

NOT TO BE CITED WITHOUT PRIOR REFERENCE TO AUTHORS

International Council for the Exploration of the Sea

Anadromous and Catadromous Fish Committee CM 1995/M:43

BID Schurel M

THE MOVEMENTS OF WILD SEA TROUT (Salmo trutta L.) SMOLTS IN THE LOWER RIVER AND ESTUARY OF THE RIVER CONWY, NORTH WALES.

A. Moore,* M. Scott,[†] M. Ives,* I.C. Russell,* M. Challiss,* E.C.E. Potter* and W.D. Riley*.

* Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, United Kingdom.

‡ National Rivers Authority, Highfield, Priestley Road, Caernarfon, Gwynedd LL55 1HR, United Kingdom

ABSTRACT

Wild sea trout (Salmo trutta L.) smolts, tagged with miniature acoustic transmitters, were tracked in the River Conwy, North Wales, to describe the freshwater and estuarine patterns of migration. Migration in freshwater was predominantly nocturnal, although there were changes in this pattern in the lower reaches of the estuary with fish moving during both the day and night. The nocturnal pattern of migration in freshwater would appear to be the result of a rhythm of swimming activity which results in the smolts moving up into the water column after dusk and migrating seawards. Smolts tagged earlier in the study spent significantly longer in the river before migrating into coastal waters than fish tagged later in the study. The movement of smolts through the estuary was indicative of a selective ebb tide transport pattern of migration. All the smolts migrated seawards on an ebb tide close to the surface and within the fastest moving section of the water column. Smolt migration in the lower portion of the estuary was indicative of active directed swimming and there was no apparent period of acclimation required when moving from fresh to saltwater. The behaviour of the smolts is discussed in relation to the possible environmental and physiological cues controlling estuarine migration.

Keywords: Sea trout, (Salmo trutta), migration, telemetry, estuary, behaviour

INTRODUCTION

Sea trout (*Salmo trutta* L.) smolts move seaward through river estuaries during their spring migration. This movement from the fresh water to the marine environment is considered to be a particularly critical period in the life history of migratory salmonids (Doubleday *et al.* 1979; Browne *et al.* 1982). The timing of this movement has for instance been suggested to be crucial to the survival of Atlantic salmon smolts and their return as adults (Larsson 1977; Cross & Piggins 1982; Hansen & Jonsson 1989). In recent years there has been increasing concern about the potential impact of estuarine constructions such as power stations and barrages on the behaviour and survival of sea trout smolts. An understanding of the environmental and physiological mechanisms controlling the behaviour and movement of sea trout smolts through estuaries is therefore important for both mitigation purposes and stock management.

A collaborative study between the MAFF Fisheries Laboratory and the National Rivers Authority was initiated on the River Conwy, North Wales. This study, carried out in the springs of both 1992 and 1993, examined the movements of wild sea trout smolts as they migrated from fresh water, through the Conwy estuary and into coastal waters. This paper describes the findings of the study.

MATERIALS AND METHODS

The study was carried out over two years, between 29th March - 5th May 1992 and 13th April - 22nd May 1993 on the River Conwy, North Wales. Current speeds are considerable within the estuary, with maximum values of 2.71 m s^{-1} (upper estuary) in a seaward direction recorded on the ebb tide during the study, and 2.59 m s^{-1} (middle estuary) in a landward direction on the flood. These currents result in sufficient mixing to minimise stratification on both ebb and flood tides.

Trapping and tracking

During 1992 sea trout smolts were trapped at two sites, the first on the River Conwy and the second on a small tributary of the main river. During 1993 smolts were trapped only on the main river. Migrating smolts were trapped using standard fyke nets attached to a 50 cm x 50 cm x 50 cm keep box.

Sea trout smolts (150-213mm in length) were tagged using a miniature 300 kHz acoustic transmitter which had been developed at the MAFF Fisheries Laboratory, Lowestoft (Moore *et al.* 1990a). The transmitter circuitry and battery were enclosed in a cylindrical polycarbonate case with hemispherical ends. It was 17 mm long x 8 mm in diameter, and weighed 1.30 g in air and 0.35 g in water. The transmitter had a maximum range in the estuarine environment of around 100 m and transmitting at 60 pulses min⁻¹, a life of approximately 30 days.

