



ENVIRONMENTAL EFFECTS OF THE UNSUSTAINABLE HARVEST OF LIVE BAIT FOR SPORT FISHING IN THE BRAZILIAN PANTANAL BIOME – A REVIEW

Cleber José Rodrigues Alho^{1}*

¹ Universidade Anhanguera-Uniderp, Programa de Pós-graduação em Meio Ambiente e Desenvolvimento Regional, Rua Alexandre Herculano, 1400 - Jardim Veraneio, CEP: 79037-280. Campo Grande, MS, Brasil.

E-mail: alhocleber@gmail.com (*corresponding author)

Abstract: This paper offers a review and discussion on environmental aspects of live bait capture for sport fishing within the Pantanal wetland. The extractive exploitation of live bait has intensified in the region due to the growing flow of tourists in search of sport fishing, who pay for this bait, creating a consolidated market. Because baitfish are often harvested from mixed stocks in the wild, the potential for bycatch exists, also leading to the disruption of their fragile habitat, affecting species assemblages in the wetland ecosystem. These target small fish, such as *tuvira* and other organisms, live in small-depth seasonally flooded ecosystems, usually covered by aquatic macrophytes. Due to the intense demand, this market brought in a socioeconomic factor, favoring the collectors of live bait. However, extraction has been done intensively to meet the growing demand, consequently causing damage to the fragile ecosystems and natural habitats occupied by these organisms used as live bait. The macrophyte species occurring in the Pantanal wetland vary depending on seasonal inundation and on various degrees of dependence of water. There has been limited focus on the socioeconomic and ecological consequences of recreational fishing in this biome. Also, there is particularly a scarcity of information on the consequences of the current live bait harvest on the natural habitats where the organisms live. This review explores some of the complex ecological interactions that occur with regard to live bait extractivism as well as identifies and analyzes environmental damage, emphasizes the socioeconomic importance of the extractive activity, and proposes a line of action to construct a management plan looking for the sustainability of the extractive resource of live bait within the Pantanal.

Keywords: aquatic macrophytes; environmental damage; angling; flooded habitats; recreational fishery.

INTRODUCTION

The Pantanal is an extensive biome (150,355 km² with approximately 140,000 km² in Brazil), recognized as a wetland of international importance by the Ramsar treaty. It is located in the center of South America, in western Brazil, and positions of Paraguay and Bolivia, and is the wetland part of the Upper Paraguay River Basin. The major rivers feeding the Pantanal wetland are: Paraguay River, Bento Gomes, Cuiabá, São Lourenço-Itiquira,

Taquari, Negro, Aquidauana-Miranda, Nabileque and Apa. These rivers are slow moving when they reach the Pantanal depression (Alho 2005; Alho & Silva 2012).

Professional and sport fishing are traditional activities in the Pantanal, with a strong environmental and socioeconomic focus (Alho & Reis 2017). The natural aquatic habitats of the Pantanal are strongly seasonal, influenced by the water flow that determines an annual and multiannual changing regime (Alho & Silva

2012). This heterogeneous complex of habitats supports the high diversity of fish in the biome, where fish assemblages with 269 described species are found (Britski *et al.* 2007). Among the species of fish with a high socioeconomic value for professional fishing and also for sport fishing are: “cachara” (*Pseudoplatystoma reticulatum*), “pintado” (*Pseudoplatystoma corruscans*), “pacu” (*Piaractus mesopotamicus*), “barbado” (*Pinirampus pirinampu*), “dourado” (*Salminus brasiliensis*), “piavuçu” (*Megaleporinus microcephalus*), “jurupoca” (*Hemisorubim platyrhynchos*), “curimatá” (*Prochilodus lineatus*), “jaú” (*Zungaro jahu*), among others (Alho 2005). Fish communities or assemblies vary depending on the type of habitat. Large, commercially important species usually occur in large rivers, such as the Paraguay, Cuiabá, São Lourenço-Itiquira, Negro and Aquidauana-Miranda. Small species occur in smaller rivers, *corixos* (water channels) and shallow floodplains, and some species are well adapted to the seasonal regime and may remain in dry sediment during the dry season. The species migrate and disperse according to the seasonal regime and the search for reproductive and food habitats (Alho 2005).

