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The combined use of acoustic tracking and echosounding to investigate the movement and distribution of common bream (*Abramis brama*) in the River Trent, England

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Abstract

Spatial behaviour and distribution of fishes along a 7.6-km lowland reach of the River Trent, England, were examined using two complementary telemetry techniques: acoustic tracking to assess the movement and activity of common bream *Abramis brama* (L.) and quantitative echosounding for measuring the density and distribution of fish shoals. Nine adult bream (39.3–53.2 cm) were tracked by means of intraperitoneally implanted acoustic transmitters from 19 July to 12 September 2000. Home range size varied between 0.35 and 5.40 km of river length over this period. Bream were relatively inactive during daylight hours, began moving near dusk, and tended to move throughout the night. A distinct daytime residence area was occupied by most tagged fish on most occasions, while river use at night was more variable between individuals. Mobile echosounding surveys, with the transducer beaming horizontally across the river, conducted at night between July and September 2000, showed a highly contagious fish distribution within the study reach. For 200-m sections of river, there was a negative correlation between the relative frequency of acoustic tracking fixes at night and mean fish densities, as measured by echosounding for targets larger than −50 dB (c. 5-cm long). However, there was a highly significant positive rank correlation between the relative frequency of acoustic tracking fixes and acoustic targets larger than −30 dB (c. 22-cm long), most of which in this river are bream. This suggests that telemetry and echosounding can, in this part of the River Trent, be combined to provide valuable spatial information at individual and population scales for bream.

Introduction

Over the last two decades, acoustic- and radiotracking methods have provided dramatic advances in our understanding of the spatial behaviour of freshwater fishes (Lucas & Baras, 2001), including many cyprinids, which are the dominant taxa in European lowland rivers. The common bream *Abramis brama* (L.) is a benthophagous, eurytopic cyprinid that is characteristic of the fish communities of slow-flowing European lowland rivers (Mann, 1996). This species is important in the River Trent, England, both for its ecological value and the high regard it commands with recreational fishermen (Lyons et al., 2002). Because of their shoaling behaviour, bream may exhibit extremely clumped distributions and an understanding of the factors influencing their distribution and behaviour is important to the effective management of these and similar fish populations. Several tracking studies of this species have demonstrated highly ordered spatial behaviour, with bream in the rivers Witham and Thames, England, displaying excursions of up to 10 km from their 'home-site' at regular intervals (Langford et al., 1979; Langford, 1981); homing over similar distances in Irish canals (Caffrey et al., 1996) and clear diel migrations between the littoral and pela-

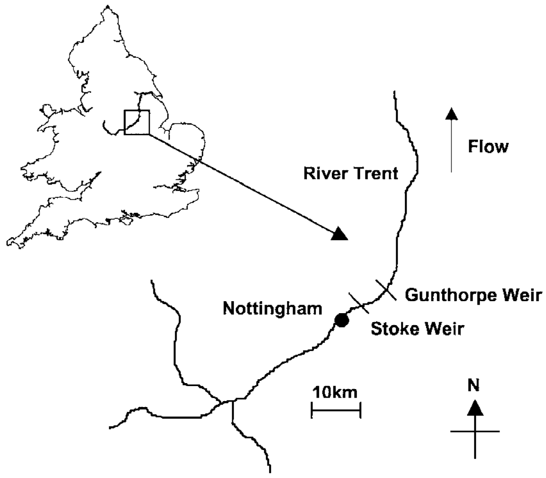

Figure 1. Location of the study area on the River Trent, England.

gic zones of Lake Constance, Germany (Schulz & Berg, 1987).

