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ABUNDANCE, SEASONALITY AND SIZE OF ATLANTIC SALMON SMOLTS ENTRAINED ON POWER STATION INTAKE SCREENS IN THE SEVERN ESTUARY

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Atlantic salmon smolts were sampled from the intake screens of the Oldbury power station in the inner Severn Estuary at weekly intervals between July 1972 and June 1977. These catches, and those taken over nearly three years from the nearby Berkeley power station, demonstrated that the abundance of smolts in the estuary peaked in autumn (October) and, to a far greater extent, in spring (April and May). However, small numbers of smolts were occasionally found in all other months of the year except July. Standard length–frequency distributions of smolts remained unimodal throughout the year. Lengths ranged from 76 to 187 mm, mean 130·2 ±1·87 mm (95% CL), and wet weights ranged from 5·4 to 68·0 g, mean 26·9 ±1·17 g. The mean monthly standard length of smolts increased slightly between the autumn of one year and the spring/early summer of the next year, suggesting that, on average, the former were six months younger than the latter. The condition factor was significantly greater in autumn (1·40) than in spring (1·23). It is estimated that the total number of salmon smolts entrained annually on the screens at Oldbury during the five years ranged from 92 to 791, with a mean of 405. Total estimated numbers at Berkeley ranged from 196 to 788 per annum. The numbers at Oldbury are lower than those estimated for the downstream migrants of the Twaite shad, another anadromous species, and far lower than those of the most abundant of the marine fish species that use the Severn Estuary as a nursery area.

INTRODUCTION

The numerous studies carried out on juvenile Atlantic salmon, *Salmo salar* L. (Pisces: Salmonidae), in the freshwaters of Europe and North America have provided information on the size at which smolting takes place (Elson, 1957), the seasonality of the downstream migration (*e.g.* Meister, 1962; Mills, 1964; Österdahl, 1969; Thorpe & Morgan, 1978; Ruggles, 1980; Youngson *et al.*, 1983), the water temperatures at which this seawards movement occurs (*e.g.* Mills, 1964; Fried *et al.*, 1978; Solomon, 1978; Ruggles, 1980; Jonsson & Ruud-Hansen, 1985) and the role of freshwater discharge in aiding this movement (*e.g.* Youngson *et al.*, 1983; Thorpe *et al.*, 1988). Information on the estuarine phase of the migration is more restricted. However, studies in eastern North America and in Scotland indicate that the seawards movement of juvenile Atlantic salmon within estuaries takes place even when temperatures are well below 10°C, that it is largely passive, occurring during both nocturnal and diurnal flood tides, and that it sometimes occupies only a few days (Fried *et al.*, 1978; McCleave, 1978; Tytler *et al.*, 1978; LaBar *et al.*, 1979; Cunjak *et al.*, 1989).

The intake screens of the power stations in the Severn Estuary and Bristol Channel entrain large numbers of fish (Claridge *et al.*, 1986). Indeed, concern that migrating salmon smolts might be collected in unacceptable numbers, led power station authorities to employ additional measures during the spring of each year in an attempt to allow these smolts to escape. However, doubt has been expressed over the effectiveness of such smolt protection devices (Mills, 1989).

The present study has analysed the numbers of Atlantic salmon smolts in samples collected once weekly over 24 h for five years from the Oldbury power station in the inner Severn Estuary. These, and similar catch data obtained from the nearby Berkeley power station for nearly three years, have been used to determine the size of salmon smolts in the Severn Estuary, and the way in which their numbers on the intake screens varied seasonally, annually, with the freshwater flow into the region, and with the prevailing salinity and water temperature in the estuary. The results are compared with published information on the biology of juvenile salmon in freshwater and with annual and seasonal abundance data recorded for other fish species at Oldbury and Berkeley.

MATERIALS AND METHODS

Juvenile Atlantic salmon were obtained weekly from the material collected on the cooling water intake screens (mesh size 13x19 mm) of the power stations at Oldbury (July 1972–June 1977) and Berkeley (September 1974–June 1977) in the inner Severn Estuary. These fish were silvery in appearance with darkened fins and lacked parr marks, indicating that they were smolts or pre-smolts (Cunjak *et al.*, 1989). The standard length (SL) and wet weight (W) of undamaged fish were recorded to the nearest 1 mm and 0·1 g, respectively. These data were used to calculate condition factors, using the relationship $^{W}/_{SL^3} \times 10^6$ (Ricker, 1975).

