



LIVE BAIT TRADE AS A PATHWAY FOR THE INTRODUCTION OF NON-NATIVE SPECIES: THE FIRST RECORD OF *Dilocarcinus pagei* IN THE PARANAPANEMA RIVER BASIN

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Abstract: We report cases of live bait introductions in Brazilian freshwater ecosystems and the first occurrence of the crab *Dilocarcinus pagei*, which is native from the Paraguay-Lower Paraná River, in the Paranapanema River basin. The literature review revealed 16 species used as live baits across Brazil, the crab *D. pagei* and 15 fish species. During our field samplings, we have captured 10 individuals of *D. pagei*. Gymnotiformes, which is native mainly from the Paraguay-Lower Paraná River, was the most common fish order that was used as live bait. The river basins that had introduction cases detected in our study were Upper Paraná, Iguaçu, and Paraíba do Sul Rivers. The Paraguay-Lower Paraná River was the system that had contributed with nine species to the most invaded ecoregion in Brazil, the Upper Paraná River basin. Anglers and live bait farmers should be aware of the risks and consequences of these constant introductions. In addition, the live bait trade must be monitored and controlled to use only native species within their original distribution range.

Keywords: biodiversity loss; conservation; propagule pressure; South America; vector.

The Amazon and Paraguay-Lower Paraná River basins are among the richest basins in freshwater fish species worldwide (Dagosta & Pinna 2019), with many medium and large species appreciated in sport fishing. Due to the great fish diversity, biomes, and watersheds, sport fishing has become increasingly popular in Brazil (Britton & Orsi 2012). The high fish species richness and variety of environments attract tourists, and represent an opportunity for ecotourism and fishing tourism in Brazil (Embratur 2018).

The socioeconomic importance of recreational fishing has increased rapidly in several countries (Arlinghaus & Cooke 2009). According to the National Association of Ecology and Sport Fishing (ANEPE), Brazil receives 10 to 15 thousand international tourists for sport fishing per year and generates about 200 thousand jobs. In the United States, sport fishing generates around US\$ 115 billion annually, while in Brazil, it moves only US\$ 3 billion (Embratur 2018).

However, there is no technical cooperation

to develop sport fishing tourism in Brazil, and important contributions are disregarded. Among them, is the translocation of fish species between watersheds (Freshwater Ecoregions), recognized worldwide as an imminent risk to freshwater ecosystems (Seebens *et al.* 2017). In addition, these environments are also threatened by damming (Agostinho *et al.* 2016), deforestation (Zeni *et al.* 2019), pollution, and some environmental laws that allow the farming of non-native species (Brito *et al.* 2018, Garcia *et al.* 2018).

The development of fishing tourism brings greater demand for live bait, which is defined as any live animal used to attract and capture fish (Alho 2020). The use of live bait varies according to the fish required, and some professional anglers have specialized in catching fish, crustaceans, and other invertebrates in the wild or raise them to meet this demand. Live baits may be included in fishing tourism ‘packages’ sold to anglers (Catella *et al.* 2009). Thus, the increase in sport fishing influences the demand and capture of fish and crustaceans to be used as bait. However, at the end of fisheries, many anglers discard their bait to avoid sacrificing the animals, regardless of their native species range (Kilian *et al.* 2012).

The transportation of non-native species used as bait in sport fishing increases the probability that they will be discarded in water bodies, resulting in species introductions that can successfully colonize new environments. Therefore, the practice of ‘discarding’ live bait is an important pathway for aquatic species introductions that allows transposition between different ecoregions (Garcia *et al.* 2015, Ortega *et al.* 2015). Therefore, we aim to: (i) check for the presence of the crab *Dilocarcinus pagei* (Decapoda, Trichodactylidae) in the Paranapanema River basin, southern Brazil (field samplings); (ii) inventory what are the most commercialized freshwater species used as live baits in Brazil, as well as their distribution in Brazilian watersheds (literature review).

