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Current status and potential contributions of fisheries statistics from artisanal fisheries for managing juvenile istiophorid billfishes in Southern Brazil

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Abstract Billfishes are considered important fishery resources and the identification of aggregation sites is imperative for proper management. Here we present evidence of a seasonal aggregation site for juvenile istiophorid billfishes in southern Brazil. We discuss the results as they relate with the need for management at a local scale and participatory monitoring with artisanal fishing communities as a way to ensure access to data on the occurrence and population status in the long term.

Keywords Artisanal fishing · Billfishes · Regional management · Genetically isolated stocks

Introduction

Billfishes are easily identified by a prolongation of the upper jaw, which exceeds the length of the lower jaw (Nakamura 1985). They are classified into two families: the monotypic Xiphiidae (swordfish or meka), comprising *Xiphias gladius* (Linnaeus, 1758), and Istiophoridae, composed by the genera *Istiophorus* (sailfish) (Lacepède, 1803), *Makaira* (marlins) (Lacepède, 1803), *Istiompax* (black marlin) (Whitley, 1931), *Kajikia* (white and striped marlins) (Hirasaka and Nakamura, 1947) and *Tetrapturus* (spearfish) (Rafinesque, 1810) (Nakamura 1985; Collette et al. 2006; Williams 2018). These apex predators are highly migratory pelagic and epipelagic species found in tropical and temperate waters worldwide (Nakamura 1983). They are considered important fishery resources, as they, along with tunas, serve as a food source for various communities in developed and developing countries (Collett et al. 2011; Pons et al. 2017). Thus, they suffer constant fishing pressure (both as targeted and as bycatch), with annual global landings, except for swordfish, close to 10,000 tons (Nakamura 1983; Uozumi 2003; Brinson et al. 2009). In addition, they also drive local economies through recreational fishing (Holland et al. 1998; Ditton and Stoll 2003). Due to their pelagic ecology, billfishes are commonly caught by industrial fishing fleets. Though capture of billfishes is commonly reported in offshore recreational fisheries, reported captures by the artisanal fleet are sporadic and usually occur incidentally (Gentner 2007; Brinson 2008). The capture of individuals by the artisanal fleet is only reliably reported for some locations, such as Venezuela, Ecuador, Africa, Mexico and Northern Brazil (Brinson et al. 2009; Arocha et al. 2015; Martínez-Ortiz et al. 2015; Freire et al. 2018; Mourato et al. 2018).

From an ecological perspective, billfishes are important apex predators and drive structure and function of lower trophic levels and high fishing pressure has the potential to disrupt ecosystem functionality, with unknown economic consequences (Burgess et al. 2013;

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Chang et al. 2019). Moreover, recent genetic data has indicated billfish populations may need to be managed at relatively small spatial scales (Smith et al. 2015; Mamoozadeh et al. 2019) to preserve unique genetic material which places emphasis on conserving regional spawning habitats (Erisman et al. 2017). This is because, although they are highly migratory pelagic species, billfishes show high fidelity to spawning and feeding sites, which significantly reduces gene flow (Graves and McDowell 2003). Such a pattern makes fishing management difficult to perform not only for isolated populations and possible philopatry but also for physiological limitations imposed by low genetic variability, possibly reducing the ability to cope with both anthropogenic and environmental stressors in a very significant way (Hughes et al. 2008).

