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ICHTHYOLOGY

Food Spectrum, Trophic and Length-Weight Characteristics of Nonindigenous Suckermouth Armored Catfishes *Pterygoplichthys* spp. (Loricariidae) in Vietnam

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Abstract—The food spectrum and trophic and length–weight characteristics of an invasive species, South American suckermouth armored catfishes *Pterygoplichthys* spp. (Loricariidae), from lotic and lentic inland waters of Vietnam have been studied. It is found that the diet of suckermouth armored catfishes consists of plant and animal food, as well as organic detritus. According to the predominant type and pattern of feeding, suckermouth armored catfishes can be classified as detritivore gatherers (janitor). Some specimens of catfish with a high consumption of animal food have been identified. It is noted that invasive suckermouth armored catfishes can be a significant food competitor for aboriginal fish species; detritivores; and, possibly, benthophages in the lotic and lentic inland waters of Vietnam.

Keywords: suckermouth armored catfishes, *Pterygoplichthys* spp., Loricariidae, nutrition, trophic characteristics, length-weight relationship, nonindigenous species, Vietnam

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INTRODUCTION

A great variety of specialized detritophagous fish, which are an important link in the food web and the energy balance of aquatic ecosystems, inhabit the water bodies and watercourses of tropical latitudes (Lowe-McConnell, 1987). The species of the families Prochilodontidae, Curimatidae, armored catfish (Loricariidae) from South America, and some species of the families Cichlidae and Cyprinidae from Africa and Asia are the most abundant and common representatives of tropical detritophagous fish (Lowe-McConnell, 1987).

Loricariid catfish are one of the largest and the most specialized group of the order Siluriformes (Gosline, 1947; Armbruster, 2011), which includes 163 genera and 1187 nominal and 1171 valid species (Eschmeyer, 2020). The native range of loricariids is the Neotropecal realm: lentic and lotic waters of South and Central America (Nelson, 2006; Armbruster, 2011).

Suckermouth armored catfishes are one of the major groups of nonindigenous species posing a serious threat to tropical freshwater ecosystems (Lowe et al., 2004; Liang et al., 2005; Godwin et al., 2016; Stolbunov and Tran Duc Dien, 2019). Suckermouth armored catfishes were first found in Southeast Asia more than 30 years ago (Weber, 1992; Kottelat et al., 1993; Welcomme and Vidthayanom, 2003; Page and Robins, 2006). The first local findings of solitary specimens of suckermouth armored catfishes (*Pterygoplichthys* spp.) in inland waters of Vietnam were recorded relatively recently: in 2003–2004 in the Mekong River in the southern part of the country (Welcomme and Vidthayanom, 2003; Serov, 2004) and in 2006 in the Red River located in the northern part (Levin et al., 2008). Later, self-sustaining highly abundant populations of loricariids were found in the Dinh River (Zworykin and Budaev, 2013) and in the Ea Kao Reservoir (Stolbunov et al., 2015). Numerous populations of *Pterygoplichthys* spp. inhabiting the basins of all relatively large rivers of Central and Southern Vietnam were recorded in 2017–2019 (Stolbunov et al., 2017; Gusakov et al., 2018; Stolbunov et al., 2017, 2020, 2021). According to the data of phenetic, morphological, and molecular genetic analyses, it was found that currently two species of suckermouth armored catfish reliably inhabit the water bodies and watercourses of Vietnam: *P. pardalis* (Castelnau, 1855) and *P. disjunctivus* (Weber, 1991), and each of them is represented by several phylogenetic lines whose representatives are able to hybridize with each other (Stol-

Table 1. Length–weight and trophic characteristics of the studied suckermouth armored catfish *Pterygoplichthys* spp.

Parameters	$M \pm SE$	min–max
Total body length, cm	25 ± 5	10–41
Standard body length, cm	19 ± 4	8–31
Body weight, g	148 ± 8	11–408
Weight of the bolus, g	5.24 ± 0.94	0.04–34.35
Length of gastrointestinal tract, cm	277 ± 17	112–606

$M \pm SE$ is the mean and its standard error; min–max is minimum and maximum values.

bunov et al., 2021). Their high adaptive potential and fecundity (Armbruster, 1998; Nico and Fuller, 1999; Mendoza et al., 2009; Rueda-Jasso et al., 2013) allow them to quickly colonize spatial and trophic niches in new habitats, replacing native fish species (Chaichana et al., 2011; Orfinger and Goodding, 2018; Stolbunov and Tran Duc Dien, 2019).