Specimens of the crab *D. pagei* were unexpectedly captured during fish fauna monitoring within the Paranapanema River basin (Projects N° 3224/2012 and N° 11218/2018). The samplings were seasonal between September 2012 and April 2016, and between July 2018 and July 2019. The crabs were caught together with

fish, using trawls and sieves operated by four people during one hour on the margins of the transition stretch of the Rosana and Taquaruçu reservoirs. Traps with baits (pieces of fish, liver, and bread), which were installed at dusk and removed at dawn, were also used.

Captured crabs were euthanized by exposure to ice and fixed in 10 % formalin for 48 hours, then preserved in 70 % alcohol. *Dilocarcinus pagei* has a convex carapace in the anteroposterior direction and is usually red in live specimens, with six or seven teeth on the anterolateral margins. They are identified by a distinct transversal carina along the anterior margin of the third abdominal somite (Magalhães *et al.* 2005). Voucher specimens were added to the Museu de Zoologia da Universidade Estadual de Londrina (MZUEL 508, 509), and a specialist confirmed specimens identification (Dr. G. M. Teixeira, Universidade Estadual de Londrina). The collection license is N° 16578, and the Animal Ethics Committee authorized field sampling (CEUA N° 30992.2014.33).

In order to inventory the most commercialized freshwater species, as well as their occurrence, we have followed the specialized literature in order to consider a species as non-native, which should not have occurred naturally in Brazilian freshwater ecoregions due to biogeographic factors. Fish considered to be non-native, included species from other South American Ecoregions, such as the Amazon, Paraguay, and Lower Paraná ecoregions.

A literature review was carried out to investigate the origin of the introduction of *D. pagei*, as well as to carry out an inventory of non-native aquatic species. The review was based on searches in Web of Science, Scopus, Scielo, and Google Scholar, starting with ‘live bait’ and ‘Brazil’ in ‘title’ searches, then using Boolean operators to combine the following words in different ways ‘*Dilocarcinus pagei*’, ‘*Dilocarcinus*’, ‘bait’, ‘knifefish’, ‘sporting fish’, ‘non-native’, ‘introduced’, ‘release’. These searches provided articles that have resulted in a list of species used as live baits in Brazil. In addition to the articles, a reference list was also obtained from books and technical reports. Whenever the information about the taxonomic and native range were not available from our reference list, we have searched for it in the following references: Reis *et*

al. (2003), Britski *et al.* (2007), and Eschmeyer *et al.* (2019).

Field samplings have resulted in the first record of the crab *D. pagei* at two sites in the Paranapanema River basin. Ten individuals were captured, one female in the Rosana Reservoir (22°36'02.11" S; 52°09'56.67" W); and two juveniles, one female, and six males in the Taquaruçu Reservoir (22°39'37.00" S; 51°37'49.06" W). The new records were added to the complementary bibliographic survey, making it possible to map the distribution of this species in the Upper Paraná and Paraíba do Sul River basins (Figure 1).

From the literature review, we have found that 15 fish species were introduced in different Brazilian river basins (Table 1). Species introduction by live bait releases occurred in the following river basins: Upper Paraná River (*D. pagei* and 10 fish species), the Iguazu River (seven fish species), and the Paraíba do Sul River

(*D. pagei*). Gymnotiformes (knifefishes) showed greater species richness (eight species), being represented mainly by the genus *Gymnotus* (four species). The most invaded ecoregion in Brazil (Upper Paraná River basin) had received nine species only from the Paraguay-Lower Paraná.

The main vectors responsible for the introduction of freshwater organisms in Brazil are aquaculture escapes (Ortega *et al.* 2015), the release of sport fish (Britton & Orsi 2012) and live bait (Garcia *et al.* 2015), the aquarium trade (Magalhães & Vitule 2013), and the use of fish as a biological control agent (Ortega *et al.* 2015). In Brazil, there are 22 freshwater ecoregions (Abell *et al.* 2008), with species translocations been previously reported between many of them (Vitule *et al.* 2019). The release of live bait at the end of fisheries is a pathway for introducing species that has received little attention from inspection, and should be further investigated due to the fishing tourism increase in the country.

