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The occurrence of non-native tubenose goby *Proterorhinus semilunaris* in the pelagic 0+ year fish assemblage of a central European reservoir

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In July 2008, early juvenile tubenose goby *Proterorhinus semilunaris* were found in nocturnal pelagic waters of the Vranov Reservoir, Czech Republic. Presence of benthic-living prey in the guts of these fish suggested migration between benthic and pelagic habitats.

Key words: diel migration; diet; dispersal; Gobiidae; invasive species.

The freshwater tubenose goby *Proterorhinus semilunaris* (Heckel) has long been regarded as a synonym of *Proterorhinus marmoratus* (Pallas). Using combined molecular and morphological analyses, Neilson & Stepien (2009) recently found marked divergence, indicating a species-level separation between freshwater and marine populations formerly confused under the name *P. marmoratus*. The authors concluded that the original *P. marmoratus* occupies coastal and estuarine habitats of the Black Sea, while the tubenose goby in freshwater drainages of the Black Sea basin comprises another species, *P. semilunaris*, which is a valid taxon.

Historically, the westernmost part of the *P. semilunaris* distribution range included the Danube River drainage up to about Vienna (Ahnelt *et al.*, 1998). Expansion of this species has been registered in central Europe since the 1970s (Harka & Bíró, 2007). *Proterorhinus semilunaris* spread upstream through the Danube River to southern Germany (Ahnelt *et al.*, 1998) and via the Rhine–Maine–Danube canal, it penetrated the Rhine River (*i.e.* North Sea basin) and extended as far as the Netherlands in 2002 (Von Landwüst, 2006; Kottelat & Freyhof, 2007). Recently, the species has also been reported in France (Manné & Poulet, 2008). In Eastern Europe, *P. semilunaris* expanded through the Ukrainian part of the Dnieper River to the Pripyat River in Belarus (Rizevsky *et al.*, 2007). In 2008, the species was found

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in the Polish Vistula River (Grabowska *et al*., 2008), where it arrived probably *via* the Pripyat–Bug canal connecting the Dnieper drainage (*i.e.* Black Sea basin) to the Vistula drainage (*i.e.* Baltic Sea basin). *Proterorhinus semilunaris* also successfully settled in the North American Great Lakes during the 1990s, presumably after being introduced in ballast water of transoceanic ships (Jude *et al*., 1992; Hensler & Jude, 2007).

In the Czech Republic, *P. semilunaris* is a non-native species that was first registered in 1994 (Lusk & Halačka, 1995) in the littoral zone of the shallow lowland Mušov Reservoir, lying on the Dyje River (r. km 68·5–78·0; Danube River drainage). Soon after the first occurrence, *P. semilunaris* became abundant in the shoreline assemblage of this reservoir, as well as another two large reservoirs (Věstonice and Nové Mlýny) located just below the Mušov impoundment (Prášek & Jurajda, 2005). The species spread in the whole lower Dyje River up to river km 84 (Prášek & Jurajda, 2005), and a small isolated population was found far upstream at the river km 207–209, directly above the deep-valley Vranov Reservoir (Švátora *et al*., 2000). The most probable origin of *P. semilunaris* in the Mušov Reservoir, and perhaps also in the upper Dyje River above the Vranov Reservoir, seems to be a release of baitfish by anglers arriving from Danubian countries (Austria and Slovakia; Prášek & Jurajda, 2005).

In 2008, juvenile and adult fish assemblages were surveyed in different habitats of the Vranov Reservoir (Vašek *et al*., 2009). During this survey, *P. semilunaris*, which is considered a typical benthic species (Pinchuk *et al*., 2004; Naseka *et al*., 2005), was recorded in the littoral assemblage and, surprisingly, also in the pelagic assemblage of juvenile fishes. Using the data obtained in the Vranov Reservoir in 2008, the present paper provides detailed information on the pelagic habitat use in juvenile *P. semilunaris* and discusses the results in the context of the invasion potential.