The transmitters were surgically implanted into the peritoneal cavity of the smolts as described by Moore *et al.* (1990b). This technique of transmitter attachment has been shown to have negligible physiological and behavioural effects on Atlantic salmon smolts (Moore *et al.* 1990b), and has previously been used successfully to track both

salmon and sea trout smolts within the River Avon (Moore *et al.* 1990c; Moore *et al.* 1992 and Moore and Potter 1994).

The movements of the smolts within the riverine and estuarine sections of the River Conwy were monitored using an array of 300 kHz acoustic sonar buoys and automatic listening stations (Moore *et al.* 1992; Moore & Potter 1994), (Figure 1).

Data analyses

The mean time of day and the mean time in the tidal cycle at which the smolts were detected by the acoustic signal relay buoy closest to the middle of each of section (Fig. 1) were calculated using vector analysis (Batschelet 1981). The lengths of the mean vectors were further used to test whether movement of the smolts through each section was random with respect to time and state of tide using the Rayleigh test ('r' value) (Batschelet 1981). High water at Conwy has been used as a reference time for all tidal cycles.

Environmental data '

A range of environmental monitoring equipment was placed at a number of sites within the fresh water and estuarine sections of the River Conwy. These included RCM 7 Recording Current Meters (Aanderaa Instruments, Bergen, Norway). Datasonde 3 Multiparameter Water Quality Data Loggers (Hydrolab, England) and a 600 kHz Broad Band Acoustic Doppler Current Profiler (ADCP) (RD Instruments, San Diego). The ADCP, towed behind a small research vessel, obtained water velocity profiles across and along the estuary throughout the tidal cycle.

RESULTS

Nineteen sea trout smolts were tagged and released during the two year study. Fourteen of these were tracked through the lower freshwater reaches and estuary of the River Conwy and were last detected by the sonar buoy at the exit of the estuary. The remaining sea trout smolts resided within the freshwater section above the tidal limit.

In 1992 there was a relationship between the day of release of the tagged smolts that migrated out into coastal waters and the total residency time within the River Conwy downstream of the trap site (Figure 2). As the smolt season progressed the released smolts spent less time within the River Conwy before migrating into coastal waters (least square regression: r = -0.680; p < 0.02). As a result most smolts (75%) left the river in a five day period, which coincided with the peak of a spring tidal cycle (Figure 3). In 1993 there was insufficient data to carry out a similar analysis.

The downstream movements of smolts were detected by all of the acoustic sonar buoys in fresh water and by the majority of the buoys in the freshwater/tidal, upper, middle and lower estuary. This indicates that the fish must have passed within 50-75 m (the detection range) of the sonar buoys, and thus probably followed the course of the low water channel down the estuary.

Diurnal pattern of migration

In both years the movement of tagged sea trout smolts within the fresh water section of the River Conwy was predominantly nocturnal (Table 1). In 1992 the mean time of day that the sea trout smolts passed the tidal limit of the river was 23 59h, and the movement was non-random with respect to time with an 'r' value of 0.641 (p<0.05). The nocturnal pattern of migration was evident within the freshwater/tidal and upper estuary (mean time 23 52h; 'r'=0.807; p<0.05), but did not occur in the middle and lower estuary where movement was random with respect to time. Sea trout smolts migrated into coastal waters during both the day and night

In 1993, the movement of tagged sea trout smolts within the fresh water section of the River Conwy was also predominantly nocturnal (Table 1). The mean time of day that the sea trout smolts passed the tidal limit of the river was 00 02h, and the movement was non-random with respect to time with an 'r' value of 0.921 (p<0.001). However, the subsequent movement of the sea trout smolts through all the lower sections of the River Conwy was random with respect to time with smolts moving downstream during both the day and night (Table 1).