Suckermouth armored catfish are characterized by the presence of a ventral oral disk and jaws specialized for surface attachment to submerged objects and different substrates and benthic feeding (Power, 1984a, 1984b; Schaefer, 1988). The trophic specialization of loricariids is determined by the morphological diversification of the structure of the oral and maxillary apparatus, feeding habits, and digestive processes of fish (Gerking, 1994; Lujan, 2009; Lujan, Armbruster, 2012). A number of studies have been devoted to the functional morphology, trophic specialization, and feeding behavior of loricariids (Angelescu and Gneri, 1949; Power, 1983; Py-Daniel, 1984; Schaefer and Lauder, 1986, 1996; Fugi, 1993; Buck, 1994; Buck and Sazima, 1995; Fugi et al., 1996; Armbruster, 1998; Lujan, 2009; Lujan and Armbruster, 2012). Loricariids feed by scraping organic detritus, periphyton, remains of higher plants (including woody debris by some species), and aquatic invertebrates (mainly benthic ones) (Arcifa, and Meschiatti, 1993; Castro et al., 2003; Chaichana et al., 2011; Lujan et al., 2011, 2012 etc.). Suckermouth armored catfish may also feed on eggs and juveniles of other fish species (Cook-Hildreth, 2009; Chaichana and Jongphadungkiet, 2012; Chaichana et al., 2013). The relationship between the morphological similarity and the similarity of the diet of sympatric loricariid species indicates the importance of feeding specialization in the fish trophic niche segregation (Delariva and Agostinho, 2001). In some cases, armored catfishes manifested clearly expressed agonistic and territorial behavior in relation to other fish species aimed at obtaining preferential access to the most energetically valuable food resources: benthic compared to plant detritus (Lujan et al., 2012).

It has been currently established that suckermouth armored catfishes *Pterygoplichthys* spp. inhabit the basins of practically all large river systems of Vietnam at different altitudes above sea level, from lowlands to mountain regions: Mekong, Dong Nai, Serepok, Da Rang, Cai, and many others (Gusakov et al., 2018; Stolbunov and Tran Duc Dien, 2019; Stolbunov et al., 2017, 2020, 2021). Apparently there are close competitive interactions, including for food resources, between numerous populations of armored catfish and native fish species. Accordingly, a number of questions arise: what sources play the main role in the diet of the invaders (loricariids) in new habitats and how can this affect the native species of the fish population in water bodies of Vietnam?

The aim of this study is to analyze the food spectrum of suckermouth armored catfish in lentic and lotic waters of Vietnam.

MATERIALS AND METHODS

Ichthyological material was collected in Decembe–February 2016–2017 in the Ea Kao (12°36.554′ N, 108°2.439′ E) and Suoi Trau (12°30.302′ N, 109°2.694′ E) reservoirs, the Dinh River (12°29.740′ N, 109°7.686′ E), and the Serepok (12°49.000′ N, 107°51.045′ E) and Am Chua channels (12°17.436′ N, 109°6.063′ E). Fish were caught using fixed gill nets (22–40 mm mesh size) and a frame lift net (Kinalev's net).

The total body length, standard body length, and the length of the gastrointestinal tracts of fish were measured. The weight of fish and their food boluses were determined. Fish feeding habits were studied using qualitative and quantitative techniques (*Metodicheskoe* ..., 1974). The recovered weight of food organisms was obtained using the equation of the length–weight relationship, tables of standard weights, and nomograms (Mordukhai-Boltovskoi, 1954; Chislenko, 1968; Balushkina and Vinberg, 1979; Kurashov, 2007 etc.). A total of 155 specimens were analyzed according to the length–weight characteristics and 40 fish specimens according to trophic ones.