According to literature, there are seven species described in Brazilian waters: *Makaira nigricans* (Lacepède, 1802), *Tetrapturus pfluegeri* (Robins and de Sylva, 1963), *T. georgii* (Lowe, 1841), *Istiophorus platypterus* (Shaw, 1792), *I. albicans* (Latreille, 1804), *Xiphias gladius* and *Kajira albida (=Tetrapturus albidus)* (Poey, 1860). Of these, the most commonly fished are the blue marlin (*M. nigricans),* the sailfish (*I. albicans*), swordfish (*X. gladius*) and the white marlin (*Kajira albida = T. albidus*) (ICCAT 2019). Furthermore, most published studies are of industrial fishing landings or from fishing tournaments, with data from artisanal captures being very scarce. Among the states with the largest reported catches and scientific reports documenting fishing activities are Bahia, Rio Grande do Norte, Pernambuco, Espírito Santo, Rio de Janeiro and São Paulo (Freire et al. 1998; Mourato et al. 2018). Also, Istiophoridae larvae (sailfish and white marlin) and Xiphiidae eggs (swordfish) were identified in these states (except Bahia) and Santa Catarina - Southern Brazil (Schmidt et al. 2015; Rodrigues et al. 2017). Moreover, studies show that the southeastern coast of Brazil might be an important spawning site and a nursery area for istiophorids, possibly supplying recruits to populations throughout the South Atlantic (Arfelli and Amorim 1981; Mourato et al. 2014, 2018).

Regarding fisheries management in Brazil, the legislation in force is the Ordinance n. 445 from Ministry of Environment (MMA 2014) which establishes that *M. nigricans* and *K. albida (=T. albidus)* cannot be captured, transported, stored, handled, processed and traded, unless there is a specific management plan with proper procedures for sustainable use. In the case of incidental capture, live animals must be immediately released. For dead animals, the carcass must be discarded. In both cases, official report must be made accordingly. There is also the Normative Instruction n. 12 from Special Secretariat for Fisheries (SEAP 2005). The normative regulates the capture of *M. nigricans, I. albicans, T. pfluegeri* and *K. albida (=T. albidus)* and requires immediate release when *M. nigricans* and *K. albida* are caught alive, in agreement with the Ordinance n. 445. *I. albicans and T. pfluegeri* can be eviscerated and sold, however, the first dorsal and first anal fins must be attached until landing to allow proper identification by inspectors. Upon landing, fins should be donated to scientific institutions or for charities (SEAP 2005). The capture of other billfish species is authorized but the animal must be landed with fins attached to the body. Additionally, other species taken as bycatch from various fishing modalities can be kept and sold but need to be landed intact. Still, the Interministerial Normative Instruction n. 10 published by the Ministry of Fisheries and Aquaculture and the Ministry of Environment (MPA-MMA 2011) sets maximum catch limits for swordfish (*Xiphias gladius*) in the South Atlantic. However, the Normative does not provide catch limits for other species that occur in Brazilian waters. Currently, Normative Instruction n. 5 (published in March 2019) amends Annex IV of Normative Instruction n. 10, granting supplementary authorization for *T. pfluegeri*, *I. albicans* and *X. gladius* capture by seine fishing (MAPA/MMA 2019).

In Brazil, basic biological information and stocks assessments for billfishes are scarce, and management plans considering genotypic peculiarities (i.e., genetic isolation among populations) and physiological vulnerability to capture (i.e., post-capture and post-release mortality rates; sublethal effects of capture) are non-existent. Still, even though occurring all along the Brazilian coast, studies are restricted to only a few states, and the published data come from occasional recreational fishing data logs and previous industrial fishing landings, without any fishery statistics and landings monitoring currently in force. Juvenile istiophorid billfishes are constantly caught by the artisanal fleet in the state of Paraná (Southern Brazil) (personal observation). However, nothing is known about their occurrence, interaction with fishing and conservation status in the region. To shed light on this matter, informal conversations with local fishers were performed and data on fishing spots, capture patterns and seasonality were accessed. Moreover, the landing of an important artisanal

community was monitored during 2019, in addition to landing reports received via WhatsApp at the beginning of COVID-19 restrictions in Brazil (March and April 2020).

