Seasonal changes in diel activity of juvenile European catfish Silurus glanis (Linnaeus, 1758) in Byicka Lake, Central Bohemia

Article *in* Journal of Applied Ichthyology · July 2016

DOI: 10.1111/jai.13146

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Received: 20 January 2016 | Accepted: 23 April 2016

DOI: 10.1111/jai.13146

ORIGINAL ARTICLE

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Seasonal changes in diel activity of juvenile European catfish *Silurus glanis* (Linnaeus, 1758) in Byšická Lake, Central Bohemia

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Summary

Dualism in activity has been described in many fish species, including larger individuals of European catfish (*Silurus glanis*), which are able to switch their activities from nocturnal to diurnal in winter and spring. During the multi-year telemetry study, seasonal changes in diel activity of 45 juvenile European catfish were investigated. These juveniles exhibited no dualism in movement and were strictly nocturnal and crepuscular with no period of diurnal activity. During winter, the same juvenile European catfish were completely inactive throughout the 24-hr cycle. Also investigated was the impact of temperature, dissolved oxygen levels and water clarity on fish movement, relocation of resting places and home range size. The only significant correlations were that relocation and home range size increased with rising water temperatures.

1 | INTRODUCTION

In fishes as in other vertebrates, behavioural and physiological processes are rhythmic, and the light-dark (L-D) cycle is considered the primary synchronizer (Reebs, 2002). How an animal reacts to the L-D cycle usually depends on the species and its diel activity rhythm, which may be diurnal, crepuscular or nocturnal (Thorpe, 1978). The diel activity rhythm may, however, also differ within species, depending on the age or social rank of the individual. Subdominant individuals, for example, use other periods of the day than dominant individuals to avoid intraspecific aggressiveness (Alanärä, Burns, & Metcalfe, 2001; Brännäs, 2008; David, Closs, Crow, & Hansen, 2007). Preferences to light or dark may also reverse in different seasons, when individuals change their activity period completely, for example, to reduce the risk of predation (Fraser, Metcalfe, & Thorpe, 1993; Heggenes, Krog, Lindas, Dokk, & Bremnes, 1993; Riehle & Griffith, 1993; Valdimarsson, Metcalfe, & Huntingford, 1997). Fish activity may also be influenced by temporal changes in food availability (Bolliet, Aranda, & Boujard, 2001) or changes in environmental parameters such as turbidity (Utne-Palm, 2002). All of these aspects result in great intraspecific variation in diel activity and disparity among age or social groups, in different seasons or in various habitats.

The European catfish (*Silurus glanis*) is considered a nocturnal species (Boujard, 1995; Carol, Zamora, & García-Berthou, 2007) with light-sensitive larvae (Copp et al., 2009). The diel activity pattern of this species may, however, differ depending on the season, as shown by a multi-year field study, which found peak activity during the day in winter and spring (Slavík, Horký, Bartoš, Kolářová, & Randák, 2007). However, recently published studies on catfish activity in nature are focused on adults and individuals over 0.8 kg and present no data on smaller juveniles. Small individuals may behave differently because they are at a greater risk of predation (Nilsson & Brönmark, 2000; Paine, 1976). Nocturnal activity may be the optimal strategy to minimize risk of predation (Fraser et al., 1993; Heggenes et al., 1993). European catfish live primarily in deep lowland rivers and rich, weedy lakes, exhibiting site fidelity and utilizing stable resting places (Carol et al., 2007). Having limited eyesight but well-developed non-visual sensors (e.g. olfactory receptors, feelers, taste organs, Weber's apparatus, lateral line), allows *S. glanis* to track the swimming path of its prey accurately even in complete darkness (Pohlmann, Grasso, & Breithaupt, 2001). Although *S. glanisis* is known to prefer still-water habitats (Copp et al., 2009), studies on its behaviour in this environment are rare (Carol et al., 2007).

