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Characterization and comparison of Brazilian and foreign leased pelagic longline fleets in the Southwestern Atlantic Ocean between 2003 and 2014. How different are these fisheries?

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Abstract. The pelagic zone of the Southwestern Atlantic Ocean is an important area for longline fisheries. Brazilian waters are strategic regions for the performance of this modality in International Commission for the Conservation of Atlantic Tunas - ICCAT. In order to reach international quotas government strengthened its rent policy of foreign vessels aiming to promote technology transfer to the national fleet. Knowledge of vessel characteristics, technology used in equipment and strategies used by skippers are important for the management of this activity. The present study characterized vessels from national and foreign fleets operating out of the port of Itajaí, in the state of Santa Catarina (SC), between 2003 and 2014. Results indicate that these fleets are different in relation to size of vessels, engine power, cargo hold capacity, length of the main and branchlines, and steel wire length. Despite these differences, strategies adopted are critical to achieve better yields per trip. For the national fleet, the skills acquired to the use of equipments, in understanding the behavior of the target species, and change of fishing strategies often compensate for the lack of technology.

Keywords: fleet characterization; fishing gear characterization; fishing strategies; fisheries management

Resumo. Caracterização e comparação das frotas brasileira e estrangeira arrendada de espinhel pelágico no sudoeste do Oceano Atlântico entre 2003 e 2014. Quão diferentes são estas pescarias? A região pelágica do Oceano Atlântico Sul Ocidental caracteriza-se como uma importante área para a pescaria de espinhel pelágico. As águas brasileiras são uma região estratégica para a atuação desta modalidade no âmbito da Comissão Internacional para Conservação dos Atuns do Atlântico - ICCAT. Para que o país atingisse as cotas estabelecidas e para promover a transferência tecnológica para a frota nacional, o governo brasileiro fortaleceu sua política de arrendamento de embarcações estrangeiras. O conhecimento das características físicas das embarcações, da tecnologia empregada nos petrechos, bem como das estratégias utilizadas pelos mestres é de suma importância para o ordenamento desta atividade. No presente estudo foram caracterizadas embarcações de espinhel pelágico da frota nacional e estrangeira arrendada operantes no porto de Itajaí, estado de Santa Catarina (SC) entre os anos de 2003 e 2014. Os resultados indicam que estas duas frotas são bastante distintas em relação ao tamanho das embarcações, potência de motor, capacidade de porão, comprimento da linha madre e secundária, e em relação ao comprimento do fio de aço – estropo. Apesar desta diferença tecnológica as estratégias adotadas pelos mestres são fundamentais para obtenção de melhores rendimentos por viagem. Para a frota nacional, a habilidade adquirida no uso do petrecho, no entendimento do comportamento das espécies-alvo e alterações das estratégias de pesca muitas vezes compensam a falta de tecnologia de ponta.

Palavras-chave: caracterização da frota; caracterização do petrecho; estratégias de pesca; ordenamento pesqueiro

Introduction

The pelagic zone of the Southwestern (SW) Atlantic Ocean is characterized by circulatory processes of great ecological and economic importance (Campos *et al*., 2000). These oceanographic processes are complex, including the confluence of warm, high saline and oligotrophic waters of the south-bound Brazil Current and the cold, low saline, nutrient-rich waters of the north-bound Malvinas/ Falkland Current (Olson *et al*., 1988; Seeliger *et al.,* 1998; Cirano *et al*., 2006). This mixing of these two major water bodies results in this biogeographic transition zone (Sharp, 1988) further shown by the extensive areas over the continental shelf of temperate Patagonia meeting the tropical Brazilian waters (Stramma & England, 1999). The confluence of these two currents plays a key role in the physical and biotic processes (Campos *et al*., 2000), which support important fish stocks and a considerable number of top predators (Seeliger *et al*., 1998).

The pelagic longline fisheries in this region is of great economic importance worldwide of notable significance in the capture and landing of large catches of target species with high market value (Evangelista *et al*., 1998; Hazin, 2006a), including shark fins (Mazzoleni & Schwingel, 1999; Quaggio *et al*., 2008). These fisheries became well established in Brazil after they were initiated by foreign fleets, but currently the national fleets now has the technology and strategies to capture the main species such tunas (*Thunnus alalunga*, *T. obesus*, and *T. albacares)*; swordfish (*Xiphias gladius);* and blue shark (*Prionace glauca*) (Brothers & Løkkeborg, 1999; Watson & Kerstetter, 2006).

In southeastern and southern (SE/S) Brazil the main fishing ports are Itaipava, state of Espírito Santo (ES), Santos, state of São Paulo (SP), Itajaí, state of Santa Catarina (SC) and Rio Grande, state of Rio Grande do Sul (RS) (Sales *et al*., 2008). Historically both national and foreign vessels have operate out of Rio Grande (Meneses de Lima *et al*., 2000). At Itajaí, the main fishing port of the SE/S region, the longline fishery was exclusively conducted by foreign vessels until 1996, when national vessels started to operate (see Meneses de Lima *et al*., 2000 for details). In 2009, the last foreign vessel ended its operations from this port, and currently only national vessels are active, with a total of 118 vessels registered between 2010 and 2014 (Projeto TAMAR - National Sea Turtle Conservation Program, database). These vessels change their capture strategies throughout the year and even switch to other fisheries, according to the availability of target species and the demand of internal and external markets (Fiedler *et al*., 2015). In addition, many vessels migrate away from their home ports during certain seasons; for example, during summer months (November to January) there is an increase of vessels from the Itaipava port based out of Itajaí, corresponding to the dolphinfish (*Coryphaena hippurus*) season which is most productive farther south than Espírito Santo (Dallagnolo & Andrade, 2008; Fiedler *et al*., 2015).

