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THE MOVEMENTS OF ATLANTIC SALMON (*Salmo salar* L.) IN THE ESTUARY OF THE ABERDEENSHIRE DEE IN RELATION TO ENVIRONMENTAL FACTORS: II. WATER TEMPERATURE

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SUMMARY

It has been suggested that temperature differences which occur between the sea and UK rivers in the summer months may contribute to delays in salmon entering rivers. However, published data on the relationship between water temperature and the movements of salmon remain contradictory. A study was conducted over the months May to September between 1987 and 1989 to investigate the relationship between water temperatures in the estuary of the Aberdeenshire Dee and the entry of salmon into the river.

At a fixed point in the estuary, water temperatures in the top 5 m of the water column were monitored by means of a chain of thermistors at 30 cm depth intervals and revealed significant vertical stratification throughout the summer months. Mean daily temperatures of the low salinity water in the upper layer of the estuary reached a maximum of 20°C during the study, while differences of up to 10°C were recorded between the water masses within the estuary. Such extreme temperature conditions were relatively isolated events, temperatures generally dropping to much lower values within one or two days.

Over the study period, 27 returning adult salmon were radio tagged in the estuary and were subsequently recorded entering the river. For 18 of these fish, river entry was delayed by over 24 hours and up to 38 days after tagging. However, there was no evidence that temperature conditions in the estuary played a significant role in determining when tagged fish entered the river.

A comparison of temperature conditions on the day of tagging for those fish entering the river within 24 hours of tagging with those for fish whose river entry was delayed by at least 24 hours, showed no significant differences either with river temperature (Mann Whitney test; N=27, U=98, P=0.381) or with temperature differences between water

masses in the estuary (Mann Whitney test; N=27, U=92, P=0.571). Similarly for fish delayed for more than 24 hours, a comparison of temperature conditions on the day of tagging with those on the day of river entry, showed no significant differences either with river temperatures (Wilcoxen paired sample test; N=18, Z=0.632, P=0.582) or with temperature differences between water masses in the estuary (Wilcoxen paired sample test; N=18, Z=0.849, P=0.396).

It is suggested that movements of returning adult salmon into the Aberdeenshire Dee and perhaps other major Scottish rivers are unlikely to be inhibited by temperatures in the estuary.

INTRODUCTION

Estuaries are complex environments which returning adult Atlantic salmon (*Salmo salar* L.) must negotiate if they are to successfully complete their spawning migration. River flow is often cited as the dominant factor controlling upstream migration in salmon (Banks, 1969) and much work has been published on the relationship between river flow and salmon movements (Huntsman, 1948; Hayes, 1953; Banks, 1969; Clarke *et al.*, 1991; Smith *et al.*, 1994). Nevertheless, other environmental factors such as temperature, tide and wind may also affect river entry by salmon (Banks, 1969), in particular perhaps inhibiting upstream movement when flow conditions would otherwise appear to be suitable. An understanding of the behaviour of salmon in relation to such environmental features may be important if we are to understand more fully those factors which act to delay river entry, affecting the exposure of fish to coastal fisheries and mammalian predators and ultimately perhaps affecting the size of any given year's spawning stock.

In the summer months, adult salmon returning from the sea into UK rivers must successfully migrate between water masses whose temperatures differ significantly (Hawkins, 1989). Published data on the relationship between water temperature and the movements of salmon remain contradictory, however. For example, the returns of salmon to a trap above the head of tide on the River Thames have been shown to be negatively correlated with water temperature during the summer months (Alabaster *et al.*, 1991). Hawkins (1989) has suggested that one advantage of fish entering rivers early in the year is that they may avoid "thermal barriers to entry which exist during the summer" and which might otherwise result in the fish experiencing long delays in the estuary, compromising their chances of reaching spawning areas. On the other hand, Banks (1969) in a review of the literature on the upstream migration of adult salmonids noted that 'several examples have been published of instances where a difference in temperature between a river and the sea, or between a stream and a lake has had no effect on migration between the two'.

The present study describes in some detail water temperatures in the estuary of the Aberdeenshire Dee over three summers and examines the extent to which these affected the movements of radio tagged returning adults from the estuary into the river.

MATERIALS AND METHODS

The Aberdeenshire Dee is a major salmon river in the north east of Scotland. The estuary consists of a single river channel which opens into Aberdeen harbour, the head of tide is some 5.25 km from the mouth of the estuary (Smith *et al.*, 1995). Salinity surveys have indicated strong vertical stratification of the lower estuary, low salinity surface water being identifiable for some distance downstream of the river channel, although becoming progressively more saline and thinner. A wedge of high salinity water is evident at lower depths, penetrating some distance into the river channel. In much of this lowest stretch of the channel, distinct layers of high and low salinity water overlap with little indication of mixing between the layers (Smith *et al.*, 1995).

