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Research Article

Non-native and native fish occurrence and distribution in the Suoi Trau reservoir (Central Vietnam)

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Abstract

Several non-native fish successfully occupy many water systems in Vietnam, including reservoirs. The aim of our study was to identify non-native and native fish species in the Suoi Trau reservoir and to estimate their distribution during the dry season. Gill nets and sectional net traps were used at multiple locations of the reservoir to capture and identify fish during the year 2019–2020. To assess the distribution and abundance of fish in the Suoi Trau we maintained numerous gill nets near bottom and near surface across the reservoir from April to May 2024. Thirty-four native species and three non-native species were identified: the African catfish *Clarias gariepinus* (first recorded in the reservoir), Nile tilapia *Oreochromis niloticus*, and loricariids *Pterygoplichthys* spp. In 2024, were captured only eleven native fish species, as well as non-native Nile tilapia and armoured catfish. We observed that loricariids frequently occupied areas in the reservoir along with native fish, and their numbers positively correlated with the numbers of native fish. However, the high occurrence of Nile tilapia did not correspond with a high occurrence of native fish in the reservoir. The total biomass of the two non-native species constituted 19% of the total biomass of all captured native fish in Suoi Trau reservoir, and the biomass of armoured catfish highly dominated in four of the nine sampled locations. The loricariids are gradually could replace the native ichthyofauna in the reservoir.

Key words: armoured catfish, tilapia, freshwater tropic fish, fish biomass, fishing effort, Khanh Hoa province

Introduction

Several major rivers in Vietnam have been predominantly regulated by dams for hydroelectricity and agricultural irrigation. This artificial flow regulation has transformed rivers from lotic systems with flowing water to lentic systems with predominantly still water. Instream modifications, including dam construction associated with urban development, can create ideal habitats for introduced species to establish populations (Bowles and Bowles 2015). Suoi Trau reservoir is one of the largest artificial lakes in the northern part of Khanh Hoa province, characterized by a high species diversity compared to other reservoirs in the province (Stolbunov 2014).

According to data from 2010–2011, the Suoi Trau reservoir is inhabited by thirty-two fish species from twenty families, with the most dominant family being Cyprinidae, which includes eleven species. The first registered non-native species was Nile tilapia *Oreochromis niloticus*, recorded in 2014 (Stolbunov 2014). The South American suckermouth armoured catfish (Siluriformes: Loricariidae: *Pterygoplichthys*) was first recorded in the reservoir in 2015, with several individuals captured between December 2016 and February 2017 (Gusakov et al. 2018).

Climate change and global warming, which have evident negative effect to native fish (Alix et al. 2020), could accelerate the spreading of more adaptive non-native species. Armoured catfishes have become invasive in tropical and subtropical freshwaters as a result of the ornamental fish trade (Orfinger and Goodding 2018) and due to water temperatures more than 15 °C that are suitable for their habitats (Marr et al. 2024). Unlike many other freshwater fish, armoured catfish have a highly protected body with dermal plates and various protective mechanisms (Ebenstein et al. 2015), which likely prevent predation, especially in new bodies of water. Armoured catfish exhibit parental care, nest-building behavior, produce large eggs, and have high fecundity rates (Gibbs et al. 2017; Orfinger and Goodding 2018; Araujo and Langeani 2020), which contribute to their successful reproduction. These species features provide a clear understanding of the reasons for their wide potential spread in new bodies of water and successful competition with native fish.

Nowadays, the loricariid fish genus *Pterygoplichthys*is widely distributed and successfully inhabited inland waters of South China (Wei et al. 2017), the central Indo-Pacific region, including the Indo-Burma biodiversity hotspot, which is one of the world's most species-rich inland water area (Orfinger and Goodding 2018; Marr et al. 2024). In the bodies of water of South Vietnam, this invasive genus was registered in 2003–2004 (Welcomme and Vidthayanom 2003; Serov 2004), and by 2010 it spread to Central Vietnam (Zworykin and Budaev 2013) and Northern Vietnam (Levin et al. 2008). Over the past decade, *Pterygoplichthys* spp. have been discovered in various types of Vietnamese bodies of water, including reservoirs (Stolbunov et al. 2020; Dien et al. 2022a, b; Dien et al. 2023; Pavlov et al. 2023a, b). According to species distribution modeling and decision-support tools, these species pose a high potential risk of invasion in water ecosystems of Vietnam (Ruykys et al. 2021; Zworykin and Đinh 2023). The high invasion risk suggests that these highly adaptable non-native species could gradually replace natural fish species and become dominant in water ecosystems. Anthropogenic activities such as unregulated fishing may exacerbate this process, as fishermen often prefer to capture native fish in Vietnam. Additionally, armoured catfishes have lower economic value compared to native and other non-native species, including tilapia (Orfinger et al. 2019).