The study of physical and operational characteristics of longline vessels is fundamental to carry out detailed analysis about the impacts on pelagic communities, both target species and bycatch, necessary for establishing management measures populations of impacted pelagic species and ensuring the maintenance of the fishing activity itself.

The present study aimed to characterize the pelagic longline industrial fishery of both national and foreign fleets that have operated in the SW Atlantic Ocean from the port of Itajaí between the years 2003 and 2014. Physical characteristics of vessels and fishing gear as well as temporal and geographic distributions and organizational aspects are described and analyzed.

Material and methods

Information used in this study was obtained from two different Brazilian monitoring programs. The first one, specific to the national fleet, provided data managed by Projeto TAMAR, within the Brazilian National Action Plan to Reduce Incidental Capture of Sea Turtles in Fisheries. The second one related to the foreign fleet, was collected through the Onboard Observers Program - PROA of the Universidade do Vale do Itajaí - UNIVALI, as established in agreements for scientific and technical cooperation with the Federal Government. Data from 58 vessels of the national fleet and seven vessels of the foreign fleet that all primarily targeted sharks, swordfish and tunas were included in this study. Data were organized in two matrices, one for each fleet (*i.e.* national and foreign), organized into four categories: 1) vessel: hull material (wood or steel), total length, hold capacity, engine power, and catch storage method (ice or flash freezing); 2) fishing gear: longline type (continuous or segmented), start and end time of the launching and hauling, materials of the mainline and the branchline, gauge of the mainline and the branchline, minimum and maximum length of the mainline, length of the branchline, steel wire use, steel wire length, hook type, minimum and maximum number of hooks deployed in each set, number of hooks between buoys, minimum and maximum number of buoys (bullet, balloon and radio), length of buoy cables, bait type, use of lightstick and color if used; minimum and maximum depth of water column; 3) temporal distribution (only national fleet): months in which this fishery operated, associated fishery (when vessel changes fishing); months that this associated fishery operated; and 4) organizational aspects: fishermen's organization in unions or other associations (only national fleet), crew size, port of origin, landing ports and days at sea. These matrices were initially used to provide a general descriptive analysis for each fleet. In a second step fleets were differentiated by: 1) vessel length; 2) engine power; 3) fish hold capacity; 4) minimum and maximum length of the mainline; 5) length of branchlines; and 6) steel wire length. When the statistical assumptions for parametric distributions were met, differences were tested using Student's t-test. Otherwise, non-parametric Mann-Whitney test was used (Zar, 2010). In addition, a Pearson's correlation analysis was conducted for certain values within each fleet considering the following parameters: 1) engine power *x* total vessel length; 2) fish hold capacity *x* total vessel length; and 3) fish hold capacity *x* engine power. In these analyses correlation values were assigned to the rankings/categories established by Dancey & Reidy (2006): *r* between 0.10-0.30 = weak correlation; *r* between 0.40-0.60 = moderate correlation and *r* between 0.70-1.00 = strong correlation. In this last-named rank/category, the closer the value of *r* is to 1, the greater is the degree of dependence between the two variables under consideration.

Results and discussion

For the national fleet, 83% of vessels are built of wood and 17%, of steel (Table 1). In contrast, 100% of vessels from the foreign fleet are built of steel. The large proportion of wooden hulls in the national fleet is mainly related to the presence of the Itaipava fleet (see Guesse *et al.*, 2013 for more information) that adapts older vessels built originally for other fisheries to operate with pelagic longlines. According to Oliveira (2009), wood is still used in Brazil as the main boat-building material, even though there have been some economic incentives to build steel vessels. As Beverly (1996) explained, steel vessels have advantages over others because they are easier to build, maintain, and repair, and they also resist better collisions with the bottom, other vessels or piers.

In relation to the longline type, 100% of the national vessels operated with the continuous longline (where the mainline is launched from a single basket). In the foreign fleet (seven vessels), three operated with continuous longline; two with segmented longline (where the launch is carried out in parcels and mainlines were stored separately and joined at launching); and two other vessels alternated their fishing activities varying between continuous and segmented longlines. This change probably happened in these two vessels of Chinese origin, because they initially operated with segmented longline and after evaluation of catches of the national fleet they adopted to the continuous type.

Regarding type of the mainline material, all 58 vessels of the national fleet used nylon monofilament, of which 24 vessels (41%) used 3.6 mm gauge, and 16 (27.5%) with 4.0 mm gauge. The remaining 18 vessels varied the gauge used. For the foreign fleet, six vessels used nylon monofilament (with either 3.0, 3.5, or 3.6 mm thicknesses), while only one vessel used nylon multifilament (8.0 mm thickness). According to Amorim & Arfelli (1984), nylon multifilament was used at the beginning of the longline fishery in Brazil, and then replaced with nylon monofilament because of increased interest in catching swordfish, as better conditions in the international swordfish market encouraged Brazilian ship owners to use this technology (Hazin, 2006b).