Water temperatures in the top 5 m of the water column were monitored at a fixed point in the Dee estuary 1.6 km from the mouth in an area where distinct layers of high and low salinity water were found to overlap (Smith *et al.*, 1995). A chain of thermistors each 30 cm apart was installed and data was logged from each thermistor at 30 minute intervals throughout the study, except for periods of equipment malfunction. The temperature monitoring equipment was deployed over three summers (May to September) in the years 1987 to 1989.

Returning adult salmon were intercepted by fixed engine (Shearer, 1992) at the mouth of the estuary. The fish were anaesthetized, a radio tag pushed gently into the stomach via a perspex tube placed in the mouth, and the fish was allowed to recover for up to 10 minutes before being returned to the water close to the point of capture (Hawkins and Smith, 1986; Smith *et al.*, 1995). The movement of tagged fish into the river was recorded using an automatic listening station (Hawkins and Smith, 1986) deployed less than 0.5 km above the head of tide.

In total, water temperatures at the time of tagging and river entry were available for 27 salmon radio tagged in the river estuary and subsequently recorded entering the river.

RESULTS

Temperatures

Analysis of the temperature data confirmed that, throughout the study, the estuary consisted of two distinct layers of water. At any given time, the temperature within each layer remained relatively constant with depth. The water temperature between layers, however, often showed a very rapid change within a very short distance (Fig. 1). Analysis of mean daily temperatures (Fig. 2) showed that while the upper layer exhibited significant day to day temperature variations, the lower layer underwent more gradual changes through each summer. The temperature difference between layers (Fig. 3) was also subject to wide day to day variation. Thus, although temperature differences between layers reached at least 8°C during each year of the study, such extreme temperature differences were relatively isolated events, temperature differences generally dropping to much lower values within one or two days.

Analysis of the frequency distributions of mean daily water temperatures within the estuary also showed that although maximum water temperatures encountered in the surface layer each year were high, most days were associated with much less extreme conditions. Mean daily temperatures of the upper layer within the estuary, for example, approached a maximum of 20°C in each of the three years of the study (Fig. 4). On between 60% and 82% of days in the three summers, however, mean temperatures were less than 15°C. Similarly temperature differences between water layers in the estuary approached a maximum of 10°C in two of the summers studied (Fig. 4). However, between 75% and 92% of days in the three years were associated with temperature differences of less than 5°C.

Salmon Movements

Water temperatures at the time of tagging and river entry were available for 27 salmon radio tagged in the river estuary and subsequently recorded entering the river. Of these fish, nine entered the river within 24 hours of tagging and for the purposes of the present analysis have been deemed to have experienced no delay in entering the river. Of the remaining 18 fish, three entered the river more than 10 days after tagging, one of which returned 38 days after tagging.

Water temperature appeared to play no role in determining whether river entry by salmon was delayed following radio tagging. There was no significant difference between the temperatures in the upper layer within the estuary on days when salmon experienced no delay in river entry and on days when tagged salmon were delayed for more than 24 hours following tagging (Mann Whitney test; N=27, U=98, P=0.381, Fig. 5a). Similarly, temperature differences between the two water masses in the estuary on days when salmon experienced no delay in river entry were not significantly different from those on days when tagged salmon were delayed for more than 24 hours following tagging (Mann Whitney test; N=27, U=92, P=0.571, Fig. 5b).

Water temperature also appeared to play no role in determining when fish which had been delayed, subsequently entered the river. Restricting the analysis to fish delayed for more than 24 hours, temperatures in the upper layer within the estuary on the day of tagging were not significantly different from temperatures when the fish entered the river (Wilcoxen paired sample test; N=18, Z=0.632, P=0.582). Temperature differences between water masses in the estuary on the day of tagging were also not significantly different from temperatures when the fish entered the river (Wilcoxen paired sample test; N=18, Z=0.849, P=0.396).

During the study, tagged fish entered the river on days when mean daily temperatures in the upper water layer in the estuary reached 18°C (Fig. 6a) and mean daily temperature differences in the estuary reached 6°C (Fig. 6b).

DISCUSSION

In common with a previous review of the literature (Banks, 1969) the present study showed no statistically significant relationship between the temperature of water masses within the estuary of the Aberdeenshire Dee and the subsequent entry of radio tagged fish into the river. Such conclusions are in contrast to the data presented by Alabaster *et al.* (1991), which showed that the returns of salmon to a trap above the head of tide on the River Thames were negatively correlated with water temperature during the summer months.