Therefore, we propose that it is necessary to assess the distribution and abundance of non-native fish, especially armoured catfish, to predict and potentially prevent their significant impact on native ichthyofauna in Vietnamese artificially regulated bodies of water.

The aim of the study is to estimate occurrence and distribution of non-native armoured catfish and native fish in the Suoi Trau reservoir.

Materials and methods

Characteristics of Suoi Trau reservoir

The Suoi Trau reservoir of Khanh Hoa province, Central Vietnam (12.50N; 109.04E) was constructed in 1979. The basin area is 0.6 km^2, but it often varies seasonally (wet or dry season) due to flow-through dam operations. The average depth of the reservoir is 1.5 m, with a maximum depth of 9 m, and the bottom sediment type is gray clay with a thin layer of silt (Gusakov et al. 2023). The wide littoral zone, comprising sand and silt soils, covers 10% of the basin area. The reservoir is characterized as eutrophic and used for irrigation and drinking water. The reservoir banks and neighboring territory are utilized for agriculture. During periods of low water, phosphate and nitrate levels in the water increase significantly (Gusev et al. 2014).

To perform the scheme of visual changes of water level in Suoi Trau during wet and dry season (Figure 1), we used open source of Earth Engine Data Catalog. GIS images were extracted and processed from the Copernicus Sentinel-2 collection. The normalized difference water index (NDWI) was computed for each extracted image using the formula: NDWI = (B3 – B8) / (B3 + B8), where B3 represents the green band and B8 represents the near-infrared band. The resulting "water areas" were then converted into vector polygons with a ten-meter level of detail and compared with GIS coordinates using QGIS 3.24.0.

Sampling locations and fish collection

The samplings were conducted twice: from March 2019 to February 2020, and from April 14th to May 8th, 2024, in the Suoi Trau reservoir. The goal of the first sampling (2019–2020) was to identify fish species in the reservoir through fishing surveys conducted during two rainy seasons and two dry seasons. Various types of fishing gear were used in Suoi Trau: gill nets with a length of 80 m and mesh sizes of 20 mm and 35 mm, as well as a single line of ten sectional net traps on the bottom with a total length of ten meters and a mesh size of 10 mm (Pavlov et al. 2023a). Gill nets were maintained at all nine sampling locations and net traps were used at five sampling locations where the water depth was greater (Locations No. 5, 6, 7, 8, 9) (Figure 1). The fishing gear was set up two to three times per month in the evening (17:00–18:00, GMT+7) and left in place at each location

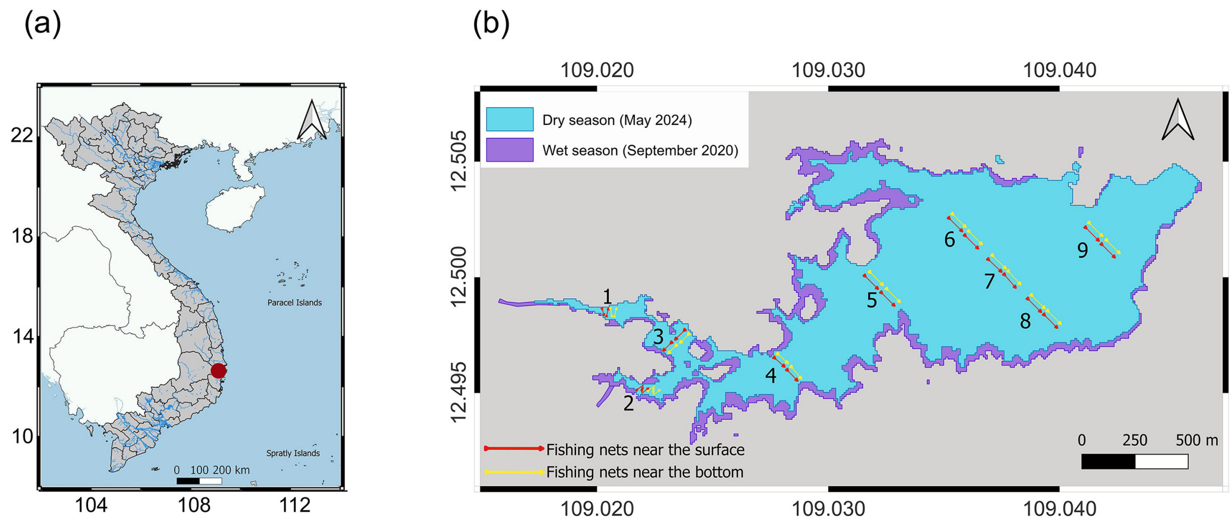

Figure 1. The Suoi Trau reservoir (red dot) on a national map of Vietnam (a) and a scheme (b) of the reservoir during the wet season (September 2020) and the dry season (May 2024), including sampling locations in 2024 (QGIS 3.24.0) (for details see Supplementary material Table S1).

throughout the night. The nets were checked the following morning (5:00–6:00, GMT+7). In total, more than 30 fishing surveys were conducted over this period.