Related to the hook type, national vessels used J-type, circular and tuna hooks, with the J-type size 9/0 the most common (58%). Foreign vessels used J-type and tuna hooks and the J-type hook size 9/0 was also the most frequent (44%). Domingo *et al.* (2012) reported the same type of hook as the main hook used by Uruguayan fleet. Likewise, Vega & Licandeo (2009) also reported the greater use of hook size 9/0 for the capture of swordfish by the American longline fleet that operates in the South Pacific.

In Brazil there is no legislation for hook type in longline fisheries; however, fisheries regulation that includes the types of hooks allowed in Brazil longlining vessels is currently

Table 1. General characteristics for Brazilian and foreign leased pelagic longline fleets. Note: * three vessels reported two forms of fish conservation; ** four vessels using two different branchlines gauge.

	Characteristics	Brazilian	Foreign
Vessel	Hull material	Wood (n=48); Iron (n=10)	Iron (n=7)
	Full length (m)	12 - 37	27 - 50
	Hold capacity (ton)	9 - 120	30 - 141
	Engine power (Hp)	111 - 474	400 - 1468
	Fish conservation	Ice (n=57); Refrigerated chamber (n= 4)*	Refrigerated chamber (n=7)
Fishing gear	Longline type	Continuous (n=58)	Continuous (n=5); Segmented (n=2); Alternate (n=2)
	Start time of launching	00:00 - 23:00	
	End time of launching	00:00 - 23:30	
	Start time of hauling	04:00 - 20:00	
	End time of hauling	00:00 - 23:00	
	Mainline material	Monofilament nylon (n=58)	Monofilament nylon (n=6); Multifilament nylon (n=1)
	Mainline gauge (mm)	3.0 (n=6); 3.5 (n=8); 3.6 (n=24); 3.8 (n=3); 4.0 (n=16); 5.0 (n=1)	3.0 (n=3); 3.5 (n=2); 3.6 (n=3); 8.0 (n=1)
	Mainline minimum length (nm)	6 – 52	15 - 62
	Mainline maximum length (nm)	6 – 60	44 - 62
	Branchline material	Nylon (n=58)	Nylon (n=7)
	Branchline gauge (mm)	1.4 (n=2); 1.6 (n=1); 1.8 (n=1); 2.0 (n=46); 2.1 (n=1); 2.2 (n=5); 2.5 (n=1); 3.6 (n=1)	1.5 (n=1); 1.6 (n=1); 2.0 (n=6); 2.5 (n=4); 3.0 (n=1)**
	Branchline min/max length (m)	4.5 – 45	7 - 40
	Use of steel wire	Yes (n=52); No (n=6)	Yes (n=7); No (n=2)
	Steel wire length (m)	0.2 (n=1); 0.3 (n=7); 0.4 (n= 4); 0.5 (n=35); 0.6 (n=1); 0.7 (n=4)	0.4 (n= 1); 0.6 (n=1); 0.7 (n=2); 1.0 (n=1); 1.5 (n=1)
	Hook type	J (7/0 n=1; 8/0 n=6; 9/0 n=37; 12/0 n=1; 13/0 n=1; 14/0 n=1); Circle (12/0 n=1; 14/0 n=2; 15/0 n=3; 18/0 n=3); Tunna hook (3.0 n=2; 3.2 n=1; 3.4 n=1; 3.6 n=2; 3.8 n=1; 4.0 n=1)	J (7/0 n=1; 8/0 n=1; 9/0 n=7; 16/0 n=2); Tunna hook (4.0 n=1; 4.2 n=1; 5.0 n=2; 5.3 n=1)
	Min/max number of hooks	250 – 1600	970 - 1626
	Hooks between buoys	4 (n=1); 5 (n=41); 6 (n=6); 7 (n=2); 8 (n=4); 9 (n=1); 10 (n= 2); 12 (n=1)	4 (n=4); 5 (n=4); 6 (n=1)
	Min/max number of bullet buoys	25 - 320	17 - 300
	Min/max number of balloon buoys	1 - 200	17 - 30
	Min/max number of radio buoys	2 - 20	4 - 17
	Min/max length of bullet buoys cables (m)	7.2 - 32	11 - 20
	Min/max length of balloon buoys cables (m)	7.2 - 32	17 - 20
	Min/max length of radio buoys cables (m)	7.2 - 36	20
	Bait type	Mackerel (n=38); Argentine squid (n=28); Skipjack tuna (n=26); Brazilian sardine (n= 20); Frigate tuna (n=2); *Mugil* spp (n=2)	Argentine squid (n=4); Mackerel (n=3); Skipjack tuna (n=2)
	Use of lightstick	Yes (n=47); No (n=11)	Yes (n=7); No (n=2)
	Lightstick color	green (n=34); yellow (n=2); blue (n=1)	green (n=5); blue (n=2); white (n=2)
	Min/max water column depth (m)	100 - 5000	170 - 5500
Temporal Distribution	Months of fishery performed	all year (n=17); jan/oct (n=1); feb/jul (n=1); feb/sep (n=1); feb/oct (n=7); mar/aug (n=1); mar/sep (n=3); mar/oct (n=2); mar/nov (n=2); apr/nov (n=3); apr/dec (n=2); may/sep (n=1); may/dec (n=3); jun/sep (n=1); sep (n=1); nov/feb (n=1)	
	Associated fishery	handline (n=12); longline for albacore (n=2); dolphinfish (n=15); bottom longline (n=1)	
	Months of associated fishery	jan/mar (n=1); jan/apr (n=3); jan/may (n=1); feb/oct (n=1); jun/aug (n=1); sep/jan (n=1);oct/jan (n=2); oct/apr (n=1); oct/may (n=1); nov/jan (n=5); nov/feb (n=2); nov/dec (n=1); dec/feb (n=3); dec/mar (n=3)	
Organizations Aspects	Fishermen organization	Sindicates (n=21); Fishing associations (n=15); Fishing colonies (n=2); without link (n=1)	
	Crew size	5 - 15	12 - 22
	Port of origin	São Paulo (n=3); Espírito Santo (n=14); Santa Catarina (n=23); Rio Grande do Norte (n=1); Rio de Janeiro (n=3); Rio Grande do Sul (n=3)	
	Landings ports	São Paulo (n=7); Espírito Santo (n=4); Santa Catarina (n=39); Rio Grande do Norte (n=4); Rio de Janeiro (n=15); Rio Grande do Sul (n=12)	
	Days at sea	8 - 100	12 - 116