The aims of our study were to evaluate the diel activity of juvenile European catfish in an oxbow lake in different seasons and to determine how environmental variables affect their behaviour. We expected to find nocturnal activity of juveniles throughout the year because we presumed it would give them a foraging advantage (due to their well-developed non-visual senses) and expose them to lesser predation pressure. In this study, we also examined the impact of water clarity, temperature and dissolved oxygen on catfish movement, relocation of resting places and home range size.

2 | MATERIALS AND METHODS

2.1 | Study site

The study was undertaken at Byšická Lake situated in Central Bohemia, Czech Republic (50°10′48.005″N; 14°47′32.713″E (Fig. 1). The lake represents a highly valuable natural habitat that is part of the Hrbáčkovy tůně natural reserve as well as the European network of nature protection areas Natura 2000. The lake is ca 1 km long, 40 m wide in its widest place and up to 2.3 m deep. According to a recent ichthyological survey (T. Daněk, unpubl. data), the fish stock consists of: *Cyprinus carpio*, *Scardinius erythrophthalmus*, *Rutilus rutilus*, *Esox lucius*, *Sander lucioperca*, *Blicca bjoerkna*, *Tinca tinca*, *Anguilla anguilla*, *Abramis brama*, *Ctenopharyngodon idella*, *Aspius aspius*, *Perca fluviatilis*, *Gymnocephalus cernuus*, *Hypophthalmichthys molitrix*, *Alburnus alburnus*, *Leuciscus idus*, *Squalius cephalus*, *Rhodeus amarus*, *Ameiurus nebulosus*, *Carassius gibelio* and *Silurus glanis*.

2.2 | Fish trapping and tagging

Forty-five juvenile European catfish were tracked from 2 November 2010 to 20 November 2012. The first 19 individuals were caught at the study site by electrofishing (650 V, 4 A, pulsed D.C.) from 7 to 9 October 2010. The fish were equipped with transmitters and released at the location on 10 October 2010. An additional 26 individuals were successively caught using fishing rods, tagged, and released between July 2011 and April 2012. The fish weighed between 203 and 1150 g (mean = 358.5 g, *SD* = ±216.5 g), with standard lengths 285–552 mm (mean = 378 mm, *SD* = ±51.1 mm).

The fish were equipped with radio transmitters MST-930, 4 g in air, 9.5 × 26 mm, 24 cm external whip antenna (Lotek Engineering Inc., New Market, Ontario, Canada). Transmitters were surgically implanted into the peritoneal cavity through a lateral incision ca 1 cm above the pelvic fin. The surgery was performed under 2-phenoxy-ethanol (0.2 ml/L) anaesthesia. The incision was closed with two separate stitches using sterile braided absorbable suture Ethicon Coated Vicryl W9113 (Johnson & Johnson, St. Stevens Woluwe, Belgium). The transmitter mass never exceeded 2% of the fish body mass in air. A previous study (Kalous, Daněk, Kopecký, & Petrtýl, 2014) ascertained that the implantation of transmitters this size does not affect the catfish significantly. To prolong the functioning of the transmitters, which were quite small and had a low battery capacity, they were programmed to only emit a signal on 1 day of the week (ON for 1 day/OFF for 6 days). The programming extended the calculated battery life to 438 days (otherwise the battery life would be 117 days). The Animal Use Protocol (No. 6/2010), issued by the Czech University of Life Sciences Prague, was approved by the Ministry of Education, Youth and Sports of the Czech Republic (permit No. 22103/2010-30).

2.3 | Fish tracking

The fish were tracked on a weekly basis, always for a 24-hr period. Positions of fish during the 24 hr cycle were determined by triangulation at eight subsequent 3-hr intervals. An SRX 400A/W5XS radio receiver equipped with a three-element Yagi antenna F 140-3FB (Lotek Engineering Inc.) was used for the tracking. Prior to the study, the entire bank of Byšická Lake was marked with stable landscape markers spaced 2–4 m apart that were placed on trees, shrubs or wooden pegs. The number on each marker determined the distance in metres from the northwest corner of the lake. This system of stable landscape markers allowed us to quickly determine our position with great accuracy without using GPS during the tracking. The accuracy of the fish position determination was estimated to be ±1 m based on a calibration procedure repeatedly performed using a tag positioned on the lakebed (Daněk, Kalous, Petrtýl, & Horký, 2014).

