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Activity patterns in pike (*Esox lucius*), as determined by motion-sensing telemetry.

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Abstract

Activity patterns of pike fitted with motion-sensing radio tags were recorded using novel automated monitoring equipment. Activity was categorised into short duration (<5 s) and long duration (≥5 s) events. Pike displayed short duration activity events throughout the day and night. Long duration activity events were very sporadic and were often followed by long periods (>24 h) of quiescence. Experimental and observational records (based on over 8500 tracking observations) indicated that these long duration events followed by quiescent periods could be associated with the fish feeding. In total, active pulse patterns (both long and short duration) were only recorded for ~5% of the time that the fish were monitored. Analysis of the temporal patterns in the long duration activity events showed distinct diel patterns, and some seasonal variation associated with sunrise and sunset times. Results from the automated system are compared with results obtained from manual tracking. Data show that activity monitoring could be a useful method for determining the feeding periodicity of these fish and would enable a greater understanding of predator – prey interaction.

Introduction

The fish populations of the lower River Frome in southern England have been extensively studied, and much is known about the diet, numbers and age structure of the commonest species. In particular, research has concentrated on the pike (*Esox lucius* L.) (Mann, 1976; Mann, 1980; Mann, 1982; Mann and Beaumont, 1991) However, until recently little was known about the movements or activity and feeding patterns of these fish. As one of the top fish predators in northern European waters, knowledge of these factors would be of considerable ecological importance (and economic importance where predation on game fish is a factor).

The development of telemetry techniques has allowed some information on the movements of pike to be documented (Diana, 1980; Mackay and Craig, 1983). In addition, information regarding activity and feeding behaviour of pike has been collected by attaching heart-rate telemetry tags to fish (Armstrong *et al*., 1989; Lucas *et al*., 1991). Whilst these tags give excellent high precision data, tag longevity is low, and a maximum data run of only 90 hours was achieved by Lucas *et al*., (1991). All the above studies however are in still waters and the movement and activity patterns of pike in rivers are much less understood. Where data on movement in rivers does exist (Masters *et al*. 2002; Ovido and Phillipart, 2002) they have been shown to be capable of making extensive movements.

The interaction between pike and their prey in rivers is also poorly understood. Whilst Clough and Ladle (1997) proposed that the diel movement shown by dace in the river was a strategy to avoid predation by pike, Pitcher and Turner (1986) found that predators have an advantage at dawn when stalking shoaling prey. However it is not known whether pike activity patterns reflect this diel pattern and potential advantage at low light conditions. In addition, the hunting strategy of the pike in the river was not known. Pike are usually described as ambush predators (Savino and Stein, 1989); however, whether they attack their prey from a single, regular ambush site, or whether they move between several potential ambush sites has not been well established. Within lakes there is some evidence that pike are mobile between ambush sites (Diana, 1980); however, in a river environment, energetic cost associated with swimming against flow needs consideration. Pike are adapted for rapid acceleration rather than prolonged swimming (Jones *et al.*, 1974; Webb, 1984) thus it was thought that in rivers they might exhibit a less active hunting technique. The study described here was designed to elucidate pike feeding strategy and timing in order to further investigate this hypothesis.