Since the once-weekly collections from Oldbury represented all the fish entrained on the screens during the previous 24 h, the numbers caught during each of these periods have been used to estimate the total number of smolts that would have been taken at this station in each month and in each year. Although the screens at Berkeley were regularly cleared of material, this did not necessarily take place at such precise time intervals. Since only fish in relatively good condition were sampled, however, it is assumed that they would, in most cases, have been entrained during the previous 24 h. These data have thus been used to provide 'broad' estimates of the monthly and annual numbers of smolts taken on the screens at Berkeley. N.B. The term 'year', as used in this study, refers to the 12 months between July and the June of the following year.

A smolt protection device was fitted to the intake screening system by the Oldbury power station authorities between late February and early June of each year. This comprised a vertical metal chute, approximately 2 m long and 0·5 m square, that penetrated the bottom of the intake screen trash basket. Wash water from the screens was directed across the top of the chute which was protected by a series of sloping tines that were 100 mm apart and designed to allow fish to pass down the chute and back into the estuary, whilst deflecting any weed and other debris into the basket for disposal. However, the efficiency of the bypass system was reduced when fish came off the screens together with weed or if weed became entangled in the tines. The retention of salmon smolts and other fish was therefore influenced, at least in part, by the large quantities of weed present during this period. Examination of the data for the total numbers of all species of fish collected at Oldbury power station (Claridge *et al.*, 1986; Claridge, unpublished data) provided no indication that the catches underwent a conspicuous decline when the smolt protection device was in place.

Data on freshwater flow in the River Severn at Gloucester were obtained from the Severn Trent Water Authority, while intake water temperatures at Oldbury were provided by the power station authorities. Salinities were recorded at Oldbury at the time of the weekly collections between July 1974 and June 1977. Mean monthly salinities prior to this were estimated from the relationship between salinity and freshwater discharge.

RESULTS

Environmental variables and seasonal abundance of smolts

Freshwater discharge in the River Severn followed similar seasonal trends in each year, with maxima always being attained between December and February, and minima occurring in the summer and early autumn. However, discharge varied markedly among years, with maximum monthly values ranging from as low as 94 $m^3 s^{-1}$ in the winter of 1974/75 to as high as 420 $m^3 s^{-1}$ in the winter of 1976/77 (Figure 1). Monthly salinities at Oldbury showed the inverse trend to freshwater discharge, with maxima of 22–29‰ being attained in August or September and minima of 6–18‰ being recorded in December to February (Figure 1). Monthly water temperatures at Oldbury reached their annual maximum of 18–21°C in July or August and declined to their minimum of 4–6°C in December to March (Figure 1).

The seasonal trends exhibited by the abundance of salmon smolts at Berkeley (September 1974 to June 1977) closely paralleled those recorded at Oldbury during the same period and using samples known to have been collected over precisely 24 h (Figure 1). From the data for the once-weekly 24-h samples at Oldbury, it has been calculated that the total number of smolts that would have been entrained on the screens in each of the five years ranged from 92 in 1976/77 to 791 in 1972/73 (Figure 1), with an annual mean of 405 (Figure 2). Corresponding broad estimates for the total number of smolts entrained at Berkeley in the two years for which there are complete data sets (1975/76 and 1976/77) are 788 and 196, respectively, with 485 being collected in the 10 months from September 1974 to June 1975 (Figure 1).