Littoral and pelagic young-of-the-year (YOY, 0+ year) fish assemblages were examined in the deep-valley Vranov Reservoir (dam coordinates: 48° 54′ 25″ N; 15° 49′ 8″ E) on 28–30 July 2008. The reservoir has a surface area of 761 ha, a volume of $132{\cdot}7 \times 10^6$ m^3, an altitude of 350 m a.s.l. and maximum depth of 45 m. The Vranov Reservoir is characterized by an elongate morphology (the total length *c*. 28 km), with its depth increasing towards the dam. Most of the reservoir shoreline consists of bedrock and steep stony banks; macrophytes are nearly absent in the inshore areas. The main reservoir tributary is the Dyje River, with a mean long-term annual flow of 9·7 m^3 s^{-1}. The reservoir became operational in 1934 and, at present, it is used for water supply, hydropower generation, recreation and flood control.

The pelagic 0+ year fish assemblage was sampled with a fixed-frame trawl (rectangular mouth opening of 3 m × 3 m, total length of 5·4 m, mesh-sizes of 6·5 mm in the belly and 4 mm in the codend) (Jůza & Kubečka, 2007). Trawling was carried out at night in uplake (r. km 193·5–195·0) and downlake (r. km 175·5–177·3) areas of the reservoir [Fig. 1(a)]; the trawl was towed either 50 m (in the uplake area) or 100 m (in the downlake area) behind a research vessel, usually for 10 min, at a speed of 0·9–1·1 m s^{-1}. Five tows were made in the uppermost surface stratum of 0–3 m (two and three tows in the uplake and downlake areas, respectively) and a single tow was done in the deeper surface stratum of 3–6 m (in the downlake area only). The trawling focused on the surface stratum because a previous study in

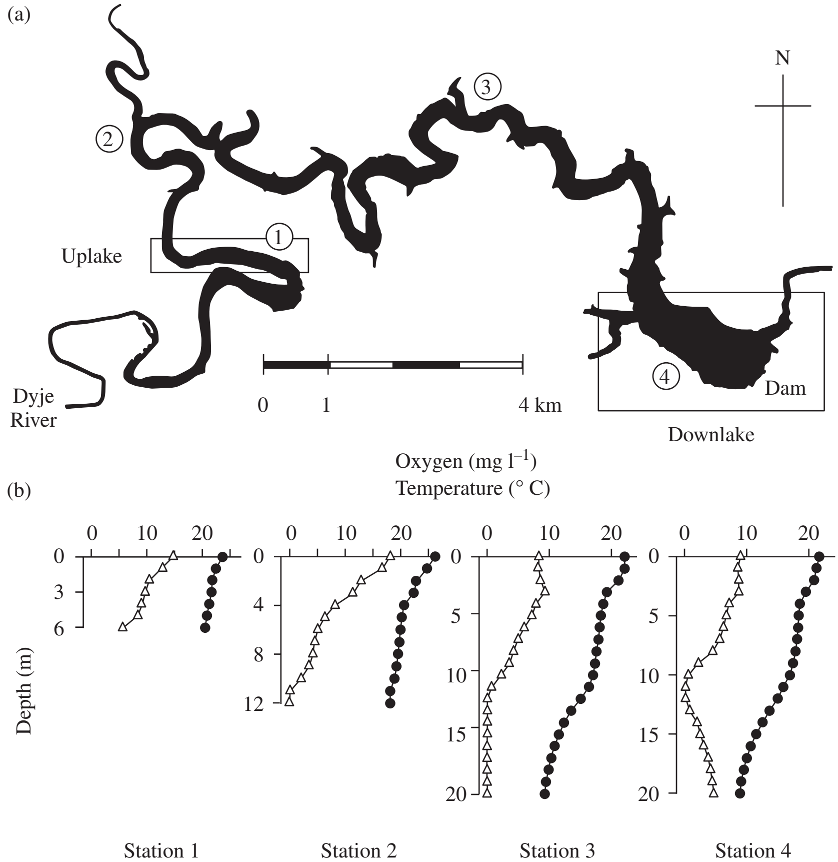

FIG. 1. (a) Map of the Vranov Reservoir (Czech Republic) with relative positions of the sampled sites in July 2008. Night trawling was conducted at uplake (maximum depths from 5 to 7 m) and downlake (maximum depths from 33 to 40 m) areas (▭). Daytime boat electrofishing was done at the four stations (stations 1–4). (b) The vertical profiles of water temperature (●) and dissolved oxygen (△) in the reservoir mid-channel at stations 1–4.

another thermally stratified and eutrophic Czech reservoir revealed that the majority of pelagic 0+ year fishes were present in the uppermost layers of the water column (Jůza *et al*., 2009). In both reservoir areas, tows were performed in the mid-channel, approximately above the former river bed (*i.e.* above maximum depths). The trajectory of the trawl during towing was generally out of the vessel's wake and the fishes were thus caught outside the directly disturbed area. Captured 0+ year fishes were killed in a lethal dose of anaesthetic and stored in a 5% formaldehyde solution for later laboratory processing.

