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The effect of the moon phase and seasonality on the behaviour of pikeperch in the Elbe River

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A b s t r a c t . We tested the influence of the moon phase on the diurnal behaviour of the visually oriented nocturnal predator pikeperch *Sander lucioperca* (L.) in the channelized Elbe River, located in the Czech Republic. Both the new moon phase and winter season predicted an increase in pikeperch diurnal activity. The distance moved in the longitudinal orientation of the river peaked in spring and autumn, indicating pre-spawning and feeding behaviour.

Key words: Percidae, nocturnal activity, feeding migrations

Introduction

It is generally understood that moon light intensity influences behaviour in various species of animals with nocturnal activity. For example, different species of rodents forage less and tend to stay closer to bushes on full moon nights (L o c k h a r d & O w i n g s 1974, P r i c e e t a l . 1984). Additionally, fruit eating bats (M o r r i s o n 1978) and arid scorpions (S k u t e l s k y 1996) lower their foraging activity to reduce the risk of predation during the full moon, since the illumination may enhance the efficiency of visually oriented nocturnal predators (D i c e 1945, C l a r k e 1983, L o n g l a n d & P r i c e 1991). Similarly, in aquatic systems, the foraging activity of fish is modified by variations in moonlight intensity (H o b s o n 1965, A l l e n & W o o t t o n 1984). The pikeperch is a visually oriented crepuscular or nocturnal predator (F e d o r o v a & D r o z z h i n a 1982); a special layer of the retina cells, the *tapetum lucidum,* enables it to effectively utilize even low light conditions (A l i e t a l . 1977). As argued by K o e d e t a l . (2000), variations in moonlight intensity among the moon phases appeared to have an impact on the behaviour of this large percid species. Furthermore, the low light periods preferred by the pikeperch for feeding and hunting corresponded with the peaks of its movement activity (P o u l e t 2005).

Migrations of the species in the longitudinal profile of a river varied across seasons, being the highest in spring and autumn (K o e d e t a l . 2000), while a high intensity of migrations in the reservoirs occurred only in autumn (V e h a n e n e t a l . 2003). Data on diurnal activity across seasons are available only from the reservoir, and showed the maximum of its movement activity during summer (J e p s e n 1999).

In our study we focused on the diurnal and longitudinal movement activity of the pikeperch, and investigated the assumptions of whether diurnal activity of the species in rivers i) would correspond with the findings from the reservoirs (J e p s e n 1999); ii)

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would be influenced by moonlight intensity and show a positive effect of the moonlight on its predation success; iii) would correspond with the intensity of its migrations in the longitudinal orientation of a river. To test our hypotheses we radio-tracked eight specimens of the pikeperch in the Elbe River, Czech Republic across the time span of twelve months.

Study Area

The study was carried out on the Elbe River, located in the Czech Republic. The river rises at 1383 m above sea level. It has a total length of 1091.47 km with a catchment area of 148,268 km^2. The Czech portion of the river is 367.95 km long and has a catchment area of 51,394 km^2. The primary river stretch studied was about 40 km long, limited by the weir at Střekov (40 river km) and the frontier with Germany. During spawning migrations, the studied river stretch was elongated due to the specimen relocation as to as far as Dresden, Germany. The riverbanks are reinforced with rocks and concrete. Across the whole study period, the average flow was 293 $m^3 s^{-1}$, with the maximum in winter (748 $m^3 s^{-1}$) and the minimum in early autumn (79 $m^3 s^{-1}$).

Materials and Methods

Fish capture and tagging

Fish for tag implantation were obtained by electrofishing (650 V, 4 A, pulsed D.C.) from the local populations. Eight specimens of pikeperch were radio tagged. The individuals were measured (L_S, standard length) to the nearest mm and weighed to the nearest gram (Table 1). Fish were anaesthetized with 2-phenoxy-ethanol (0.2 ml l^{-1}). Radio transmitters (MCFT 3B, 11 g in air, 14 x 43 mm, with an operational life estimated to be 399 days; MCFT 3EM, 8-9 g in air, 11 x 49 mm, with operational life estimated to 278 days; Lotek Engineering, Inc., Canada) were implanted into the body cavity through a midventral incision that was closed by three separate stitches, using a sterile, braided, absorbable suture (Ethicon Coated Vicryl). The weight of the transmitter never exceeded 2 % of fish body weight in the air (Winter 1983). Fish were released close to the capture site after they recovered their equilibrium, and showed spontaneous swimming activity (*c.* 5 min. after surgery).