The goal of the second sampling (2024) was to assess the distribution and abundance of fish in Suoi Trau. This period fell in the middle of the dry season when water levels in the reservoir were low. The dry season is typically associated with a reduction in available fish habitats, leading to higher competition among fish species in a flood-pulse system (Heng et al. 2018). We selected a period when increased competition could potentially contribute to a decline in native species. During this study, nine sampling locations were selected from the river inflow to the dam of the reservoir (Figure 1). We used vertical nets with a length of 100 m and a height of 3 m, consisting of three parallel sections with mesh sizes of 150 mm, 20 mm, and 150 mm. The number of locations depended on the distance between opposite banks and the length of the fishing nets. In each location, we set vertical nets from one bank to another. Each location spanned a length of 200 m, equivalent to the combined length of two connected fishing nets. If the distance between two opposite banks was less than 200 m, the vertical nets were positioned in a zig-zag pattern (Location No. 1 and Location No. 2). When the distance between banks exceeded 200 m, more than one sampling location was included (Locations No. 6, No. 7, and No. 8). The distance between parallel positioned locations ranged from 400 to 500 m.

Fishing in the Suoi Trau reservoir was conducted under the fishing license issued by Khanh Hoa province, which was granted to the Coastal Branch of the Joint Vietnam-Russia Tropical Science and Technology Research Center for the management of fish resources in the Suoi Trau reservoir. Simultaneously, at each sampling location, four fishing nets were deployed: two nets with positive buoyancy for surface fishing and two nets with negative

Figure 2. The fishing net with captured non-native armoured catfish *Pterygoplichthys* spp. (identified by reddish) and native fish in Suoi Trau reservoir. Photograph by Tran Duc Dien.

buoyancy for bottom fishing. Both types of nets were set in parallel lines at a distance of 5–10 meters from each other. The depth at which the nets were maintained was consistent, provided the water depth at the location was less than 3 m. Water depth measurements were taken along each location.

The fishing nets were set up in the evening (17:00–18:00, GMT+7) and left in place at each location throughout the night. The nets were checked the following morning (5:00–6:00, GMT+7). Consequently, the majority of fish were caught during the night. We replaced damaged nets, primarily caused by numerous captured armoured catfish, with new similar ones (Figure 2). Fish catching was repeated three times over consecutive nights (totaling 12 maintained fishing nets over 72 hours) at each study location. Throughout the study period, the water level remained stable, with a temperature of 33–35 °C, predominantly cloudy conditions, no rain, and light winds (2–6 km/h). The dissolved oxygen level in the water ranged from 7.2 to 7.4 mg/L (Hanna Instruments HI 9829, Romania), and water mineralization was measured at 72 ppm (Xiaomi Mi TDS Pen, PRC).

Fish sampling

After the capture, the fishing gear with fish was transported to a bank. From the period 2019 to 2020, individual species were sampled and preserved in 10% formaldehyde for subsequent systematic identification (Rainboth 1996; Kottelat 2001a, b; Serov et al. 2003, 2006; Zworykin 2014). For identifying non-native armoured catfish, identification keys were primarily based on the number of dorsal-fin rays and body color patterns (Armbruster and Page 2006). The armoured catfish in the study were predominantly identified as *P. disjunctivus*. While it is possible these fish were hybrids (Godwin et al. 2016), they were referred to as *Pterygoplichthys* spp. for the purposes of this study.

In 2024, fish were removed from the nets and separated into non-native and native species groups. The non-native group was further subdivided into loricariid and tilapia species. Total numbers were counted and total weights were measured using scales (Kendy KD-TBED-3000, Taiwan; Nhơn Hòa 5 Kg, 20 Kg, 60 Kg, Vietnam) for loricariids, tilapia, and native fishes.

To estimate the approximate distribution of species with limited fishing during the dry season, we compared our 2024 fish species identification results with our previous study of species identification from 2019 to 2020. We used FishBase (fishbase.se) to verify the habitat depth range of each identified species in Suoi Trau reservoir to assess potential competition interactions between demersal native species and armoured catfish. Additionally, species with a market price greater than $2 per kilogram were selected to evaluate their economic importance.

Fishing data analysis

The catch per unit effort (CPUE) was calculated using the modified formula (Hulbert et al. 2012):

$$CPUE = (N*24)/ (a*g)$$

Where N is the total number of captured fish, g is the total number of fishing hours (12 hours), and a represents the total length of nets (meters) placed at the sampling locations. We did not use a catchability coefficient for fishing gear into the formula because the same type of fishing nets was used at each sampling location. CPUE was calculated separately for armoured catfish, tilapia, and native fish; for both bottom and surface nets at each sampling location deeper than 3 m.

The ratio of captured non-native fishes was determined for each sampling location using the formula:

$$R_{Ni} = N_i/N$$

Where N is the total number of captured fish at the sampling location, and N_i is the total number of captured non-native fish (loricariids and tilapia).