being discussed (personal observation). On the other hand, in the United States, an important fishing area around the Hawaiian archipelago was closed for four years because of high bycatch rates of sea turtles, and was later opened with some restrictions, including the use of circular hook 18/0 (Pradhan & Leung, 2006). The use of circular hook 18/0 reduces bycatch of some unwanted species (*e.g.* sea turtles) and extends the post-capture survival also of the target-species (Horodysky & Graves, 2005; Watson *et al.*, 2005; Kerstetter & Graves, 2006; Read, 2007; Sales *et al.*, 2010), therefore improving catch market value (Watson *et al.*, 2005).

The number of hooks used per set varies considerably between national and foreign fleets in the SW Atlantic. However, for the national fleet this variation was greater due to vessels from Itaipava, which often perform more than one set per day (Dallagnolo & Andrade, 2008). In addition, according to the oceanographic conditions (*e.g.* entrance of cold fronts) a fewer number of hooks per set could be used in order to avoid losing the fishing day. For the foreign fleet most of the monitored sets were performed with the total number of hooks, probably because these vessels are larger and remain at sea longer, sometimes operating under rough sea conditions.

The number of hooks between buoys is comparable in both fleets. For the national fleet, five hooks are most common, recorded in 71% of the vessels, while 44% of the foreign fleet used between four and five hooks. According to Rice (2008) there is a direct relationship between the number of hooks between buoys and the fishing strategy being used. When the objective is capturing species no deeper than 150 m, a maximum of seven hooks between buoys is used. With deeper sets (between 150 and 300 m) more than seven hooks between buoys are usually deployed. This strategy was confirmed by Araújo *et al.* (2013) for the Japanese fleet that targeted tunas in northeastern Brazil, with a mean of 18 hooks between buoys. A significant decrease in shark catches was observed when hooks were set below 100 m depth (Rey & Muñoz-Chapuli, 1991; Galeana-Villasenor *et al.*, 2008; Walsh *et al.*, 2009), explaining why the national fleet normally operates between the surface and 100 m depth, as the sharks - mainly blue shark, are fundamental catch components for this fleet.

Other factors that influence fishing strategies are the market price of bait and also the preference of the skipper for capturing certain species, as each bait has distinct attractiveness for each target species (personal observation). It is usual to utilize a combination of different baits in the same set, in order to catch a variety of species (Carruthers *et al.*, 2011). In general, both fleets used the same species of bait; for the national fleet: mackerel (*Scomber colias*) (33%); Argentine squid (*Illex argentinus*) (24%); skipjack tuna (*Katsuwonus pelamis*) (22%); and Brazilian sardine (*Sardinella brasiliensis*) (17%), while the foreign fleet used Argentine squid (44%), mackerel (34%) and skipjack tuna (22%). These data differ from those reported by Kotas *et al.* (2005), who only recorded the use of Argentine squid for vessels operating out of Itajaí port. Squid bait was part of the adaptation of the national fleet in the early 1980s used to capture swordfish (Meneses de Lima *et al.*, 2000).

Regarding the use of light attractors (lightstick), 81% of the national and 78% of foreign vessels used them. Although both fleets used chemical and electronic attractors, the preference of both fleets was for green light chemical attractors (92% for the national fleet and 56% for the foreign fleet). Poisson *et al.* (2010) found a significant influence of the use of green light attractor on the catches of tunas and swordfish for the longline fishery around Reunion Island. According to Fritches *et al.* (2005) this relation is due to visual sensitivity in the blue and green color wavelengths. Hazin *et al.* (2005) also observed higher catches of swordfish using green light attractors in northeastern Brazil. Eleven vessels from the national fleet confirmed that they did not use any device to attract target species, all of them focused on the capture of dolphinfish and/or tunas, operating mostly during day time, which corroborates earlier studies (Bugoni *et al.*, 2008; Dallagnolo & Andrade, 2008; Foster *et al.*, 2015).

Both fleets operated virtually on the same water column stratum (Table 1), being different at the depth of the gear, which is related to the fishing strategy adopted by the vessel's skipper. This partially indicates that for the foreign fleet tunas were not the main target species since they are caught in deeper water, as reported in different studies (Hampton *et al.*, 1998; Bigelow *et al.*, 2006; Kanaiwa *et al.*, 2008; Fiedler *et al.*, 2015).