The conclusions of the present study are based upon relatively few fish which were tagged and subsequently recorded entering the river. Radio tracking is a relatively time consuming and labour intensive operation and only a very small proportion of a population of migrating salmon can be monitored by this method compared, for example, with the significant proportion of the total run of fish which may be sampled by a fish trap. It is unlikely, however, that this difference in experimental method is sufficient to explain the differences in the results obtained in the two studies. Radio tagging allows direct comparison of the behaviour of individuals under different environmental conditions. Thus, for example the temperature conditions when individual fish did not enter the river may be compared with conditions associated with river entry. Tracking is thus a powerful tool in the study of fish behaviour in the wild and despite the small sample sizes monitored has been shown to be capable of demonstrating, for example, the close relationship between river entry and river flow (Smith *et al.*, 1994).

Although the effects on handling and tagging on the subsequent behaviour of the salmon can also never entirely be dismissed when interpreting the results of tracking studies, the rapid entry of tagged fish when environmental conditions appear suitable for river entry (Hawkins and Smith, 1986; Smith *et al.*, 1994; Smith *et al.*, 1995) would suggest the results of handling the fish are insufficient to explain the differences between the studies.

One possible explanation for the difference in the results between the present study and that on the River Thames (Alabaster *et al.*, 1991) is that temperature conditions were very different between the two estuaries. River temperatures of 20°C were relatively rare and isolated events in the upper layer of the Dee estuary. In contrast, Alabaster *et al.* (1991) report maximum values for temperatures in the Thames estuary as between 19.9°C and 22.5°C. Similarly, Alabaster *et al.* (1991) quote average temperatures in the River Dee in Wales of 26.6°C, in the River Axe of 24.8°C and in the River Frome of 23.9°C during periods when no upstream migration of salmon were observed.

While significant differences exist in the water quality of the Thames estuary compared to the Aberdeenshire Dee, making detailed comparison of the results of the two studies difficult, nevertheless it is clear that the temperature conditions experienced by salmon attempting to enter some rivers elsewhere in the geographical range of the salmon may be expected to be considerably more severe than encountered in the Dee.

Although long term data sets for water temperature in the Dee were not available, circumstantial evidence suggests that the current study period included some of the more extreme summer temperature conditions likely to be encountered by salmon in the Dee estuary. Smith *et al.* (1994) showed that river flows in the Dee dropped to less than 50% of the long term mean flows in the summer of 1989 while at the same time air temperatures averaged between 0.8°C and 1.7°C above the expected monthly values.

Thus the results of the present study would suggest that the movements of returning adult salmon into the Aberdeenshire Dee and perhaps other Scottish rivers are unlikely to be inhibited by temperature conditions in the estuary. It is not clear, however, the extent to which these conclusions may be generalised to the movements of salmon in other areas where more extreme estuarine temperature conditions may be experienced, particularly if the problems of high river temperature were accentuated by low river flows.

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Figure 1 Vertical distribution of temperatures in the estuary of the Aberdeenshire Dee. Data was recorded at 12:00 GMT on 18 June 1989.