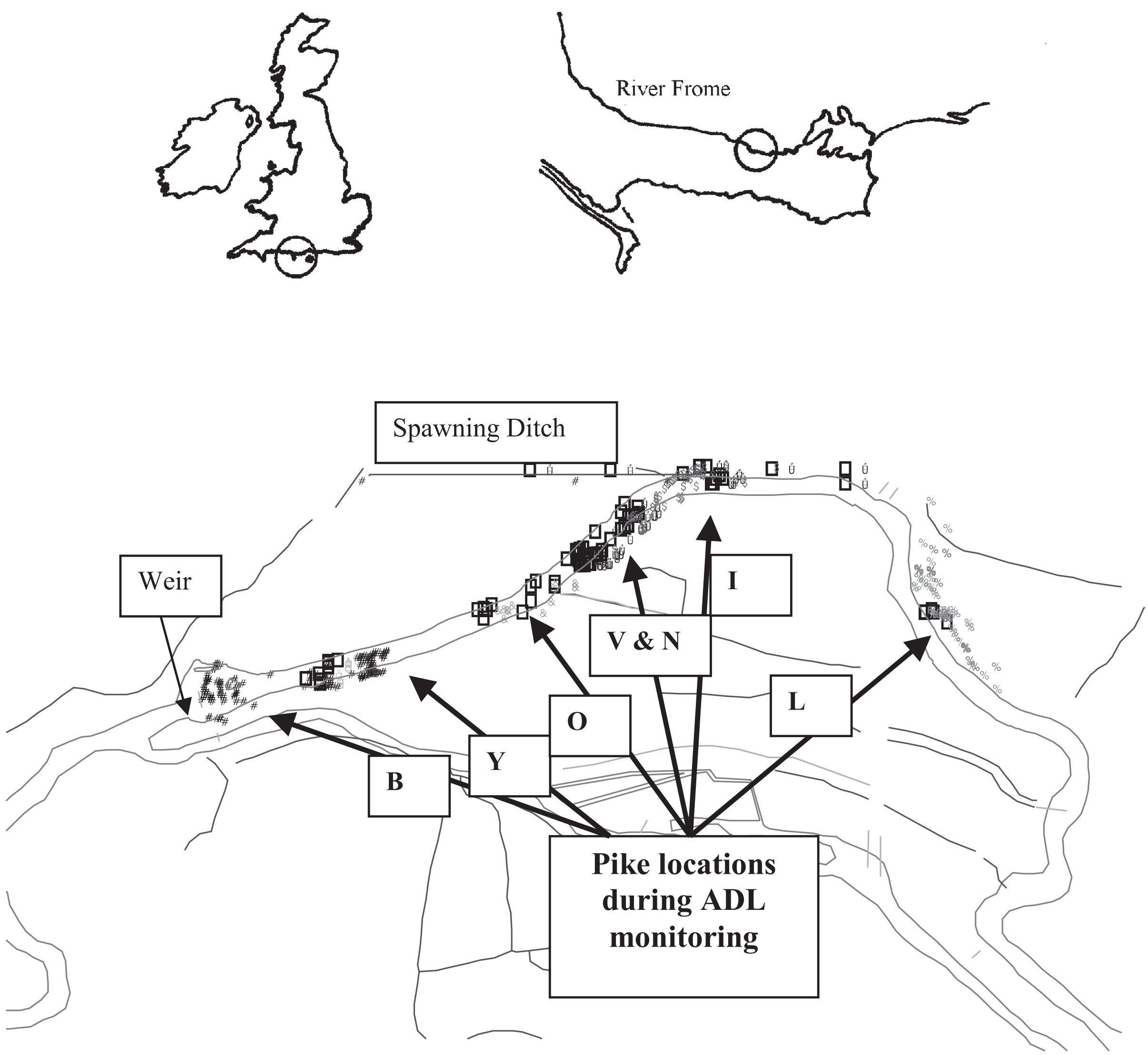

Fig. 1 – River reach studied and locations of fish during study period.

Materials and methods

Study Area
The part of river chosen for the activity study (Fig. 1) was about 500 m long and was an area known to contain several pike. At the upstream end of the area was a weir pool and near the mid-point was an area of gravel shallows. Also present was a small drainage ditch known to be used by pike for spawning. The study site was typical (apart from the weir pool) of much of the lower Frome. Sections encompassing the core home range areas (Kenward and Hodder, 1996) of the pike being automatically monitored were generally straight (Welton *et al*., 2002). This made tag reception by the monitoring equipment simpler than if a very meandering section had been used.

Tagging
Pike were tagged with TW-5 activity sensing radio tags (Beaumont *et al*., 2002), manufactured by Biotrack Ltd., Wareham, Dorset, BH20 5AX, UK. These tags react to high levels of omni-directional movement by reducing the interval between the pulses transmitted from the tag. Whilst normal swimming activity will not trigger the fast pulse rate, burst swimming will (e. g. during pursuit of prey or if the fish is startled). Tag life is dependent upon the degree of activity by the fish (due to the higher energy consumption of the tag whilst transmitting at high pulse rates) but in general a life of >2 years should be expected. In this study a maximum tag life of 2.5 years has been achieved.

The relatively large size of the tags (80 mm long, 16 mm diameter, weight 22 g in air 7 g in water) required that only pike longer than 500 mm (fork length) were tagged. The tags were implanted into the body cavity of the fish under general anaesthesia. Full details of the tagging procedure and logging system used to record the pulse intervals of the tags are described in Beaumont *et al*. (2002).

To date, during the three years of the study a total of 35 pike (comprising 15 males and 20 females) have been tagged in the river and over 8800 fixes recorded for them. Of the pike tagged, eight have been monitored by the Automatic Data Logger (ADL) system (Table 1).

Activity Data Logger (ADL)
Activity status of the tag was assessed by recording the number of activity events on a purpose designed Biotrack ADL. Unlike the majority of listening stations, where the logger records the presence or absence of a tag at pre-selected time intervals, the ADL system can be set to continuously record the time interval between tag radio pulses for a single tag. Based upon feeding experiments (Beaumont *et al*., 2002), bursts of continuous high activity over a defined time period were considered to be potential feeding activity by the fish. In Beaumont *et al*. (2002) a ≥3-second time discriminator was used to categorise potential feeding events, however, experimental feeding data subsequent to that study (CEH, unpublished data) have led us to move to the use of a ≥5-second time discriminator. Activity data from the ADL was thus stratified into two categories, continuous periods of activity <5-seconds (minor activity events) and continuous periods of activity ≥5-seconds (major activity events). The time length of these major activity events could be >60 seconds duration.

The ADL was connected to a 3-element Yagi antenna mounted on a 4-metre mast. Both H-Adcock and dipole antennae were tested on the ADL, but reduced range (from the dipole) and null points (from the H-Adcock) in reception resulted in our favouring the Yagi. Due to the Yagi antennas directionality (5º peak reception), and its front loading characteristics, it was necessary to position the ADL at one end (upstream or downstream) of the pike core range with the antenna pointing towards the core range area. In this way maximum signal range with minimum null errors could be achieved. Receiving range of the ADL with the mast-mounted antenna was about 80 m. This was lower than the range for a standard receiver due to the signal strength required for the ADL to adequately discriminate true tag pulses from radio noise. Moderately high water conductivity (specific conductivity ~500 μScm^{-1}) may also have reduced received signal strength.

Table 1 – Details of pike monitored by ADL and duration of monitoring periods

Pike	Length (cm)	Weight (kg)	Sex	No. ADL monitoring runs	Time of year	Max time data run (Hrs)	Min time data run (Hrs)	Total time (Hrs)	% time gaps
B	71	3.6	M	18	Sept 01-Mar 02	469	0.2	1592	12
C	69	3.9	F	6	Sept 01–Nov 01	250	4	582	2
I	87	5.8	M	3	Feb 02–Mar 02	339	7	569	5
L	79	4.2	F	1	Jun 02	133	133	133	Not analysed
N	65	1.9	F	6	Jun 01			480	Not analysed
O	60	1.8	F	4	Oct 01–Nov 01	107	48	311	Not analysed
V	52	1.7	F	5	Mar 02–Apr 02	259	5	499	2
Y	64	2.2	M	6	Dec 01–Feb 02	576	18	1314	Not analysed
TOTAL				43				5480	5.3% (average)

Setting-up the ADL was a relatively complex procedure with several parameters requiring precise tuning to ensure a strong, clean signal for the ADL to record. In particular it was critical to set the threshold levels for the signal recognition in order to separate out extraneous noise from true signals. Unfortunately the precision required also meant that when the signal varied in intensity, and/or background noise levels varied after initial calibration, false data could be recorded.