The weight ratio of captured non-native to native fish was calculated using the modified formula (Gu et al. 2018):

$$R_{Wi} = N_s*W_i/W_T$$

Where W_i is the total weight of captured invasive (non-native) fish (loricariids or tilapia) in the sampling location, N_s is the total number of native species in the reservoir, and W_T is the total weight of all captured non-native and native fish at the sampling location. R_{Wi} indicates the relative biomass of non-native fish compared to the average biomass of one native species, given that the water volume of Suoi Trau is constant for all species. We infer that non-native fish biomass dominates at a location if this parameter exceeds 1.

Statistical data analysis was performed using Minitab 18.1. The Shapiro-Wilk test assessed the normality distribution of samples. The Kruskal-Wallis H test was used to detect significant differences in calculated parameters of captured fish (CPUE and weight ratio). Correction for multiple comparisons was carried out using Holm's sequential Bonferroni procedure. Spearman's rank correlation was employed to explore statistical dependencies between calculated parameters and the distance of locations from the river flow. If parametric statistics were used, we indicated the mean value of the studied parameter and the standard error before the parentheses, with the minimum and maximum values in parentheses. If non-parametric statistics were used, we indicated the median of the studied parameter before the parentheses and the quartiles (Q1–Q3) in parentheses.

Results

Fish species of Suoi Trau reservoir

Overall, the thirty-seven species were identified in the reservoir (Table 1) during the dry and wet seasons 2019–2020. The most frequently found in fishing gear was the fish family Cyprinidae (13 species). Other caught species were related to the following 18 families: Ambassidae, Anabantidae, Anguillidae, Bagridae, Channidae, Cichlidae, Clariidae, Cobitidae, Cranoglanididae, Eleotridae, Gobiidae, Loricariidae, Mastacembelidae, Osphronemidae, Osteoglossidae, Synbranchidae, Xenocyprididae and Zenarchopteridae. In 2019–2020, fifteen economically important native species were selected, each with a market value greater than $2 per kilogram. Four years later (in 2024), only three of these species were still present. Two non-native fish were found in 2019–2020 and in each studied location at 2024: *Pterygoplichthys* spp. and *O. niloticus*. In 2019–2020, the non-native North African catfish *Clarias gariepinus* (Clariidae) was first recorded in the reservoir, but their capture was infrequent. During a year of fishing (2019–2020), a total of 311 loricariids were captured using three types of fishing gear: 26 ± 2.6 (7–40) fish per month.

In 2024, only thirteen species were caught, including eleven native fish: five species from Cyprinidae, and one each from Ambassidae, Anabantidae, Channidae, Eleotridae, Osphronemidae, and Osteoglossidae (Table 1). The total number of captured native species was used to calculate the weight ratio of captured non-native to native fish (R_{Wi}). In 2019–2020, thirteen demersal and twenty benthopelagic native fish species were identified, whereas in the current study, only five demersal and six benthopelagic native fish species were found. In 2024, only three economically important species were captured, compared to fifteen species in 2019–2020 (Table 1).

The number of native and non-native fish

The bottom and surface fishing of the native fish did not significantly differ in CPUE value ($H_{1;\,42} = 13.96$; $p = 0.0002$) (Table 2, 3). The average weight of native fish near the bottom was higher ($H_{1;\,42} = 13.96$; $p = 0.0002$) compared

Table 1. Fish species in the Suoi Trau reservoir (Khanh Hoa province, Vietnam) in 2019–2020 and 2024.