Table 1. Length and weight of tagged individuals of pikeperch.

Individual code	19	33	35	36	37	39	53	54
Standard length (mm)	690	585	656	617	538	608	530	595
Weight (g)	3946	1660	2520	2148	1595	1920	1293	1781

Sampling procedures

All fish were tracked weekly from the boat during the period from 11 September 2003 to 21 September 2004. Two radio receivers (Lotek SRX_400 receiver, firmware versions W5, W31) and a three-element Yaggi antenna were used for the telemetry. Fish positions were recorded using a GPS receiver. In addition, once all of the fish were positioned, one individual was chosen for 24 h tracking. Fish positions during a diurnal cycle were determined in eight subsequent 3-hour intervals. Locations of fish were accurate to within 5 metres.

Habitat measurements

Water temperature (°C), dissolved oxygen concentration (mg. l^{-1}), conductivity (μS) and pH were measured by microprocessors (Oxi 196 WTW, pH/Cond 340i / SET). Measurements of the atmospheric pressure and the moon phase were conducted with help of the Remote Weather station BAR 928 H (Huger Electronics, Germany). The Elbe River Authority measured water discharge daily at the Střekov gauging station located within the study stretch.

Data analysis

The intensity of movements during a diurnal cycle was defined as the distance moved (m) of a fish between two subsequent three-hour intervals during a 24 hour cycle, and is further referred to as "Diurnal movement activity". Although the fish was localized every time, the signal was in several cases so weak that positioning could not be precisely measured. These data were excluded from further analyses. The intensity of migration in the longitudinal orientation was evaluated as the difference (m) between the positions of a fish at two successive weekly intervals, and is further referred to as "Migrations in the longitudinal orientation". Data on fish movements were transferred from the GPS to a PC and analyzed with the help of the Map Source Version 5.3 (Garmin Ltd., USA). Based on the measurements from the Remote Weather station, eight moon phases were considered, which were subsequently assigned with numbers. Phase number one indicated a new moon, number five a full moon, and the remaining numbers (2–4; 6–8) were transitions between those two stages.

Statistical analyses

Associations between the variables were tested using the multivariate General Linear Mixed Model (GLMM). The dependent variables were diurnal movement activity and migrations in the longitudinal orientation. To account for the repeated measurements of the same individuals across different time intervals, seasons, etc., all analyses were performed using mixed model analysis with individual fish as a random factor, using PROC MIXED (SAS, version 9.1). The fixed effects included the classes 'moon phase' (8 levels) and 'season' (spring, summer, autumn, winter) and the continuous variables were: 'fish mass' (1293–3946 g); 'water temperature' (0–24 ºC); 'flow' (79–748 $m^3 s^{-1}$); 'atmospheric pressure' (992–1033 hPa); 'conductivity' (332–425 μS) and 'dissolved oxygen' (5.5–12.9 mg.l^{-1}). The significance of each fixed effect in the mixed GLMM was assessed by the F-test, upon sequential dropping of the least significant effect, starting with a full model. In unbalanced designs with more than one effect, the arithmetic mean for a group may not accurately reflect the response for that group, since it does not take other effects into account. Therefore, we used least-squares-

Table 2. Type 3 tests of fixed effects for diurnal movement activity and migrations in the longitudinal profile.

Effect	Num DF	Den DF	F	P<
For diurnal movement activity				
moon phase	7	83	19.02	0.0001
season	3	83	6.45	0.0006
For migrations in the longitudinal orientation				
season	3	182	3.63	0.0141

means (LSM) instead. LSM are, in effect, within-group means appropriately adjusted for the other effects in the model. LSM (further referred as 'adjusted means') were computed for each class and differences between classes were tested by a t-test. For multiple comparisons we used the Tukey-Kramer adjustment.

Results

The final GLMM models included the fixed factors "Moon phase" and "Season" for "Diurnal movement activity", and "Season" for "Migrations in the longitudinal orientation". Details of both models are shown in Table 2.