Due to the very mobile behaviour of the pike, within the ADL data there were periods when no signal was received by the ADL. These periods varied from <1 second to several hours. Whilst the long duration gaps were a result of the fish moving out of range of the antenna, shorter periods could have been due to signal attenuation by aquatic vegetation or conductive material in the riverbed. The small null point at either end of the tag could also have caused gaps if the tag directly lined up with the antenna; these are likely to be of very short duration however due to the small angle of the null. Whilst gaps in the data only accounted for <4% of the time recorded by the ADL, the presence of the data gaps resulted in periods where we could not be certain that the fish had not had a ≥5 second activity (and thus potential feeding) event.

In addition to the gaps in the data, extraneous "noise" was also recorded by the ADL. These noise events were characterised by pulse widths less than the shortest duration pulses of the tag (c. 260 ms). The cause of this interference is not known but the area where the ADL was deployed is near an electric rail line, a military gunnery and tank training range and a fish counting facility running a computer (renowned for creating radio noise). Although generally infrequent and of very short duration these noise events did, on occasions, create false active signals (≥5 seconds duration) in the data.

The presence of the gaps and noise in the data presented considerable challenges for analysis of the data. The ADL produced considerable amounts of data: one record every 1300 ms while the fish was at rest and every 300 ms during active events. This resulted in between 66,000 and 288,000 data points per day. The computer programs written to analyse the data partially enabled some automation in detecting the gaps and noise in the data, however final manual editing of the data was still required.

ADL data was edited for gaps by collating activity data into minute intervals, and then recording whether any >5 second gaps occurred within that minute. Minutes where gaps of this duration did occur were coded.

Noise editing was carried out by filtering <260 ms pulse intervals from the data and assessing whether sufficient numbers of these "false" signals occurred during >5 second activity events to render the event invalid.

Manual Data Collection

In addition to the data being collected by the ADL, activity of the fish was also evaluated using manual tracking methods. During the manual tracking (3-tracks a day for 13-days at four different seasons) output from the tag was listened to for 5-minutes. The number of fast pulse "bursts" in that time was then recorded. No stratification into major and minor events was made with the data obtained from the manual tracking records. The number and identity of pike present during each track varied, due to immigration/emigration from the study section, natural mortality, and new pike being tagged after the beginning of the study (Table 2). All tagged pike within the study section were followed on each date shown in table 2 in order to provide as large a sample as possible from which to make inferences about the patterns of activity of the pike population. The inclusion of pike that did not reside within the section over the entire study period reduced the potential for bias that might have occurred had only 'resident' fish had been followed.

The proportion of five minute periods during which activity was detected was determined separately for each individual pike. The proportion of five-minute periods during which activity occurred (from all pike combined) were then compared between time periods morning (1-hour before sunrise to 2-hours after sunrise), mid-day (10:00 to 14:00) and evening (1-hour before sunset to 2-hours after sunset) using Kruskal-Wallis tests (Table 2).

In addition, the mean number of activity events heard in each time period was calculated for each pike individually. Mean numbers of activity events were then compared between time periods (for all pike combined), within each 13-day track, using Kruskal-Wallis tests (Table 2).

Activity data for individual pike collected at hourly intervals by manual tracking were also compared with concurrent data collected from the ADL to assess the comparability of the data collection methods.

Results

In excess of 5400 hours (228 days) of data has been collected from a total of 8 fish monitored by the ADL (Table 1). The longest run of data, without any gaps >5-seconds was approximately 4-days, and up to 12-days of almost continuous data have been obtained with some gaps of between 5 and 10-seconds duration. A 21-day run of data was obtained for one fish (including an 8-hour gap due to ADL battery failure).

Table 2 – The dates of manual tracks, together with the number of pike included in each track and results of Kruskal-Wallis tests for differences between time periods during each track.

Date	No. Pike tracked	K-W test significance–No. events			K-W test significance–Proportion		
		DF	H	P	DF	H	P
September 2000	5	2	2.13	0.34	2	2.77	0.25
December 2000	7	2	4.09	0.13	2	2.22	0.33
July 2001	8	2	5.02	0.08	2	2.63	0.27
September 2001	10	2	2.95	0.23	2	3.86	0.15
December 2001	11	2	1.48	0.48	2	0.74	0.69
March 2002	12	2	0.22	0.89	2	0.13	0.94