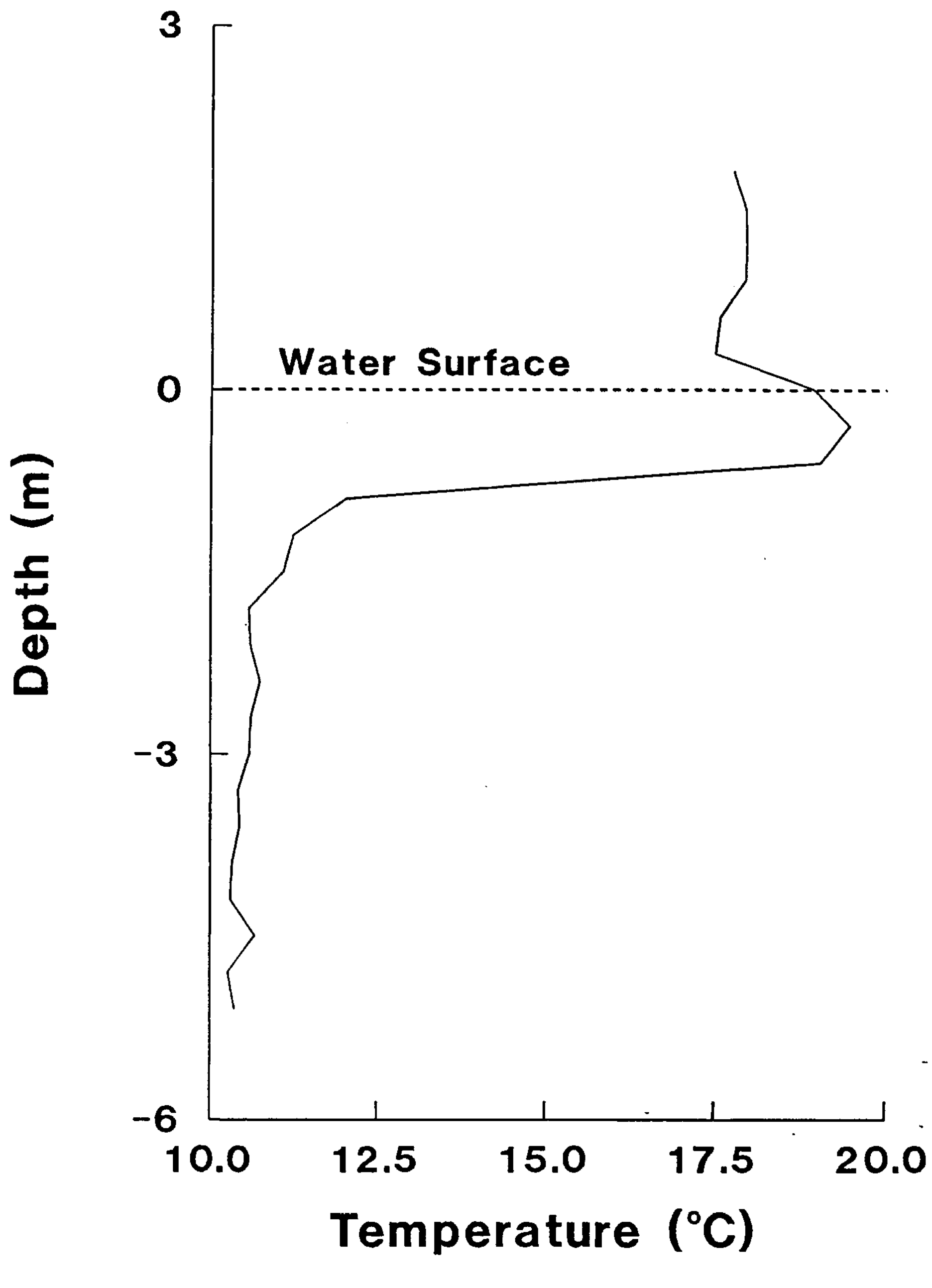

Figure 2 Mean daily temperatures of the upper layer (line) and lower water layer (bar) within the estuary of the Aberdeenshire Dee over the study period.