Methods and Results

In 2019, our team had access to three individuals captured by the artisanal fleet, one adult female *M. nigricans* (January) and two juvenile *I. albicans* (May). The animals were caught in mackerel fisheries (*Scomberomorus spp.*). The *M. nigricans* specimen hitched on the net's rope and when retrieved, it was already dead. No other fish were caught in the same campaign. The adult specimen was 3.55 m in total length (TL) and weighed over 300 kg (Fig. 1a). According to local fishers, it was the largest specimen caught by the community. The two specimens of *I. albicans* were caught together in another campaign, measuring 1.83 and 1.92 m TL and weighing 26.75 and 31.20 kg, respectively (Fig. 1b). Subsequent to biometric measurements, biological samples (blood and muscle) were collected for future studies. Sampling was approved by the Brazilian Ministry of the Environment (IBAMA/ICMBio-SISBIO # 68069). No ethics permit was necessary as the animals sampled were landed death as bycatch of artisanal fleets. In February 2020, a juvenile *I. albicans* measuring 1.26 in TL and weighing 19 kg was incidentally caught in a fishing campaign targeting coastal sharks (Fig. 2a). In March 2020, reports of two catches were passed on to our team. Both individuals were later identified as juveniles of *I. albicans*, measuring 1.52 and 2.11 m in TL and weighing 23 and 36.1 kg, respectively (Fig. 2b-c). Most fishing activities were interrupted in April and May due to the government decree that led to the closure of the fish market, so there were no other catch reports for the 2020 season.

All specimens of *I. albicans* were captured around Itacolomis island (Fig. 3). This island has a total area of 4.245 m^2, it is formed by two main rocks and is located in front of Ponta de Matinhos (25°50′27"S - 48°24′20"W). The eastern portion is composed by a group of rocks, up to 10 m high without vegetative cover. The western portion reach approximately 17 m, with a vegetative cover. Both portions are surrounded by clusters of smaller rocks and are not protected from waves, making access to the region difficult (Daros 2010). Itacolomis presents a high diversity of fauna, with many species of reef fish (Daros 2010; Santos et al. 2018). It is the furthest islet off the Paraná coast, located approximately eight nmi from Municipality of Matinhos, 7.3 nmi from the Guaratuba Bay mouth and 7 nmi from Currais Island (Lorenzi and Borzone 2009; Daros 2010; Santos et al. 2018). In addition to artisanal fishing carried out around the island, recreational fishing (i.e., spearfishing and angling targeting sook fish and tunas) is also performed. The specimen of *M. nigricans* was captured offshore, however, we did not have access to the exact location of the capture.

Discussion

Historically, the fishing community of Matinhos catch and consume billfishes. Occurrences are regular but peak catches occurs during austral summer (December to March) and early fall (April and May), indicating that these animals use the region seasonally (Fig. 4). According to fishers, catches have occurred every year since the 1960s, when the community was founded. Still, all captures are incidental, and fish are caught with 10 mesh between opposite nodes on drift nets. An average of 50 juveniles are caught per season, totaling around 1.200 t - additionally to individuals captured sporadically throughout the year (without estimates). When catches of adult individuals occur (as in the case of *M. nigricans* in 2019), the estimated total weight may be higher. Despite the constant landings in the region, there are only two published papers, both reporting a negative interaction between a bather and a sailfish in front of the fish market (Haddad Jr. and de Figueiredo 2009; Bornatowski et al. 2011). The close proximity of the animal to the coast that led to the reported interaction demonstrates that the patterns of habitat usage in the region may be unique and studies are needed to elucidate such ecological aspects. The proximity to the coast has already been reported in some regions, being a constant focus of research. For example, sailfish are captured near shore in eastern-coastal Taiwan by set nets which intercept a meander of the Kuroshio Current (Chiang et al. 2011) and near shore off the Kona coast of the Big Island, Hawaii (Hyde et al. 2005, 2006).