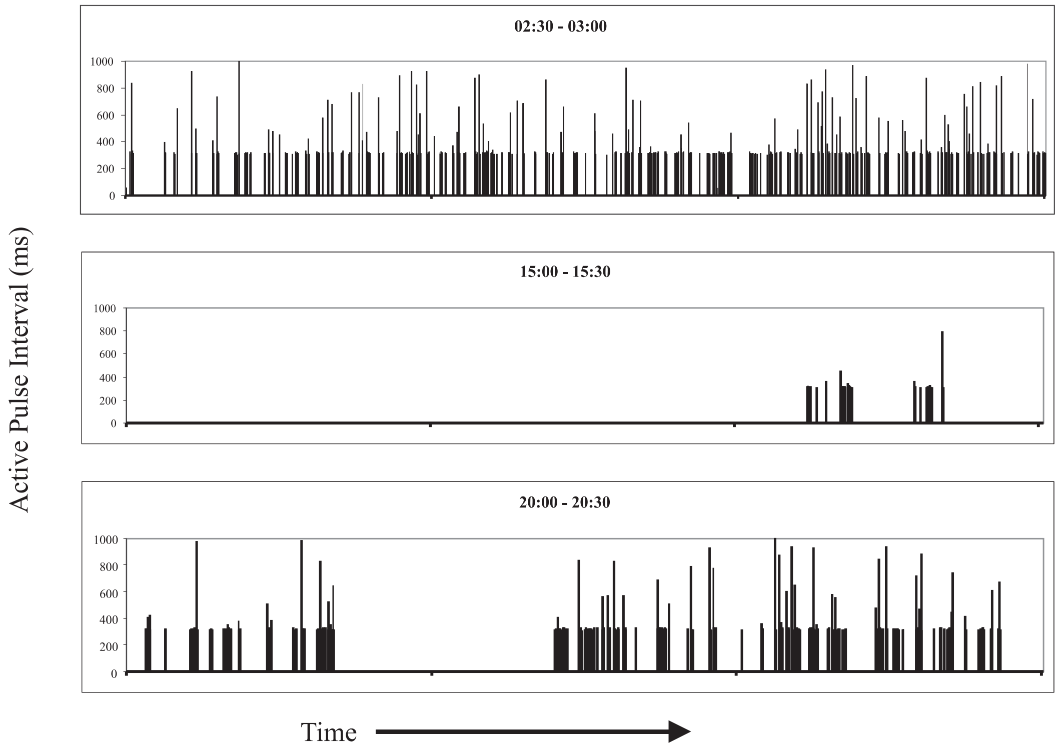

Fig. 2 – Total activity pulses recorded by ADL over three, 30-minute periods from pike N, June 2001.

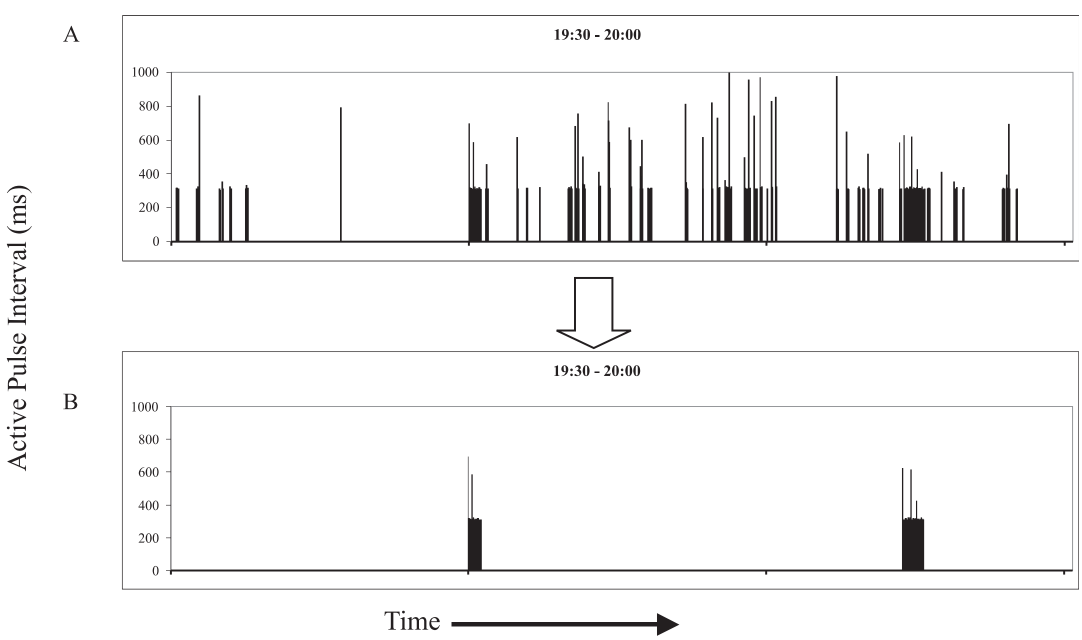

Fig. 3 – Total activity data between 19:30 to 20:00 for pike N June 2001 (A) and filtered ≥5-s activity data (B) for the same period.

In general, pike appeared to exhibit many minor activity events throughout the day and night with very few totally quiescent periods. Figure 2 shows an example of activity pulses recorded by the ADL for Pike N in June 2001 for three, 30-minute time periods throughout the day. When the minor activity events are filtered from the data however, a much-reduced pattern of major activity events is apparent (Fig. 3 A and B). Collation of these 'major events' into 1-hour time periods indicates activity peaks roughly corresponding with dawn and/or dusk: individual fish showing some variation between being predominantly active at dawn, dusk or both times (Fig. 4).