RESULTS

The length–weight and trophic characteristics of the studied suckermouth armored catfishes are given in Table 1. Fish caught during the period under study were characterized by a negative allometric growth (Mina and Klevezel, 1976) (Fig. 1). The linear growth of loricariids prevailed over the growth in weight of fish and this was manifested to a greater degree in fish under lotic conditions (Fig. 1a) than in lentic ones (Fig. 1b).

The length of the gastrointestinal tract of the studied armored catfishes of different sizes varied widely (Table 1) and exceeded the total length of fish 12–17 times. A significant linear relationship was found between the total body length and the length of the gastrointestinal tract of fish (Fig. 2).

The food spectrum of suckermouth armored catfish included mineral, plant, and animal ingredients (Table 2). The main mineral and plant components of the food bolus were mostly represented by small fractions of bottom sediments (clay, pelitic, and powdery sands), microscopic and larger detritus particles of uncertain origin, and plant remains. The weight of the food bolus of the studied specimens of suckermouth armored catfish varied widely from 0.04 g to 34.35 g (on average ~5 g) (Table 1).

Sediments and fine various detrital particles prevailed in the diet of most studied specimens. However, a high content of relatively large (>5 mm) remains of higher semiaquatic and aquatic vegetation, as well as medium and large fractions of sand, which constituted 1–3% of the total mass of the fish food bolus, was found in the food bolus of some fish.

The content of animal food in the digestive tract of armored catfishes was relatively low. Benthic, planktonic, and amphibiotic groups of organisms were found (Fig. 3).

A suckermouth armored catfish (Dinh River) was found in which amphibiotic organisms constituted the main portion of animal food in terms of abundance and biomass, unlike other fish. The food bolus of this specimen contained 620 amphibiotic larvae of biting midges (in other fish, it was 0–26 specimens) and 212 larvae of flies from the family Dolichopodidae (0–5 specimens in other fish). Terrestrial mites, ants, and other terrestrial insects were also found (Table 2).

The total biomass of animal food components of suckermouth armored catfishes was on average ~0.1% of the total weight of the fish food (in some specimens, 0.3–1.0%). Nematodes, cladocerans of the genus *Bosminopsis*, cyclopoids, and ostracods *Cypria* cf. *furfuracea* and chironomid larvae prevailed in respect to the frequency of occurrence in the animal food of suckermouth armored catfishes. Copepods and the ostracod *C.* cf. *furfuracea* prevailed in the bolus in terms of abundance (Table 2). The average size of invertebrates in fish diet did not exceed 3–5 mm.

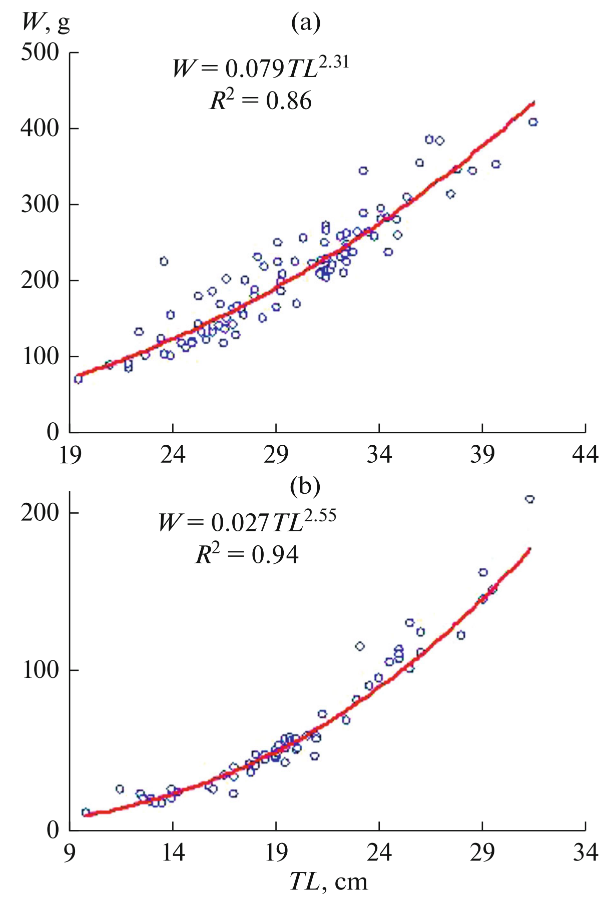

Fig. 1. Length–weight relationship of suckermouth armored catfishes in different habitats; (a) lotic conditions (n = 92 ind.): Dinh River, Serepok channel, and Am Chua channel; (b) lentic conditions (n = 63 ind.): Suoi Trau Reservoir and Ea Kao Reservoir. *TL*, total body length and *W*, body weight.