Fishing where the primary objective is not to produce food or generate income through the sale or trade of fishing products is commonly termed “sport fishing”, “recreational fishing” or “angling” (Arlinghaus *et al.* 2007). The motives of recreational fishers are diverse and differ from one person to another. However, specific motives such as “sport fishing” are unsuitable for defining recreational fishing as they do not embrace the attitudes and value systems of all recreational fishers.

Sport fishing constitutes a substantial recreational pursuit throughout the Pantanal. The use of live bait is a current practice across the Pantanal and live baits are often harvested from mixed stocks in specific natural ecosystem, leading to the destruction and relocation of non-target species, as well as to disruption of fragile ecosystems (ANA/GEF/UNEP/OAS 2005). Given the high demand for sport fishing throughout much of the Pantanal, this activity has significant socioeconomic and ecological implications.

With the considerable increase in the arrival of tourists in the Pantanal for sport fishing, there is also a marked increase in the catch of small fish and crustaceans, to be used as live bait. This

activity has attracted local people, participating as important actors in this market that involves a socioeconomic chain on the banks of rivers of the Pantanal. It turns out that, in addition to the enormous pressure on these live bait targets, it was observed in field work that the disturbance caused in the aquatic environments has led to damage in natural habitats where the organisms caught as bait occur. This type of catch generally occurs in the vicinity of tourist infrastructure facilities, which are prepared for visitors and the intermediaries known as *pesqueiros*, who work in the market chain between bait collectors and the final consumers, sport fishermen.

The number of tourists has been growing in the Pantanal since the beginning of the 1990s and includes those who are interested in sport fishing, with consequent pressure to search for live bait. The Pantanal still keeps a complex environmental and biological diversity, valuing the natural ecosystems, which is crucial for tourism, supporting the biome's integrity. The increased number of inns, locally named *pousadas*, which are specialized in receiving fishing tourists, is also an evidence of this boom, as is the larger fleet of fishing boats or hotel boats, mainly with departures from Corumbá to go along the Paraguay River. Similarly, the socioeconomic importance of recreational fishing in many areas of different countries is increasing rapidly (Arlinghaus & Cooke 2009). This increasing search for recreation in still protected biomes has been pointed out in different publications (Sharma *et al.* 2012, Tortato *et al.* 2017, WTTC 2018).

To illustrate the increasingly demand for recreational fishing, between May 1994 and April 1995, 1,433 tons of fish were caught in the Pantanal, with about 28 % of this amount coming from professional fishing and more than 71 % from sport fishing, which shows the significance of this activity in the region (Catella *et al.* 1996). For example, in 2005 was registered the catch of 1,230,229 live bait specimens, estimated to represent about 16 % of the regional catch, mainly in the region of Corumbá (Catella *et al.* 2009). While there has been a decline in commercial and subsistence fishing since the 1990s, there has been an increase in sport fishing in the region (Alho & Reis 2017). Some local people argue that the excessive regulation of commercial fishing, to cope with the fishing decline caused by overfishing, and the consequent decline in the size of

fish caught, have caused the decline in professional fishing and led to an increase in sport fishing. For decades, local people of the Pantanal have relied on subsistence and commercial fisheries, harvesting its abundance of fish. In recent decades, however, fish were removed on a massive scale, and overfishing has been identified as a primary cause of ecosystem collapse in aquatic systems (Alho & Reis 2017). However, it is also necessary to consider the growing tourist influx in the Pantanal in recent decades. This trend can be evidenced by the growing increase in tourist facilities, including fishermen's lodges, in addition to the increase in hotel boats with facilities for fishermen.

The official control of fishery activities in the two Brazilian States with large territories in the Pantanal is carried out by the following agencies:

Sistema de Controle da Pesca do Mato Grosso do Sul - SCPESCA/MS (Fishery Control System of the state of Mato Grosso do Sul) and *Sistema de Controle e Monitoramento da Pesca de Mato Grosso SISCO/MT* (Control and Monitoring System of the state of Mato Grosso) — <https://www.embrapa.br/en/busca-de-noticias/-/noticia/18028890/sistema-de-controle-de-pesca-atualiza-dados-e-analisa-informacoes>.

The objectives of this review are to (i) identify the mainly devices used for catching live baits; (ii) determine the preferred environments for catching live baits; (iii) identify the organisms most caught and their role on the ecosystem; (iv) verify the environmental damage caused by unsustainable catch of live baits; (v) propose actions for sustainable management and future research.