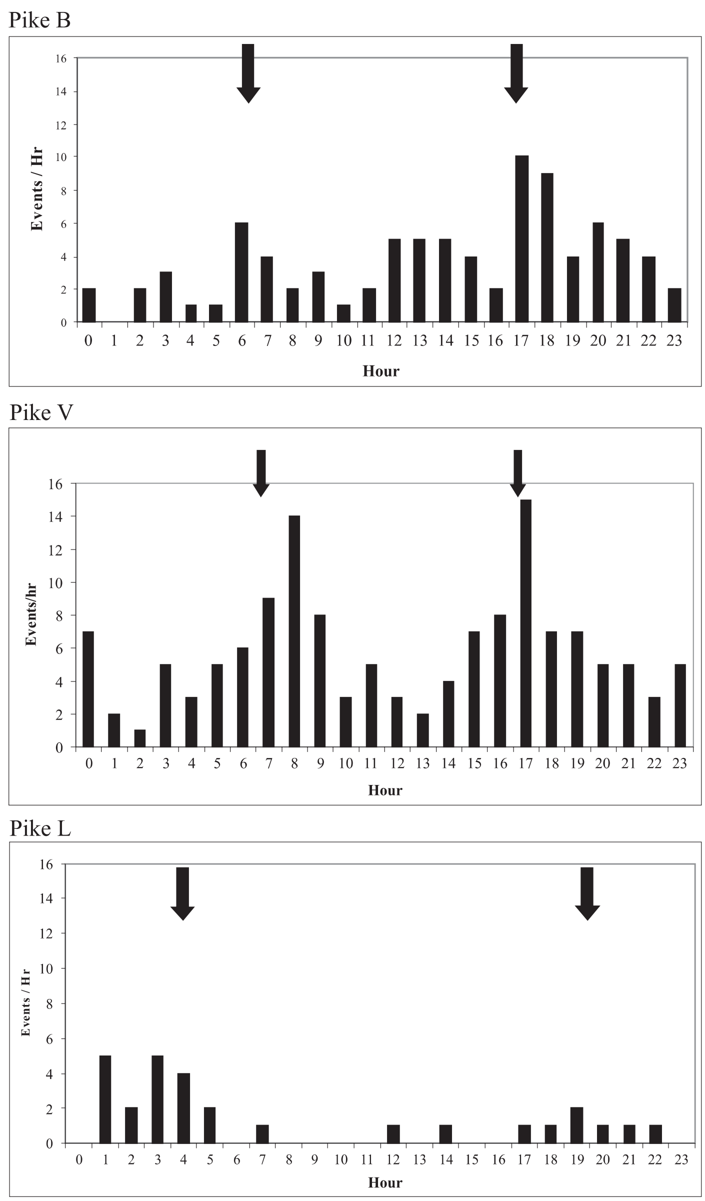

Fig. 4 – Major activity events per hour recorded by ADL for three pike: Pike B (collated over 12-day period in March 2002), Pike V (collated over 19-day period in March 2002), Pike L (collated over 5-day period in June 2002). Arrows indicate sunrise and sunset.

Hourly activity data for the male pike I, recorded in March 2002 (Fig. 5), did not conform to the pattern of movement observed in other fish: there was a much higher general level of activity (some days in excess of 1000 major activity events) and a higher proportion of major activity events occurring during the middle of the day. Fig. 6 shows data for one day (collated into activity per minute) of the high level of continuous activity (sometimes in excess of 60-seconds) exhibited by pike I during this period, and also shows an example of the high level of activity that occurred during the night on some occasions.

Data collected during the manual tracking were assessed for activity patterns. Whilst for individual tracking periods there appeared to be a trend towards lower proportions of activity events occurring during the day, as compared to during dawn or dusk, no significant differences occurred between the proportion of five-minute periods containing activity events in different time periods (Fig. 7, Table 2). Pooled data for all tracking periods also did not show any significant pattern (Kruskal-Wallis test: all d.f. = 2, H = 4.12, p = 0.13). Similarly, whilst there also appeared to be a trend towards lower median numbers of activity events for individual tracking periods being recorded during the day, no significant differences occurred between the number of activity events recorded in each time period for any of the tracks (Fig. 8, Table 2) or for the pooled data (Kruskal-Wallis test: all d. f. = 2, H = 2.49, p = 0.29).

Agreement between the ADL data and the hourly-recorded manual diurnal data was variable, but often showed good agreement for periods of high activity (Fig. 9). When the hourly data for fish being tracked manually (not all of which had been monitored by the ADL) were collated, and grouped into hourly activity events however, a clear pattern of crepuscular activity peaks similar to that registered by individual fish monitored by the ADL was found (Fig. 10).

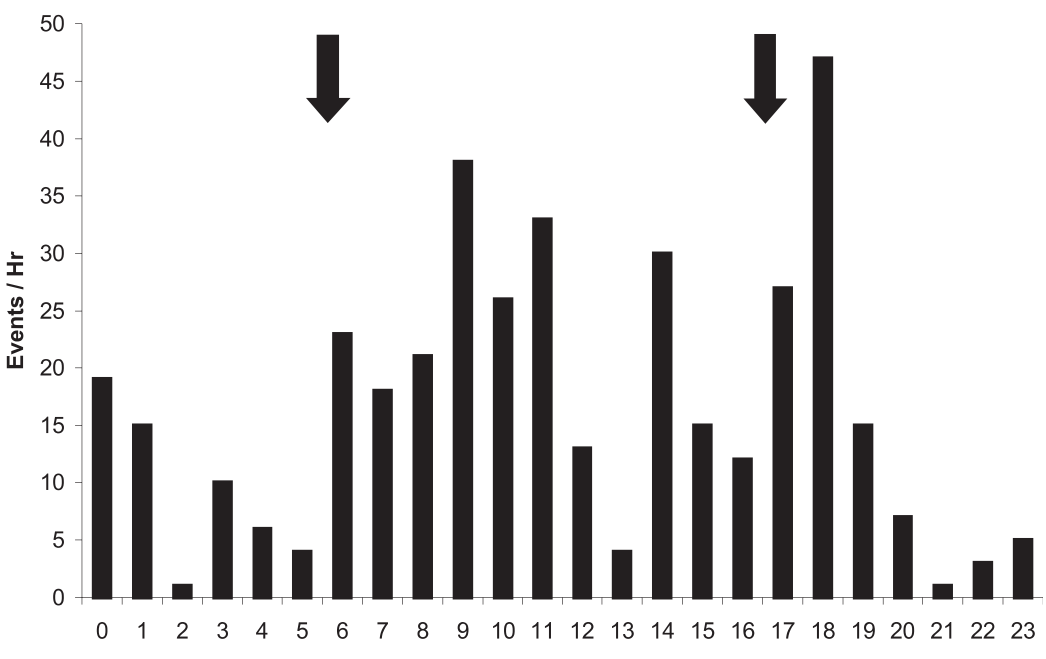

Fig. 5 – Activity events per hour recorded by ADL collated over 26-day period for pike I March 2002. Arrows indicate sunrise and sunset.