Tidal pattern of migration

• • •

The movement of sea trout smolts in the middle and lower estuary of the River Conwy was also significantly related to the direction of current flow (Table 2). Downstream movement within the upper, middle and lower sections occurred mainly during an ebbing tide with mean times between 2h 48min and 4h 11min after high water (1992 and 1993 data were similar and have been combined). Movement upstream of sea trout smolts was also significantly related to direction of flow. Mean times after high water for upstream movement of smolts within the lower, middle and upper estuary sections were 9h 06min, 10h 13min and 10h 37min, respectively

There was no apparent relationship between observed changes in the pattern or rate of smolt movement through the estuary with measured changes in water quality, salinity and temperature. The greatest range in temperature, pH, salinity and dissolved oxygen was experienced in the upper and middle estuary: in the upper estuary movement of smolts coincided with water temperatures of between 7.6 and 15.0 ° C; in the middle estuary smolts experienced a range of pH between 6.1 and 8.4 and salinities from 0.5 to 31.0 psu. The range of dissolved oxygen throughout the estuary when fish were migrating was $6.3 - 11.2 \text{ mg.}I^{-1}$ with the lowest values being recorded in the upper estuary. There was no evidence that movements were affected by changes in dissolved oxygen, although the lowest levels observed would not be expected to any deleterious effects.

There was no apparent relationship between river flow and the movement of smolts within the estuary. The times that sea trout smolts were recorded passing the sonar buoy situated in the middle estuary in relation to the river flow are shown in Figure 4.

The movement over the ground of smolts through the middle estuary was not significantly different to that of an inert object travelling at comparable states of the tide within the main flow (df = 6; t = 1.04; p>0.05 - two tailed t-test, unequal variances). However, within the lower estuary smolts moved significantly faster over the ground than inert objects (df = 6; t = 3.14; p<0.01 - two tailed t-test, unequal variances). These results suggest that smolts moved passively through the middle estuary with the flow, but with some degree of orientation that maintained them in the main current. However, on reaching the lower estuary smolts began to move at speeds in excess of the current.

Current speeds measured with the ADCP were significantly greater in the upper water column throughout the middle and lower estuary. Typical current speeds in the middle estuary, measured 2h 40mins after HW were 152cm s⁻¹ in the upper 30% of the water column and 69.5cm s⁻¹ in the lower part of the water column. Maximum current velocities also occurred in the vicinity of the main channel. Smolts moving downstream on an ebbing tide, close to the surface and within the main channel of the middle and lower estuary would therefore experience the maximum current velocities.

DISCUSSION

The migration of sea trout smolts in the fresh water and tidal fresh water sections of the River Conwy was predominantly nocturnal. The pattern of migration would appear to be the result of a nocturnal rhythm of swimming activity with fish maintaining position within the river during the daylight hours and then moving up into the water column after dark and migrating downstream (Moore 1995). This nocturnal pattern of migratory behaviour in fresh water was similar to that demonstrated by sea trout smolts in the River Avon (Moore & Potter 1994). There was also a significant seasonal change in the residency time of the sea trout smolts, with fish tagged later in the season spending less time in the River Conwy before migrating into coastal waters.

Nocturnal migration by sea trout smolts may reduce the chances of avian predation particularly by cormorants (*Phalacrocorax carbo*) and herons (*Ardea cinerea*) which prey on smolts in the River Conwy (Moore pers obs). Predation by birds on the Atlantic salmon smolts may be as high as 70% in some areas (Larsson 1985; Kennedy & Greer 1988) and as the majority of these birds feed visually during the day (Kennedy & Greer 1988), refuging of salmonid smolts close to the bed of the river during the day and migrating at night may reduce predation pressure.

The nocturnal pattern of migration of sea trout smolts indicate that light level was the most important environmental stimulus controlling migration in fresh water. Previous studies have suggested that a number of other environmental factors may also initiate and modify Atlantic salmon and sea trout smolt migration in fresh water. Migration may occur when a certain temperature threshold has been exceeded (Osterdahl 1969;

McCleave 1978) or by variations in the patterns of temperature over a prolonged period (Jonsson & Ruud-Hansen 1979). During this study smolt migration in the main river coincided with temperatures of above 10° C, the threshold reported in other studies (Osterdahl 1969; Solomon 1978). Movement in the tributary of the River Conwy occurred at much lower temperatures but coincided with a rapid increase in flow rate, which has also been implicated in the initiation of salmon smolt migration (Solomon 1978). In the main river there was no observable correlation between increased water flow and smolt migration in any of the sections of the Conwy. However, the data on river flow was obtained only from one gauging station and may therefore not reflect the flow regimes throughout the river catchment. In addition, more subtle changes in river flow which are not evident from the recorded data may be important in initiating and controlling smolt migration.