Littoral 0+ year fish assemblage was sampled by boat electrofishing. A flat-bottom aluminium boat 6 m long and 1·8 m wide, serving as the cathode, was used. The boat was equipped with two booms extending 2·5 m forward from the bow; the distance between the foremost ends of the booms was 1·9 m (Miranda & Kratochvíl, 2008). Each boom supported an anode array consisting of six droppers (each 5 mm in diameter and 1 m long, made of a stainless steel cable) equally spaced in a circle.

During fishing, the droppers penetrated 0·6–0·8 m into the water. A Hans Grassl EL 65 II GL system (13 kW; www.hans-grassl.com) provided electric power; 60 Hz pulsed DC output was used. Electrofishing was conducted during daytime at four sampling stations equally spaced along the longitudinal reservoir axis [stations 1–4; Fig. 1(a)]. At each station, 300–500 m of shoreline with a relatively steep bottom (slope *c*. 30°) composed of coarse gravel and rocks were sampled; shoreline of this type constitutes most of the reservoir littoral zone. During electrofishing, the boat was operating slowly along the shoreline with the electrical field continuously activated. Two workers with fine-mesh dip-nets collected stunned fishes from the front of the boat. Captured 0+ year fishes were killed in a lethal dose of anaesthetic, preserved in a 5% formaldehyde solution and later identified, counted and measured in the laboratory. All fish sampling was conducted during calm weather conditions. Concurrently, the water temperature and concentration of dissolved oxygen were measured with YSI-556 MPS probe (www.ysi.com) at the stations 1–4. At each station, the measurement was done in the mid-channel at 1 m intervals from the surface down to the bottom or to a maximum depth of 20 m [Fig. 1(b)].

Captured 0+ year *P. semilunaris* were analysed to ascertain their diet composition. In the laboratory, the whole gut was cut-off under a dissecting microscope and its content was placed into polyvinyl alcohol medium on a microscope slide. Prey items or their remains were identified, counted and measured under a compound microscope. Fresh masses of prey organisms were reconstructed from length and mass relationships (Přikryl, 1980; Mehner *et al*., 1995; Höhn *et al*., 1998). Altogether, the gut contents of 23 fish were examined. Diet composition was described by percentage of total prey numbers and percentage of total prey fresh mass.

A total of 810 individuals of 0+ year fishes representing six species were collected in surface pelagic waters of the Vranov Reservoir (Table I). Bream *Abramis brama* (L.) dominated trawl catches at the uplake area while bleak *Alburnus alburnus* (L.) was the most abundant species in the downlake area (Table I). The total density of pelagic 0+ year fishes was higher at the uplake than the downlake area. Thirty-one individuals of 0+ year *P. semilunaris* were caught in trawl tows at the uplake area and the next three individuals were captured in trawl tows at the downlake area. The densities of *P. semilunaris* in the surface pelagic stratum, calculated only from the tows where this species appeared, varied between 0·02 and 0·81 individuals 100 m^{-3}. *Proterorhinus semilunaris* was the third most represented species within the pelagic 0+ year fish assemblage (Table I). Nine 0+ year fish species were collected in the littoral zone (Table I). Three 0+ year juveniles of littoral *P. semilunaris* were caught in the uplake area and none were recorded in the downlake area, where, however, the total littoral catch was extremely low and consisted of a single species, *Esox lucius* L. (Table I).

The length–frequency distribution of 0+ year *P. semilunaris* in trawl catches was unimodal. The standard length (L_S) of the 34 captured fish ranged from 18·5 to 32·5 mm, with an average of 24·8 mm. The three 0+ year juveniles collected in the littoral zone attained 23·5, 32·0 and 33·5 mm L_S.