MATERIAL AND METHODS

This review paper treats sport fishing as the aquatic complement to the recreational activity in the Pantanal wetland. Recreational fishing is today predominantly conducted within the region using hook and line fishing. Live bait is defined as any live organism, generally a small fish, used to attract and catch fishes. The use of live organisms as bait has traditionally been popular among sport fishers in the Pantanal. The type of bait used often varies with the species of fish being sought. Recent complementary field inspections were carried out by the present study at different points of the wetland where sport fishing occurs: the port of Corumbá,

Paraguay River (19°00'33" S, 57°39'12" W); sub-region of Abobral (19°26'25.51" S, 57°03'45.24" W); sub-region of Miranda (19°50'20.20" S, 56°49'39.53" W) and sub-region of Porto Murtinho (21°48'02.37" S, 57°49'47.18" W). A review of relevant publications and unpublished reports was carried out, highlighting the studies conducted during the ANA/GEF/UNEP/OAS (2005) program. Additionally, technical reports were consulted such as "Subprojeto 5.1 MS - Diretrizes para o Manejo Sustentável da Atividade de Coleta de Iscas Vivas no Pantanal de Mato Grosso do Sul. Relatório Final" (ANA/GEF/PNUMA/OEA 2003a) and "Subprojeto 5.1 - Caracterização Socioeconômica da Atividade de Coleta e Comercialização de Isca Viva na BAP-MT. Relatório Final" (ANA/GEF/PNUMA/OEA 2003b). This data base resource was fundamental for this review. Complemented fieldwork was developed over more than 30 years of research experience by the author in the Pantanal, providing a wide range of information on the subject of live bait capture to supply the market for sport fishing. Throughout the biome, the author interviewed stakeholders involved in live bait extractivism. The overall bibliographic references were important to integrate the focal problem on an ecological perspective. Nomenclature and other aspects of fish are in accordance with Reis *et al.* (2003), and aquatic macrophyte species based on Pott & Pott (2000) and Pott *et al.* (2011).

DEVICES USED FOR CATCHING LIVE BAIT

The most commonly used tool is the mesh, also known as a sieve, which consists of a rectangular metal frame, approximately one-meter-long and two wide, covered by a thin mesh. Two people hold the rigging, which is dragged on the catchment bed in an area dominated by aquatic macrophytes, thus capturing all living organisms in the habitat, which are then selected for use or disposal. The collectors enter the *baías* (depressions in flat terrain filled with water) or *corixos* (water channels) in the midst of the "mat" of aquatic macrophytes, locally known as *camalotes de aguapé*, and submerge the sieve under the macrophyte banks. They raise the mesh, the aquatic macrophytes are removed and the *tuviras* are selected and kept in pails with water.

Fish and crab species are selected and stored in plastic containers. Before submerging and dragging the mesh, the aquatic macrophytes are removed

to allow this drag. In other cases, larger trawling devices are used. This form of catch is usually done during the day in the dry season. In the wet season, the collection is reduced, and is done with a stick with a hook. The bait is selected and stored in large flasks or canisters with water, then being sent to the sales outlets where the bait species are arranged in larger tanks.

The coarse-type trap is usually used at night in deeper places, with the aid of the spinning device. The trap is hung by a handle from a cable made of a tree branch, where it will be attached to a turning device named a *girau* during the period that is submerged. Termites are used as bait and are placed inside the trap to attract the *tuviras*. A black canvas cover is also used to prevent the passage of light.

There are other artifacts used in capturing the live bait, among them the *jiqui*. This is a trap that uses nylon mesh and an iron frame for its preparation. It is about one-meter-long by about 70 cm in diameter. In its sides there are two circular openings of about 30 cm each, and in these openings there are funnels made of nylon fabric, approximately 30 cm long.

Traditionally in the Pantanal, the live bait routine is comprised of harvesters, dealers, and sport fishers. A harvester is a local individual who freely harvests live bait from a focal designated area using harvest equipment. Most harvesters sell the majority of their bait to dealers. A bait dealer is an individual who sells bait to tourists interested in sport fishing. All this routine occurs freely without any formal license or environmental control.