In all sections of the estuary, movements were mainly with the direction of flow and were thus strongly influenced by tidal currents. Movements seaward occurred during both day and night. Movement through the middle estuary also appeared to be passive but with some degree of orientation with respect to the main flow in the channel (Moore & Potter 1994). There was evidence that on reaching the lower estuary fish remained close to the surface swimming actively in a seaward direction. Migration seaward throughout the day and night close to the surface would allow smolts to move quickly out of the estuary, although it may also have made them more susceptible to avian predation.

It has been argued that salmonid smolt migration in estuaries is either passive, (Tytler *et al.* 1979; Thorpe *et al.* 1981; Greenstreet 1992a), partly active (Thorpe & Morgan 1978; McCleave 1978; Solomon 1978; Kennedy *et al.* 1984, Burgeois & O'Connell 1988) or active (Hansen & Jonsson 1985; Moore *et al.* 1992; Moore & Potter 1994). In the River Conwy migration through the estuary differed both spatially and temporally. Migration through the upper and middle estuary was passive during the hours of darkness but with some degree of orientation that maintained the smolts in the upper part of the water column and within the main current. During daylight hours movement over the ground was significantly slower. This difference in migratory behaviour may be explained by fish attempting to seek refuge close to the bottom of the estuary during daylight hours but nevertheless being unable to maintain station in the tidal currents.

The movement of sea trout smolts through the estuary and into coastal waters was unaffected by changes in water quality. Increasing salinity did not appear to affect the behaviour of the smolts and there was no apparent period of salt water acclimation required as previously suggested in other salmonid smolts (Moser *et al.* 1991). This implies that physiological adaptation to a saline environment had previously occurred in fresh water (Primett *et al.* 1988). A physiological requirement to move to a saline environment may therefore be an important cue in initiating smolt migration in the River Conwy.

An understanding of the environmental cues initiating smolt migration through estuaries is important in evaluating the potential impact of estuarine constructions such as barrages on the behaviour and survival of migratory salmonids. One major concern relates to the potential changes in the flow regimes above a barrage and the effects on smolt migration. The removal of a significant tidal cycle in the impoundment of a barrage would result in a reduction of the ebb tide cues that the smolts appear to use during their seaward movement. The consequences of such an event may be that fish reside for longer periods in an impoundment with the potential for an increase in predation, or that the timing of the movement into coastal waters is delayed and that the fish do not move into the sea at the optimum time. As previously noted, it has been suggested that the timing of smolt movement into coastal waters may be crucial to their survival and return as adult fish (Larsson 1977; Cross and Piggins 1982; Hansen and Jonsson 1989).

REFERENCES

Batschelet, E. 1981. Circular Statistics in Biology. London: Academic Press. 371 pp.

Browne, J., Eriksson, E., Hansen, L.P., Larsson, P.O., LeCompte, J., Piggins, D.J., Prouzet, P., Ramos, A., Sumuri, O., Thorpe, J.E. & Toivonen, J. 1982. Ocean ranching of Atlantic salmon. Action COST 46, *Mariculture*. KII/1199/82, EEC, Brussels.

Burgeois, C.E. & O'Connell, M. F. 1988. Observations on the seaward migration of Atlantic salmon (*Salmo salar* L.) smolts through a large lake as determined by radiotelemetry and Carlin tagging studies. *Canadian Journal of Zoology* 66, 685-691.

Cross, T.F. & Piggins, D.J. 1982. The effect of abnormal climatic conditions on the smolt run of 1980 and subsequent returns of Atlantic salmon and sea trout. *ICES C.M.* 1982/M:26: 1-8.

Doubleday, W. G., Ritter, J. A. & Vickers, K.U. 1979. Natural mortality rate estimates for north Atlantic salmon in the sea. *ICES C.M.* 1979/M:26: 1-15.