Regarding the months when the fleets operated, only the national longline fleet changed fishing gear at different times of the year depending on the target species, in contrast the foreign fleet operated year round with specific goals and fishing licenses. The changes in the national fleet are mainly associated with two factors. The first stems from the fact that the Itaipava fleet (a major component of the national fleet) targets dolphinfish during summer months, after which many of these vessels continue operating from Itajaí port, but with other gear meant for other target species: hand line, swordfish longline and bottom longline; The second factor is related to vessels registered in Itajaí port, which performed a new tuna fishery technique developed in the early 2000s called "Associated Schools Fishery" (see Schroeder & Castello, 2007 for more information) when the objective is capturing the bigeye tuna (*Thunnus obesus*), currently expanding and subject of intense debate on its regulation or prohibition.

Considering all 58 national vessels analyzed in this study, 48% landed their catch in Santa Catarina state, 18% in Rio de Janeiro, 15% in Rio Grande do Sul, 9% in São Paulo and 5% in either Rio Grande do Norte (RN) or Espírito Santo. This landing frequency analysis demonstrates that, although there was variation in landing ports, nearly half of the landings were recorded in the two neighboring ports of Santa Catarina, Itajaí and Navegantes. This is possibly explained by an association of many of these vessels with local fish processing industries, something that was observed for the Itaipava fleet when operating in these ports. Landings in other ports may be related to the need to repair vessels during trips, or even to take advantage of better market prices.

Finally, for the number of days at sea, there was considerable variation for both national and foreign fleets, but the few data for the latter do not warrant further discussion. For the national fleet, 39% remained at sea for 15 days on average, 19% for 20 days, 14% remain for 25 days, 14% between 16 and 18 days, 10% less than 15 days, and 4% more than 30 days. The fact that nearly half the fleet reported being at sea for 15 days or less is possibly related to the limitations of the Itaipava fleet, which has smaller vessels and therefore less autonomy, as well as the market forcing/ considerations. By remaining less time fishing, these vessels landed the freshest fish, thus obtaining a greater market value per weight for the same species than larger vessels that stayed more time at sea.

The total length of the vessel was significantly different between the national and foreign fleet (Figure 1a – Student's t-test $p < 0.0001$). This difference was mainly due to the presence of larger leased vessels (between 27 and 50 m) and the fact that there is a large group of smaller national vessels (between 12 and 16 m) that migrates from Itaipava to Itajaí port during the summer months, where they fish primarily for dolphinfish: the Itaipava vessels account for approximately 70% of the landings of this species at this port (Dallagnolo & Andrade, 2008). Larger vessels (45 and 55 m total length) have previously been reported at the port of Itajaí (Andrade, 1998; CEPSUL/ IBAMA, 1994, respectively) however, smaller vessels had not been described before the present study, indicating that the Itaipava fleet did not operate from this port at the time, a conclusion corroborated by Martins *et al.* (2005). According to Guesse *et al.* (2013), there was an increase in the construction of longline vessels in Espírito Santo from 2001, and currently more than 50% of these vessels have total lengths over 10 m. For the foreign fleet, data from this study corroborate the findings of Araújo *et al.* (2013), who reported that the Japanese fleet operating in northeast Brazil had vessel lengths varying between 49 and 52 m.

Likewise, engine performance data also showed significant differences (Mann-Whitney test $p < 0.0001$) between the national and foreign fleets, which has more powerful engines (Figure 1b). This difference is mainly related to higher total lengths of the foreign vessels, which have a greater autonomy of days at sea and use refrigerated chambers rather than ice (which is used by the national fleet); hence, the foreign vessels require greater engine power for preservation of the catch. These results differ from those found by Araújo *et al.* (2013), where engine power of the Japanese fleet fishing off NE Brazil was reported to vary between 1000 and 1200 hp. In addition, the mean hp of the national fleet must take into account the effect of the large proportion of smaller vessels from the Itaipava fleet, where mean engine power is just 198 hp, consistent with data presented by Dallagnolo & Andrade (2008), but higher than that reported by Martins *et al.* (2005) and Zanchenta (2009), where the mean engine power was given as 100 hp and 150 hp, respectively.

Data on the fish hold capacity (Figure 1c) also showed a significant difference between the national and foreign fleets (Mann-Whitney test $p < 0.0001$). National vessels, in general, have smaller fish hold capacities, and just the Itaipava fleet had even lower capacity (mean = 13 t). Foreign vessels have larger fish holds, with holds of some vessels more than 120 t. Nonetheless, these values are well below those recorded by Araújo *et al.* (2013), who found fish hold capacities over 200 t for the foreign fleet.

A significant difference was found between both the minimum (Student's t-test $p = 0.001$) and maximum (Mann-Whitney test $p < 0.0001$) mainline total lengths used by the two fleets (Figure 1d). This difference is highly influenced by the fishing strategies of Itaipava fleet, operating with smaller longlines, and setting them close to the sea surface as well as using fewer hooks per set, as deployments are often done twice a day (Dallagnolo & Andrade, 2008), and/or the Itaipava vessels often inspect the lines before hauling (Fiedler *et al.*, 2015), a conclusion corroborated earlier by Bugoni *et al.* (2008). On the other hand, the largest minimum and maximum lengths for the foreign fleet were influenced by the values from two vessels of Chinese origin, whose main target was tunas, which they fished at depths greater than other vessels, both national and foreign, whose capture strategies were directed at swordfish and blue shark. This matches the findings of Bigelow *et al.* (2006) on the Hawaiian longline fleet, where a clear difference between both set depths and number of hooks was found when vessels targeted either swordfish or albacores. With the Japanese fleet off NE Brazil, Araújo *et al.* (2013) found a maximum total length for the mainline of 81 nm, almost the double observed in this work.