All inspected 0+ year *P. semilunaris* ($n = 23$) contained prey in their guts (Table II). The diet of juveniles in both pelagic and littoral habitats was numerically dominated by cyclopoid copepods (Table II). In terms of fresh mass, however, the large cladoceran species *Leptodora kindtii*, a typically pelagic prey, comprised the bulk of gut contents in *P. semilunaris* collected in the pelagic zone. This prey

TABLE I. Relative abundance (%) of species recorded in the littoral and pelagic 0+ year fish assemblages at the uplake and downlake areas of the Vranov Reservoir (Czech Republic) in July 2008. In case of the littoral fish assemblage, the stations 1 and 2, and 3 and 4 (see Fig. 1) were considered to represent the uplake and downlake areas, respectively. Total catch of 0+ year fishes and mean ± S.D. total catch per unit effort (CPUE) are indicated

	Uplake		Downlake	
Species	Littoral	Pelagic	Littoral	Pelagic
Abramis brama	1·75	82·15	—	0·38
Alburnus alburnus	3·51	2·19	—	84·67
Rutilus rutilus	24·56	8·56	—	13·79
Aspius aspius	3·51	—	—	—
Leuciscus cephalus	7·02	—	—	—
Proterorhinus semilunaris	5·26	5·65	—	1·15
Perca fluviatilis	40·35	0·91	—	—
Sander lucioperca	—	0·55	—	—
Esox lucius	12·28	—	100·00	—
Silurus glanis	1·75	—	—	—
Total catch (individuals)	57	549	4	261
Mean ± S.D. total CPUE*	5·70 ± 0·71	6·53 ± 0·30	0·53 ± 0·19	1·25 ± 1·86

*CPUE is the number of fishes per 100 m of shoreline for the littoral assemblage and the number of fishes per 100 m^3 of filtered water for the pelagic assemblage.

constituted 59 and 44% of the total fish diet at the uplake and downlake areas, respectively (Table II). Typical benthic prey, *e.g.* chironomid or ephemeropteran larvae, chydorids, *Asellus aquaticus*, was also found in guts of 0+ year *P. semilunaris* sampled in the surface pelagic stratum (Table II). The mean number of prey per gut and mean fresh mass of total food in the gut were higher in fish collected in the pelagic zone at night than those fish sampled in the littoral zone during the day (Table II).

No previous studies have documented the use of the pelagic habitat in lakes and reservoirs by *P. semilunaris*. In riverine systems, however, juvenile *P. semilunaris* were found to enter the current, which they use for downstream dispersal (Zitek *et al*., 2004*a*, *b*). In contrast, the present survey was carried out in stillwater habitats. The Dyje River, which is the major reservoir inflow, entered the reservoir waters 2·8 km upstream of the uppermost locality where fish were collected, and even at this locality the pelagic waters were stagnant during the survey. Therefore, the pelagic occurrence of 0+ year *P. semilunaris* in the Vranov Reservoir could not be directly attributed to drift transport from inflowing rivers. Wind-induced displacement from inshore to offshore areas was also unlikely to cause the observed pelagic distribution, because the fish samples were taken in calm weather and moreover the reservoir is relatively wind-protected due to its location in a deep valley. The results of this study suggest that 0+ year *P. semilunaris* most probably entered the surface pelagic stratum actively, by swimming.

Recent studies (Hensler & Jude, 2007; Hayden & Miner, 2009) reported the use of the pelagic habitat in the round goby *Neogobius melanostomus* (Pallas), a species of Ponto-Caspian origin that successfully invaded the North American Great Lakes and currently is spreading in many large rivers of Europe. The use of pelagic waters

Table II. Diet composition of 0+ year *Proterorhinus semilunaris* collected in the littoral and pelagic habitats of the Vranov Reservoir (Czech Republic) in July 2008. Frequency of particular prey items are given as mean percentage by numbers (% *N*) and mean percentage by fresh mass (% *M*). Mean ± s.d. number of total prey per fish gut and mean ± s.d. fresh mass of total food per fish gut are indicated