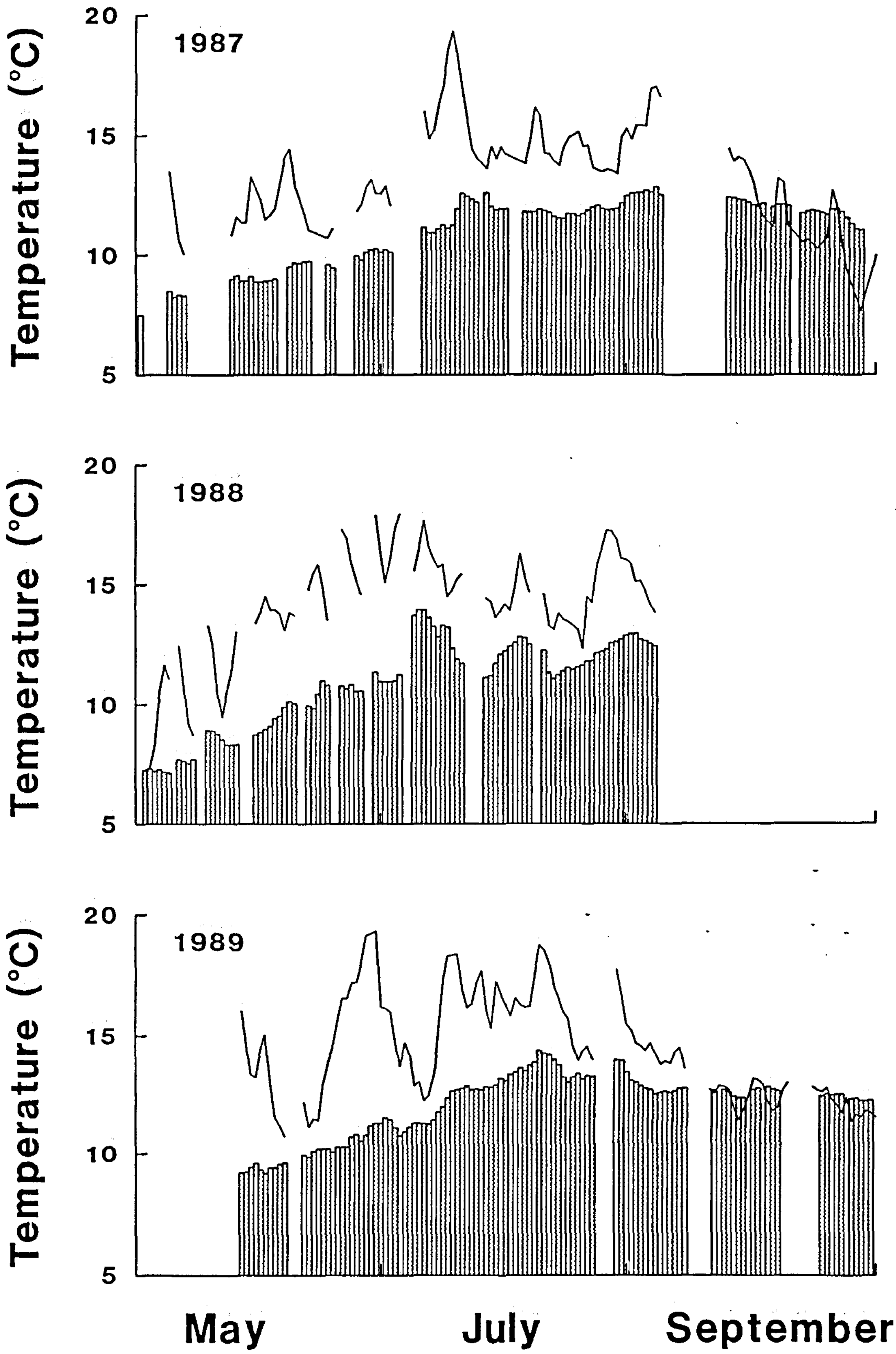

Figure 3 Mean daily temperature differences between the two water layers within the estuary of the Aberdeenshire Dee over the study period.