Fried, S.M., McCleave, J.D. & LaBar, G.W. 1978. Sea ward migration of hatcheryreared Atlantic salmon, Salmo salar, smolts in the Penobscot River estuary, Maine: Riverine movements. *Journal of Fisheries Board of Canada* 35, 76-87.

Greenstreet, S. P. R. 1992. Migration of hatchery reared juvenile Atlantic salmon, *Salmo salar* L., smolts down a release ladder. 3. Reactions on exiting the ladder. *Journal of Fish Biology* **40**, 683-694.

Hansen, L. P. & Jonsson, B. 1985. Downstream migration of hatchery-reared smolts of Atlantic salmon (*Salmo salar* L.) in the River Isma. *Aquaculture* 45, 237-248.

Hansen, L. P. & Jonsson, B. 1989. Salmon ranching experiments in the River Imsa; Effect of timing of Atlantic (*Salmo salar*) smolt migration on the survival to adults. *Aquaculture* 82, 367-373.

Jonsson, B. & Ruud-Hansen, J.1985. Water temperature as the primary influence on timing of seaward migrations of Atlantic salmon (*Salmo salar*) smolts. *Canadian Journal of Fisheries and Aquatic Sciences* 42, 593-595.

Kennedy, G.J.A., Strange, C.D., Anderson, R.J. & Johnston, P.M. 1984. Experiments on the descent and feeding of hatchery-reared salmon smolts (*Salmo salar L.*) in the River Bush. *Fisheries Management* 15, 15-25.

Kennedy, G.J.A. & Greer J.E. 1988. Predation by cormorants, *Phalacrocorax carbo* (L.), on the salmonid populations of an Irish river. *Aquaculture and Fisheries Management* **19**, 159-170.

Larsson, P.-O. 1977. The importance of time and place of release of salmon on the results of stocking. *ICES C.M.* 1977/M:42, 1-10.

Larsson, P.-O. 1985. Predation on migrating smolts as a regulating factor in Baltic salmon, *Salmo salar L.*, populations. *Journal of Fish Biology* **26**, 391-397.

McCleave, J.D. 1978. Rhythmic aspects of estuarine migration of hatchery reared Atlantic salmon (*Salmo salar*) smolts. *Journal of Fish Biology* **12**, 559-570.

Moore, A., Storeton-West, T., Russell, I.C., Potter, E.C.E. & Challiss M.J. 1990a. A technique for tracking Atlantic salmon (*Salmo salar* L.) smolts through estuaries. *ICES C.M.* 1990/M:18, 1-5.

Moore, A., Russell, I.C., & Potter, E.C.E. 1990b. The effects of intraperitoneally implanted dummy acoustic transmitters on the behaviour and physiology of juvenile Atlantic salmon, *Salmo salar* L. *Journal of Fish Biology* 37, 713-721.

Moore, A., Russell, I.C., & Potter, E.C.E. 1990c. Preliminary results from the use of a new technique for tracking the estuarine movements of Atlantic salmon (Salmo salar L.) smolts. Aquaculture and Fisheries Management 21, 369-371.

Moore, A., Potter, E.C.E. & Buckley, A.A. 1992. Estuarine behaviour of migrating Atlantic salmon (*Salmo salar* L.) smolts. In: Priede, I.G. and Swift, S.M. (ed) *Wildlife Telemetry Remote Monitoring and Tracking of Animals*, p. 389-399.

Moore, A. & Potter, E.C.E. 1994. The movements of sea trout (*Salmo trutta* L.) smolts through the estuary of the River Avon, Southern England. *Fisheries Management and Ecology* **1**, 1-14.

Moore, A. 1995. The movements of Atlantic salmon (*Salmo salar* L.) and sea trout (*Salmo trutta* L.) smolts in the lower river and estuary of the River Conwy, North Wales. NRA R&D Report No.312.

Moser, M.L., Olson, A.F. & Quinn T.P. 1991 Riverine and estuarine migratory behaviour of coho salmon (*Oncorhynchus kisutch*) smolts. *Canadian Journal of Fisheries and Aquatic Sciences* 48, 1670-1678.