Diurnal movement activity of the pikeperch varied according to moonlight phases of the lunar cycle (Fig. 1); however, the differences were not statistically significant (2–8) with the exception of the new moon phase (1). The peak of diurnal movement activity across seasons occurred in the winter with non-significant differences among other seasons (Fig. 2a).

Migrations in the longitudinal orientation achieved a maximum in spring and autumn with prevailing stationary behaviour occurring during summer (Fig. 2 b). Furthermore, summer was the only season when the diurnal movement activity correlated with the migrations in the longitudinal orientation, showing minimal values for both observed parameters.

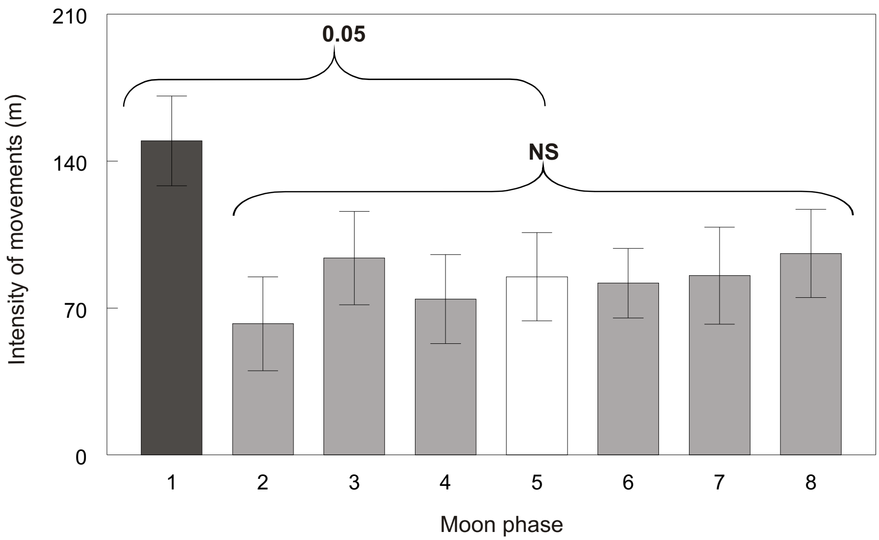

Fig. 1. Relationship between pikeperch diurnal movements (adjusted means +/- S. E.) and the moon phase (1 – new moon; 5 – full moon). (NS – non-significant differences among classes; 0.05 – significant differences among classes at $P < 0.05$).

Discussion

Not the full but the new moon was the main predictor of changes in the pikeperch diurnal activity in the Elbe River. Moonlight is generally considered an important factor that affects the behaviour of both predators and their prey (Lang et al. 2006). As demonstrated with the Atlantic salmon *Salmo salar* (L.), visually oriented nocturnal predators may benefit from the moonlight since their prey is easier to detect (Fraser & Metcalfe 1997).