The branchline (Figure 1e) also presented a significant difference (Student's t-test $p < 0.05$) between the national and foreign fleet. For both fleets there was large variation between the minimum and maximum lengths, which is related to the different fishing strategies adopted. For 17 national pelagic longline vessels operating in the Brazilian northeast capturing swordfish and tunas, Afonso *et al.* (2012) recorded a branchline length of approximately 32 m. Minimum lengths of 50 m and maximum of 60 m were recorded by Araújo *et al.* (2013) for the foreign fleet. These data differ from those of Bach *et al.* (2009),

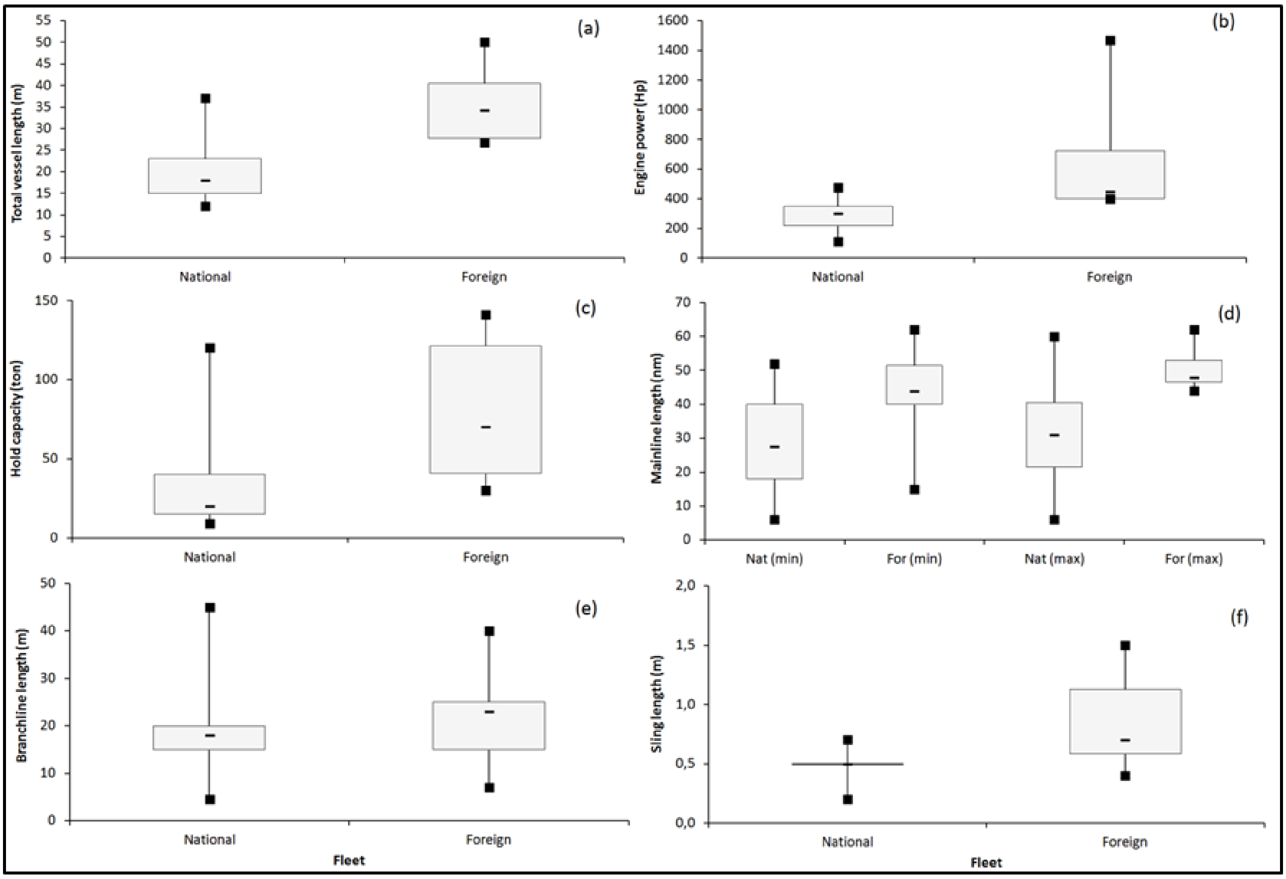

Figure 1. Comparison between some characteristics of national and foreign pelagic longline fleet (2003 to 2014) **(a)** Total vessel length distribution; **(b)** Engine power distribution. **(c)** Fish hold capacity distribution; **(d)** Minimum (min) and maximum (max) size of the mainline distributions; **(e)** Branchline (in meters) used for both fleets; **(f)** Steel wire sling (in meters) used for both fleets. Box and whiskers' plots represent the 25th percentile, the median and the 75th percentile and the error bars indicate the minimum and maximum values.

who monitored the tuna fishery (*Thunnus albacares* and especially *T. obesus*) in French Polynesia, and recorded branchline length of 12 m. In conclusion these studies show that although target species may be the same, fishing strategies used in different areas can be completely distinct.