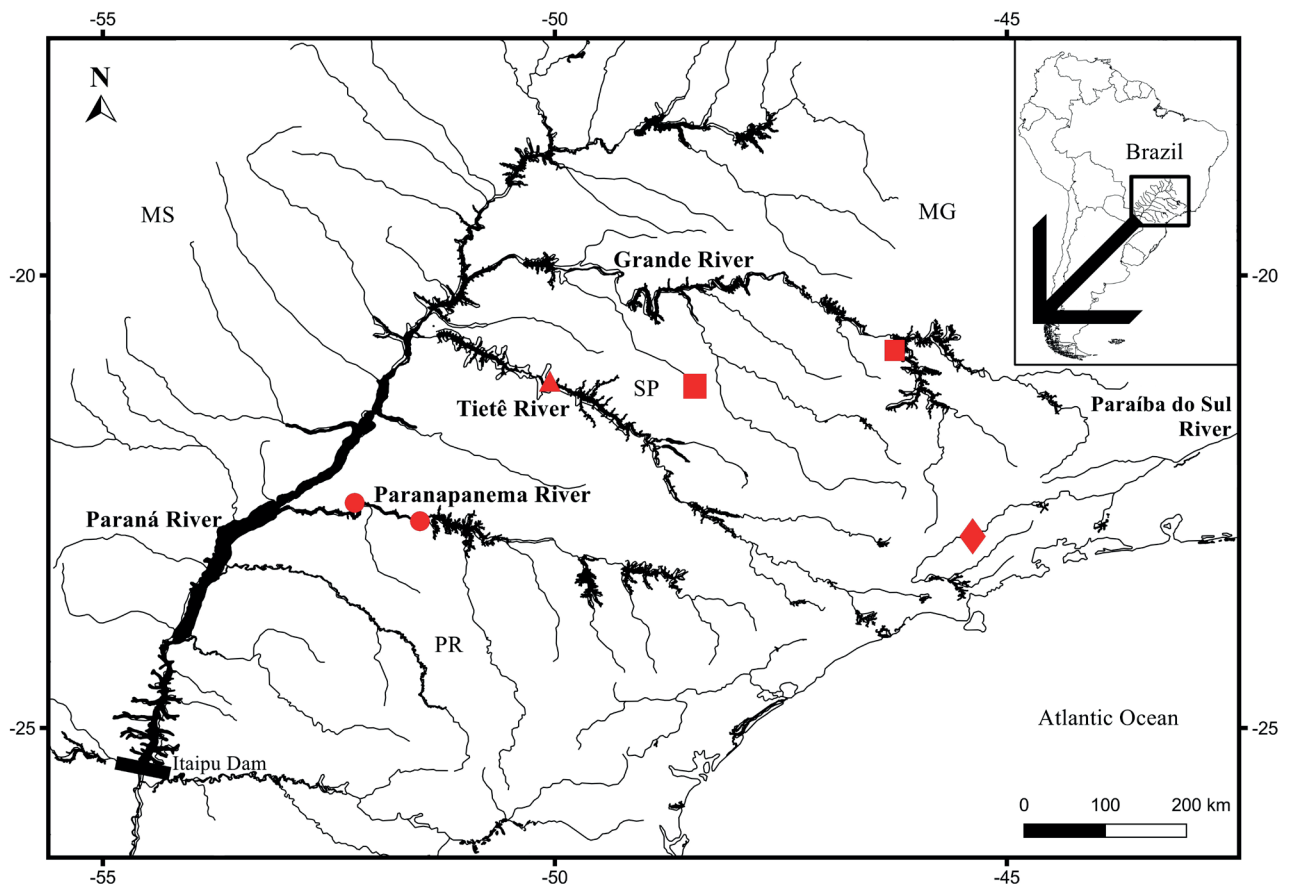


Figure 1. Distribution of *Dilocarcinus pagei* in the Upper Paraná (Paranapanema, Tietê and Grande rivers) and Paraíba do Sul River basins. Circles: Paranapanema River; triangle: Tietê River; squares: Grande River; losangle: Paraíba do Sul River. MS: state of Mato Grosso do Sul; MG: state of Minas Gerais; SP: state of São Paulo; PR: state of Paraná.