Smolts were not present in July in any of the five years, and were caught in August only in 1972. The estimated mean monthly numbers at Oldbury rose in the autumn to reach 39 in October, before declining to between 17 and 23 from November to March (Figure 2). The number of smolts entrained on the screens increased sharply in April. Indeed, numbers on the screens at Oldbury were greatest in April followed by May in four years, *i.e.* 1972/73, 1973/74, 1974/75, 1976/77, and greatest in May followed by

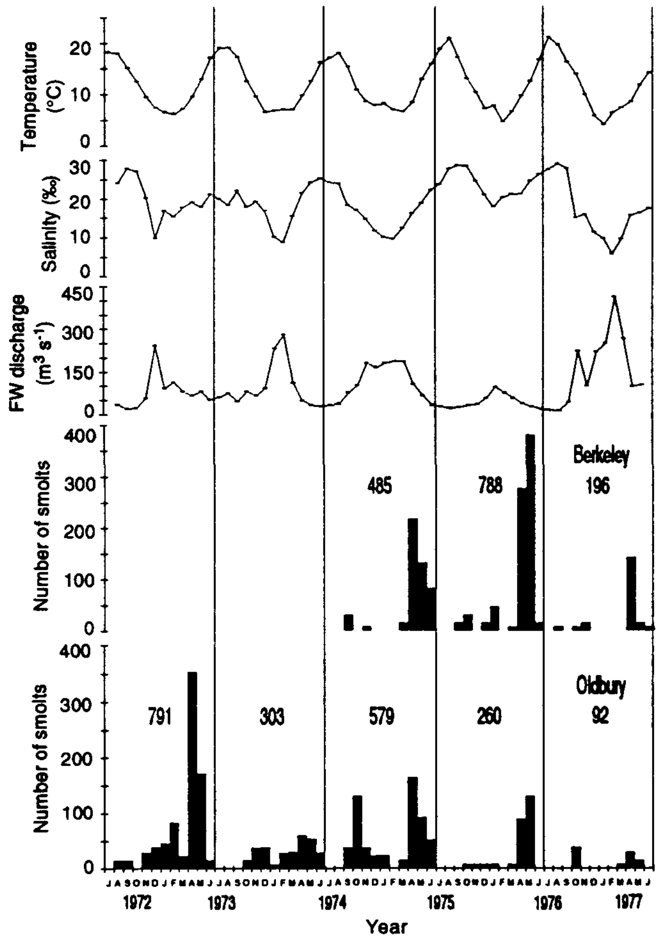

Figure 1. Estimated numbers of Atlantic salmon smolts taken monthly on the intake screens of the power stations at Oldbury between July 1972 and June 1977, and at Berkeley between September 1974 and June 1977. Estimated total numbers at the two power stations each year, and mean monthly values for freshwater discharge ($m^3 s^{-1}$) in the River Severn at Gloucester, and for salinity (‰) and water temperature (°C) at Oldbury in the Severn Estuary, are also shown.

April in the fifth year, *i.e.* 1975/76; a pattern mirrored at Berkeley in 1975–77 (Figure 1). This accounts for the fact that the estimated overall mean numbers of smolt at Oldbury in both April (140) and May (93) were far greater than in any other month of the year (Figure 2). The percentage contribution made collectively by the numbers in April and May was 58%, with individual annual contributions for those two months ranging from 38% in 1973/74 to 85% in 1975/76. The numbers in any given month of the year showed considerable interannual variation, with those in May, for example, ranging from 16 in 1977 to 171 in 1973. The mean number of smolts at Oldbury fell sharply in June (Figures 1 & 2). The capture of the majority of smolts in the Severn Estuary during April and May is consistent with the time that these juvenile salmon typically migrate downstream in rivers in Britain (Mills, 1964, 1989).