One criticism that is frequently applied to fish tracking studies is that, even with relatively large sample sizes, data may not always reflect behaviour at the population scale. Echosounding is a well-established tool for fish studies in large waters (MacLennan & Simmonds, 1992; Brandt, 1996) which has the capacity to provide information on abundance and distribution at a scale approaching or approximating to the population, although it suffers from limited species discrimination in mixed-species systems (Lucas & Baras, 2000). In recent years, mobile echosounding has been used to quantitatively evaluate fish populations in relatively shallow (typically 1.5–4 m), lowland rivers in Europe, including England (Duncan & Kubecka, 1993, 1996). This development involved the application of a horizontally directed acoustic beam for both mobile and fixed location surveys in relatively shallow water (Duncan & Kubecka, 1993; see also Lucas & Baras, 2000). Echosounding in lowland rivers has primarily been used to estimate fish abundance and size composition. The technique also provides its user with an ability to continuously sample over a large scale (up to 30 km of river during a night survey) of river in a relatively short time. This approach has been applied to study the spatial heterogeneity of fish in large lowland rivers including the rivers Thames (Duncan & Kubecka, 1996) and Trent (Lyons, 1998), England.

Tracking and echosounding have almost exclusively been applied in isolation, although they are both telemetric methods (Priede, 1992). One notable exception is the study carried out by Malinin et al. (1992) in which the complementary use of both techniques was applied to investigate the behaviour and distribution of bream in the hypoxic regions of four Russian reservoirs. The study demonstrated that, when used in combination, tracking and echosounding can be highly effective at interpreting behaviour at individual and population scales. The objective of the work presented here was to assess the utility of combined acoustic tracking and echosounding techniques to investigate the spatial behaviour of bream in the River Trent, during the summer months, post-spawning.

Materials and methods

Study area

The River Trent is one of the UK's largest rivers. It is 286-km long, from its source in Staffordshire to the Humber Estuary and drains an area of 10 435 km^2. The study area (Fig. 1) is typical of the lower Trent basin, being an area of mostly alluvial and gravel deposits, the river having a meandering course, with natural floodplain and washlands adjoining the channel. The 7.6-km study reach lies 9 km downstream of Nottingham, a large city (population c. 0.5 million) that is situated in the centre of England.

The river's substantial width, depth, flow and turbidity make the use of conventional fish capture methods (electric fishing, netting, trapping) inappropriate for determining fish species composition of the main river channel (Cooper & Wheatley, 1981). Hence angling catch data is the only method currently available to determine species composition and their relative abundance in the river. Standardisation of the method of recording and analysing catch composition data from the Trent (Hyatt, 1999) has limited possible bias from this method, so that it should be sufficiently robust to reflect the rank order of abundance of fish species. On the basis of frequency of occurrence in angler catches for seasons between 1995/1996 to 1998/1999 (the most recent for which data are available), the fish community of the study reach comprised, in order of importance, roach *Rutilus rutilus* (L.) (median 41%), common bream (median 15%), Eurasian perch *Perca fluviatilis* (L.) (median 15%), chub *Leuciscus cephalus* (L.) (median 11%), gudgeon *Gobio gobio* (L.) (median 8%) and northern pike *Esox lucius* (L.) (median 3%) (Hyatt, 1999).

Table 1. Characteristics and longitudinal movement of the fish

Fish No.	Age (years)	Sex	Length (mm)	Track duration (days)[a]	Max. range upstream (km)[b]	Max. range downstream (km)[b]	Cumulative minimum distance moved (km)[b]
1	12	F	444	55	2.55	0	10.75
2	11	F	435	49	1.10	0.10	4.40
3	12	F	532	50	2.55	0	10.25
4	Unknown	F	429	55	5.40	0	13.05
5	12	F	434	15	2.65	0	2.55
6	12	F	466	50	2.40	0.05	4.55
7	11	F	429	48	2.05	0	5.10
8	8	M	393	48	0.30	0.05	0.95
9	13	F	500	55	4.15	0	26.0

[a]Number of days each pinger was transmitting from 19 July 2000.
[b] Distance measured is the cumulative total from the daytime residence reference position to each fish for all tracking occasions from the 28 July–6 September 2000.