	Uplake: Littoral		Uplake: Pelagic		Downlake: Pelagic	
Prey taxa	% *N*	% *M*	% *N*	% *M*	% *N*	% *M*
Cyclopoida (copepodites and adults)	90·1	90·3	32·0	10·2	35·0	2·7
Leptodora kindtii	—	—	9·5	59·5	11·1	43·6
Daphnia sp.	—	—	25·1	9·9	16·1	3·0
Bosmina sp.	2·6	1·3	21·8	1·9	—	—
Diaphanosoma brachyurum	—	—	7·2	0·5	1·7	0·1
Chydoridae	—	—	—	—	15·3	0·8
Ostracoda	7·3	8·4	1·5	0·3	—	—
Asellus aquaticus	—	—	0·3	1·9	3·0	7·2
Chironomid larvae	—	—	2·6	15·8	12·6	17·6
Ephemeropteran larvae	—	—	—	—	5·3	25·1
Mean ± s.d. number of prey per digestive tract	9·3 ± 3·2		24·4 ± 15·9		16·7 ± 4·9	
Mean ± s.d. fresh mass of gut content (mg)	0·6 ± 0·2		8·3 ± 4·5		15·7 ± 2·9	
Number of fish examined	3		17		3	

by *N. melanostomus* had not been known previously and nor had it been suspected because of its morphology adapted to benthic mode of life, the lack of a swimbladder, which causes restricted buoyancy, and absence of true larval stage since larval development occurs inside the benthic eggs (Pinchuk *et al*., 2003; the same characteristics are typical also for *P. semilunaris*; Leslie *et al*., 2002; Pinchuk *et al*., 2004). Nonetheless, Hensler & Jude (2007) and Hayden & Miner (2009) documented diel vertical migration of early juvenile *N. melanostomus* in Lake Erie; juveniles entered pelagic waters at night while during daytime they were largely missing in the water column. Similarly, Zitek *et al*. (2004*b*) reported that *P. semilunaris* in a side channel of the Danube River entered the drift nearly exclusively during night. Taking into account these observations, it is possible that at least some part of the 0+ year *P. semilunaris* population in the Vranov Reservoir travelled into pelagic waters during night. Clear evidence for the likelihood of such a diel habitat shift in juvenile *P. semilunaris* was provided by diet analyses.

Diet analyses demonstrated that 0+ year *P. semilunaris* were actively feeding in the pelagic waters of the reservoir at night. The typical pelagic zooplankter *L. kindtii* was the most important prey consumed. Fifty-five per cent of *P. semilunaris* individuals collected in surface pelagic waters, however, also contained benthic-living prey (*i.e.* ostracods, isopods, benthic chydorids, small chironomid and ephemeropteran larvae). The inspection of gut contents showed that benthic prey usually occurred in the distal part of gut, while zooplankton was present in the foregut. These results indicate that 0+ year *P. semilunaris* migrated to the surface pelagic stratum from either bottom or littoral habitats. Such nocturnal migration to pelagic waters might be viewed as a behaviour optimizing foraging success (Clark & Levy, 1988; Gliwicz & Jachner, 1992) and as a dispersal strategy (Hayden & Miner, 2009).

The ability of 0+ year *P. semilunaris* to enter pelagic waters may have important implications for dispersal success and, therefore, invasiveness of the species. For example, by using a water column the species has higher probability to become entrained in the ballast water of ships (Hayden & Miner, 2009) and transported far beyond its native or actual range (Jude *et al*., 1992; Wonham *et al*., 2000). Adaptation to feeding in darkness might enhance survival of fish in ballast tanks. Once the species is introduced to and established at a new site, natural dispersal of juvenile stages through currents (*i.e.* downstream drift in rivers; Zitek *et al*., 2004*a*, *b*; or within-lake dispersal *via* advection; Hayden & Miner, 2009) may facilitate further range expansion, including downstream passage across man-made barriers (*i.e.* dams and weirs; Prášek & Jurajda, 2005).

Proterorhinus semilunaris is probably not adapted for long distance swimming in open water habitat (Leslie *et al*., 2002; Pinchuk *et al*., 2004). Nevertheless, the results of this study suggest that 0+ year juveniles of *P. semilunaris* actively migrated to the surface pelagic stratum either from the bottom or littoral habitats. It means, that 0+ year fish travelled by swimming a distance of up to several tens or hundreds of metres, depending on whether they were migrating from the nearest bottom or shoreline. These findings show that, despite being described as benthic (Pinchuk *et al*., 2004; Kottelat & Freyhof, 2007), *P. semilunaris* has the capacity to actively utilize open water habitat during the juvenile stage.

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