DISCUSSION

The results of a study into the food spectrum of suckermouth armored catfishes have shown that most food organisms detected in the boluses of fish are typical representatives of hydrofauna of water bodies in Vietnam (Gusakov et al., 2014; *Ekologia* ..., 2014). The frequency of occurrence of hydrobionts detected in the food of loricarids is obviously determined by their availability, prevalence, and abundance.

The analysis of the relative role of different ecological groups of animal origin in the food spectrum of suckermouth armored catfish has showed that they are mainly represented by benthic and planktonic invertebrates. Amphibiotic and terrestrial organisms were also found in the diet of loricariids. Similar feeding patterns and food composition were previously observed in other detritophagous fish that swallow the sediments together with its inhabitants, the Nile *Oreochromis niloticus* (L.) and the Mozambique *O. mossambicus* (Peters) tilapia, in different water bodies in Vietnam (Stolbunov et al., 2015; Stolbunov and Gusakov, 2015).

It should be mentioned that the studies were conducted during the rainy season, when all water bodies and watercourses were overflowed and, as a result, large coastal areas of the land were flooded. The presence of a significant number of amphibiotic and terrestrial animals in the catfish diet is explained by the fact that some of the studied fish obviously foraged on flooded territories, where invertebrates living on land and in moist coastal soils were consumed together with sediments and detritus. Thus, a specimen of suckermouth armored catfish was found in the Dinh River, in which ~95% of its animal food was composed of amphibiontic organisms (larvae of biting midges and other dipterans) (Table 2). Taking into account

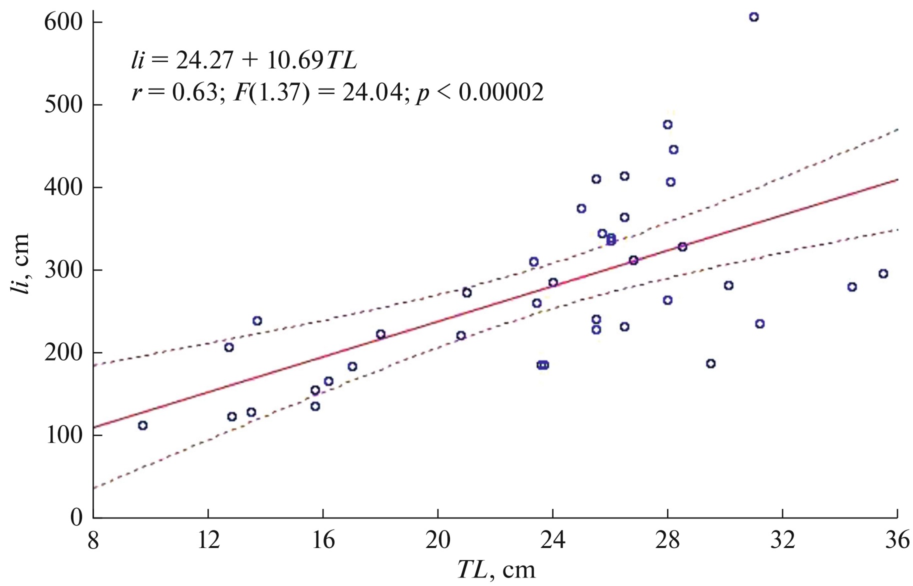

Fig. 2. Regression dependence of the intestinal length (*li*, cm) on the total body length (*TL*, cm) of suckermouth armored catfishes. The dotted line indicates a 95% confidence interval.

the large number and the pattern of location of forage invertebrates in the fish intestine (larvae of amphibiontic insects and ants occurred in groups of several specimens), it may be suggested that this specimen chose "feeding spots" in areas with high concentrations of animals for feeding. Nevertheless, the total recovered weight of its animal food was only 1% of the mass of the food bolus even with such feeding behavior.