Finally, there was significant difference in steel wire length between national and foreign fleets (Mann-Whitney test $p < 0.005$) (Figure 1f). The mean length for the foreign fleet was of 0.82 m, and the maximum length refers to a Spanish vessel that worked in the region during 2006, but there was no explanation why the skipper used such a long steel wire length, since sharks were not the main target species. Yokota *et al.* (2006) reported 2.5 m long steel wires in two vessels that targeted blue sharks in Japanese waters. According to Marín *et al.* (1998), the use of the steel wire can increase the capture of sharks. Data presented in the present study differ from those obtained by Araújo *et al.* (2013) who did not report the use of steel wire in a fishery that targeted tunas. However, the present study coincides with Afonso *et al.* (2012), who recorded steel wire with a mean length of 0.20 m in vessels that targeted swordfish and tunas. A study conducted in Australia reinforced the importance of the prohibition of the steel wire to reduce the catch of sharks and billfish (Ward *et al.*, 2008). This same study reported an increase in the captures of *T. obesus*, probably because nylon wire is almost invisible, in contrast to the steel wire. Therefore, the use of a steel wire depends on the capture strategy adopted for each vessel. As for the length of the steel wire, there seems to be a consensus that 0.50 m is sufficient to prevent the escape of hooked sharks, critical to the earnings of the vessel, especially considering much higher values obtained from fins (Mazzoleni & Schwingel, 1999; Quaggio *et al.*, 2008).

Correlation analysis

Different pelagic longline studies around the world have considered the physical characteristics of the vessels in an effort to standardize catches. However, this basic information has not always been given due importance, missing the opportunity to streng the fisheries management strategies (Batista, 2003), for low quality information is insufficient to account for differences in fisheries yields (Hilborn & Ledbetter, 1985). Historically, studies correlating/investigating the relationship between environmental variables and fishery yields have been performed (Podesta *et al.*, 1993; Rijnsdorp *et al.*, 2000; Murray & Griggs, 2003; Lan *et al.*, 2014), but other variables – such as the gear and vessels - also need to be evaluated.

A moderate positive correlation between engine power and total length of the vessel was found for the national fleet (Figure 2a). For the foreign fleet a strong positive correlation was found (Figure 2b). This indicates that the larger the vessel, the greater the engine power. In the present study, an exception occurred with two vessels of the national fleet based at Itaipava port with 14 and 15 m long used powerful engines (366 hp); and the largest vessel (17 m) used a less powerful engine with 120 hp. The largest vessel of the foreign fleet (50 m) had the most powerful engine (1468 hp), which is well above that the largest hp recorded by Araújo *et al.* (2013) for the Japanese fleet (1000-1200 hp). A study of the longline fleet at Vietnam (Long, 2003) concluded that an increase in engine power did not directly relate to an increase in catches. Hence, an increase in engine power not necessary will improve fishing yields but would likely lead to higher operating costs. In Canada, the length of vessels remained stable over time because of fishing regulations, while engine power, not regulated by legislation, continued to increase (Neis *et al.*, 1999). Schwingel & Occhialini (2003) found a higher rate of increase of engine power than vessel length during characterization of the purse-seine fleet at Itajaí port between 1997 and 1999. According to Le Pape & Vigneau (2001), because there is generally a direct relationship between these two variables, engine power could be used as indicator of vessel size, and could also serve as a parameter to be used for regulating fishing effort.

The positive correlation between hold capacity and vessel length was strong for the national fleet (Figure 2c). For the foreign fleet there was a moderate positive correlation (Figure 2d). However, all of these foreign vessels had refrigerated chambers. It is likely that national vessels require larger fish holds because all of them use ice flakes for fish preservation/storage. The quantity of ice required depends on the target species, but in general it takes 1 kg of ice to 2 kg of fish (Oliveira, 2009). Andrade (1998) states that the use of inadequate proportions of ice is one a critical factor that determines the quality of fish landed. In the present study, there were special cases involving the hold: in four national vessels, three from Itajaí, used a combination of ice and freezing, and one registered in the port of Natal/RN, but operating out of the port of Itajaí, used Freon gas to refrigerate. According to Beverly (1996), Pacific longline vessels commonly use this gas to cool the sea water to preserve the fish. In Brazil, Evangelista *et al.* (1998) and Araújo *et al.* (2013) reported foreign longline vessels operating in northeastern Brazil that use Freon gas for conservation. For the three vessels of Itajaí, fish with higher market values (*i.e.* tunas and swordfish) were put in the refrigerated chamber, which maintains the natural organoleptic properties of the meat and thus improves their selling price abroad (Araújo *et al.*, 2013); while fish with lower value (*e.g.* blue shark or oilfish), that are primarily intended for the domestic market (Kotas *et al.*, 2005), are kept on ice flake, corroborating studies of Swenarton & Beverly (2004) and Foster *et al.* (2015).

Finally, the analysis between engine power and fish hold capacity presented a moderate positive correlation, for both the national and foreign fleets (Figure 2e and 2f). As described above, foreign vessels have more powerful engines due to the increased vessel length and also freezers for fish conservation. National vessels, in general, do not have onboard freezers, which requires that they provide large holds to accommodate large amounts of ice, thereby increasing weight and fuel consumption and thus the costs of travel (Oliveira, 2009). Le Pape & Vigneau (2001) found a direct relationship between engine power and tonnage, concluding that either variable can be