2.4 | Abiotic variables

Dissolved oxygen concentration (mg/L) and water temperature (°C) were measured on each tracking day at dawn using the Multi 3420 WTW (WTW Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) and Gryf 464 (GRYF HB, s.r.o., Havlíčkův Brod, Czech Republic). The European catfish is a benthic species, thus the values were measured at a stable reference point approximately 10 cm above the bottom in the central part of the lake. Water clarity

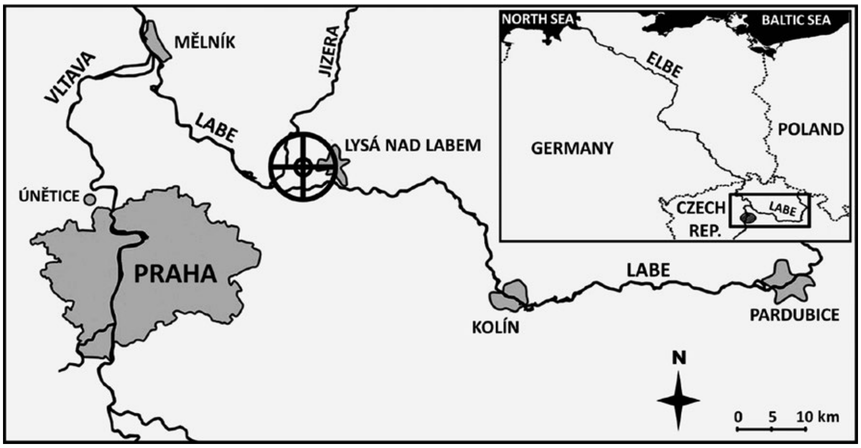

FIGURE 1 Byšická Lake location in Europe (target)

was determined as Secchi depth (cm) measured with a Secchi disk (20 cm in diameter). Light intensity (lx) was measured with a PU 550 photometer (Metra Blansko a.s., Blansko, Czech Republic).

2.5 | Data analyses

Two individuals died after being affected by an oxygen deficiency event (for more information, see Daněk et al., 2014). The carcass of another fish was found in May 2012 (cause of death unknown). In several cases, an operating transmitter was found on the lakebed, but which did not prove the individual's death, as living fish can expel transmitters from their bodies (Daněk & Kalous, 2013). Fish positions were plotted on a map using Quantum GIS (ver. 1.6.0. "Copiapo"); azimuths were plotted with the plugin "Tarsius" (www.tarsiusproject.org/download). The term "resting place" was defined as a restricted square area of less than 2 × 2 m where fish dwell during daytime (for at least three subsequent 3-hr intervals, of which at least two were during daytime; see Daněk et al., 2014). "Movement" was defined as the distance (m) each individual moved during a three-hour interval. "Relocation" was defined as the distance (m) between the centres of each resting place of each individual between two successive weeks. "Home range" (HR) was expressed in m^2 and determined as the minimum convex polygon (MCP) of fish positions recorded during a 24 hr period, using the Home Range Analysis plugin for Quantum GIS. Although size usually influences catfish behaviour (e.g. Slavík & Horký, 2012), it was not our target variable, as we were interested in analysing behaviour independent of fish size. To ensure that the movement, relocation and home range size variables were independent of fish size, we corrected these variables by dividing them by the weight of the individual fish (Aarestrup, Jepsen, Koed, & Pedersen, 2005). In further analyses, we only used values corrected for fish weight. A fish was considered to be alive until its last measurable position shift. Data from 14 to 28 December 2010 were excluded from the analyses because of an oxygen deficiency in this period, which seriously affected fish behaviour. This extraordinary event was analysed in a separate study (Daněk et al., 2014). Data samples were grouped by season: spring (21 March to 20 June), summer (21 June to 20 September), autumn (21 September to 20 December) and winter (21 December to 20 March), following Slavík et al. (2007). Four "daily light intervals" were defined within the 24 hr cycle: dusk and dawn (light intensity 1–500 lx), night (<1 lx) and day (>500 lx).