Table 1. Species introduced as live bait in Brazil. Native Freshwater Ecoregion according to Reis *et al.* (2003).

Species	Situation	Locality of introduction (basin or system)	References	Native Freshwater Ecoregion
CRUSTACEA				
Decapoda				
Trichodactylidae				
<i>Dilocarcinus pagei</i> Stimpson 1861	Introduced as live bait	Upper Paraná and Paraíba do Sul River basins	Magalhães <i>et al.</i> (2005), Azevedo-Santos & Lima-Stripari (2010), Latini <i>et al.</i> (2016)	Amazon, Paraguay and Lower Paraná River basins
ACTINOPTERYGII				
Characiformes				
Curimatidae (Toothless characiforms)				
<i>Steindachnerina brevipinna</i> (Eigenmann & Eigenmann 1889)	Introduced as live bait	Iguaçu River basin	Daga <i>et al.</i> (2016)	Uruguay, Paraguay and Lower Paraná River basins
Erythrinidae (Trahiras)				
<i>Erythrinus erythrinus</i> (Bloch & Schneider 1801)	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná River basin	Langeani <i>et al.</i> (2007), Graça & Pavanelli (2007), Júlio Júnior <i>et al.</i> (2009), Ortega <i>et al.</i> (2015), Ota <i>et al.</i> (2018)	Orinoco, Guianas, Amazon, Paraguay and Lower Paraná River basins
<i>Hoplerythrinus unitaeniatus</i> (Agassiz 1829)	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná River basin	Langeani <i>et al.</i> (2007), Graça & Pavanelli (2007), Júlio Júnior <i>et al.</i> (2009), Ortega <i>et al.</i> (2015), Ota <i>et al.</i> (2018)	Amazon, Paraguay, Lower Paraná, Orinoco, São Francisco, and Magdalena River basins, and coastal rivers in Guyana, Suriname, and French Guiana.
Triporthetidae				
<i>Triporthetus angulatus</i> (Spix & Agassiz 1829)	Introduced as live bait	Upper Paraná River basin	Ortega <i>et al.</i> (2015)	Amazon River basin

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Species	Situation	Locality of introduction (basin or system)	References	Native Freshwater Ecoregion
Siluriformes				
Callichthyidae (armored catfishes)				
<i>Callichthys callichthys</i> (Linnaeus 1758)	Introduced as live bait	Iguaçu River basin	Baumgartner <i>et al.</i> (2012), Daga & Gubiani (2012), Ortega <i>et al.</i> (2015)	Most Cis-Andean South American river drainages north of Buenos Aires.
<i>Hoplosternum littorale</i> (Hancock 1828)	Introduced as live bait	Iguaçu River basin	Baumgartner <i>et al.</i> (2012), Daga & Gubiani (2012), Ortega <i>et al.</i> (2015)	Most Cis-Andean South American river drainages north of Buenos Aires.
Gymnotiformes				
Gymnotidae (Naked-back knife-fishes)				
<i>Gymnotus inaequilabiatus</i> (Valenciennes 1839)	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná and Iguaçu River basins	Baumgartner <i>et al.</i> (2006), Graça & Pavanelli (2007), Baumgartner <i>et al.</i> (2012), Daga & Gubiani (2012), Ortega <i>et al.</i> (2015)	Paraguay and Lower Paraná River basins and some coastal drainages
<i>Gymnotus pantanal</i> Fernandes <i>et al.</i> 2005	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná River basin	Graça & Pavanelli (2007), Margarido <i>et al.</i> (2007), Ota <i>et al.</i> (2018)	Paraguay and Lower Paraná River basins
<i>Gymnotus paraguensis</i> Albert & Crampton 2003	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná River basin	Graça & Pavanelli (2007), Ota <i>et al.</i> (2018)	Paraguay and Lower Paraná River basins
<i>Gymnotus sylvius</i> Albert & Fernandes-Matioli 1999	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná and Iguaçu River basins	Agostinho <i>et al.</i> (2002), Baumgartner <i>et al.</i> (2006), Graça & Pavanelli (2007), Baumgartner <i>et al.</i> (2012), Daga & Gubiani (2012), Ortega <i>et al.</i> (2015)	Ribeira de Iguape, Paraíba do Sul and Pardo River basins
Rhamphichthyidae (Sand knife-fishes)				
<i>Gymnorhamphichthys britskii</i> Carvalho, Ramos & Albert 2011	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná River basin	Ota <i>et al.</i> (2018)	Paraguay and Lower Paraná River basins