Considering the traditional capture of these animals in proximity to Itacolomis island over time, the ecological importance remains enigmatic. Since most individuals caught by fishers in the region are juveniles, the island may be used as habitat or refuge. In fact, some highly migratory pelagic species tend to aggregate near oceanic

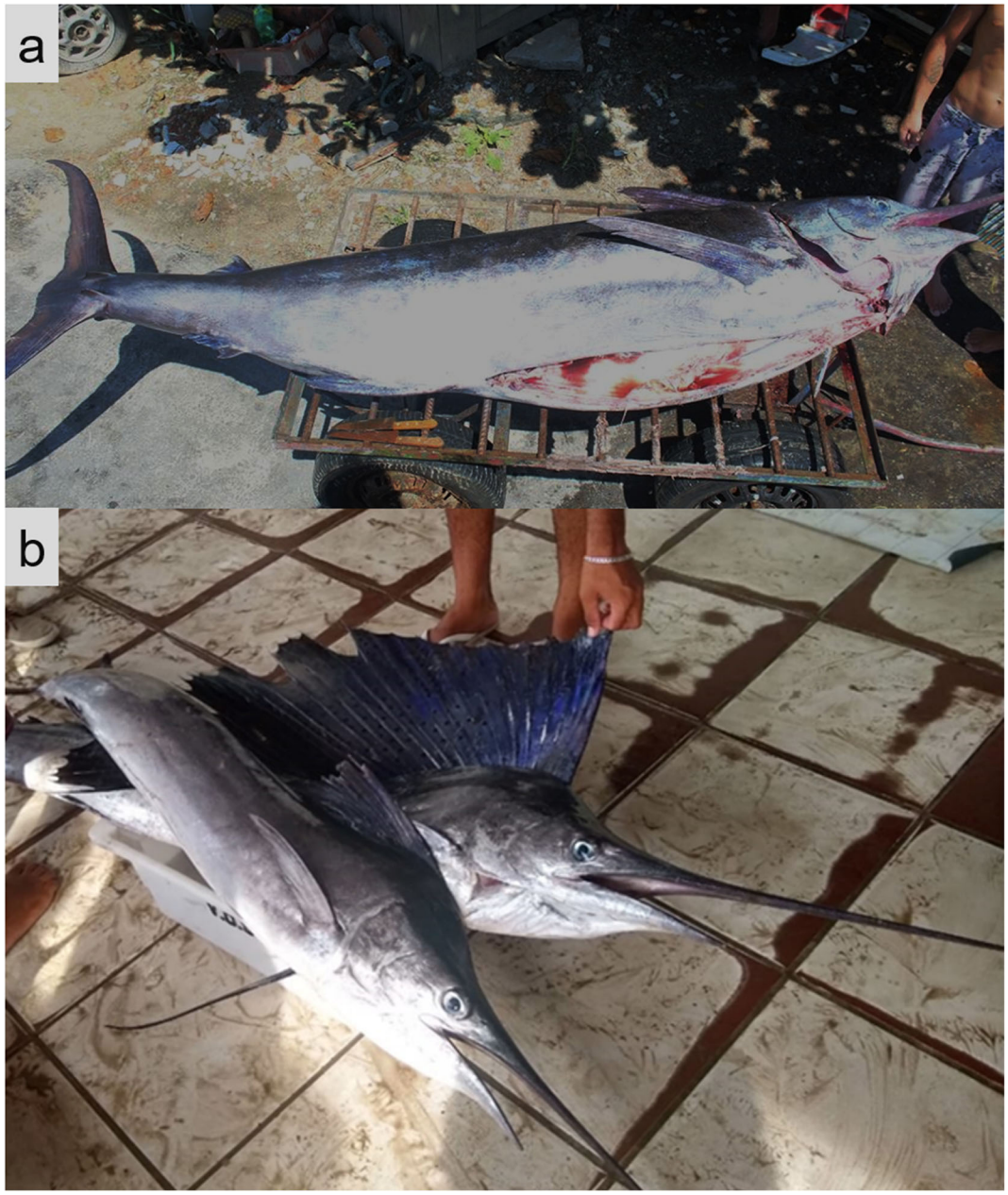

Fig. 1 Some of the individuals captured in 2019 by the artisanal community of Matinhos

islands or underwater seamounts, including billfishes, due to food availability and greater ecological complexity of these regions (Worm et al. 2003, 2005; Hearn et al. 2010; Morato et al. 2010). The seasonal aggregation and possible spawning habitat of these species near the islands is a concern for conservation as they could eventually become fishing hotspots (Sadovy and Domeier 2005; Domeier and Speare 2012) or succumb to other anthropogenic stressors (e.g., pollution, habitat degradation). Still, considering the capture of an adult female in the region, Paraná may be a migratory route to *M. nigricans*.