Species No	Species	Depth range	Time of fishing	
			2019–2020	2024
1	*Anabas testudineus* (Anabantidae)	D	+	+
2	*Barbonymus gonionotus* (Cyprinidae)	BP	+	+
3	*Channa striata* (Channidae)	BP	+	+
4	*Cirrhinus molitorella* (Cyprinidae)	BP	+	+
5	*Notopterus notopterus* (Osteoglossidae)	D	+	+
6	***Oreochromis niloticus*** (Cichlidae)	BP	+	+
7	*Osteochilus* sp. (Cyprinidae)	BP	+	+
8	*Oxyeleotris marmorata* (Eleotridae)	D	+	+
9	*Parambassis* sp. (Ambassidae)	D	+	+
10	***Pterygoplichthys* spp.** (Loricariidae)	D	+	+
11	*Puntius* sp. (Cyprinidae)	BP	+	+
12	*Systomus* sp. (Cyprinidae)	BP	+	+
13	*Trichopodus microlepis* (Osphronemidae)	D	+	+
14	*Anguilla marmorata* (Anguillidae)	D	+	
15	*Barbonymus* sp. (Cyprinidae)	BP	+	
16	*Channa orientalis* (Channidae)	BP	+	
17	***Clarias gariepinus*** (Clariidae)	BP	+	
18	*Clarias macrocephalus* (Clariidae)	BP	+	
19	*Ctenopharyngodon idella* (Cyprinidae)	BP	+	
20	*Cyprinus carpio* (Cyprinidae)	BP	+	
21	*Dermogenys siamensis* (Zenarchopteridae)	BP	+	
22	*Esomus metallicus* (Cyprinidae)	BP	+	
23	*Glossogobius aureus* (Gobiidae)	BP	+	
24	*Hemibagrus wyckii* (Bagridae)	D	+	
25	*Hemibagrus wyckioides* (Bagridae)	D	+	
26	*Hypophthalmichthys nobilis* (Cyprinidae)	BP	+	
27	*Hypsibarbus wetmorei* (Cyprinidae)	BP	+	
28	*Labeo rohita* (Cyprinidae)	BP	+	
29	*Mastacembelus favus* (Mastacembelidae)	D	+	
30	*Misgurnus anguillicaudatus* (Cobitidae)	D	+	
31	*Monopterus albus* (Synbranchidae)	D	+	
32	*Ompok bimaculatus* (Cranoglanididae)	D	+	
33	*Rasbora paviana* (Cyprinidae)	BP	+	
34	*Rhinogobius* sp. (Gobiidae)	D	+	
35	*Toxabramis* sp. (Xenocyprididae)	BP	+	
36	*Trichopodus trichopterus* (Osphronemidae)	BP	+	
37	*Trichopsis vittata* (Osphronemidae)	BP	+	

Bold text indicates non-native species. Underlined text indicates economic important species (market price > 2$ per one kilogram). Gray cells indicate absence of species in the fishing gear. D – demersal fish, BP – benthopelagic fish.

to the weight of fish near the surface. The maximum CPUE value for native fish and the low CPUE value for non-native fish were recorded at sampling location No. 3.

The number of non-native fish was higher ($R_{Ni} \geq 0.16$) in sampling locations No. 1, No. 2 and No 6 (Table 2) compared to other studied locations (No. 3–5, No 7–9). Non-native armoured catfishes were captured more often ($H_{1;\ 42} = 5.01$; $p = 0.025$) in the bottom vertical nets than in the surface nets (Table 3). Fish near the bottom and fish near the surface had similar average weight ($H_{1;\ 31} = 1.21$; $p > 0.05$).

Non-native tilapia was significantly less often ($H_{1;\ 42} = 14.52$; $p = 0.0002$) caught in the bottom vertical nets than in the surface nets (Table 3). Tilapia near the bottom and fish near the surface had a similar average weight ($H_{1;\ 26} = 1.95$; $p > 0.05$).

Table 2. The catch per unit effort (CPUE) of native fish, non-native armoured catfish and non-native Nile tilapia using bottom (b) and surface (s) fishing nets and the ratio of captured non-native fish (R_{Ni}) in the sampling locations of the Suoi Trau reservoir.

Sampling location number	Depth (Min–Max), m	Maintenance type of the fishing nets	CPUE				R_{Ni}
			Native fish	Armoured catfish	Nile tilapia	All fish	
1	2.0–3.0	b, s *	29.63	**8.08**	0.26	37.96	**0.22**
2	1.5–3.0	b, s	21.95	**7.03**	0.34	29.31	**0.25**
3	1.3–4.0	b	37.75	0.43	0.04	38.22	0.01
		s	36.96	0.33	0.03	37.32	
4	2.0–4.5	b	3.63	0.31	0.04	3.98	0.04
		s	12.40	0.17	0.10	12.67	
5	2.0–5.0	b	6.62	0.09	0.02	6.73	0.02
		s	12.23	0.10	0.10	12.43	
6	1.0–4.0	b	0.67	0.11	0.03	0.81	**0.16**
		s	1.50	0	0.28	1.78	
7	4.0–7.0	b	0.56	0.13	0.13	0.82	**0.2**
		s	2.49	0.14	0.35	2.98	
8	4.0–6.5	b	4.73	0.19	0.00	4.92	0.05
		s	2.02	0.03	0.15	2.20	
9	4.0–8.0	b	9.41	0.30	0	9.71	0.02
		s	19.51	0	0.30	19.81	

* indicates that bottom and surface fishing nets were maintained at a similar depth due to the depth of sampling location < 3 meters. Selected numbers indicate high values of captured non-native fish.

Table 3. The catch per unit effort (CPUE) of native fish and their median weight based on fishing near the bottom (b) and near the surface (s) in the sampling locations No 3–9 of the Suoi Trau reservoir.

Maintenance type of the fishing nets	Native fish	Armoured catfish	Nile tilapia
CPUE			
b	1.46 (0.25–2.79)	0.05 (0.02–0.09) [a]	0 (0–0.02) [b]
s	2.07 (0.6–7.79)	0.02 (0–0.07) [a]	0.06 (0.02–0.10) [b]
Weight, g			
b	33.6 (30.6–46.0) [c]	50.0 (50.0–75.0)	71.7 (37.5–100.0)
s	27.3 (25.1–29.6) [c]	71.4 (50.0–92.3)	51.7 (37.1–61.7)

Same letters (a, b, c) indicate significant differences (according to Kruskal-Wallis H test).