The study reach is impounded at both the upstream and downstream limits by navigation weirs that are impassable to cyprinids. The channel along most of the study reach is typically 80-m wide and 3-m deep, with a fine gravel, sand, and silt substrate. The habitat at the upstream 1 km of the reach is noticeably different, being narrower (65-m wide) and shallower (1.5–2 m). These differences have created a habitat in which faster currents and a river bed with a coarser substrate exists for approximately 1 km of river length. The river is used by large boat traffic, but this activity occurs mostly during daylight hours. Whilst movement out of the study reach may be possible through the navigation locks situated adjacent to each weir, preliminary tracking studies in 1999 suggested that, for adult bream, this is unlikely (J. Lyons, unpublished data). For this species the reach therefore appears to be a relatively closed system.

Acoustic tracking

Previous pilot studies demonstrated that, because of the high conductivity of the lower Trent, often exceeding 1000 μS cm^{-1}, radiotracking was not feasible due to the low range achieved. Therefore, acoustic tracking was used to follow the movements of individual adult bream. The fish (fork length = 39.3–53.2 cm, mass = 1.10–3.30 kg) tagged in this study were captured by rod and line within the study reach, all within 10 m of each other and over a period of 5 h on 19 July 2000. Acoustic tags (3-cm long, 0.8-cm diameter and 4.0 g in air; V8SC-2L, Vemco, Halifax, Nova Scotia) with a battery life of 90 days were implanted into the peritoneal cavity using a method similar to Moore et al. (1990). Table 1 summarises the characteristics of the nine adult bream tracked. The maximum tag life achieved during the study was 55 days and this may have been due to a 1-year storage period and a subsequent loss of power in the silver oxide batteries used in these tags.

Following surgery, each fish was placed in a recovery tank that had a constant supply of oxygen and a lid to provide a dark, reduced-stress environment. These fish were held until surgery was completed on all of the individuals and the transmitters were confirmed as working correctly, a procedure that took 2 h to complete. The tagged fish were then all released together at the capture site.

Tracking of fish was carried out, using a manually-operated receiver (Vemco VR60) and a 15° beam-width directional hydrophone, in a small boat powered by an outboard motor, between 19 July and 12 September 2000. Each fish, once detected, was located to within an accuracy of 10 m, using a combination of gain setting (dB) and hydrophone angle (degrees off longitudinal boat axis). Each transmitter was identified by its unique frequency and pulse period combination. Care was taken to minimise disturbance from the tracking boat. When locating the position of fishes the motor was run at low throttle and fish were generally not approached closer than c. 50 m. A total of 24 location sessions were made between 28 July and 12 September 2000. Fish were located on at least three separate days each week and, in total, on 24 occasions

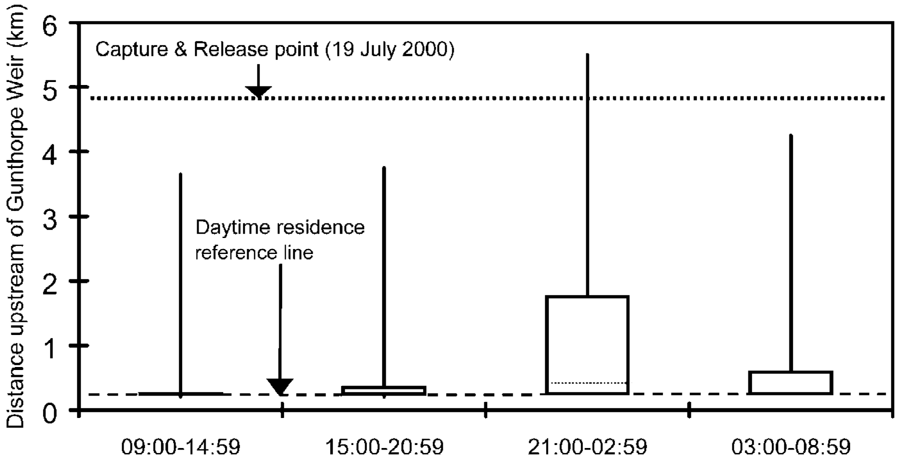

Figure 2. Diel variation in locations (maximum upstream, maximum downstream, median, 1st and 3rd quartiles) between four time periods for nine adult bream *Abramis brama* acoustically tracked along the study reach of the River Trent between 28 July and 6 September 2000.