A suckermouth armored catfish was found in the discharge channel of the Serepok Reservoir downstream the dam of the hydroelectric power plant; the predominant component of its animal food was composed of planktonic crustaceans, cyclopoids, *Diaptomus* species, and cladocerans (species of the genus *Bosminopsis* and family Sididae etc.) (Table 2). The abundance of Sididae gen. spp. in the intestine of this catfish reached 668 ind., Cyclopoidae gen. spp. 20177 ind., and Diaptomidae gen. spp. 315 ind. Meiobenthic crustaceans (harpacticoids, ostracods) and nematodes were also found in the food. The total recovered weight of animal food of this specimen was 0.6% of the total weight of the food bolus. The rest of the content of the digestive tract of the fish was composed of bottom sediments (red clay) and fine, mainly plant detritus. It is known that, in some cases, planktonic organisms entering the water intake (culvert) of hydraulic structures can receive injuries and die (Loginov and Gelashvili, 2016). Dead zooplankton organisms settle to the bottom as the current weakens in the zone of discharge (*Ekologicheskie* ..., 2001; etc.). The considered specimen of suckermouth armored catfish probably preferred to feed in this area for some time after finding a feeding spot that was relatively rich in animal components. Further studies, including experimental ones, are required to exactly determine individual features of the feeding habits of suckermouth armored catfishes.

CONCLUSIONS

The first studies on the spectrum and feeding habitats of invasive suckermouth armored catfish (*Pterygoplichthys* spp.) that have invaded water bodies and watercourses of Vietnam have shown that in new habitats they behave as typical detritophage gatherers, similar to what is observed in their initial range in South and Central America, where they are commonly known as Janitor fish (Lujan et al., 2012; Froese and Pauly, 2012). The analysis of the qualitative and quantitative composition of the food bolus in the studied specimens has showed that the fish feed mainly on silted areas rich in different detritus and plant residues, swallowing bottom sediments together with invertebrates. Some specimens apparently prefer habitats with high concentrations of animal food that is more typical for facultative zoophages. However, based on a low mass fraction of animal food in the boluses of fish and taking into consideration the microscopic sizes of food objects, it is unlikely that zooplankton and benthic organisms are selectively consumed by armored catfishes. Apparently, they should be considered an accompanying food of loricariids. The results indicate that, when a high abundance of the population is achieved, armored catfishes are able to strongly compete for food resources with local detritophagous fish and probably benthophages.

Table 2. Occurrence (P, %), average abundance (N, ind.), and average recovered weight (w_i, mg) of the bolus components of suckermouth armored catfishes from different habitats and in the integrated fish sample.