Spearman correlation analysis indicated that the CPUE value for native fish was related to the CPUE value for armoured catfish ($r_s = 0.60$, $p < 0.001$). These CPUE values significantly decreased from the river flow towards the dam of the reservoir, with $r_s = -0.63$, $p < 0.001$, and $r_s = -0.76$, $p < 0.001$, respectively. No correlation was found between CPUE of tilapia and CPUE of native fish.

Relative biomass of non-native fish

The biomass of armoured catfish was higher in the shallow locations compared to the average biomass of native fish in locations No. 1 and No. 2 (Table 4). In these locations, the biomass of catfish was four times higher than the average biomass of native fish. Additionally, the biomass of this non-native species dominated in the middle part of the reservoir (location No. 7).

The biomass of Nile tilapia was high in the middle of the reservoir in the locations No. 6 and No. 7 (Table 4). The total biomass of armoured catfish was significantly higher ($H_{1;\,54} = 9.25$; $p = 0.002$) than the biomass of tilapia.

Table 4. Weight ratio of non-native fish compared to the median weight of native fish (R_{Wi}) in the sampling locations of the Suoi Trau reservoir.

Sampling location number	R_{Wi}		
	Armoured catfish	Nile tilapia	Both non-native species
1	4.88 (3.29–6.16)	0.10 (0.04–0.15)	4.99 (3.36–6.24)
2	3.98 (3.64–4.41)	0.20 (0.09–0.38)	4.19 (3.92–4.63)
3	0.39 (0.25–0.52)	0.00 (0–0.04)	0.43 (0.25–0.52)
4	0.38 (0.23–0.77)	0.11 (0–0.25)	0.50 (0.27–1.09)
5	0.10 (0.06–0.32)	0.11 (0.06–0.21)	0.28 (0.14–0.55)
6	0.37 (0–2.47)	1.35 (0–2.70)	2.58 (1.76–2.96)
7	1.29 (0–3.31)	1.26 (0.81–4.19)	3.75 (2.75–5.44)
8	0.60 (0–0.85)	0.20 (0–2.11)	0.97 (0.53–2.26)
9	0.06 (0–0.56)	0.08 (0–0.57)	0.26 (0.13–1.37)
Total	0.56 (0.11–2.64)	0.11 (0–0.47)	1.41 (0.41–3.69)

* Gray cells indicate high values (> 1.0) of non-native fish biomass.

The biomass of non-native species was high in four studied locations, which were at the beginning and middle part of Suoi Trau reservoir. The average biomass of the two non-native species was 1.4 times higher as the average biomass of each native species. The total biomass of two non-native fish consisted of 19% of the total biomass of all native fish.

Spearman correlation analysis indicated that the weight ratio of armoured catfish significantly decreased from the river flow to the dam of the reservoir: $r_s = -0.57$, $p < 0.001$.

Discussion

The results of our study revealed heterogeneous distribution of non-native and native fish in the Suoi Trau reservoir. Non-native armoured catfish and tilapia have successfully established populations in the Suoi Trau reservoir, and in some parts, they were highly abundant. We captured eleven species of native fish, which outnumbered the non-native fish species. However, the total biomass of non-native fishes constituted 19% of the total biomass of all native fish in the Suoi Trau reservoir.

Captured fish species in different years

As mentioned earlier, thirty-one native species were observed in Suoi Trau in 2010–2011, with *Cirrhinus molitorella*, *Parambassis* sp., *Osteochilus* sp., and *Puntius* sp. being numerous in the fishing gears maintained near the banks (Stolbunov 2014). In 2019–2020, these four species were also present in the fishing gears, but we identified additional species: thirty-five native species and three non-native species, including the first recorded instance of *C. gariepinus* in Suoi Trau. During sampling in 2024, only eleven native species were captured in vertical nets maintained at various locations in the reservoir. We hypothesize that the one type of fishing gears used over a short period may have reduced the likelihood of catching other fish species that were occasionally found in Suoi Trau. Possibly, high fishing pressure over the past few years has led to a decline in native species. Moreover, fishermen may have focused on catching predominantly native species, with fewer loricariids, which damaged fishing gear. Partly, our field study revealed differences in the habitat locations of native and non-native fish in the reservoir. The reduction of native species in quantity may have affected the possibility of capturing these species in 2024.

Additionally, competing interactions involving non-native armoured catfish could significantly reduce the number of native species. In 2024, we identified only five native demersal species compared to seventeen demersal species in 2019–2020. The competition between demersal non-native catfish and demersal native fish may be even more pronounced compared to native benthopelagic fish. Further studies are necessary to clarify these dynamics.