Osterdahl, L. 1969. The smolt run of a small Swedish river. In: *Salmon and trout in streams*. Northcote, T.G. (ed.). H.R. Macmillan lectures in fisheries, University of British Columbia, Vancouver, B.C. pp 205-215.

Primmett, D.R.N., Eddy, F.B., Miles, M.S., Talbot, C. & Thorpe, J.E. 1988. Transepithelial ion exchange in salmon. 1. Seaward migration may be caused by ion regulatory stress. *Fish Physiology and Biochemistry* 5, 181-186.

Solomon, D.J. 1978. Some observations on salmon smolt migration in a chalk stream. *Journal of Fish Biology* **12**, 571-574.

Thorpe, J.E. & Morgan, R.I.G. 1978. Periodicity in Atlantic salmon Salmo salar L. smolt migration. Journal of Fish Biology 12, 541-548.

Thorpe, J.E., Ross, L.G., Struthers, G. & Watts, W. 1981. Tracking Atlantic salmon smolts *Salmo salar* L. through Loch Voil, Scotland. *Journal of Fish Biology* **19**, 519-537.

Tytler, P., Thorpe, J. E. & Shearer, W. M. 1978. Ultrasonic tracking of the movements of Atlantic salmon smolts (*Salmo salar*) in the estuaries of two Scottish rivers. *Journal of Fish Biology* **12**, 575-586.

Table I. The downstream movements of sea trout smolts through each of the five sections of the River Conwy in relation to time of day. The mean times at which fish were recorded passing the sonar buoy positioned closest to the middle of each section has been calculated from the mean vectors (Batschelet 1981). The 'r' value provides a measure of randomness of movement with respect to time calculated using the Rayleigh test. The value n is the total number of fish movements past the respective sonar buoy in each section.

		FRESH WATER	FRESH WATER/TIDAL	UPPER ESTUARY	MIDDLE ESTUARY	LOWER ESTUARY
1992	mean time r value p n	23h 59min 0.641 < 0.05 8	23h 52min 0.807 < 0.05 5	Insufficient data	Random movement 0.024 > 0.05 9	Random movement 0.169 > 0.05 11
			<u> </u>			
1993	mean time	00h 02min	Random movement	Random movement	Random movement	Random movement
1993	mean time r value	00h 02min 0.921	Random movement 0.493	Random movement 0.15	Random movement 0.183	Random movement 0.208
1993	mean time r value p	00h 02min 0.921 < 0.001	Random movement 0.493 > 0.05	Random movement 0.15 > 0.05	Random movement 0.183 > 0.05	Random movement 0.208 > 0.05

Table II. The downstream movements of sea trout smolts through the upper, middle and lower estuary sections of the River Conwy in relation to the tidal cycle. The mean times are the period after high water that fish were recorded passing the sonar buoy positioned closest to the middle of each section. Key as for Table I.

		UPPER ESTUARY	MIDDLE ESTUARY	LOWER ESTUARY
1992	mean time	Insufficient	3h 39min	3h 25min
	r value	data	0.795	0.577
	p		< 0.004	< 0.02
	n		9	11
	· · · · · · · · · · · · · · · · · · ·			
1993	mean time	2h 48min	3h 50 min	4h 11min
	r value	0.696	0.8	0.679
	p	< 0.001	<0.001	< 0.05
	'n	14	9	7



Figure 1. Map of the River Conwy showing the five sections of the river referred to in the text. • denote the positions of the acoustic signal relay buoys in each section used to calculate the movements of sea trout smolts with respect to mean time of day and mean time in relation to the tidal cycle.



Figure 2. The relationship between transit time within all sections of the River Conwy after tagging and day of release of sea trout smolts in 1992. Details of the fitted regression line are given in the text.



Figure 3. The migration of sea trout smolts (●) out of the River Conwy estuary in relation to the Spring - Neap tidal cycle in 1992. The tidal height is the difference between the high and low waters each day.



Figure 4. The movement of sea trout smolts past the sonar buoy positioned in the middle estuary in relation to river flow in 1992.