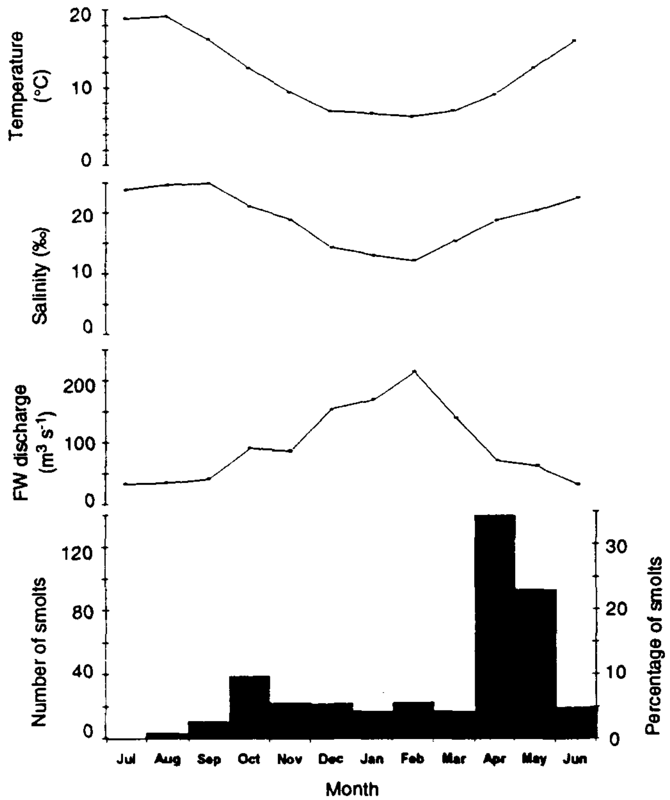

Figure 2. Overall trend in seasonal abundance of Atlantic salmon smolts taken on the intake screens of the Oldbury power station during the 5-y study, expressed as an estimated mean number for each month of the year, and as the percentage that each mean contributes to the total. Mean monthly values for freshwater discharge ($m^3 s^{-1}$) in the River Severn at Gloucester, and for salinity (‰) and water temperature (°C) at Oldbury in the Severn Estuary, are also shown.

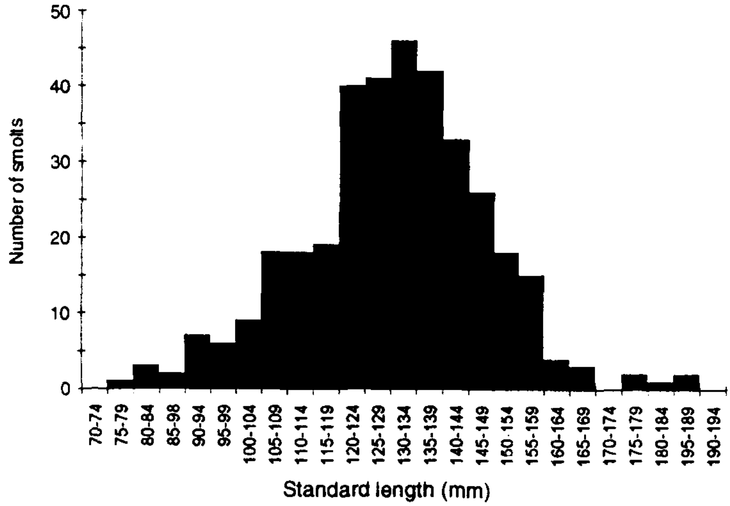

Figure 3. Length-frequency histogram for 356 undamaged Atlantic salmon smolts collected on the intake screens of the Oldbury and Berkeley power stations between July 1972 and June 1977.

Lengths and weights of smolts

The standard lengths of the 356 salmon smolts collected in an undamaged state during this study have been used to illustrate their overall size distribution in the Severn Estuary (Figure 3). Standard lengths ranged from 76 to 187 mm, with the majority (95%) lying between 100 and 159 mm (Figure 3). The median, mean ±95% confidence limits and modal class for the lengths was 131, 130·2 ±1·87 and 130–134 mm, respectively. These length data are consistent with those recorded for Atlantic salmon smolts caught during their downstream migration in freshwater elsewhere (*e.g.* Mills, 1964; Jessop, 1975).

Both the median and the mode for the standard length lay between 120 and 137 mm in each of the twelve months of the year. However, the regression slope for the mean standard length of smolts (SL in mm) versus month (M) between September and June was positive and significantly different from zero ($P<0·05$): SL=118·84+1·49 M (t=2·387, N=10).

Wet weights ranged from 5·4 to 68·0 g, with a mean ±95% confidence limits of 26·9 ±1·17 g. The logarithmic relationship between standard length (SL in mm) and wet weight (W in g) was: log W=–4·70+2·90 log SL ($P<0·001$, r^2=0·916, N=293).

