

Salmon passage at the Great Village River aboiteau was investigated by Dominey (1970b). The available information from this study and other unpublished data concerning the Great Village aboiteau indicate that aboiteau structures can provide adequate passage for anadromous fishes. Dominey (1970b) estimated that Great Village River could produce about 400 adult salmon each year. A trap net located upstream from the aboiteau took 207 in 1973; hence, if commercial salmon landings in local and distant fisheries are taken into account, the river appears to be producing salmon near its potential. At electrically operated lift-gates, such as those on the Tantramar River, the problem has been to get the owners to open the gates when water levels on the seaward and landward sides of the gates are near equalization. Observations indicated that under such conditions, anadromous fishes can successfully pass upstream into a tidal impoundment while there is positive flow seaward.

While fish passage at existing tidal barrages in the Maritime Provinces is not quantitatively well defined, the available evidence would suggest that passage is delayed (Riley 1970, Dominey 1970a) and for this reason there may be more straying of homing species like salmon, shad, alewives and striped bass away from their natal rivers.

In rivers where dams have been created above tidal influence and where fishways have been installed to pass shad and striped bass, passage success for these species has in many cases been disappointing (Talbot 1966, Jessop 1975). On the other hand, fishways for salmon (Clay 1961) and some of the more recent fishways for shad (Dalley 1980) have been more successful, provided that the entrance is properly located.

In the Bay of Fundy and Maritime Provinces, shad and striped bass were abundant in the Saint Croix (Walburg and Nicholas 1967), the Saint John (Ruggles and Watt 1975), and the Petitcodiac and Tusket rivers (local accounts). Hydroelectric dams in these rivers, or the causeway in the case of the Petitcodiac River, have nearly eliminated these species from areas above the dams despite the fact that fishways were provided. Not all of the blame for the demise of shad and striped bass in the river reaches affected by these dams is due to fish passage problems. Water quality and spawning and rearing habitats for these species have also been impaired. This is amply demonstrated in the case of the Saint John River (Ruggles and Watt 1975, Jessop 1975).

FISH PASSAGE AT A TIDAL POWER BARRAGE

Emmigration Through Sluice Gates

In order to maintain the production of anadromous fish stocks from the freshwater rivers embraced by proposed tidal power barrages, passage of fish beyond the barrages will be necessary.

The seaward migration of anadromous species that have spawned, and of juvenile fish originating from the spawning, will probably be less difficult than for adult fish trying to reach their home rivers inside the barrage.

Not much is known about the movements of juvenile and adult anadromous species after they enter the ocean (Scott and Crossman 1973). Atlantic salmon originating from Maritime waters are intercepted as far away as West Greenland and Newfoundland (Stasko et al. 1973). Shad, striped bass and alewives that have spawned in Maritime rivers have been recaptured as far south as Virginia and South Carolina (Jessop, pers. comm.). In any event, at some time within the year it is likely that underyearling alewives, shad, striped bass and 1 to 3-year old salmon smolts will be emmigrating out of the areas that would be embraced by the proposed tidal power barrages.

Moreover, it is probable that most emmigrant anadromous species will move out of the tidal headpond(s) during the massive export of water in the power generation phase of tidal power operation. At times, when the tidal inflow through the filling gates creates velocities up to 10 m s^{-1} (Swales 1977), egress through the filling sluice gates will be barred since such a velocity exceeds the maximum swimming speed of most fishes. After extensive review of the literature, Blaxter (1969) concluded that salmonids are capable of burst speeds of 10 b.l.s. (body lengths per second) while weaker swimmers such as alewives probably can only reach speeds of 8 b.l.s.

The orientation of emmigrating anadromous fishes to currents created by emptying (power generation) and filling the tidal headpond(s) will also have a bearing on whether these species leave the tidal headpond(s) through the turbines or through the sluices. Although little is known about the orientation of spent adult shad, alewives, smelt and striped bass (and their juvenile stages) to water currents, the subject has been dealt with extensively for juvenile salmonids (Arnold 1974, Stasko et al. 1973, Ruggles 1980). These reviews suggest that salmon smolts, while in freshwater, orient and swim with the current in low velocity water, but in accelerating currents they orient themselves upstream against the current and are carried passively downstream.

Emmigration Through Turbines

Anadromous fish passing through turbines will be subjected to rapidly changing pressures and the possibility of contact with the rotating turbine blades (Collins 1984). In hydraulic turbines, the velocity is relatively slow and the pressure strongly positive in water passages leading to the turbine (Cramer and Oligher 1964). After passage through the turbine, negative pressures may develop depending on the relative elevation of the turbine runner to the tailwater elevation. This condition can be minimized by setting the turbine runner below the minimum low tide level. The significance of negative pressures in the turbine draft tube is that it can cause cavitation or the violent collapse of vapor masses severe enough to remove small particles of metal from turbine blades; hence, it is potentially harmful to fish using this route.