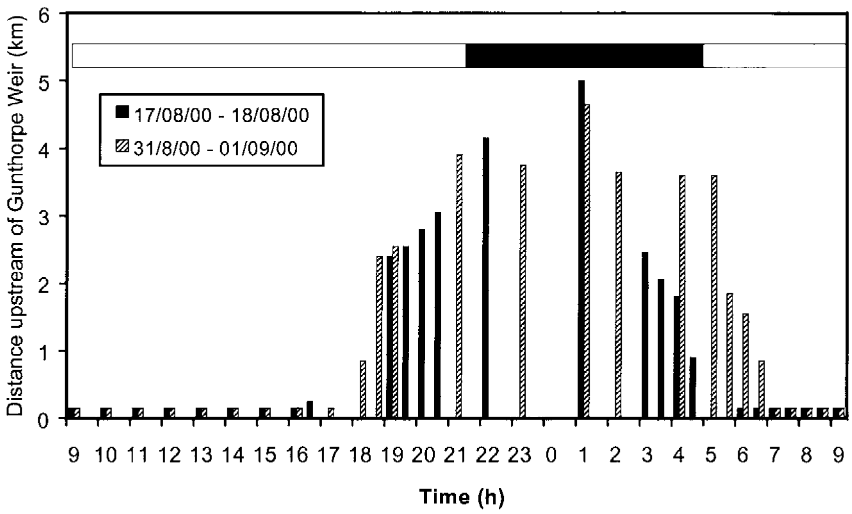

Figure 3. The diel movement pattern of *Abramis brama* #9 during two tracking surveys along the study reach of the River Trent. The horizontal bar at the top of the graph indicates the median day (sunrise −1 h to sunset +1 h, open portion of bar) and night (sunset +1 h to sunrise −1 h, shaded portion of bar) periods for the two surveys.

during the study period. Data collection was stratified over four equal time windows according to the time of first location of fishes on a given day. These were 09:00–14:59 British Summer Time (BST) (41.7% of locations); 15:00–20:59 BST (16.7% of locations); 21:00–02:59 BST (25.0% of locations) and 03:00–08:59 BST (16.7% of locations). On two occasions the activity and movement of selected individuals was monitored throughout a 24-h cycle. Since most fishes were sedentary and usually grouped together by day, the location of all fish was relatively easy to determine simultaneously. At night, because the main group of fishes split up into several groups, frequent fixes were gathered on a few individuals, with locations of other tagged fishes obtained where possible.

Echosounding

Three echosounding surveys were conducted along the study reach on the nights of 26/27 July, 11/12 September and 12/13 September 2000. Surveys were carried out between 22:00 and 04:00 BST, a time when fish are relatively active in the water column and so detectable by horizontal echosounding, and when boat traffic interference is at its lowest level (Duncan & Kubecka, 1993, 1996). Each survey involved a single upstream (right bank) and downstream transect (left bank) of the study reach with the boat kept at a constant ground speed of 5 km h^{-1}.

The acoustic data were collected with a Simrad EY500 portable scientific echosounder (Simrad Co., Horten, Norway), operating at a frequency of 120 kHz. The echosounder was operated at its maximum ping rate of 10 pings s^{-1}. A pulse duration of 0.3 ms, and a bandwidth of 12 kHz were used, and complete compensation for reduction in echo level with increasing range (40 Log R), was employed for both echo counting and sizing. Minimum target strength thresholds were set at −50 dB, with single echo targets filtered within 0.8 and 1.2 of the echo pulse length. The split-beam transducer (8.3° × 4.2° beam angles, at the −3 dB points of the directivity pattern) was mounted on rigid scaffolding 1 m in front of the boat, and at 80-cm depth, as described by Duncan & Kubecka (1993), with the sonar beam directed horizontally and perpendicularly across the middle part of the river, to achieve maximum coverage of the water column. This also enables the equipment to insonify most fish in their side aspect, because in rivers most fish are aligned parallel to the direction of flow (Duncan & Kubecka, 1993; Kubecka et al., 2000). Sample range was maximised (20–25 m) by the manual adjustment of the transducer scaffolding arrangement. Acoustic data were recorded onto a laptop computer.