CHARACTERIZATION OF THE PREFERRED ENVIRONMENTS FOR CATCHING LIVE BAIT

The Pantanal's aquatic macrophyte habitats, forming a green "mat", locally known as *camalotes*, *baceros* or *batumes*, were found to occur in shallow waters of rivers, *baías*, *corixos* and in man-made depressions, which accumulate water in the rainy season (Pott *et al.* 2011). The main species of aquatic plants in the region are *Eichhornia crassipes* and *E. azurea*. Both can uproot the soil and become buoyant (Pott *et al.* 2011). Other floating plant species that compose the mat are *Pistia stratiotes*, *Salvinia auriculata*, *Oxycaryum cubense*, and *Eleocharis* spp.

In aquatic habitats where live bait is

preferentially captured, many other aquatic macrophyte species occur, which show how complex and sensitive the habitats are. These species are: Acanthaceae: *Justicia laevilinguis*; Alismataceae: *Sagittaria guyanensis*, *Echinodorus paniculatus*, *Echinodorus grandiflorus*; Amarantaceae: *Alternanthera philoxeroides*; Araceae: *Pistia stratiotes*; Azollaceae: *Azolla* sp.; Cabombaceae: *Cabomba* sp.; Cannaceae: *Canna glauca*; Characeae: *Nitella* sp.; Convolvulaceae: *Ipomea* sp.; Cyperaceae: *Oxycaryum cubense*; Euphorbiaceae: *Phyllanthus fluitans*; Fabaceae: *Senna* spp.; Hydrocharitaceae: *Limnobium laevigatum*, *Egeria najas*; Lemnaceae: *Lemna aequinoctialis*, *Wolffia brasiliensis*; Lentibulariaceae: *Utricularia* spp.; Limnocharitaceae: *Hydrocleis* sp., *Limnocharis flava*; Marantaceae: *Thalia geniculata*; Menianthaceae: *Nymphoides* sp.; Nymphaeaceae: *Nymphaea* spp.; Onagraceae: *Ludwigia* spp.; Polygonaceae: *Polygonum* spp.; Pontederiaceae: *Pontederia* spp., *Eichhornia* spp.; Rubiaceae: *Diodia kuntzei*; and Salviniaceae: *Salvinia* spp.

The organisms caught as live bait compose the ecological communities dominated by these aquatic macrophytes (Poi de Neiff & Neiff 1980, Poi de Neiff 1983, Bronmark 1985, Cyr & Downing 1988). In addition to the natural environments of rivers, *corixos* and *baías*, there are also depressions formed in land alongside roads. These environments vary in the dynamics of their ecological community structure, but all are seasonal due to the wet and dry hydrodynamics of the Pantanal, and they make up the list of environments explored by live bait scavengers (Figure 1).

LIVE BAITS MOST CAUGHT

The use of live organisms as bait has traditionally been popular among sport fishers in the Pantanal (ANA/GEF/PNUMA/OEA 2003a, 2003b). Harvest equipment for live bait includes traps, dip nets, and seine nets and traps that are usually baited. Fish are often sorted (by species) and graded (by size) before being moved to some form of holding tank. The small fish species most sought to supply the market of live bait living in the habitats described above are: "jeju" (*Hoplerhythrinus unitaeniatus*, Erythrinidae); "tuvira" (*Gymnotus carapo*, Gymnotidae); "cascudo" (*Corydoras britskii*, Callichthyidae); "mussum" (*Synbranchus marmoratus*, Synbranchidae);



Figure 1. The aquatic habitats of the Pantanal are influenced by seasonal river flood, supporting the floristic diversity of aquatic vegetation, as well as the structure of the local ecological community, where live bait species occur. The ecological assemblages dominated by macrophytes, occurring in shallow water, are integrated by fish species and other organisms captured as live bait. Unsustainable capture that damages the entire ecosystem needs to be managed in order to better balance the mutual benefit of the local people and the conservation of nature.

“cambota” (*Callichthys callichthys*, Callichthyidae); “chimbore” (*Leporinus amblyrhynchus*, Anostomidae.); “piramboia” (*Lepidosiren paradoxa*, Lepidosirenidae) and “acará-açu” (*Astronotus ocellatus*, Cichlidae). *Hoplerhynchus unitaeniatus* prefers standing waters, while *S. marmotarus* is a swamp-eel living in habitats with a low oxygen level, being a burrower species found in the mud. *Callichthys callichthys* is a small armored catfish showing a preference for more active water.