Component	Dinh River $n = 9$			Suoi Tran Reservoir $n = 7$			Am Chúa channel $n = 7$			Serepok channel $n = 7$			Ea Kao Reservoir $n = 10$			Total for the studied water bodies $n = 40$		
	P	N	w_i	P	N	w_i	P	N	w_i	P	N	w_i	P	N	w_i	P	N	w_i
Detritus, mineral, plant and other undetermined remains	100	–	5674	100	–	1355	100	–	4987	100	–	12896	100	–	3473	100	–	5511
Sand	22	–	31	–	–	–	14	–	7	–	–	–	–	–	–	8	–	8
Nematoda (ind.)	78	6	<1	14	<1	<1	86	3	<1	43	22	<1	30	1	<1	50	6	<1
Acari (aquatic; ind.)	11	<1	<1	–	–	–	–	–	–	–	–	–	–	–	–	3	<1	<1
Acari (terrestrial; ind.)	56	9	<1	14	<1	<1	–	–	–	14	<1	<1	–	–	–	18	2	<1
Cladocera (*Bosminopsis* sp.)	11	<1	<1	57	3	<1	29	1	<1	–	–	–	90	17	<1	40	5	<1
Cladocera (Chidoridae gen. spp.)	–	–	–	43	1	<1	–	–	–	43	13	<1	10	<1	<1	18	3	<1
Cladocera (Macrothricidae gen. spp.)	11	1	<1	–	–	–	43	<1	<1	14	<1	<1	–	–	–	13	<1	<1
Cladocera (*Ilyocryptus* spp.)	11	1	<1	29	1	<1	57	2	<1	–	–	–	30	1	<1	25	1	<1
Cladocera (Sididae gen. spp.)	–	–	–	–	–	–	43	1	<1	14	95	1	60	1	<1	25	17	<1
Cladocera (ind.)	33	1	<1	–	–	–	–	–	–	14	1	<1	40	2	<1	20	1	<1
Copepoda (Cyclopoidae gen. spp.)	100	4	<1	43	2	<1	100	47	1	100	2897	17	60	2	<1	80	517	3
Copepoda (nauplii)	–	–	–	–	–	–	14	<1	<1	14	1	<1	–	–	–	5	<1	<1
Copepoda (Diaptomidae gen. spp.)	11	<1	<1	–	–	–	–	–	–	14	45	4	–	–	–	5	8	1
Copepoda (Harpacticoida; ind.)	11	<1	<1	–	–	–	–	–	–	29	<1	<1	20	<1		13	<1	<1
Ostracoda (*Cypria* cf. *furfuracea*)	44	2	<1	86	56	1	100	215	1	57	14	<1	90	356	4	75	139	1
Ostracoda (ind.)	22	3	1	43	<1	<1	71	6	<1	29	1	<1	50	2	<1	43	3	<1
Trichoptera (ind.)	11	1	<1	–	–	–	–	–	–	–	–	–	–	–	–	3	<1	<1
Ephemeroptera (ind.)	22	<1	<1	–	–	–	–	–	–	14	1	<1	–	–	–	8	<1	<1
Hemiptera (Pleidae gen. sp.)	22	<1	<1	–	–	–	–	–	–	–	–	–	–	–	–	5	<1	<1
Hemiptera (*Micronecta* spp.)	11	<1	<1	14	<1	<1	57	1	<1	29	1	<1	60	3	<1	35	1	<1
Coleoptera (larvae; ind.)	22	1	<1	–	–	–	–	–	–	–	–	–	–	–	–	5	<1	<1
Culicidae gen. spp.	11	<1	<1	–	–	–	–	–	–	–	–	–	–	–	–	3	<1	<1
Ceratopogonidae gen. spp.	44	73	5	–	–	–	29	<1	<1	43	2	<1	–	–	–	23	17	1
Chironomidae gen. spp.	67	13	2	71	6	<1	86	1	<1	57	18	<1	90	13	2	75	10	1
Chironomidae (pupae; ind.)	11	<1	<1	–	–	–	–	–	–	–	–	–	10	<1	<1	5	<1	<1
Diptera (Dolichopodidae gen. spp.?)	11	11	4	–	–	–	–	–	–	–	–	–	–	–	–	3	2	1
Diptera (larvae; ind.)	33	20	4	–	–	–	–	–	–	–	–	–	–	–	–	8	5	1
Insecta (Formicidae)	22	4	<1	–	–	–	–	–	–	–	–	–	–	–	–	5	1	<1
Insecta (terrestrial; ind.)	11	<1	<1	–	–	–	–	–	–	–	–	–	–	–	–	3	<1	<1
Mollusca (*Hippeutus* sp.?)	–	–	–	–	–	–	14	<1	<1	–	–	–	–	–	–	3	<1	<1
Mollusca (Pisidiidae gen. spp.)	11	<1	<1	–	–	–	14	<1	<1	–	–	–	–	–	–	5	<1	<1
All animal components:	100	151	17	100	747	11	100	278	2	100	3111	23	90	398	6	98	739	10
Benthic	89	33	29	100	65	1	100	229	1	71	71	1	90	376	6	90	165	3
planktonic	100	5	<1	57	5	<1	100	49	1	100	3039	22	90	22	<1	90	548	4
amphibiotic	33	100	13	–	–	–	–	–	–	–	–	–	–	–	–	8	22	3
terrestrial	56	13	1	14	<1	<1	–	–	–	14	<1	<1	–	–	–	18	3	<1

n is the sample size and a dash indicates absence in the bolus; <1 is the average abundance and average recovered weight, <1 ind. and <1 mg, respectively.