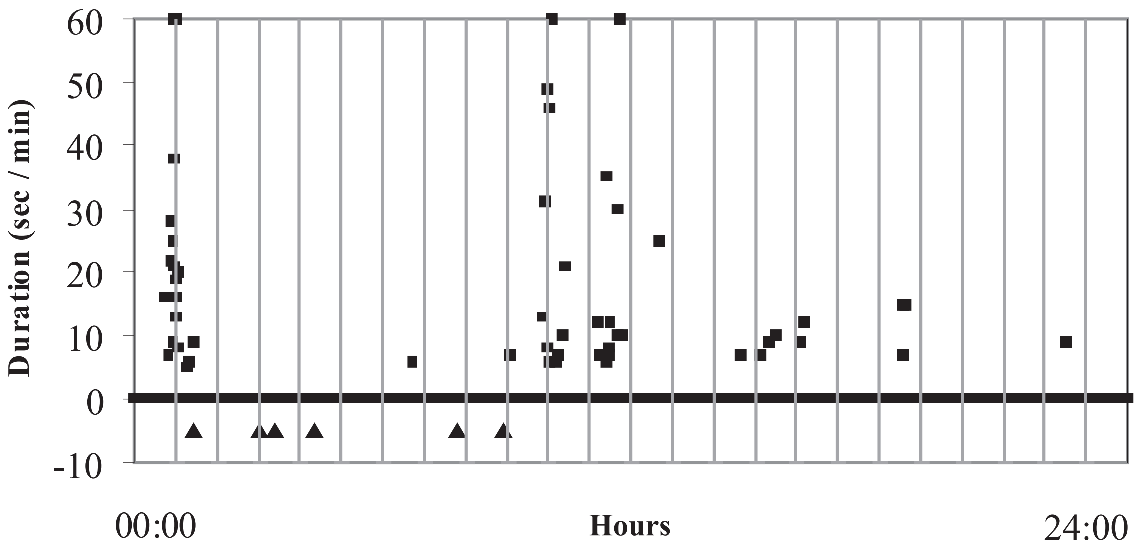

Fig. 6 – Major (≥5-second) activity events (seconds per minute) for pike I over one day (11-03-2002). Vertical lines indicate hours, triangles below baseline indicate the six, 1-minute periods where >5-seconds gaps in data exist.

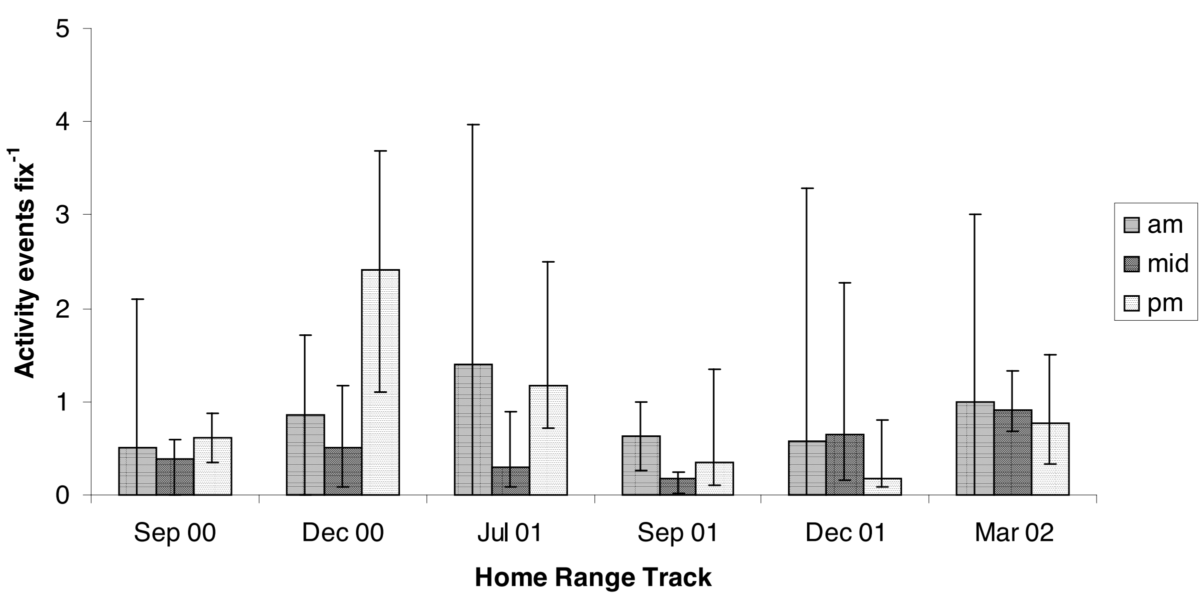

Fig. 7 – Proportion (median and interquartile range) of occasions where activity events were recorded during morning, mid-day and evening manual tracking.