Also, considering that larvae were found in the adjacent state of Santa Catarina - it is likely that both regions have connectivity to southern populations and possibly to larger stocks. By determining the connectivity between areas, it will be possible to establish the degree of importance and geographical boundaries, thus supporting the implementation of priority areas for the

Fig. 2 Juveniles of *I. albicans* captured around Itacolomis Island in 2020

conservation of South Atlantic populations. Currently, no study is being conducted off the coast of Paraná, even with individuals being landed constantly, to determine the ecological and biological significance of this

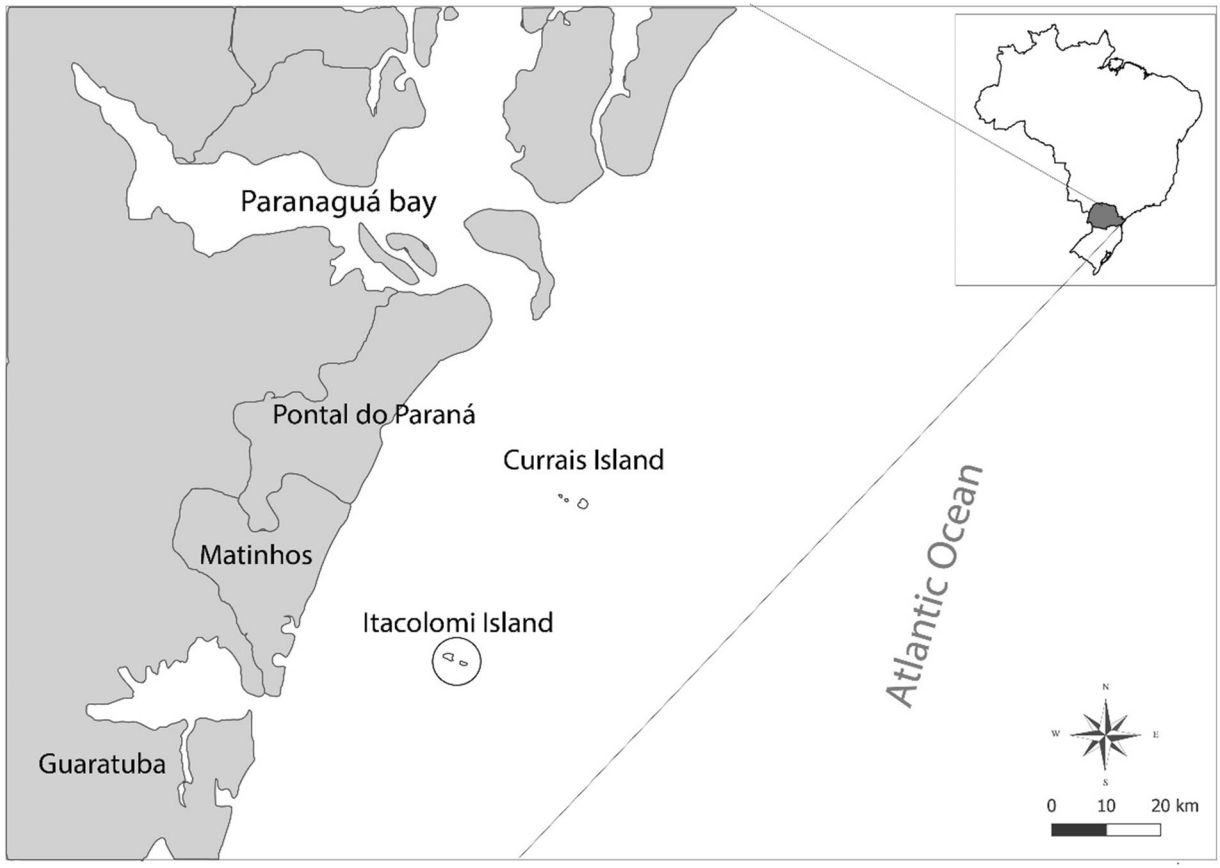

Fig. 3 Map of the region highlighting Itacolomis Island where juvenile billfish aggregations occur seasonally

Fig. 4 Historical captures of istiophorid billfishes around Itacolomis Island, with a predominance of juveniles of *I. albicans* (**a**-**c**). (**d**) *Makaira nigricans* incidentally caught offshore

location. The proximity to fishing communities of the region and the unlimited access to landing brings added benefits and opportunities for future studies, focusing on basic biological aspects and fishing statistics of the artisanal sectors in the region. Obtaining biological data on these species (e.g., feeding habits, age, growth, and maturity), as well as determining priority areas for conservation (e.g., feeding, spawning and larval habitat) is extremely important, so that productivity and the actual status of stocks can be determined (Uozumi 2003).

It is important to consider that although already established by previous molecular studies, billfishes' South Atlantic populations remains poorly studied. Indeed, the failure or complete absence of fishing statistics in most South American countries makes the conservation status of South Atlantic populations difficult to access. Still, connectivity and genetic diversity between regions remains unknown and little is known about spawning sites and nursery areas, making management plans difficult to implement but nevertheless important. Management plans and conservation strategies for migratory species are established by international commissions, usually taking into consideration populations already established in the literature (e.g., North Atlantic and South Atlantic populations). Also, domestic legislation that establish limits for capture and trade are established at the federal level, disregarding regional uniqueness of the stocks. Due to fishing profiles of each region, populations may need to be managed at small spatial scales for effective conservation. However, even with available fine-scale /regional data, it might be necessary a change in fisheries policy to account for