Number and biomass of captured fish

Native and non-native fish were mostly caught in the western part of the reservoir, in shallow water near the river flow. There was no visible water flow due to the dry season, but these locations likely had abundant food resources. In the nearest sampling locations, No. 1 and No. 2, non-native armoured catfish comprised more than a quarter of the total catch. However, numerous native fish were captured in the closest location, No. 3, where non-native species were rarely present. It seems that, at times, native fish choose habitats that are not suitable for non-native fish. The reasons for armoured catfish avoiding these habitats are not clear.

The number of captured native species and armoured catfish decreased towards the middle part of the reservoir (locations No. 4–8), with fewer fish observed near the dam (location No. 9). This distribution pattern may be related to food availability, which decreases with distance from the river flow and possibly with increasing water depth (deeper locations No. 7–9). The quantity and occurrence of benthic invertebrates in the deep zones of Vietnamese reservoirs are low (Gusakov et al. 2023), which likely influences the distribution of benthic fish in the Suoi Trau reservoir. Our findings align with earlier data indicating that fish in Vietnamese reservoirs often occur in shallow water near the banks (Stolbunov 2014).

It appears that armoured catfish, like other benthophagous fish (Quintana et al. 2023; Parvez et al. 2023), move to the zones with higher number of benthic invertebrates. Additionally, fish distribution in Suoi Trau is related to temperature and oxygen stratification, with low values of these parameters in the deep zones of the reservoir. Despite being relatively shallow, the reservoir exhibits stratification parameters similar to deeper reservoirs (Gusev et al. 2014). However, surface and bottom water exchange can be observed when the dam gates are opened, which likely significantly influences fish distribution in the reservoir.

Native fish and armoured catfish were more frequently caught in the bottom nets compared to the nets maintained near the surface. This result indicates the dominance of benthic fish species over pelagic species in the reservoir. We identified three locations in the Suoi Trau reservoir where the biomass of armoured catfish was 1.3–4.9 times higher than the average biomass of native species: locations No. 1, No. 2, and No. 7. In locations near the river flow (No. 1 and No. 2), we captured significantly more native fish and armoured catfish than in other locations. According to Spearman correlation, the occurrence of armoured catfish often coincides with the occurrence of native fish in Suoi Trau. This indicates that loricariids have a high potential to interact with native species, which could involve competition for space and food resources. Also, we suggest that the number and biomass of armored catfishes were higher than what we found in the study. It should be noted that in 2024 we maintained fishing gears more frequently across the reservoir (transverse maintenance) compared to maintenance along the reservoir banks. The second method of fishing could result in high numbers of loricariids because they are facultative breathers and frequently occur in shallow water for air respiration (Gibbs et al. 2021) or for algae feeding (Power 1984).

Despite armoured catfish, Nile tilapia was mostly caught in nets near the surface and this species was often not numerous in the Suoi Trau reservoir. We selected two locations (No. 6 and No. 7) where the biomass of this species was 1.3 times the average biomass of native species. Based on the lower CPUE values for native fish in these sampling locations (CPUE = 0.56–2.49) and its weak correlation with CPUE of native fish, we doubt that Nile tilapia had a noticeable impact on the native fish population in Suoi Trau. In 2024, we did not catch non-native *C. gariepinus*, and it is likely that this species also had no effect on native fishes.

Possible impact of armoured catfish on native fish species

As of 2024, we selected only three species in the Suoi Trau reservoir that were frequently caught in the nets and had a market price of more than two dollars per kilogram during this period: *Channa striata*, *Notopterus notopterus*, and *Oxyeleotris marmorata*. Other captured fish species, including non-native tilapia, had significantly lower economic importance, with a market price of approximately $0.5 per kilogram.

We assume that numerous non-native species as loricariids, which occur in zones with abundant native benthophagous fish can affect the native species. This is supported by stable isotope analysis, which showed that invasive *Pterygoplichthys* spp. impact the trophic ecology of native fish in the Usumacinta Basin (Quintana et al. 2023). Additionally, experimental evidence has shown that the diet of *Pterygoplichthys disjunctivus* remained stable across density treatments, but the diet of native fishes deviated increasingly from control values as catfish density increased (Parvez et al. 2023). According to Seshagiri et al. (2021), carp aquaculture in India was affected by 19% to 23% due to the spread of suckermouth armoured catfish to cultured ponds. Moreover, Hoover et al. (2004) suggested that armoured

Figure 3. Discarded captured armoured catfishes on the banks of Eo Kao (Dak Lak province, May 2020) (a) and Tri An (Dong Nai province, April 2021) (b) reservoirs. Photographs by Tran Duc Dien.

catfish can consume the eggs of some native species, leading to a reduction in the population of these fish. Later studies found that *Pterygoplichthys pardalis* consumed the eggs of cyprinid fish, as well as eggs and larvae of some other native fish (Audai and Laith 2022). However, fish eggs were not found in the stomachs of non-native *Pterygoplichthys* spp. in Vietnamese bodies of water (Stolbunov et al. 2021).