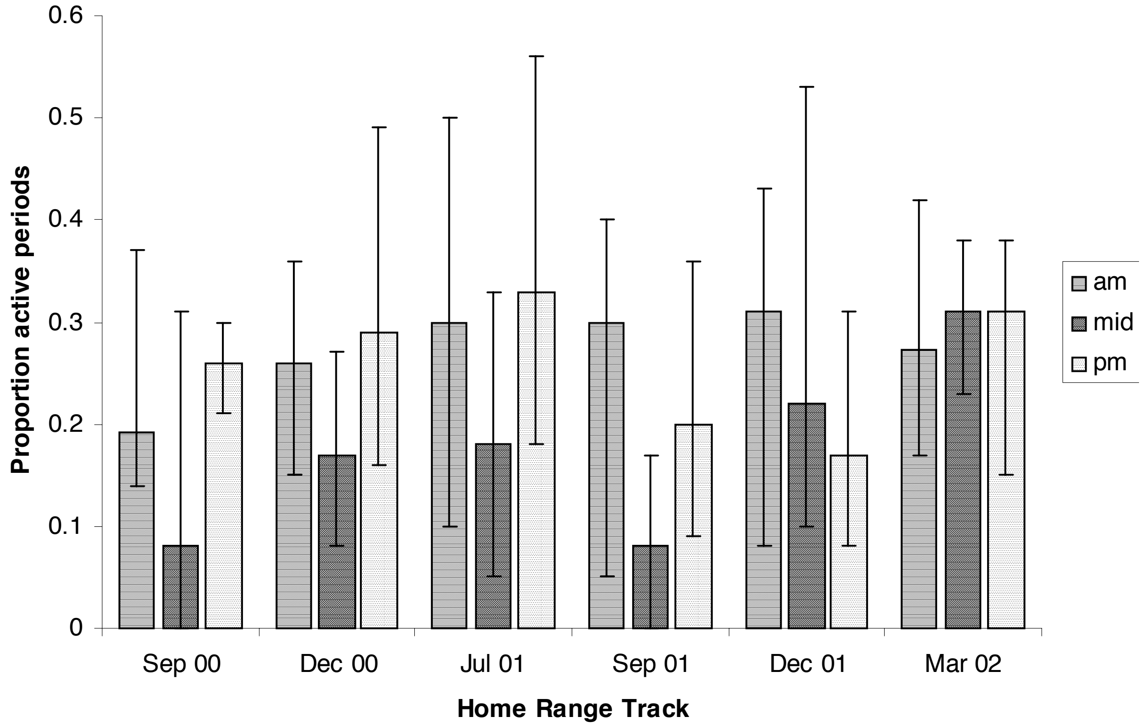

Fig. 8 – Mean number of activity events, from all pike, recorded during morning, mid-day and evening manual tracking (Median and interquartile range).

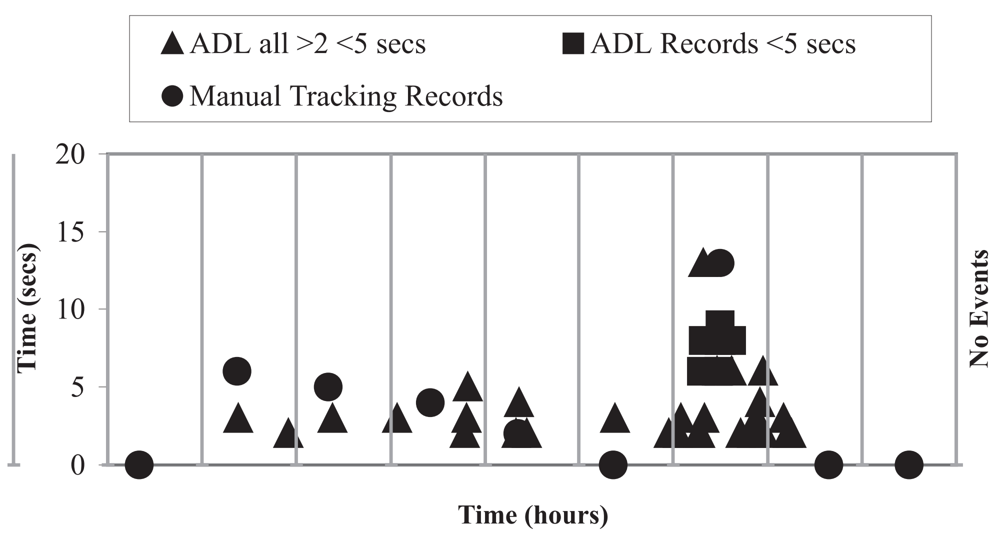

Fig. 9 – Comparison of activity status results obtained from ADL (duration of active events >2<5-seconds (triangles) and ≥5-seconds (squares) and manual tracking – the number of activity events in 5-minute periods per hour (circles). Pike I, 1-3-2002.