The aquatic vegetation or *baceiro* is also home to the crab *Dilocarcinus paguei*, widely used as bait in the Pantanal (Pivari *et al.* 2008, Pott *et al.* 2011). This crab lives among macrophytes, with preference for environments with large branches and dead trunks. In general, all these species are associated with aquatic macrophytes. The *tuvira* species, belonging to genus *Gymnotus*, lives in shallow water habitats among the roots of macrophytes. Gymnotids prey on invertebrates, are nocturnal aggressive predators, exhibit territorial behavior and build nests. The *jeju* has a preference for standing waters. The *mussum* is a swamp eel living in habitats with a low oxygen level, being a burrower species found

in the mud, the *cambota* is a small armored catfish showing a preference for more active water. *Tuviras* are preferred by harvesters and consequently most captured for trade. This species has a high survival rate when compared to other live bait species, as they are also able to breathe atmospheric air through their swim-bladder system on certain occasions, which allows greater survival in their transport and storage. Again, it is particularly popular as bait because it has been shown to be effective in catching large fish such as *pintado*, *cachara* and *jaú*, which have a high value and are seen as a “trophy” for sport fishermen.

Fishermen prefer live bait, especially *tuviras* (*G. carapo*, *G. inaequilabiatus*), and probably other species of this genus, which are the most preferred and captured in the trade. These small fishes are slightly electric; while their electric charge is not perceived by man. The fish use electrical organs for communication and electro-localization, and large predators such as *surubim* and *cachara* detect this electricity and locate their prey. Hence, there is high demand for *tuviras* as live bait; however, this demand depends on the time of the year, or more

specifically, on the seasonal phase of the Pantanal. The peak is in early April, at the beginning of the dry season, with a lower peak in August-October, the end of the dry season (Alho & Silva 2012). In addition to supplying the local trade in Mato Grosso do Sul state, bait is also exported to the states of Mato Grosso, Paraná, Goiás, and Santa Catarina, according to information obtained at the commercial sites.

There is potentially the possibility of translocating live bait from one place to another when the bait accidentally escapes from the hook or accidentally escapes the fisherman's reach. Although there is no study clearly showing the habitat specificity of these organisms, however, transport from one location to another may potentially lead to the reintroduction of species, causing effects on the assemblage of fish from this relocated site. As there is still information that these baits are exported to more distant locations, this potential negative impact deserves further study. And yet, the management plan must also consider these aspects of the activity.

There is, in fact, a proven socioeconomic value arising from live bait extractivism for local people (Marques 2017). The Pantanal sites most sought after by sport fishermen are those that most demand the trade of live bait. The port of Corumbá, on the banks of the Paraguay River, where large fishing boats are concentrated for tourism, is where this trade is most registered, followed by the region of Porto Murtinho and Miranda, in the state of Mato Grosso do Sul. In the northern Pantanal, in the state of Mato Grosso, the regions of Cáceres, Poconé and Barão de Melgaço are the largest trade centers of live bait. These areas are the hotspots of recreational fishing in the Pantanal.

In addition to the *tuviras*, in the regions of Poconé, Cáceres and Barão de Melgaço, there is a search for *mussuns* (*S. marmoratus*) as live bait to supply trade. Among the live bait most preferred by the fishermen are the *tuvira*, the *mussum*, the *jeju* and the crab, which obtain a greater commercial value in the sale. These species are most easily captured at the beginning of the ebb and in the dry season, from April to September. The places of occurrence of the *tuvira* are basically *baías*, *corixos*, and shallow flooded areas, with abundant aquatic vegetation. *Tuviras* are usually captured in shallow areas under dense clumps of aquatic macrophytes

with well-developed roots, such as *Limnobium laevigatum* and *Oxycaryum cubense* associated with *Eichornia crassipes*, *Eichornia azurea*, *Salvinia auriculata*, *Ludwigia lagunae* and *Utricularia gibba*. The *tuvira* fish feeds preferentially on insects and micro-crustaceans. It reproduces in the Pantanal's floodplain, through spawning in stages, when flood waters arrive in the region, usually from February to April.

THE ROLE OF LIVE BAITS ON ECOSYSTEM

Biogeochemical, chemical and biological processes, as well as the level of conservation of riparian vegetation and floodplains carry the nutrient loads from the watersheds that make up the Pantanal (Alho 2005). It should also be considered that the loads from deforestation and other environmental changes, such as wild fires, can be transported to the rivers and flood areas, in the form of pulses, according to the precipitation indexes and, therefore, may represent an occasional increase in the concentration of nutrients.