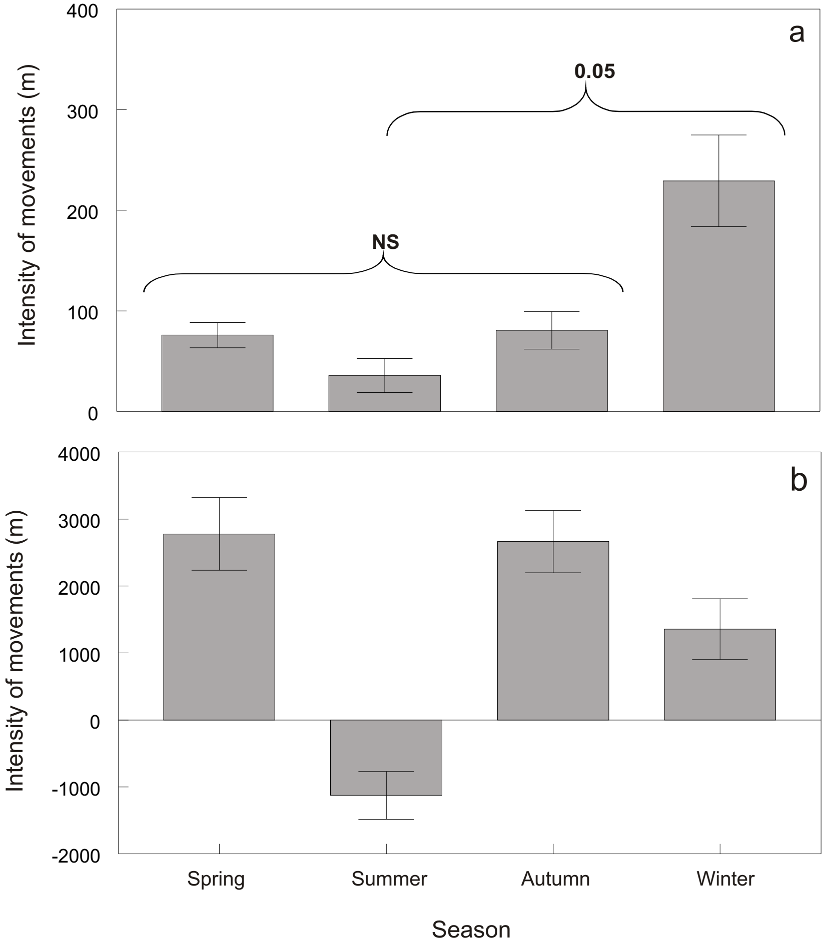

Fig. 2. Intensity of (a) pikeperch diurnal movement activity and (b) migrations in the longitudinal profile (adjusted means +/- S. E.) across seasons. (NS – non-significant differences among classes; 0.05 – significant differences among classes at P < 0.05).

Correspondingly, pikeperch did not show any differences among the activity during the light phases of the moon cycle, suggesting that any moonlight intensity could be utilized with comparable predation effectiveness. On the other hand, its diurnal activity during the new moon significantly increased. Various species of fish vulnerable to predation were observed to adapt their activity according to the rate of moonlight illumination, indicating that they use the new moon as protection against predators (M a s o n 1975, S t o k e s b u r y & D a d s w e l l 1989). Provided that prey utilize the new moon phase for protection, an increase in pikeperch diurnal activity at this time may be a consequence of lowered predation success.

Habitat requirements of fish usually alter across seasons, being associated with migrations between species-specific habitats (e.g. N i k o l's k i j 1963). Migrations of the pikeperch in the longitudinal orientation of the Elbe River reached the maximum in spring and autumn. Previous studies accordingly associated spring activity of the pikeperch with its reproductive behaviour and related spawning migrations (for review see L a p p a l a i n e n e t a l .

2003). The autumn migratory peak, however, was interpreted differently for the riverine environment and reservoirs, being attributed to feeding migrations in rivers (Koed et al. 2000) and to wintering behaviour in reservoirs (Vehanen et al. 2003). The observed disparity of pikeperch behaviour could also be caused by differences in winter conditions between these studies. While Vehanen et al. (2003) defines winter as a period of months of ice cover and zero water temperatures, in other studies (Jepsen 1999, Koed et al. 2000) winter is considered as a period of no ice cover and temperatures above zero as well. Our results corresponded with the Koed et al. (2000) findings and suggested that high migratory activity in autumn was aimed to find suitable and appropriate feeding areas. Furthermore, as argued by Koed et al. (2000), the pikeperch feed during the winter. Additionally, Jepsen (1999) described pikeperch as a fish that rarely seems to rest and remains active throughout the winter. Correspondingly, in the Elbe River, high migration activity in autumn was followed by high diurnal activity in winter. Considering that the pikeperch hunting strategy was described as an active chasing of the prey (Turesson et al. 2004), a peak in diurnal activity could be attributed to lowered predation success during winter. Small fishes, whose mortality rate in winter increases (e.g. Henderson et al. 1988, Thompson et al. 1991, Johnson & Evans 1996, Hurst et al. 2000) represent the predominant component of the pikeperch diet (Turesson et al. 2004). Furthermore, a general decrease in the abundance of small fishes as a result of a disturbed natural reproductive process was reported in channelized rivers (Copp 1997). Consequently, the lack of prey may result in an increase of the winter diurnal activity of pikeperch in the channelized stretch of the Elbe River. The applied methodology, however, does not allow us to precisely determine the relationship between the pikeperch activity and prey density. Moreover, not only prey can be considered as a limiting resource in the Elbe River; e.g. a lower availability of refugees result in an increase of fish activity in the channelized rivers as well (Bruylants et al. 1986).

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