Data analysis involved echo counting (40 Log R) to provide results for fish volume density (fish per 1000 m^3) and target size (dB). The results were then further analysed at two different target strength thresholds, −50 dB and −30 dB and converted from acoustic size (dB) to predicted real size (mm) using the straight line calibration equation for cyprinid and percid fish insonified in side aspect, $Y = 29.2X - 98.3$, where X = log 10 fork length (mm) and Y = target strength (dB) ($P < 0.001$) from Kubecka & Duncan (1998a).

Results

Fish movements

The fish were continually tracked during the first few hours of their release on 19 July 2000. Large movements (>100 m) were not observed in the first hour after release, and five fish (#4, #5, #6, #7 and #9) remained within 200 m of the release site for the first 12 h. The remaining fish all moved 1.5–3.1 km downstream of the release point. Within 24 h of their release all nine individuals had taken up a daytime position 150 m upstream of Gunthorpe Weir (Fig. 2). After 28 July 2000 this daytime location was vacated only on three out of 111 occasions during the tracking of all fish in the time period 09:00–14:59 h BST. This location is therefore used as a daytime residence reference point for the measurement of diel activity in the tagged fish. Data for the immediate post-tagging period of 19–28 July 2000 were excluded from any further analysis in order to minimise the risk of including data reflecting ‘abnormal behaviour’ in the initial period after release. From here on all data presented reflects the tracking of all fish over the period 28 July–22 September 2000, for which transmitters were working (Table 1). The period of study was associated with a relatively low and constant discharge (mean = 33.9 m^3 s^{-1}, range = 28.1–47.0 m^3 s^{-1}) and steady water temperatures (mean = 19.0 °C, range = 16.2–20.4 °C).

A wide variation in individual movement (Table 1) was found, from a minimum cumulative distance travelled between locations of 0.95 km (fish #8) to a maximum value of 26.0 km (fish #9). The linear home range of the tagged fish was found to vary widely (Table 1). Only fish #4 was found to return to the capture and release site. The maximum sustained swimming speed recorded over the ground for any fish during continuous tracking was 1.4 BLs^{-1} for fish #9 during an upstream movement of 2.7 km over a stretch of river with a mean current velocity of 0.22 ms^{-1}.

Diel activity

The movement patterns of acoustically tagged bream indicate that different areas of the river were occupied at different times over the diel sampling periods (Fig. 2). Daytime grouping of tagged fish, 150 m upstream of Gunthorpe Weir, was normally followed by a partial or complete splitting of the group between dusk and the following dawn to occupy additional upstream locations along the study reach. Diel location data is illustrated for fish #9 for which detailed information was obtained (Fig. 3) during two 24-h cycles. Approximately 2 hours before sunset (c. 20:00 BST) the fish began to move in an upstream direction from its day location and it mostly utilised an area between 4.6 and 5.1 km upstream of Gunthorpe Weir between c. 21:00