It is important to consider that in the ecosystems where live bait species occur there are physical, chemical and biological variables, all interacting in the stability of the system (Poi de Neiff 1983). Regarding the living part of the system, plankton constitutes a life form of aquatic organisms that develop in still waters or that have small currents, therefore occurring more in lentic systems as in the *baías* (Pott *et al.* 2011). Plankton is composed of bacteria (bacterioplankton), plants (phytoplankton) and animals (zooplankton). They play important roles in the ecosystem as producers, such as phytoplankton, consumers and decomposers. Zooplankton also comprises a large variety of organisms, from protozoa to copepods. The so-called macroinvertebrates comprise a diverse number of insects of various orders, annelids, mollusks, and other species.

The ecological community that is composed of aquatic macrophytes, plus the focal species captured as live bait and, even more so, the other species of fish that occur in the habitat, participate in the nutrient cycling and energy flow of the region. These species of fish serve as food for many species of birds and other groups of regional biodiversity and develop different life cycle and reproduction strategies, adapted to the conditions that the wetland system offers. The distinct annual tides of

the rivers, causing the wet and dry seasons, result in hydrological seasonality with productivity and feeding and breeding grounds for fish in particular and wildlife in general, subject to biochemical cycles (Alho & Silva 2012). The habitats change as a function of the water discharge carrying nutrients and sediments, enriching the macrophyte habitats, where the organisms caught as live bait occur.

The literature emphasizes the role of integrated and interdependent organisms in the conservation of aquatic ecosystems (Lemmens *et al.* 2013). Microorganisms living on the macrophyte substrate form a food base for macroinvertebrates, which in turn supply food for other species in a complex food web. The macrophytes also provide cover, nesting sites, building materials, and food for the small fish caught as bait. Thus, microphytes are important for fish spawning and nursery. Human disturbance through massive removal of microphytes increases habitat vulnerability and instability, affecting the biodiversity and overall biomass of the focal ecosystem. In this way, unsustainable removal of macrophytes affects the structure and function of the aquatic community.

In the natural system of the Pantanal, macrophytes comprise a set of rooted or partially submerged plant species, in shallow water with little water circulation (Pott *et al.* 2011). These *camalotes* cover large areas. They are determined, among other factors, by sediment composition, water turbidity, nutrient availability and herbivore action. They represent one of the most productive aquatic communities. The macroinvertebrates that compose this ecosystem are insects (orders Trichoptera, Ephemeroptera, Odonata, Lepidoptera) and species of crustaceans, including the Pantanal crab.

Studies show that the distribution and diversity of fish are influenced by the heterogeneity of the habitat, involving physical, chemical and biological factors, as well as the diversity of phytoplankton, zooplankton, macroinvertebrates and aquatic macrophytes. This availability of food and habitat complexity are two factors generally invoked to explain the high density of fish in vegetated habitats (Grenouillet *et al.* 2002). Thus, the pressure of collecting small fish for bait, plus the significant disturbance with alterations in the natural habitat, are threats that reflect the unsustainable aspect of the capture of this resource of the regional biodiversity.

The removal of hundreds of thousands of small fish and other bait organisms leads, potentially, to the alteration of ecological communities, in addition of the release of non-target bait in different habitats (Arlinghaus 2007, Arlinghaus & Cooke 2009).

The distribution, diversity and abundance of the focal species that serve as live bait are directly influenced by the substrate type of the habitat, the shape and function of the ecosystem, quantity and type of organic attributes, presence and composition of aquatic vegetation, and the presence and extent of riparian forest (Grenouillet *et al.* 2002). Indirectly, they are affected by changes in nutrient concentration, the trophic chain and changes in primary productivity, given the existing threats. It should therefore be noted that focal species for bait, as well as aquatic macrophytes, are fundamental components of the food chain, essential for the maintenance of the ecosystem in which they live.