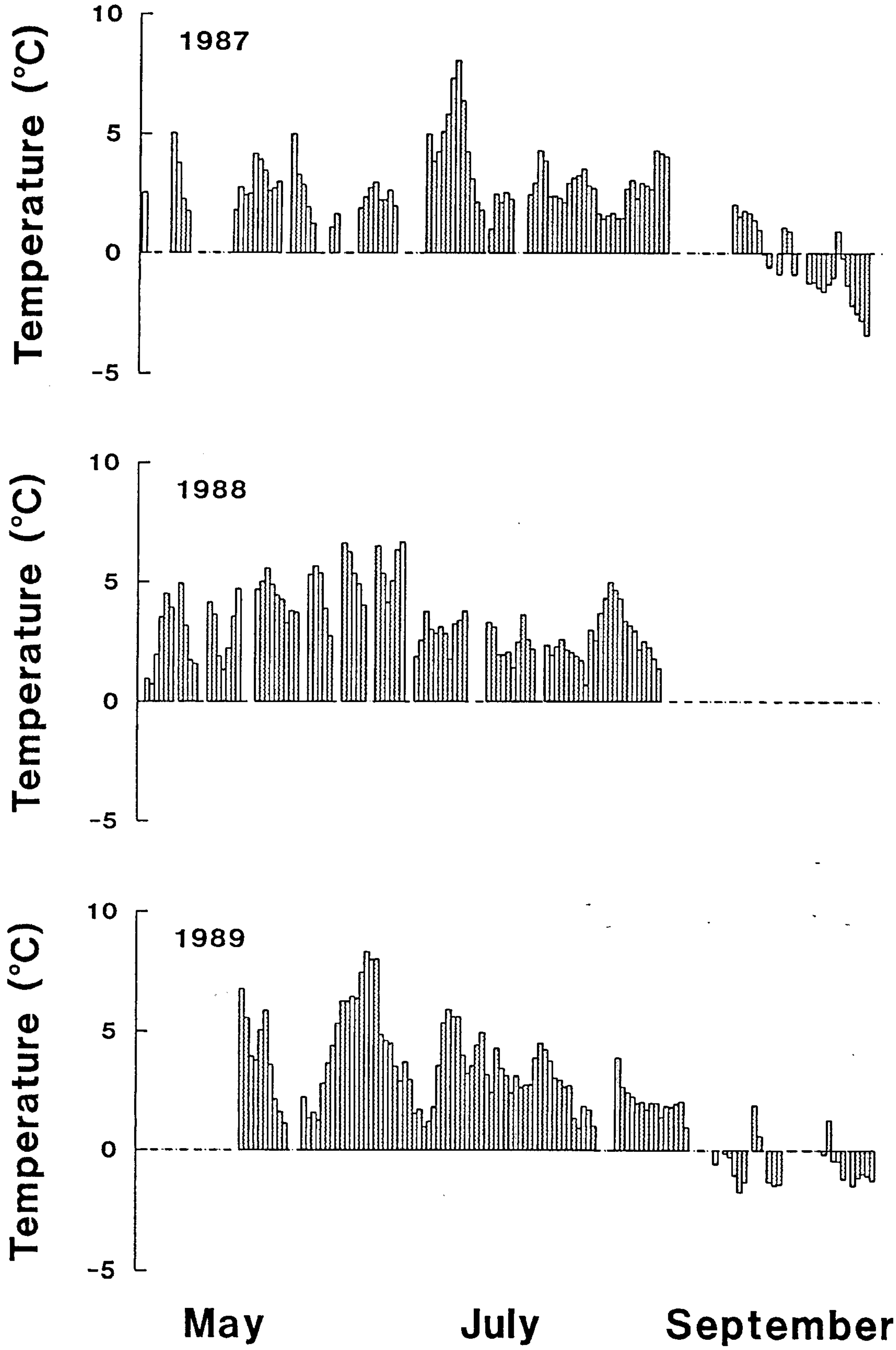

Figure 4a Frequency distribution of temperatures within the estuary of the Aberdeenshire Dee over the study period. Mean daily temperatures within the upper layer of the estuary