2.6 | Statistical analyses

Statistical analyses were performed using the SAS software package (SAS Institute Inc., version 9.2, www.sas.com). Prior to the analyses, the data were tested for normality. The movement, home range size and relocation of catfish were analysed using separate linear mixed models (LMM) with random factors (PROC MIXED). The random factors were used to account for repeated measures collected for the same experimental units (individual fish) across the duration of the experiment. The significance of each exploratory variable (i.e. fixed effect, including their interactions) in the particular model was assessed using a backward selection procedure starting with the full model and sequentially dropping the least significant variable based on the results of an *F*-test. Least-squares means (LSM), henceforth referred to as "adjusted means", were computed for each significant class exploratory variable. Differences between the classes were tested with a *t*-test with Tukey–Kramer adjustment for multiple comparisons. Associations between the dependent variables and other continuous variables were estimated by fitting a random factor model using PROC MIXED as described by Tao, Little, Patetta, Truxillo, and Wolinger (2002). With this random coefficient model, we calculated the predicted values for the dependent variables and plotted them against the continuous variables by using the predicted regression lines. The degrees of freedom were calculated using the Kenward-Roger method (Kenward & Roger, 1997).

3 | RESULTS

The course of water temperature, dissolved oxygen and Secchi depth values at the reference point during the study is shown in Fig. 2. A total of 6352 valid positions of fish were obtained. The observed behavioural variables varied as follows: movement ranged from 0 to 583 m (mean = 14.93 m, *SD* = ±51.51 m), home range size from 0 to 19850 m^2 (mean = 1341 m^2, *SD* = ±2908 m^2) and relocation from 0 to 567 m (mean = 40.3 m, *SD* = ±95.0 m).

Movements of catfish reached their greatest values in spring and summer (Tukey–Kramer adj. $p < 0.05$). In autumn and particularly in winter, by contrast, it was minimal ($F_{2,5994} = 42.18$, $p < 0.0001$; Fig. 3). The fish generally showed nocturnal and crepuscular activity ($F_{2,6312} = 65.39$, $p < 0.0001$; Fig. 4). This pattern evolved across seasons ($F_{9,6306} = 22.06$, $p < 0.0001$; Fig. 5) from strictly nocturnal and crepuscular activity in spring and summer (Tukey–Kramer adj. $p < 0.05$; Fig. 5a, b), through a similar trend with non-significant differences in autumn (Tukey–Kramer adj. $p > 0.05$; Fig. 5c), to inactivity with no trends during the 24 hr cycle in winter (Tukey–Kramer adj. $p > 0.05$; Fig. 5d). The average value of movement in winter was only 0.036 m (*SD* = ±0.027 m). In spring and autumn, average values reached 18.11 m (*SD* = ±58.95 m) and 3.49 m (*SD* = ±20.51 m), respectively. The greatest movement average occurred in summer, reaching 30.85 m (*SD* = ±70.08 m).

Relocation ($F_{1,442} = 23.16$, $p < 0.0001$; Fig. 6a) and home range size ($F_{1,321} = 99.42$, $p < 0.0001$; Fig. 6b) increased with increasing water temperature. No effects of the other environmental variables tested (water clarity and dissolved oxygen concentration within the given range) on catfish behaviour were indicated.

4 | DISCUSSION

The results indicate that juvenile European catfish (*Silurus glanis*) are most active in spring and summer and that they are inactive during winter. Slavík et al. (2007) observed activity of European catfish even