Specific disturbance, such as the massive collection of bait organisms, without a sustainable approach, has effects on other levels of the ecosystem. These effects include interaction between species, changing population parameters, and changing the structure and function of ecological communities; however, it not only involves pressure on these focal species. Indeed, environmental impact affects the whole ecosystem and not only the focal species that are drastically removed from the natural system, unless there is a focus on sustainability. In this ecosystem approach, the chemical variables (composition and water quality, pH, dissolved oxygen content, temperature, turbidity, conductivity) interact with the typical seasonal regime of the Pantanal (which depends on the rivers that rise on the surrounding plateau and the regime of precipitation and drainage). Both the variables and the regimes interact with biological factors (diversity of phytoplankton species, zooplankton, macroinvertebrates, aquatic macrophytes, fish and other species), all of which are dependent on biogeochemical cycles, such as nutrient cycling, solar radiation and precipitation (Thomaz & Cunha 2010).

ENVIRONMENTAL DAMAGE CAUSED BY UNSUSTAINABLE CATCH OF LIVE BAITS

The unsustainable extractivism of organisms used as live bait can reduce the species diversity and

abundance of both plant and animal organisms. Where wild live bait harvest occurs, our field observations emphasize that bycatch can occur with important ecological implications. Realistic opportunities for risk reduction are needed, such as harvest management, bycatch control points at retailers, and government control programs, considering the ecological risk tolerance decision. In addition, this human disturbance may potentially favor species of plant and animals that are tolerant to a disturbed habitat. For example, due to small area and shallow depth, the *baías* in the Pantanal are a complex system, with various microhabitats that support different environmental conditions for the macrophyte species as well as for the fish composing that system. This system represents a mosaic of habitats where the organisms (plants and fish) interact, composing the healthy ecosystem. Therefore, the species-specific preferences by small fish for different types of macrophytes indicate the high ecological value of the integrated system, stressing the importance of high diversity and abundance of aquatic plants in the ecosystem. Human-induced disturbance such as unsustainable extractivism involving the massive extraction of biomass, particularly macrophytes and all associated organisms, potentially disrupts the ecosystem, affecting the level of the ecological community. The ecosystem may quickly react to changes in biological, physical and chemical parameters. Practical examples of actions that could be implemented to minimize the negative impacts of live bait capture are: the development of an educational awareness program; to limit the number of live bait caught; the efficient compliance of the legislation.

Finally, it is concluded that the bait harvesting activity needs more consistent policy and enforcement direction to balance ecological protection and more accurate socioeconomic benefit.

ACTIONS FOR SUSTAINABLE MANAGEMENT

The initial assumption is that the capture of live bait should be carried out through a program of exploitation of fishing resources in a self-sustaining way. This would be at levels that are compatible with the capacity of annual renewal of the stocks of these live bait, considering their reproductive capacity in function of the Pantanal biogeochemical

cycle. The management of live bait collection, therefore, should be adaptive, considering, for example, the lower production in periods where successive years occur with changes in floods. It is also recommended the participatory approach in environmental education and consciousness of stakeholders (harvesters, dealers, and fishers) as an attempt to reach an intermediary balance between ecological conservation and socioeconomic plus recreational factors.

The local Government has tried prohibiting the collection of live bait (as was the case of the state of Mato Grosso law 7155 of July 21, 1999), which is not always effective because it is difficult to enforce the law in the huge Pantanal. Later, in 2002, that State allowed live bait capture only by professional fisherman registered with the FEMA (State Environmental Foundation), according to State Law 7881. Additionally, the state of Mato Grosso do Sul, through the State Secretary of Environment, Planning, Science, and Technology (*Secretaria de Estado de Meio Ambiente, Planejamento, Ciência e Tecnologia*), established the Resolution Nr. 03, 28 February 2011, which enforces the State Law 2.898, 29 October 2004, that refers to capture, transport, storage, trading, and cultivation of live bait (Catella *et al.* 2017). Again, our field experience has shown difficulty to enforce legislation throughout the Pantanal.

Enforcement of control is needed, for example, to avoid release of non-target organisms as bait and aquatic plants into different ecosystems from where they were harvested. In the field, some bait harvesters and dealers are reluctant or unwilling to provide accurate information of their activities when they are interviewed. Thus, the amount of bait been harvesting by fishing season may be unknown or underestimated. Lack of knowledge regarding numbers of live bait harvested is a common problem throughout the Pantanal. There have been, at least, problems of non-compliance with environmental and conservation norms and legislation, regarding ecosystem disruption and unregulated trade of live organisms, including the absence of any guarantee necessary to encourage care to environmental damage. In conclusion, there is a concern regarding the lack of knowledge about live bait productivity and sustainable levels of harvest.