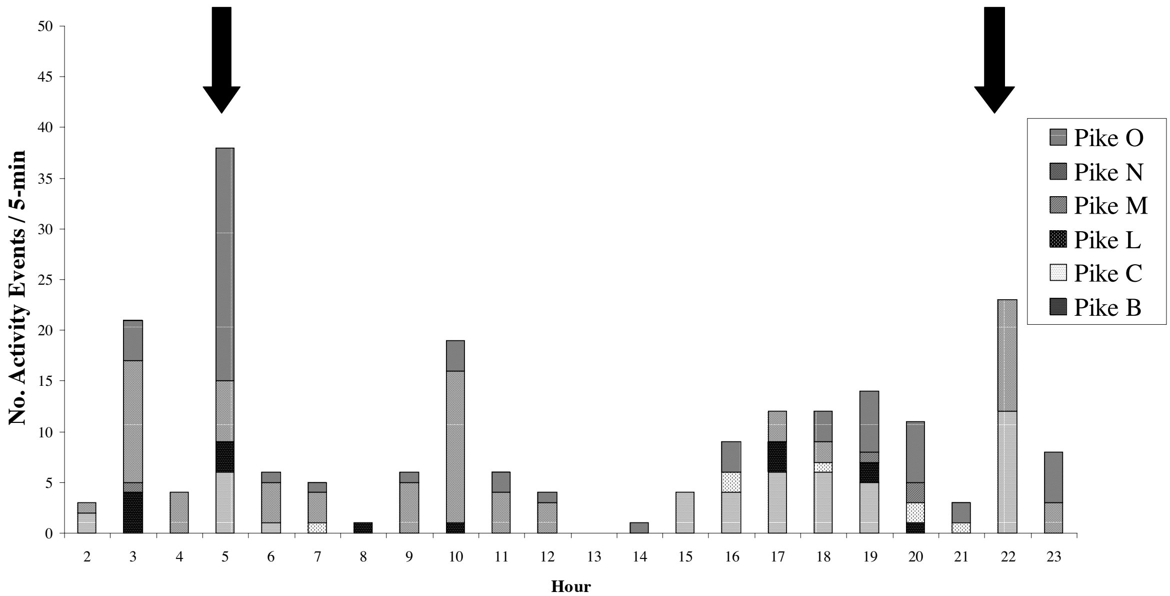

Fig. 10 – Number of activity events recorded by hourly manual tracking for all fish tracked over 24-hour period. Arrows indicate sunrise and sunset.

Discussion

The duration of the continual data from the ADL are far in excess of other previously published data on fish activity patterns and are also the only true "continuous" (notwithstanding the gaps in the data) data set known to exist. Other publications use the term continuous to describe frequent, but not continuous, records e.g. three records every 10 minutes (David and Closs, 2001).

Overall pike exhibited low levels of prolonged (≥5-seconds continuous duration) high-activity and confirms that the pike is a generally sedentary animal. Major activity events (≥5-seconds continuous duration) conformed to a pattern of night-time and mid-day minima and dawn and dusk maxima. These data correspond well to other published work on lake systems, where pike activity has been assessed on the basis of linear distance moved (Cook and Bergerson, 1988). They also support the hypothesis that pike feed at low light levels when they may have a competitive advantage over shoaling prey (the "twilight hypothesis"; Pitcher and Turner, 1986). The activity tag data indicated however that minor activity events could occur at any time over a 24-hour period. These findings are in contrast to other research (where pike are regarded as either being inactive or having low activity at night) where activity patterns based on linear movement of pike have been assessed (Diana, 1980; Lucas, 1992). Jepsen *et al.* (2001) found that pike in Lake Ring were predominantly nocturnal during June and July. However it is not clear from Jepsen's data whether fish movement occurred during true darkness or in the dawn, as data were only collected at 6-hour intervals. Whilst Diana (1980) considered that the slight movements he detected during the night-time were probably unimportant in overall time-energy budgets, the volume of activity pulses detected by the ADL during the night could indicate that cumulatively they may comprise an important component of the pike's overall activity energy budget.

The lack of a crepuscular activity pattern (as found for other pike) in the male Pike I corresponds well to other descriptions of increased pike activity patterns during spawning (Cook and Bergerson, 1988; Lucas, 1992). Lucas (1992) noting that male pike were significantly more active than females during the spawning period and that this activity was greatest during daylight hours. Whilst overall the highest peaks in activity for Pike I during this period were recorded during the day/dusk period, activity events were also recorded during the night. As Pike I moved away (5 km downstream) from the study area outside the spawning period, few data have been collected on its activity patterns at other times of the year (Masters *et al*., this volume). Daytime activity levels however were in excess of those found for other pike monitored by the ADL at non-spawning periods. Based on the evidence from over 8500 manual tracking observations (Masters, 2003) it appears that in the river the pike adopts a very mobile hunting strategy and often ranges about the river before carrying out short duration active pursuits of prey. Attempts were made to monitor the interval between major activity/feeding events for pike being recorded by the ADL. The presence of gaps >5-seconds in the data set however, meant that even though the overall duration of these gaps only accounted for <4% of the time monitored, we could not be certain that the pike had not had major activity events in those gaps, and thus the periodicity of these events could not be assessed with any certainty. Analysis that has been possible to date has shown some differences in time intervals between major activity events in different seasons but these have not been significant (CEH, unpublished data).

Whilst activity patterns determined from the manual tracking generally showed higher activity events during the morning and evening, compared to the day, the differences were not significant.

Correlation between data collected simultaneously from hourly manual tracking of the fish, and the continuous ADL data, was variable. This would be expected when only listening for 5-minutes in every hour during manual tracking. When the manually collected data from several fish were pooled, however, similar crepuscular activity peaks to those found from the ADL data were apparent.

The fact that the information obtained from 5-minute manual data collection from the activity tag so well reflects (after pooling) the result obtained from the ADL is an important finding for other studies where manual assessment of activity tag output is carried out. The greater number of fish that can be assessed manually is also likely to give a better "population" perspective on activity patterns.

Given the energetic costs of moving against the flow in a river, the adoption of a very mobile hunting strategy by the pike was surprising but confirms data obtained from lake dwelling pike (Cook and Bergerson, 1988; Diana, 1980; Lucas *et al*., 1991). The multi-nuclear nature of the home range area of the fish may also reflect this mobile hunting strategy within the river (Welton *et al*., 2002).

Limitations of the prototype ADL system and the high mobility of the study species resulted in gaps in the data that limited the analysis possible. A multiple antenna system would solve some of the problems of fish moving out of range and modern electronics would probably also assist in reducing the proportion of false data collected. One drawback of the system is that time-energy budgets cannot be calculated; as is the case when using heart rate telemetry. However the system does provide a relatively simple system that enables an insight into fine time scale pike activity and, potentially, feeding patterns.

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