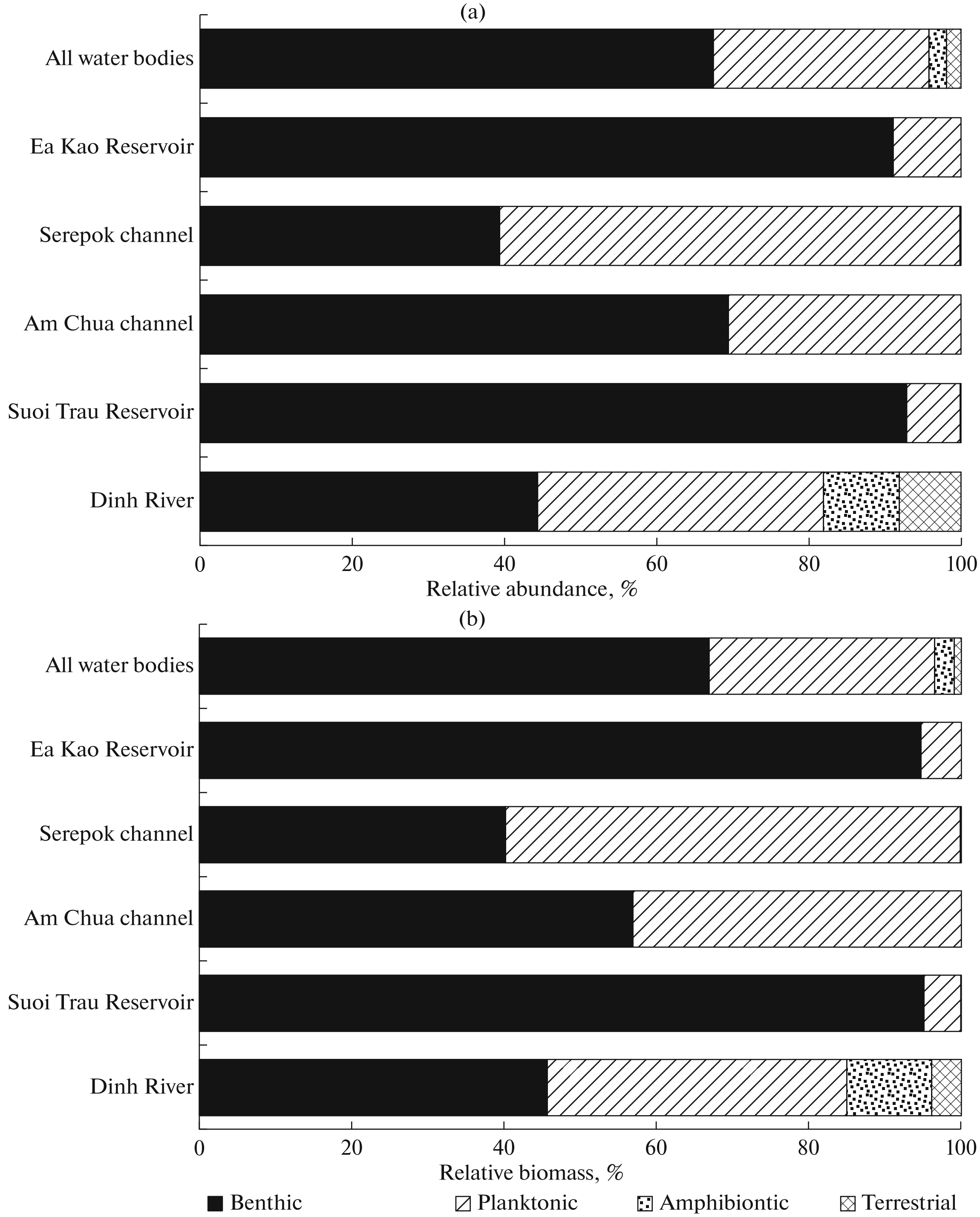

Fig. 3. Relative abundance (a) and biomass (b) of different ecological groups of invertebrates in the bolus of suckermouth armored catfishes from different habitats.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflicts of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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