migratory species on municipal scales according to uniqueness of fishing dynamics and conservation units/non-take zones of each state/microregion.

Access to animals from artisanal fisheries paves the way for the acquisition of basic biological data, such as feeding and reproduction - which are scarce for the group - as animals can be sampled on shore, reducing operational costs of monitoring industrial fishing campaigns or recreational fishers. In turn, these data are necessary for conducting stock assessments which are used to formulate management plans. That said, the inclusion of artisanal fishers in research activities through participatory monitoring is a promising tool for species management at regional level. Furthermore, by considering artisanal fisher's demands and knowledge, commitment to conservation actions may be optimized. Moreover, since recreational fishing is carried out around the island, future studies should focus on gathering data from this fishing modality. Based on the success of the Marlin Project through the partnership with anglers (southeastern Brazil, for more details see Pimenta et al. 2001), establish a tag-and-release program along with recreational fishers in Itacolomis is an alternative to fill the knowledge gap on the ecological importance of the region for istiophorid billfishes.

Lastly, the biological samples collected will be used to investigate four main aspects of istiophorid billfishes in the region. Blood samples will be used to assess juveniles' general health status and to establish species-specific stress markers, aiming at assessing their vulnerability to capture. Both data will provide relevant information for proper stock management as physiological profiles might help to elucidate population resilience. Muscle samples will be used to assess exposure to environmental contaminants and possible species-specific detoxification mechanisms. These data are of particular concern as billfishes are top predators and tend to bioaccumulate and biomagnify pollutants (e.g., mercury) with the potential to reduce their reproductive capacity. Muscle samples will also be used to assess genetic diversity, the potential effects of Fisheries-Induced Evolution in the local population, and to generate a database to be used in future population connectivity studies along the western South Atlantic.

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