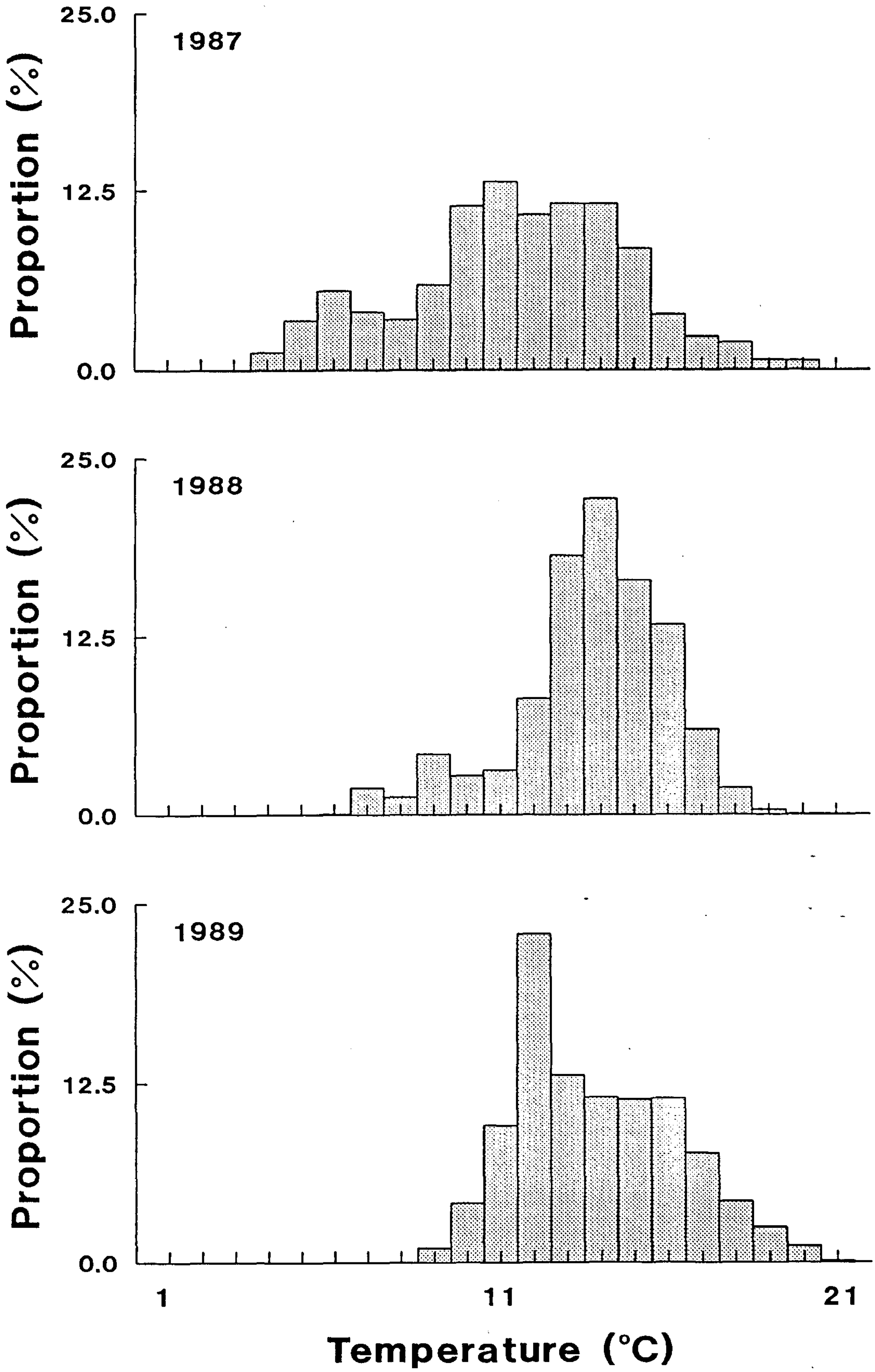

Figure 4b Frequency distribution of temperatures within the estuary of the Aberdeenshire Dee over the study period. Mean daily temperature differences between the two water layers within the estuary.

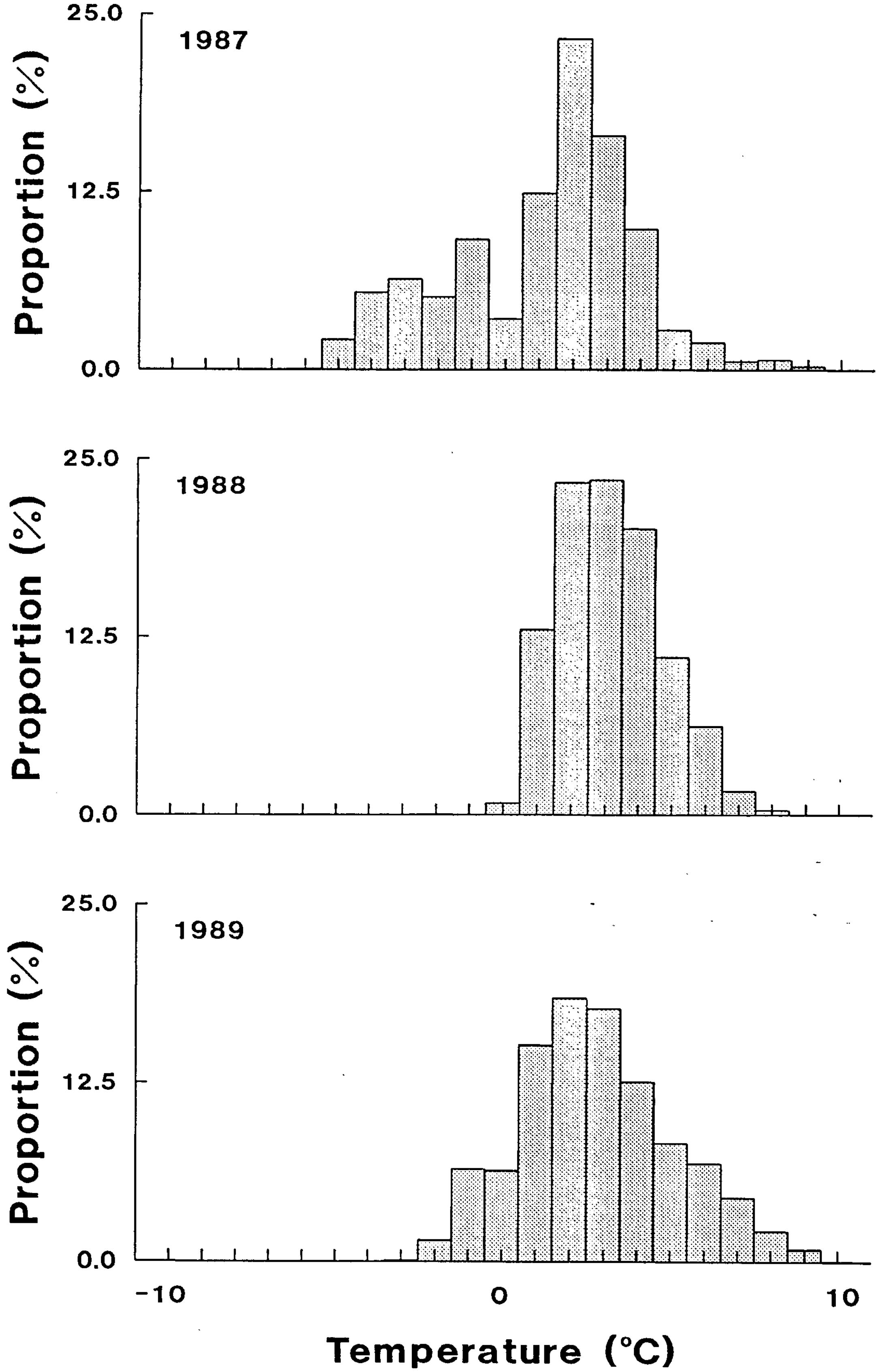

Figure 5 Frequency distribution of temperatures on the day of tagging for those fish entering the river within 24 hours of tagging (white bars) and those fish whose river entry was delayed by at least 24 hours (black bars).

a) Mean daily temperatures within the upper layer of the estuary
b) Mean daily temperature differences between the two water layers within the estuary.