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Species	Situation	Locality of introduction (basin or system)	References	Native Freshwater Ecoregion
<i>Rhamphichthys hahni</i> (Meiken 1937)	Introduced as live bait or transposition after Itaipu Dam	Upper Paraná River basin	Ota <i>et al.</i> (2018)	Paraguay and Lower Paraná River basins
Hypopomidae (Bluntnose knifefishes)				
<i>Brachyhyopomus gauderio</i> Giora & Malabarba 2009	Introduced as live bait	Upper Paraná River basin	Langeani <i>et al.</i> (2007), Graça & Pavanelli (2007), Ortega <i>et al.</i> (2015), Ota <i>et al.</i> (2018)	Orinoco, Guianas, Amazon, Uruguay, Paraguay and Lower Paraná River basins
Apteronotidae (Ghost knifefishes)				
<i>Apteronotus ellisi</i> (Alonso de Arámburu 1957)	Introduced as live bait	Iguaçu River basin	Agostinho <i>et al.</i> (2002)	Paraguay and Lower Paraná River basins
Synbranchiformes				
Synbranchidae (Swamp-eel)				
<i>Synbranchus marmoratus</i> Block 1795	Introduced as live bait	Iguaçu River basin	Baumgartner <i>et al.</i> (2012)	Mexico to northern Argentina

Dilocarcinus pagei was the only introduced crustacean used as live bait (Catella *et al.* 2009, Latini *et al.* 2016). Native from the Paraguay and Lower Paraná River basins, *D. pagei* may have reached the Upper Paraná after filling the Itaipu Reservoir (Magalhães *et al.* 2005). The crab was also recorded in the Tietê, Grande, and Paraíba do Sul River basins (Magalhães *et al.* 2005, Azevedo-Santos & Lima-Stripari 2010) (Figure 1). Nevertheless, this is a species often created and used as bait to fish ‘piapara’ (*Megaleporinus obtusidens*) and ‘piavuçu’ (*Megaleporinus macrocephalus*), and widely used as bait in *Pantanal* (Mussato *et al.* 2019).

Some species of shrimp, for example, *Macrobrachium rosenbergii* (native from the Indo-Pacific region), *Macrobrachium amazonicum* and *Macrobrachium jelskii* (both from the Orinoco, Amazon, and Paraguay-Lower Paraná River basins) have been widely used in aquaculture (Magalhães *et al.* 2005). In addition, shrimps are also used as live bait (personal observation). However, we did not find in the literature any record of non-native shrimps used as live baits in Brazil, but we warn that they may be translocated between basins due to this practice.

Fish used as live bait generally have accessory breathing, which allows good survival and is one of the reasons for its wide use in fishing. The low bait costs of the baits facilitate their acquisition, with anglers buying them in large quantities and releasing the remaining baits from the fisheries into the rivers (Garcia *et al.* 2015, Ortega *et al.* 2015). In the *Pantanal Mato-Grossense*, the live bait trade is a source of income for the riverside community. The state of Mato Grosso do Sul applies the State Law 2,898/2004, which refers to the capture, transportation, storage, marketing, and culture of live baits (Catella *et al.* 2017). However, the export of live baits from the state of Mato Grosso do Sul, Midwestern Brazil (municipalities of Corumbá, Miranda, and Porto Murtinho), to other regions of the country, such as the states of Paraná, Goiás, and Santa Catarina, may introduce new species to these areas (Catella *et al.* 2009). These states receive baits without the correct identification and inspection. In the Upper Paraná River basin, at least four species of *Gymnotus* may have been introduced by anglers release (Graça & Pavanelli 2007). This

pathway introduced *Gymnotus pantanal* and *G. paraguensis* in the Upper Paraná Basin (Graça & Pavanelli 2007). Genetic studies have correctly identified *Gymnotus*, and provided information for conservation, fishing, trade regulation, and monitoring of introduced species strategies (Orsi *et al.* 2016, Sousa *et al.* 2017, Faria-Pereira *et al.* 2019). Studies like these should be performed with all other species that are used as live baits.