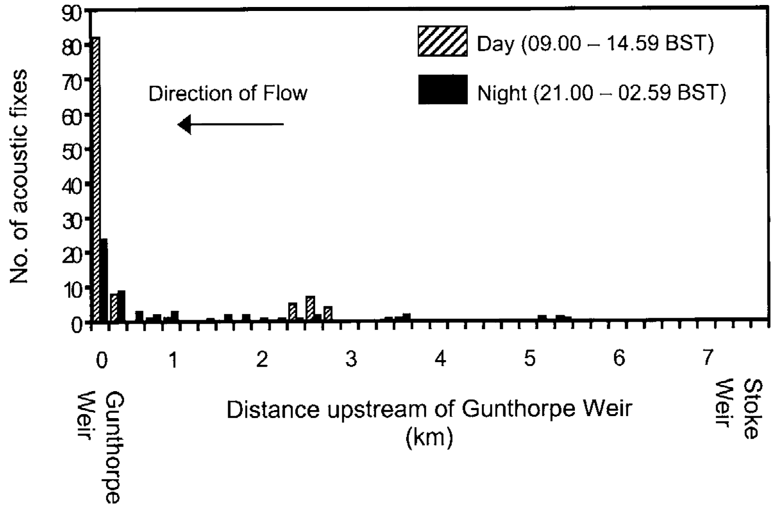

Figure 4. A comparison of the frequency distribution of acoustic fixes of bream *Abramis brama* between day (09:00–14:59 h BST) and night (21:00–02:59 h BST) along the study reach of the River Trent.

and 04:00 BST before returning to its original daytime residence area.

The effect of this diel behaviour on the locations of all tagged bream is shown in Fig. 4 for daytime (09:00–14:59) and night-time (21:00–02.59) locations. A comparison between the relative frequencies of locations of tagged bream by day (09:00–20:59) and night (21:00–02:59) within four river section categories demonstrated a significant difference in association of tagged fish between the different sections by day and night ($\chi^2 = 48.54$, df = 3, $P < 0.001$). Acoustic fixes taken during the day showed a highly skewed distribution towards the daytime residence area at Gunthorpe Weir whilst those acoustic fixes taken at night, exhibited a greater spread of location points along the river.

Comparison of fish distribution by acoustic tracking and echosounding

Given the differences in day and night distributions of tagged bream, night-time data only (21:00–02:59), were used to compare the relative distribution of tagged bream with estimates of spatial distribution from echosounding surveys (Fig. 5). Acoustic tracking data are presented as the combined number of acoustic fixes recorded in 200-m river sections between 28 July and 12 September 2000. The echosounding data represents the mean (±SE) fish densities over each 200-m section, combined for upstream and downstream runs conducted on the three separate night-time surveys. Substantial spatial heterogeneity in distribution for 'all' fish targets (target strengths greater than −50 dB) is evident along the study reach (Fig. 5a). The pattern of this variation in fish density is also size related as data analysed for all fish (TS > −50 dB; Fig. 5a) gives a different distribution pattern to that analysed for larger fish only (TS > −30 dB; Fig. 5b). At a TS of −50 dB a significant negative correlation was obtained between the frequency of tag locations and fish density, for all sections for which data was available (Spearman rank correlation, $r_s = -0.446$, $P < 0.05$). However, when the TS was set at −30 dB, to exclude fish estimated to be smaller than c. 22-cm long, a significant positive correlation between these variables was obtained (Spearman rank correlation $r_s = +0.632$, $P < 0.01$). This suggests that, at night and on this stretch of river in summer, there was concordance between population-scale acoustic surveys of the distribution of 'large' fishes and distribution patterns obtained from acoustic tracking of adult bream.

Discussion

Most of the bream tracked in this study moved within a 2.5-km linear home range, although two fish were found to occupy larger ranges of 5.0 and 4.15 km. These results are similar to those obtained from other tracking studies on bream from rivers and canals (Langford et al., 1979; Langford, 1981; Caffrey et al., 1996). Of course, at this site, the potential for