In connection with smolt passage through hydroelectric turbines, Montén (1955), reported in Mills (1971), considered that because of the short exposure time of fish to high pressure and cavitation, it is unlikely that fish will be injured by them at least up to water heads of 32.3 m. Caulderwood (1945) concluded that Atlantic salmon smolts would not be injured by them at least up to water heads of 32.3 m. From their extensive review of the literature concerning the passage of small fishes through turbines, Bell et al. (1967) indicated that Canadian and American research on the subject of cavitation and damage to fish showed this to be a significant factor. Installation specifications for the tidal power projects proposed for the upper Bay of Fundy would appear to present few problems relative to fish survival and pressure and cavitation in the turbines.

Passage of fish through the turbines will subject fish to the possibility of contact with the turbine blades. While I am not aware of any information relative to fish mortality in the type of turbine (Straflo or bulb type) being considered for potential tidal power developments in the upper Bay of Fundy, they are propeller turbines similar to Kaplan units. Bell et al. (1967) concluded that for Kaplan and Frances turbines the highest survival of fish occurs when the turbine is operated at highest efficiency. For Kaplan turbines, this is achieved by adjusting the blade angle for a given head and load. Bell et al. (1967) provided maximum and minimum fish survival estimates for Kaplan turbines at nine dams and for thirteen tests. The average maximum survival was 95.1% and the lowest maximum survival was 77.1%. The average minimum survival was 73.2% and the lowest survival rate was 0.0%. Since mortality rate in turbines increases as fish size increased (Bell et al. 1967) the mortality of smaller juvenile stages of anadromous fish passing tidal power barrages in the upper Bay of Fundy will be less than that of spent adults.

Because of the large dimensions of the turbines for the proposed developments in Cobequid Bay and Cumberland Basin and because of the relatively slow runner speeds (67.92 to 75 rpm), it is unlikely that turbine mortality of fish will be high, particularly for juvenile anadromous fishes. However, if the feeding behaviour of larger adult anadromous fishes leads to recycling through the turbines, which is quite possible, mortality could be significant.

Immigration to a Tidal Headpond and its Freshwater Tributaries

There is considerable evidence that spawning runs of Atlantic salmon (Stasko et al. 1973), American shad (Mansueti 1955), alewives (Hildebrand 1963) and striped bass (Raney 1952) return or "home" to the stream where their parents spawned. The mechanism whereby these homing species are able to navigate to their native stream is a subject which has received much research and considerable review (Arnold 1974, Liley 1982, Nordeng 1971, Hasler 1966, Stasko et al. 1973).

A widely accepted hypothesis for salmon homing is that salmonids imprint on distinctive odors of the home stream (olfactory hypothesis) during their freshwater residence. Later the adults use this information to locate their natal stream, at least during the later portion of their homeward journey. Hasler et al. (1978) reviewed much of the direct and circumstantial evidence in support of this hypothesis. The pheromone hypothesis (Nordeng 1977) proposed that homeward navigation is an inherited response to population-specific chemicals released by the fish themselves and to which the fish respond. Migrating adults are attracted to streams containing conspecifics (Liley 1982).

If homing is as dependent on olfaction as the evidence suggests, then migration of homing anadromous fish at the tidal barrage could be adversely affected since the turbines will draw the deeper saline water which is likely to lack those odors which would guide the fish to their home streams. Only for a short period of time after power generation until water level equalization would there be any seaward flow of surface waters (assuming the device gates are near water surface) containing native stream odors or pheromones. Hence, it is possible that considerable straying of homing anadromous fishes could result, and much of the fishery and production potential of freshwater tributary streams could be lost for anadromous species. Water currents also influence the route choice of fish (Arnold 1974, Banks 1968) but may be secondary to stream odor. A loss of positive rheotaxis has been observed in chinook salmon displaced upstream from home water (DeLacey et al. 1969). Banks (1968) has reviewed the importance of "attraction water" relative to passing fish at dams and the correct siting for a fishway entrance. In this connection it has been possible for instance with sockeye and chinook salmon to manipulate the spill-pattern at a hydroelectric dam to guide migrant salmon upstream (Leman and Paulik 1966). Collins (1952) found that the choice of migrating route for alewives could be influenced by the velocity of flowing water. The fish took the water with the faster flow. This is also true for salmonids (Banks 1968).