All *Gymnotus* species (electric fish) are often used as live baits, as they are considered efficient in catching several fish species in different ecoregions, facilitating their introduction due to disposal by ill-informed anglers who can translocate them between the basins. In the *Pantanal* of the state of Mato Grosso do Sul, *Gymnotus* spp. are the main live bait, accounting for more than three-quarters of sales (Sousa *et al.* 2017). These fish have high survival rates, withstanding poor maintenance conditions. Part of this is due to their ability to breathe atmospheric air through its swimming bladder system (Alho 2020).

The number of species introduced from the live bait release in the Upper Paraná River basin may be greater than our survey. For some species of Gymnotidae, Rhamphichthyidae, and Erythrinidae, there are uncertainties as to their origins, as they may also have been introduced by the transposition of the geographical barrier of the *Salto de Sete Quedas* after the construction of the Itaipu Dam (Júlio Júnior *et al.* 2009) (Table 1). In addition, the Upper Paraná Basin is a species donor that invaded the Iguazu River Ecoregion, as the case of *Callichthys callichthys* and *Hoplosternum littorale* (armored catfishes). None of the Gymnotiformes species are native to the Iguazu River: *G. inaequilabiatus*, *G. sylvius*, and *Apteronotus ellisi*. The occurrence of *Synbranchus marmoratus* (swamp-eel) and *Steindachnerina brevipinna* (toothless characiform) in the Iguazu River is also attributed to bait release (Baumgartner *et al.* 2012, Daga *et al.* 2016).

The ecological risk of live bait trade depends on bait source (capture in the wild or farmed), type of fishing (commercial or recreational), and context of release (Drake & Mandrak 2014). Fish health and pathogen certification programs undertaken by live bait farmers are an important step in reducing the possibility of release.

Surviving individuals, when released, can alter the food web and increase habitat eutrophication (Gallardo *et al.* 2016).

We emphasize the importance of using native species as live baits. The lambari fish *Deuterodon iguape* is considered as bait on the southeastern coast of Brazil (Henriques *et al.* 2018). In the Upper Paraná Basin, several *Astyanax* species may be also used as bait. However, care must be taken with fish introductions to avoid genetic pollution (Porto-Foresti *et al.* 2001).

The income of bait anglers ('isqueiros') and their families depend on the development of this activity. Many of them farm baits without the correct aquaculture techniques and sell them without supervision. This can lead to the release of individuals with low genetic variability or introgression of harmful genes into new populations, in addition to possible hybridism (Do Prado *et al.* 2012). Therefore, legislation revisions and a management plan for live baits are necessary (Sousa *et al.* 2017). Moreover, it is essential to carry out studies on live bait species biology, ecology, and genetics to support the legislation, guarantee the sustainability of the activity and allow bait anglers to continue to access this natural resource.

The practice of non-native live bait release in different watersheds is evident, but it still needs more studies to measure its impacts at various scales. Thus, there is an urgent need to raise awareness among sectors related with commercial and sport fishing about this impact factor on aquatic biotas. The following should be encouraged: (i) awareness programs to inform anglers and live bait farmers about the biological risks arising from live bait release; (ii) environmental education programs on the social, economic, and environmental problems of invasive species; (iii) raise and commercialization of live baits using only native species from the same hydrographic basin where the farming is located.

According to the National Environment Policy (Law N° 6938/1981), pollution is the degradation of environmental quality, which is an adverse change in the characteristics of the environment. Therefore, urgent awareness and inspection actions must be taken to avoid further impacts on Brazilian freshwater ecosystems.

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