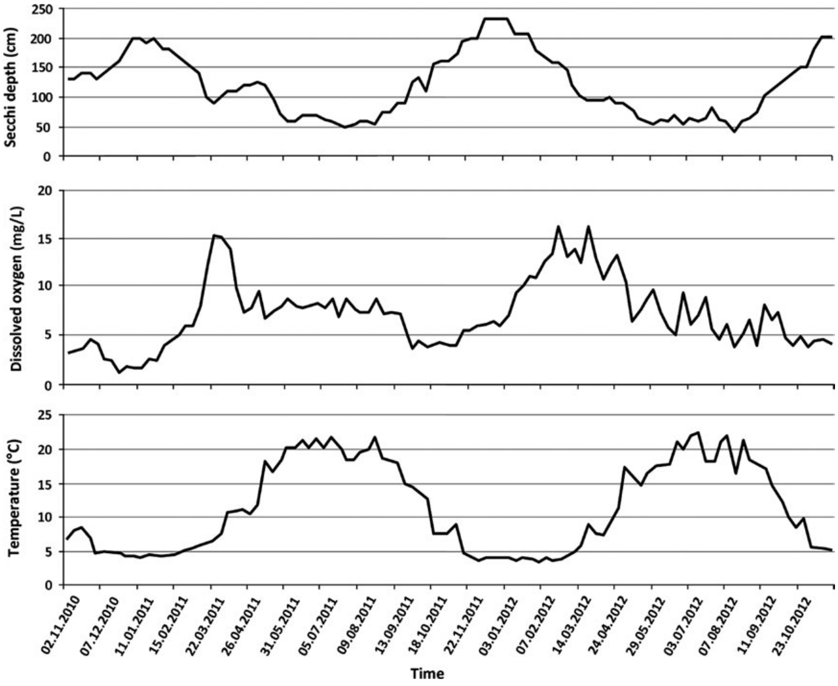

FIGURE 2 Values of water temperature, dissolved oxygen and Secchi depth at the reference point, 2 November 2010 to 20 November 2012

in winter, but the extent of this activity was low, as their movement was positively correlated with temperature and therefore generally low in winter. Some other authors suggest that in winter catfish may be completely inactive and "hibernate" in deep holes, dens and crevices in the riverbed (Lelek, Libosvárský, Peňáz, Bezděk, & Macháček, 1964).

The metabolism and activity of fishes, as of other poikilotherms, usually positively correlate with temperature (Ultsch, 1989). The optimal temperature for metabolism in European catfish is 25–27°C (Copp et al., 2009). Moreover, smaller individuals are usually more sensitive to environmental extremes (Sogard, 1997), and suboptimal temperatures may therefore inhibit their activity more seriously than that of adults. All of this is in agreement with the winter inactivity of juveniles observed in the current study. Home range size and relocation decreased with decreasing temperature (Fig. 6), and movement ceased in winter (Fig. 5), when water temperatures were around 4°C (Fig. 2). When there is danger, however (e.g. an oxygen deficit), catfish may temporarily increase their activity in winter (Daněk et al., 2014).

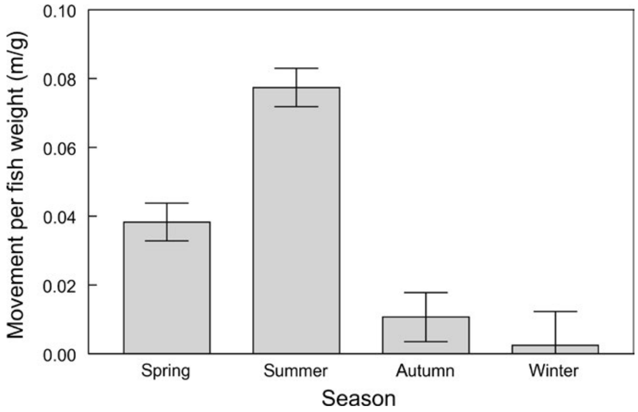

FIGURE 3 Catfish *Silurus glanis* movement per fish weight (movement values divided by individual fish weight) across seasons. Values adjusted means ± *SE*