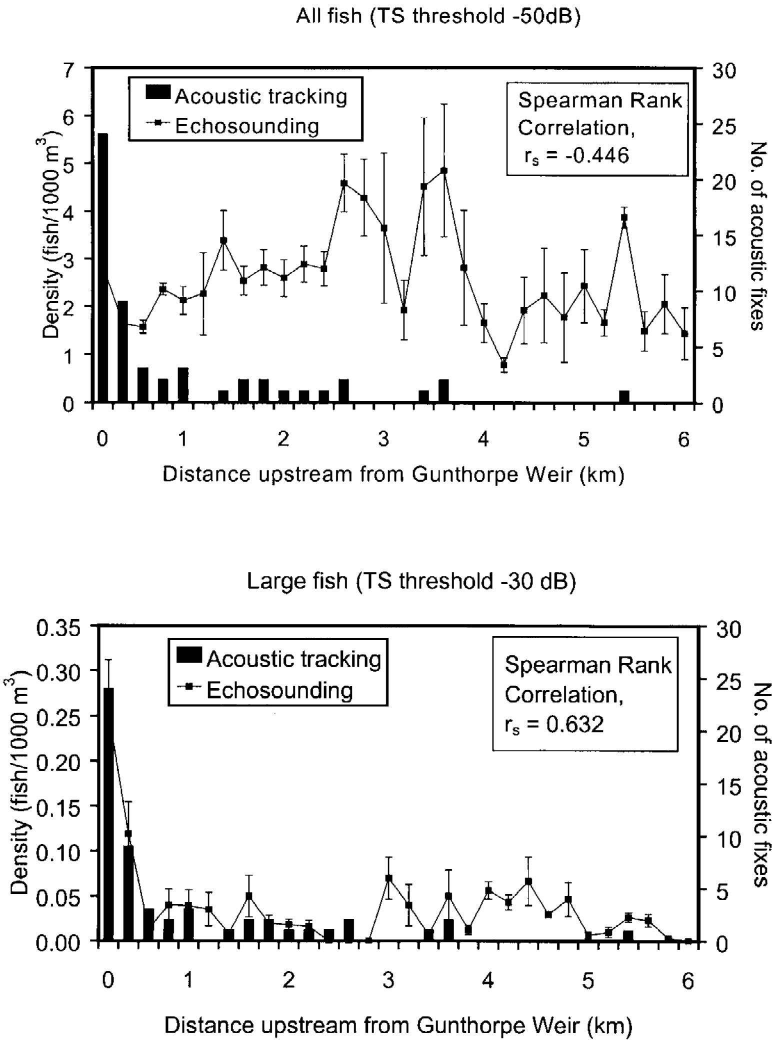

Figure 5. A comparison of the distribution of night-time fixes for acoustically tagged bream *Abramis brama* (28 July–12 September 2000) in 200-m river sections and fish densities (mean ± S.E. for each 200-m section of river) from combined results of three echosounding surveys over the same period analysed at: (a) −50 dB target strength (TS), and (b) −30 dB target strength thresholds. See text for fish-size equivalents of these target strengths.

movement is somewhat limited by the presence of weirs and navigation locks, although there is no evidence that any tagged fish made a concerted effort to leave the study reach. Recapture of conventionally-marked bream on the River Suck, Ireland (Whelan, 1983) showed that feeding bream rarely moved more than 2 km during the summer months, but that substantial spawning migrations occurred for some shoals in spring. Many other cyprinid species have also been shown to occupy restricted ranges during the normal feeding and growth period (Lucas & Baras, 2001).

The individual behaviour of the bream tracked in this study could broadly be divided into two classes. Some fishes exhibited relatively small daily movements with excursions from the daytime residence site of less than 2 km. The second group comprised individuals that undertook greater daily movements (up to 5.2 km), albeit from the same daytime residence site. This division in behaviour was documented by Malinin et al. (1990) who recognised two types of bream behaviour related to activity level and composition of diet: sedentary fish with a low-diversity diet contrasted with nomadic fish with a more diverse diet. This apparent dichotomy of behaviour within a population has also been demonstrated for some other cyprinid species (e.g. Stott, 1967), but not in others (Lucas & Baras, 2001).

Diel patterns of movement by bream and other cyprinid fishes between different habitats is widely documented. Kubecka (1993) provides some evidence that fish species, including bream, of large deep lakes migrate from offshore to inshore areas at night. Bream in Lake Constance, Germany make regular day–night excursions between the littoral and pelagic zones (Schulz & Berg, 1987). Although most of these diel-shift studies have been carried out in lakes this study shows that diel movement of adult bream may also occur on large rivers. Fixed-location horizontal echosounding of fish over a 24-h period in the River Thames, England, showed that at night, larger fish (principally cyprinids in this river) moved up into the water column and towards the littoral zone, returning to deeper layers during the day (Kubecka & Duncan, 1998b). The morphology of the River Trent is similar to that of the Thames in supporting only a narrow productive marginal area (5–10 m from each bank), the remainder of the river bed being less productive and relatively uniform in its habitat. Suitable areas for efficient foraging may therefore be limited.