The mean monthly condition factor ±95% confidence limits declined progressively from 1·49 ±0·075 to 1·21 ±0·099 between September and December, and was significantly greater ($P<0·05$) in autumn (1·40 ±0·057) than in spring (1·23 ±0·018).

DISCUSSION

Comparisons with other populations

Our five-year study demonstrates that the abundance of Atlantic salmon smolts in the Severn Estuary undergoes marked seasonal changes. Thus numbers are either zero or very low in the summer months, but then rise to produce a small peak in the autumn (October) and later a very much larger peak in the spring (April and May). These results parallel those recorded in the Western Arm Estuary in Newfoundland (Cunjak *et al.*, 1989). The implication that the downstream migration in the Severn Estuary is biphasic, with the numbers of migrants being greater in the spring than in the autumn, parallels the situation recorded in Girnock Burn in northern Scotland (Youngson *et al.*, 1983; Huntingford *et al.*, 1992). However, this latter study also indicates that emigration from freshwater can be considered as essentially continuous from the early autumn through to the late spring, with the amount of movement during the winter being depressed. This pattern of migration would again be consistent with the fact that the standard length of salmon smolts in the Severn Estuary increased slightly between the autumn and the spring. While both parr and smolts entered estuaries in autumn, the downstream migration in that season consists mainly of parr (Riddell & Leggett, 1981; Youngson *et al.*, 1983; Cunjak *et al.*, 1989). Since the juvenile salmon in the Severn Estuary are markedly silvery, it follows that many autumn migrants in the Severn would probably have undergone smoltification on entering this estuary. This would be consistent with the conclusions of Cunjak *et al.* (1989) that the larger of the parr that entered an estuary in Newfoundland in the autumn, underwent smolting in the estuary and soon thereafter entered the sea. The lower condition factor recorded in spring than autumn migrants in the Severn Estuary, is probably attributable to the utilization of stored lipid during the winter.

The downstream migration of juvenile Atlantic salmon in freshwater in the autumn tends to occur when freshwater discharge rate is elevated (Youngson *et al.*, 1983). The increase in smolts in the Severn Estuary in October likewise accompanies a marked increase in freshwater discharge further upstream in the River Severn. Juveniles of the sea lamprey, *Petromyzon marinus* L., also move downstream into the Severn Estuary in response to increases in freshwater discharge (Bird *et al.*, 1994).

In contrast to the situation in autumn, the marked rise in the numbers of smolts in the Severn Estuary in April and May followed sharp declines in freshwater discharge in the River Severn. However, the rate of freshwater discharge was still relatively high in March/April and, moreover, temperatures at this time were starting to rise from their winter minima. This is again consistent with the conditions pertaining at the commencement of the smolt migration in Girnock Burn in the spring (Youngson *et al.*, 1983).

There is evidence that greater levels of freshwater flow in one tributary than another in the Miramichi River system in New Brunswick may account for the downstream migration of juvenile Atlantic salmon occurring in autumn in the first tributary and not until spring in the second (Riddell & Leggett, 1981). It may thus be relevant that the proportion of smolts caught at Oldbury in the spring was greatest in the year (1975/76) when discharge rates were lowest in the preceding autumn and winter, and least in the year (1974/75) when discharge rates had remained high for several months.

Comparisons with other species in the Severn Estuary

The only other anadromous species that was caught in the Severn Estuary in reasonable numbers during its seaward migration was the Twaite shad, *Alosa fallax* (Lacépède), whose numbers at Oldbury peaked sharply in August and September (Claridge & Gardner, 1978; Claridge *et al.*, 1986). Extrapolation of the data given in these papers indicates that the numbers of shad in these two months were 20 times greater than those of Atlantic salmon smolts in the two months (April and May) when they were most abundant. Furthermore, extrapolation of the values given in Claridge *et al.* (1986) for the two most abundant 'species' collected in the Severn Estuary (the sand goby complex, *Pomatoschistus minutus* / *P. lozanoi* L. and the whiting, *Merlangius merlangus* L.), indicates that the mean annual numbers of these fish entrained at Oldbury would have been approximately 160 times greater than those of salmon smolts.

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