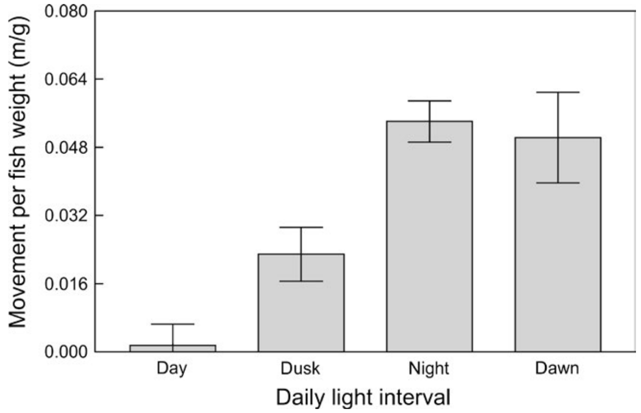

FIGURE 4 Catfish *Silurus glanis* movement per fish weight (movement values divided by individual fish weight) across daily light intervals (dusk and dawn - light intensity 1–500 lx; night < 1 lx and day > 500 lx). Values adjusted means ± *SE*

In our study, juveniles exhibited nocturnal and crepuscular activity during spring, summer and autumn. Slavík et al. (2007) found that the activity of adults may have a dualistic nature. In winter and spring, they recorded the greatest movements of catfish during the day. Other studies (Boujard, 1995; Carol et al., 2007) indicate that catfish are preferentially nocturnal; this pattern can be altered by food availability in controlled conditions (Bolliet et al., 2001) or by the temporary presence of a specific type of prey in nature (Cucherousset et al.,

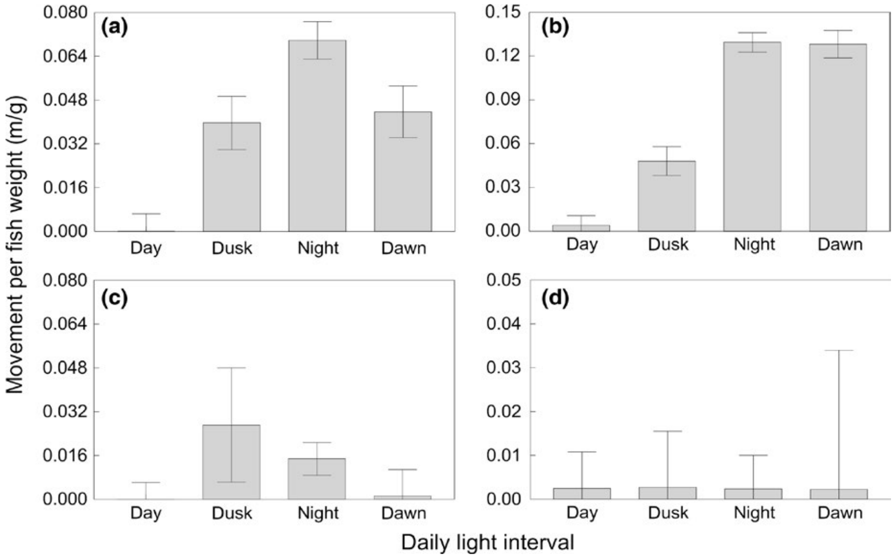

FIGURE 5 Catfish *Silurus glanis* movement per fish weight (movement values divided by individual fish weight) across daily light intervals (dusk and dawn - light intensity 1–500 lx; night < 1 lx and day > 500 lx) during (a) spring, (b) summer, (c) autumn and (d) winter. Values adjusted means ± *SE*