The above findings lead to the conclusion that if olfactory cues do not emminate from the turbine outflow in a tidal power barrage, homing anadromous species may not collect there. If the positive outflow through the filling sluice gates (between turbine shutdown and water level equalization) is only maintained for a short duration of time then anadromous fish migration into the tidal headpond could be severely limited, particularly if the sluice gates are mounted deep below the water surface where pheromones and stream odors may not be present.

If stream odors and pheromones are present during seaward flow through the turbines, then when the rising tide forces water into the tidal headpond fish may move through the sluices voluntarily or be sucked through in the high velocity water.

With regards to the orientation of anadromous fish species in tidal currents, some of the existing research is contradictory and difficult to interpret. Atlantic salmon wander in estuaries (Huntsman 1952). Stasko (1975) found that salmon bearing ultra-sonic tags spent more tidal periods progressing upstream with the current than against it. He concluded that Atlantic salmon moved upstream with flood tides but also found random movements both with and against all phases of the tide. Stewart (1971), in his studies of salmon movement in the Lune Estuary, concluded that more salmon move upstream on the ebb rather than flood tide. With American shad, Dodson and Leggett (1973) found that this species moved upstream against ebb tides while also moving upstream with flood tides. Later research by Dodson and Leggett (1974) showed that on flood tides the orientation of shad ranged from concurrent to countercurrent. Ripe striped bass drift with the tidal flow and then hold position when the tide reverses (Koo and Wilson 1972). Spent striped bass showed unpredictable movements patterns with and against tidal currents. Dudley et al. (1977) found that striped bass ascended the Savannah River to spawn on ebb rather than flood tides.

If and when a tidal power barrage is constructed in Cobequid Bay or Cumberland Basin, the mean tidal elevations and amplitude in the headpond will be changed significantly (Baker 1984). Mean high water in Cobequid Bay will be about 0.6 m lower, mean tide about 2.7 m higher and low tide about 6.0 m higher than before the barrage. Tidal amplitude will be about 5.8 m less.

The implications of the altered tidal regime within the tidal impoundment may be significant relative to anadromous fish passage at aboiteau flap gates located at the mouths of tributary streams embraced by the tidal power barrage. Depending on the sill elevations of the flap gates, the new tidal regime could decrease the available time for anadromous fish passage and result in more straying to unencumbered tributaries.

Increased erosion and sedimentation together with changes in tidal currents within the impoundment may alter the route selection of anadromous fishes and hence the traditional fishing locations and fish landings from these areas.

Since tidal power production will not always be in harmony with the power demand cycle, it is possible that additional storage sites might be created in freshwater tributaries anywhere in the Maritime Provinces and that low demand, low cost power might be used to pump water into these reservoirs to produce power at conventional hydroelectric installations when it is most needed. This could result in lost spawning and rearing habitat (inundation) for salmon, shad and striped bass and new spawning habitat for alewives. Pumped storage could also lead to fish passage problems at the storage sites if fish passage is not provided.

SUMMARY

Passage of shad and striped bass at existing tidal and non-tidal obstructions in the Maritime Provinces where fishpasses have been provided has been disappointing. Passes for Atlantic Salmon and alewives have been more successful.

Emmigration of anadromous species from the proposed tidal impoundments will likely be predominantly through the turbines and the negative impact will probably be negligible for juvenile anadromous species. Adults on the other hand could suffer significant mortality if their movement patterns leads to much recycling through the turbines.

Immigration into tidal headponds, in contrast to emmigration, may present more of a problem for homing anadromous species that are bound for natal streams embraced by the barrage. Negative impacts such as stock reduction may occur if the sluice gates are deeply submerged. The compressed time available to pass fish due to the operation mode of the power plants could also lead to a considerable amount of straying to freshwater tributaries outside the barrage or to lack of spawning.

The altered tidal regime within the headpond may also result in compressed passage time at existing tidal aboiteaux (flap gates) on freshwater streams embraced by the tidal power barrage. Moreover, changed tidal currents could effect fishing success in traditional fishing areas. Furthermore, attempts to tune power production to demand, through pumped storage at freshwater sites anywhere in the Maritime Provinces, could destroy spawning habitat for some species (salmon, shad and striped bass) and create new habitat for others (alewives). Fish passage problems could also be created at pumped storage sites if fish passage is not provided.

The overall success or failure of maintaining the passage of anadromous fishes into the tidal power impoundment and its' freshwater tributaries may well hinge on the ultimate placement, both in plan and evaluation, of the sluices and turbines.

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