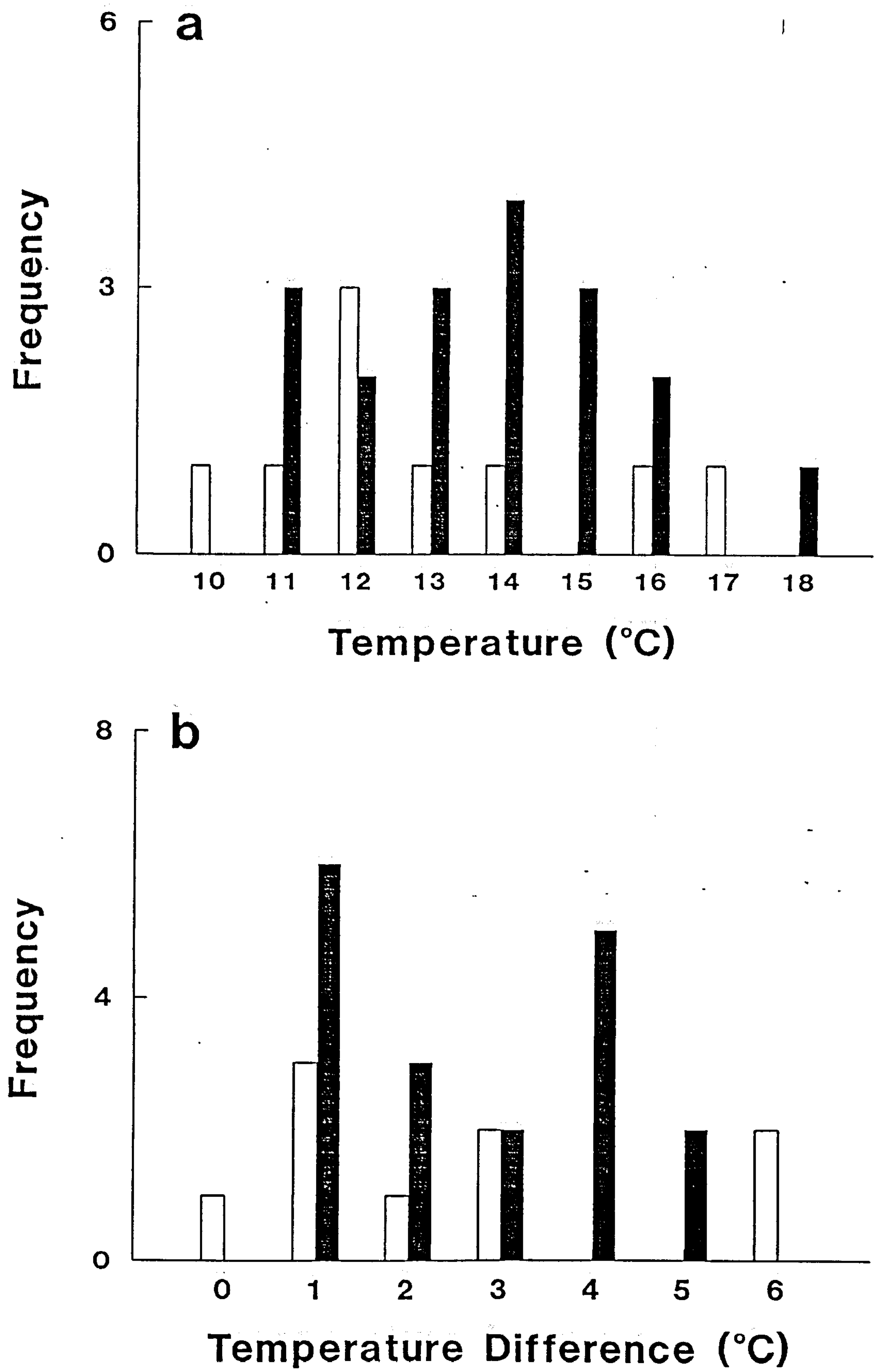

Figure 6 Frequency distribution of temperatures on the day of tagging (white bars) and on the day of river entry (black bars) for those fish whose river entry was delayed for more than 24 hours.

a) Mean daily temperatures within the upper layer of the estuary
b) Mean daily temperature differences between the two water layers within the estuary.