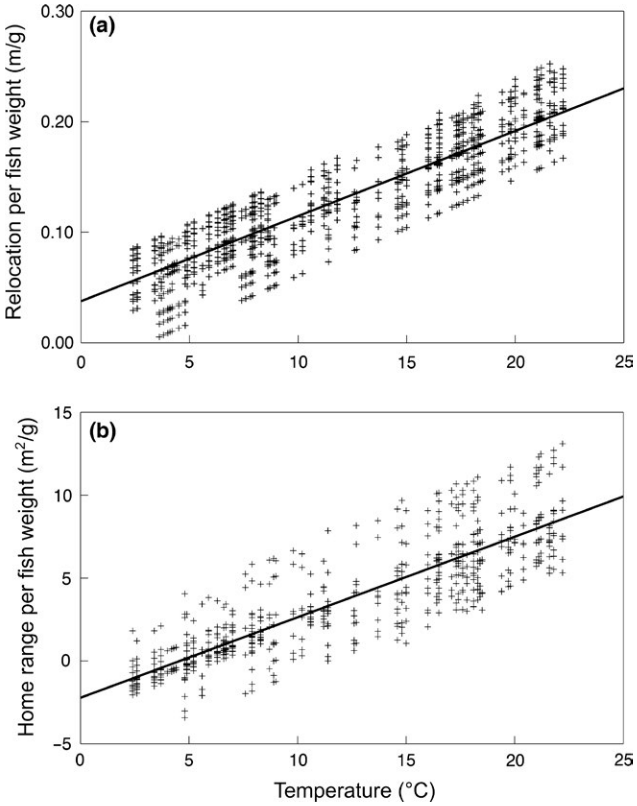

FIGURE 6 Relationship among a) catfish *Silurus glanis* relocations per fish weight and temperature; b) home range size per fish weight and temperature. Relocation and home range values are divided by individual fish weight. Predicted values are from particular linear mixed models (LMM)

2012). The strictly nocturnal activity of juvenile catfish may be influenced by two factors: better foraging conditions and lower predation risk. European catfish use non-visual senses to detect and track their prey (Pohlmann et al., 2001), which is advantageous when foraging in waters with great turbidity or in low-light conditions (at dusk, dawn or night). As the eyesight of *S. glanis* is strongly limited, it may face greater predation risk in daytime. During the day, catfish may be more threatened by predation from the banks or the air, for example, by piscivorous birds, because these predators are especially hard to detect without well-developed eyesight. Present at the locality are the great cormorant (*Phalacrocorax carbo*) and the grey heron (*Ardea cinerea*), for which catfish weighing around 350 g are suitable prey (Cook, 1978; Suter, 1997). In our study, we did not track adult fish, so we cannot rule out their possible influence on the behaviour of juveniles. Previous studies revealed possible conspecific agonistic behaviour in European catfish (Slavík & Horký, 2009; Slavík, Pešta, & Horký, 2011). On the other hand, Slavík et al. (2007) did not observe any great shifts in the activity of juveniles caused by adult fish and stated that movement of juveniles and adults occurred mostly within the same time intervals. Mutual interactions between adults and juveniles deserve further study.

We did not detect any significant effect of either water clarity or dissolved oxygen concentration (within the range of 2.4–16.3 mg/L) on catfish movement, HR size or relocation. Water clarity may generally affect fish activity and prey consumption, especially in insectivorous or piscivorous species, as predators can hardly see their prey in more turbid environments (De Robertis, Ryer, Veloza, & Brodeur, 2003; Kulíšková, Horký, Slavík, & Jones, 2009; Sweka & Hartman, 2003). European catfish, however, use non-visual senses to track their prey, thus they may not be affected by low water clarity. In rivers, great turbidity is usually connected with high water levels or water flow. These conditions may enhance prey accessibility (e.g. insects and earthworms). These better foraging conditions may increase the activity of non-visual predators, particularly European eel (*Anguilla anguilla*) and European catfish (Slavík et al., 2007; Tesch, 1977). However, changes in water clarity at our study site were seasonal in character, depending on algal development. These changes were therefore not related to the temporarily better foraging conditions for catfish. Dissolved oxygen concentrations within the given range also had no observable impact on catfish behaviour, either. In our previous work (Daněk et al., 2014), by contrast, we found a strong effect of dissolved oxygen concentrations within the range of

1.3–2.4 mg/L, which prompted catfish to start moving and relocate to oxygen refuges. The blood of European catfish contains 30%–35% haemoglobin, which helps the fish balance out different oxygen condition, including low oxygen levels (Copp et al., 2009). It is reasonable to assume that the concentration of oxygen plays a role only when the minimum threshold value is reached.

ACKNOWLEDGEMENTS

This study was supported by an S grant from the Ministry of Education, Youth and Sports of the Czech Republic and by the Czech University of Life Sciences Prague (SGS 21260/1312/3176; SGS 21260/1312/3169 and CIGA No. 20152007).

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