PROPOSALS FOR FUTURE RESEARCH

This present review allowed the identification of the following research lines: (1) More information is needed on biological knowledge on the productivity of live bait species (for example, *tuvira*) which can be used to establish possible quotas to prevent overharvest; (2) Potential evidence to suggest that some live bait species are relatively resilient to current harvest procedures; (3) Effects on the ecological community and ecosystem integrity due to current harvest procedures; (4) Time necessary for ecological community recover after harvest procedure; (5) Comparison between macrophyte community structure and function before and after bait harvest procedure; (6) Suggestion on live bait license and regulation to reach controlled harvesting and procedure to implement them in real action; (7) The socioeconomic and ecological potential benefits generated by recreational fishing in the Pantanal, as were comprehensively reviewed for other regions by Weithman (1999) and Arlinghaus *et al.* (2002); (8) Excessive exploitation of live bait through high level of anthropogenic ecological disturbance should potentially be minimized by raising some bait species in captivity to supply this market; (9) The potential ecological role of live bait translocation from one habitat to another, if there are some organisms that only occur in a specific habitat and are translocated to other places, what could be considered a pathway for introduction of species, eventually altering local/native ecological assemblage.

IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

Commercial live bait operations, such as harvesting from the wild, and retailing live bait, provide a source of employment and income for local people. For many sport fishers across the Pantanal, live bait represents a relatively inexpensive source of bait, especially for individuals trapping their own fishes from the wild. Live bait is valued by sport fishers primarily because a live, natural bait provides scent, shape, size, vibration, and visual aspects familiar to game species. These attributes may increase fishing effectiveness in a variety of recreational fishing scenarios. Despite the many positive factors associated with the use of live bait for recreational fishing, concern exists surrounding

the unsustainable use of these live resources, with ecological consequences (ecological issues associated with the use of live bait; potential bycatch leading to relocation of species; degree of space used by target organisms), as pointed out by international publications (Kerr 2012, Drake & Mandrak 2014, Monk & Arlinghaus 2017). A certain degree of biological impact may be accepted as long as this does not affect entire ecosystem where live bait is harvested, allowing continuing use of the live resource. Harvester stakeholders might conclude that the irreversible alteration of habitat structure and function is unacceptable.

It is concluded that the ecological consequences of live bait harvest for recreational fishing is negligible, at least throughout most of the searched fishing sites, such as at the Paraguay River near to the municipality of Corumbá. Some published international literature stressed that this negligence is detrimental to the long-term sustainability of the freshwater ecosystems that the fishers depend on for their recreation (Burgin 2017, Monk & Arlinghaus 2017). This concern is due to current and increasing popularity of nature recreational tourism, including sport fishing, in the Pantanal. In fact, there has been insufficient scientific information on the negative impacts to natural habitats where live bait occurs, in order to assess protection of these freshwater ecosystems.

This environmental concern is consistent with the increased awareness of human-mediated species-use, with consequent vulnerability of focal aquatic ecosystems, where live bait is harvested. Three aspects related to the trade of live bait in the Pantanal should be emphasized: (1) the socioeconomic importance for the local people who live and maintain this trade; (2) the proven negative environmental impact that this unsustainable activity has on shallow water ecosystems, covered by macrophytes; and (3) the need to adapt a management plan, with the participation of the main actors involved in this activity, in search of the sustainable use of this resource. Managers have to consider the increasing volume of live bait capture involving wild stocks. The action required for the proper management of this natural resource must balance the need to curb environmental degradation with the need to maintain the livelihood of harvesters or extractivists, given the socioeconomic importance

of this activity. However, the maintenance of the socioeconomic factor cannot be due only to the anthropocentric prerogative of human interest, denying or neglecting the conservation of this living resource, as pointed out for other regions of the world (DiStefano *et al.* 2009, Killian *et al.* 2012, Drake and Mandrak 2014). As with all sport fishery, management of live bait across the Pantanal must focus on relevant socioeconomic and ecological factors. This review assessment of the Pantanal's live bait harvest activity identifies certain socioeconomic successes, and many ecological challenges, for the future management of live bait. Improvement of measures that educate commercial harvesters about the risks of natural habitat disruption and the need for effective target species sorting are needed. The biological process relies on the reproductive potential of the organisms used as live baits and can be better exploited through appropriate management, based on ecological and administrative attributes, to ensure continued productivity of live bait for sport fishery in the Pantanal.

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