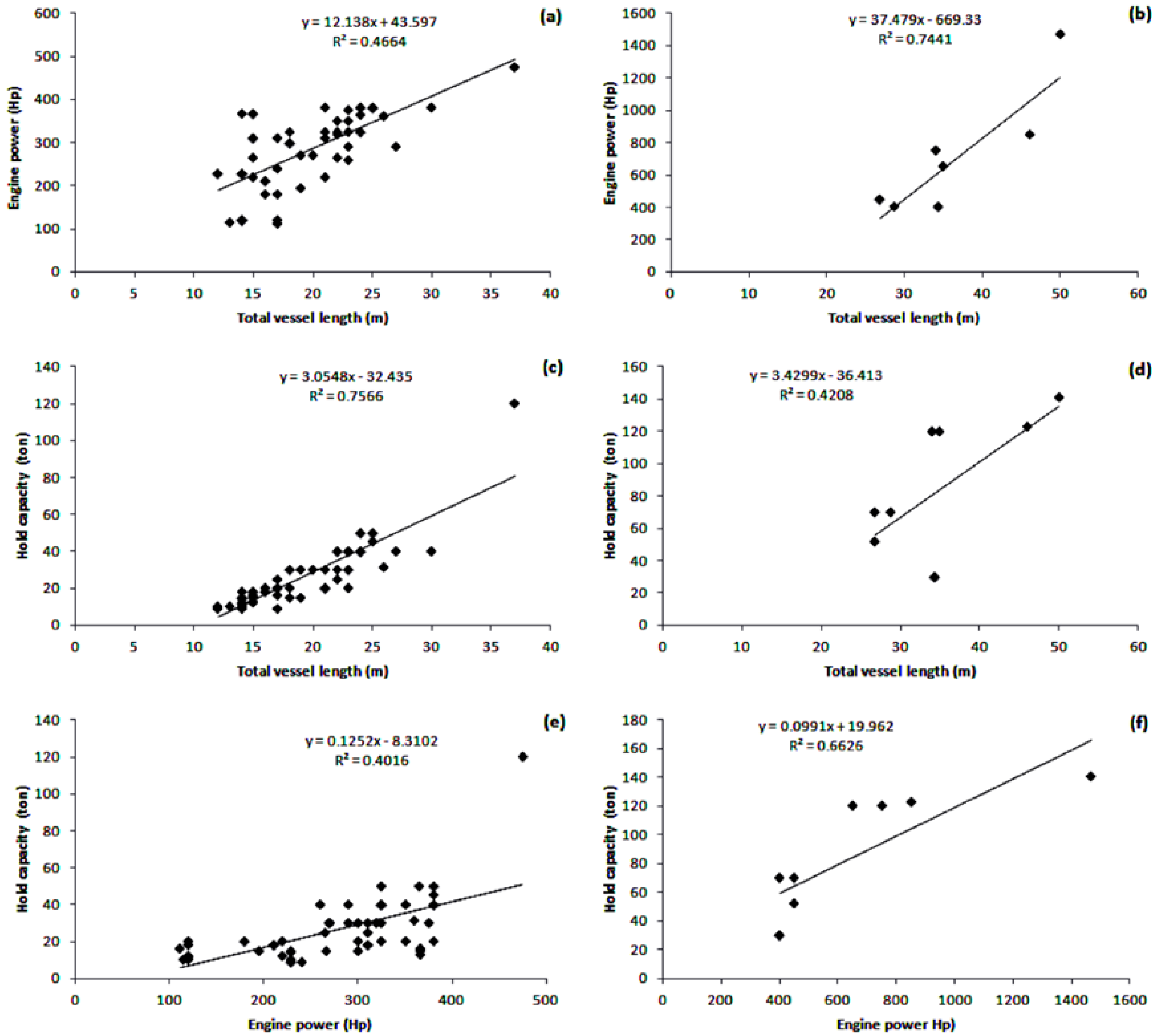

Figure 2. Correlations between national and foreign pelagic longline fleets (2003 to 2014). **(a)** National vessel's length (m) and engine power (hp); **(b)** Foreign vessel's length (m) and engine power (hp); **(c)** National vessel's length (m) and fish hold capacity (ton); **(d)** Foreign vessel's length (m) and fish hold capacity (ton); **(e)** National engine power (hp) and fish hold capacity (ton); **(f)** Foreign engine power (hp) and fish hold capacity (ton).

used for management measures of fishing effort. In addition, Casarini (2011) commented that Gross Tonnage (GT) is the most appropriate measure when employing a single operational standard for fishing vessels.

Conclusions

There are significant differences in both technological and operational aspects between vessels from the national and foreign pelagic longline fleets that have been based in Itajaí. Vessels of the foreign fleet have greater lengths and engine power, because they are from countries where pelagic fishing activities are highly developed, and greater distances need to be traveled and greater at sea autonomy is required. Moreover, all these foreign vessels have freezers for catch conservation, because this allows for greater quality of the landed catch, and consequently a higher market value, especially considering requirements of the European Union where much fish is exported. The mainline is longer for the foreign fleet, possibly because it is associated with operations in deeper water. The use of steel wire leaders by the national fleet is a strategy adopted to increase shark catches, as fin trade in the international market is highly profitable and assists in the net income of both ship owners and crews. In the foreign fleet, despite the declared target species being tunas, it is likely that they use steel wire to increase shark catches when operating in southeastern/southern Brazil.

Despite many technological advantages, the strategies adopted by skippers are also critical for obtaining good catches and landings. Many authors have reported that knowledge of such things as biological aspects of the target species (*i.e.* behavior, seasonality), and the ability of skipper to adapt fishing gear/ strategy to find good fishing grounds is often more important technological improvements.

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