The negative economic importance of non-native *Pterygoplichthys* spp. in Vietnamese bodies of water is likely due to two main reasons. Firstly, this species is not sold in markets due to they rarely used for human consumption in Vietnam. Occasionally, captured armoured catfish are used for livestock and poultry, but more often fishermen discard them back into the waterbody or leave them on the banks (Figure 3). Secondly, these species significantly damage fishing nets after capture (Pavlov et al. 2023b), resulting in increased time and financial resources required for fishermen to check and repair their gear. Similar issues have been documented in river systems in Guatemala (Schoenbeck et al. 2023) and Andhra Pradesh, India, where non-native loricariids damaged fishing gear and constituted 30% of the catch per unit effort (Seshagiri et al. 2021). During our study, we had to replace damaged nets with new ones once. Sometimes, Vietnamese fishermen leave nets with numerous loricariids in the water or on the bank, based on our visual observations. Clearly, this fishing practice causes damage not only to natural water ecosystems and native aquatic organisms but also to neighboring terrestrial ecosystems.

Conclusion

Our field results showed that eleven native fish species were frequently captured in Suoi Trau reservoir in 2024. The presence of the other twenty-five native species was not confirmed. Three non-native species have been observed in the reservoir over the past five years: *C. gariepinus*, *O. niloticus*, and *Pterygoplichthys* spp. African catfish were only found in 2019–2020 and likely had no impact on the native ichthyofauna. The occurrence of non-native Nile tilapia poorly correlated with the distribution of native fishes, and their high density was observed in locations with low density of native fish in the reservoir. Despite these two non-native species, it appears that armoured catfish are able to compete successfully with native fish for resources such as habitat and benthic food. We found that armoured catfish, often found together with native fish, occupied similar areas in the reservoir, and their numbers correlated positively with those of native fish. The total biomass of non-native fishes constituted 19% of the total biomass of all native fish in Suoi Trau reservoir, with armoured catfish biomass dominating significantly in four out of the nine studied sampling locations.

Only three economically important native species were abundant in the reservoir in 2024. Two of these species are demersal, and their native range may have been impacted by the occurrence of armoured catfish. It is difficult to calculate the increase in armoured catfish density over five years due to the different fishing methods used in 2019–2020 compared to those used in 2024. Nonetheless, we suggest that numerous loricariids may gradually displace native ichthyofauna in Suoi Trau reservoir.

Additionally, our field studies revealed that loricariids and tilapias successfully reproduced, spread, and established themselves in various local habitats of the Suoi Trau reservoir. We suggest that the invasion risks posed by loricariids to aquatic ecosystems and the economy of Vietnam are higher compared to those of non-native cichlid fishes, including tilapias. Vietnamese fishermen are more motivated to capture tilapia than armored catfish, which are considered to have a negative economic impact. This is one of the main issues, as there is no targeted fishing for loricariids in Vietnam; they are often caught as bycatch along with other fish. The lack of direct fishing efforts targeting loricariids is likely contributing to the increase in their population density in various types of Vietnamese bodies of water. To reduce the numerous populations of armored catfish, it may be necessary to implement special government regulations encouraging active fishing of loricariids.

Author's contribution

TDD, EDP conceived and designed the study. TDD and NTDH performed sampling. NTDH performed GIS scheme of the study locations. All authors made data analyses, interpretated the data. EVG, EDP and TDD wrote the original draft of the manuscript. All authors edited and approved the final manuscript.

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Ethics and permits

All experimental procedures with fish were carried out according to the guidelines and following the laws and ethics of Socialist Republic of Vietnam. The commission for the regulation of experimental research (bioethics commission) of the IEE RAS approved original study by verbal consent based on the Provisions of the commission for the regulation of experimental research of the Institute of Ecology and Evolution A.N. Severtsov of the Russian Academy of Sciences of 13.06.2017 (paragraph 1.3) (https://sev-in.ru/en/komissia-po-bioetike). The National Regulations for the Use of Animals in Research in Vietnam (Decree 32/2006/ND-CP, 2006) do not require special ethical approval or a permit for this study as catfish are not listed in groups IB (endangered and critically endangered species) or IIB (threatened and rare species) and included to the list of Invasive Species of Vietnam (Decree 35/2018/TT-BTNMT, 2018). The authors have executed their best practices for animal care and use in research, as outlined in the materials and methods.

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Web sites, online databases and software

Fishbase.se https://fishbase.se/search.php (accessed 7 January 2025)

Supplementary material

The following supplementary material is available for this article:

Table S1. Geo-referenced records of non-native fish using bottom (b) and surface (s) fishing gear in the Suoi Trau reservoir.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2025/Supplements/BIR_2025_TranDucDien_etal_SupplementaryMaterial.xlsx