During the day all of the tagged bream occupied the same residence area, but regularly moved into other areas at night. This study was carried out during a period in which reproductive behaviour had ceased and when flow and temperature were relatively constant and oxygen levels do not appear to have been depleted. The size of the fish also precluded natural predation risks, and thus predator-related avoidance behaviour is unlikely. Therefore, it is likely that foraging requirements would provide the greatest behavioural stimulus for observed diel behaviour. Riverine cyprinids have been shown to move between discrete areas at different times of the day, for foraging (e.g. barbel *Barbus barbus* (L.), Baras, 1997).

The return, in this study, by tagged bream to specific locations in the River Trent suggests that this species is capable of homing to specific locations in this river, at least during the summer months. These results are consistent with those gathered from other studies on bream (Langford et al. 1979; Langford, 1981; Caffrey et al., 1996). Further data are needed to determine whether daily homing to a daytime residence area also occurs under more adverse conditions such as high flows or low temperatures and also if such behaviour is confined to indigenous fish. This last point has implications for the stocking of non-indigenous fish into large rivers. Although the current data does not provide indisputable proof for site preference, the repeat return by tagged fishes to certain areas of the river, by day and night, suggests a degree of positive selection over the rest of the study reach.

The results of comparing the distribution of 'large' (>c. 22-cm) fish at night by echosounding and from night-time tracking records of bream suggest a concordance between the two techniques at night. Unfortunately, echosounding cannot easily be used for quantifying fish abundance and distribution in lowland rivers by day, because fishes tend to remain close to the bottom where they cannot easily be discriminated by the horizontal beaming methods that must be employed in shallow water (Duncan & Kubecka, 1993; Kubecka & Duncan, 1998b). Also, echosounding cannot directly identify species or enable the tracking of individuals over long periods (Lucas & Baras, 2000). Use of a TS threshold of −30 dB (c. 22 cm length) enabled us to filter out larger fish from the acoustic data. In the study reach bream are the dominant species that grows larger than the threshold value, with other species such as pike, *Esox lucius* (L.) and carp, *Cyprinus carpio* (L.) few in number. Chub larger than the TS threshold do exist throughout the study reach although, because of their rheophilic nature (Mann, 1996), in summer they are most likely to occur at the upstream end of the study reach. Tagged bream were almost always found downstream of this area. This reduces the likelihood that concordance between the distribution of tracked bream and 'large' fish determined by echosounding might be confounded by a high degree of mixing between the two species.

Because most fish in rivers are aligned parallel to the flow (Duncan & Kubecka, 1993; Kubecka et al., 2000) and because the transducer was aligned perpendicularly to the flow, our use of side-aspect TS – fish length conversions is appropriate. Therefore, we believe our fish size estimates from echosounding and the resultant data filtered for 'large' fish are valid for comparing with tracking data. Nevertheless, further data, including fish tagged over a wider area of the study site are required to explore further the apparent agreement between the two techniques in assessing spatial distribution of bream in the River Trent. However it does present the first successful combined use of acoustic tracking and echosounding to investigate the movement and distribution of fishes in a large, lowland river. In other river systems, especially those with a greater variety of larger fish species that require a similar habitat, such comparisons may not be possible.

The combined use of tracking and echosounding to study fish in large lowland rivers is a relatively new concept which has only been possible in recent years due to the development of shallow water echosounding techniques (Duncan & Kubecka, 1993, 1996). The contrasting distribution of fishes of different sizes along the study reach, obtained from echosounding surveys suggests differential use of space by small fish and large fish, especially adult bream. While speculative, it is possible that those areas of the river suitable for large bream are unsuitable for small fish, possibly due to differences in foraging habitat requirements. Further use of acoustic tracking and echosounding, in combination with assessment of habitat characteristics and food availability may enable this to be determined.

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