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Research Article

The dynamics of whitemouth croaker fishing by gillnet and pair trawl in Southeastern Brazilian Bight

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ABSTRACT. The whitemouth croaker is considered the main demersal resource landed in southeastern and southern Brazil, caught mainly by gillnets and pair trawls. This study evaluated the directed fishing effort at whitemouth croaker in different fishing modalities (or 'metiers'). We also investigated the bathymetric range and seasonal variations related to capture of whitemouth croaker in each modality. In the different types of gillnet, the whitemouth croaker was considered an incidental species or "by catch", a target species and a 'massive' target. For pair trawlers, the species was considered a target species. Catches occurred mainly in depths ranging between 10-20 m. However, in winter the largest catches occurred in 75 m depths. Catches of the gillnet fisheries peaked mainly between May and July. Pair trawl catches had two annual peaks one between March and May and another between August and November. This seasonal variation is probably related to the migration pattern of the species in association with physical and operational characteristics of vessels.

Keywords: *Micropogonias furnieri*, whitemouth croaker, directed effort, time series, southwest Atlantic Ocean.

La dinámica de pesca de la corvina con redes de enmalle y de arrastre en pareja en Southeastern Brazilian Bight

RESUMEN. La corvina es el principal recurso demersal desembarcado en el sureste y sur de Brasil, capturada principalmente por redes de enmalle y redes de arrastre en pareja. Este estudio evaluó el esfuerzo pesquero dirigido a la corvina en diferentes modalidades de pesca (o 'metiers'). También se analizó la distribución batimétrica y variaciones estacionales relacionadas con la captura de corvina en cada modalidad. En los diferentes tipos de redes de enmalle, la corvina se considerada como incidental, como especie de by-catch, especie objetivo y como objetivo 'masivo'. Para los arrastreros en pareja, la especie fue considerada una especie objetivo. Las capturas se produjeron principalmente en profundidades de 10 a 20 m. Sin embargo, en invierno las mayores capturas se obtuvieron a 75 m. Las capturas de las pesquerías con redes de enmalle alcanzaron su punto máximo, principalmente entre mayo y julio. Las capturas de arrastre en pareja tuvieron dos máximos anuales: entre marzo y mayo y otro entre agosto y noviembre. Esta variación estacional está probablemente relacionada con el patrón de migración de las especies en asociación con las características físicas y operativas de los buques.

Palabras clave: *Micropogonias furnieri*, corvina, esfuerzo dirigido, series temporales, Océano Atlántico suroccidental.

INTRODUCTION

The whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823) is a species of wide geographical distribution, occurring from the Yucatan Peninsula, along the West Indies, on the southern coast of the Caribbean to the Gulf of San Matias, Argentina

(Menezes & Figueiredo, 1980). Along the Brazilian coast, the species is most abundant in the Southeastern Brazilian Bight where is considered the most important demersal resource (Valentini *et al.*, 1991; Carneiro *et al.*, 2005; Vasconcellos & Haimovici, 2006). In these regions, the species comprises two distinct populations. One between 23° and 29°S (stock southeast) and the

other between 29° and 33°S (stock south) (Vazzoler, 1971, 1991; Isaac, 1988; Vazzoler *et al.*, 1999). Considering the southeast stock alone, São Paulo State accounts for roughly 50% of total annual landings (Carneiro *et al.*, 2005).

The southeast stock forms aggregates between the open sea and the coast not performing seasonal migrations. Individuals spawn multiple times during a spawning season and reproduction occurs throughout the year in continental shelf areas adjacent to estuaries and coastal lagoons (Vazzoler, 1991; Vazzoler *et al.*, 1999).

The whitemouth croaker is a relatively large-sized (maximum size 678 mm) with high longevity (estimated at 24 years for the southeastern stock) and slow growth (Carneiro *et al.*, 2005). The species is adapted to wide variations in temperature and salinity, and is most commonly found in coastal regions shallower than 50 m depths, although, catches may occur down to the 100 m isobath (Vazzoler *et al.*, 1999; Menezes & Figueiredo, 1980). These conditions favor its adaptation to tropical and sub-tropical environments, ensuring successful reproduction events and consequently sustaining elevated catches in the region (Carneiro *et al.*, 2005).

The whitemouth croaker is captured mainly by pair trawling and gillnets (Valentini & Pezzuto, 2006), comprising in both cases the bulk of the landed biomass. Early records of catches landed in São Paulo State showed that the whitemouth croaker was already the third in the list of most captured fish categories (Vieira *et al.*, 1945). In 2010 and 2011 the species ranked second and third in landings at São Paulo State, only behind the Brazilian sardine (*Sardinella brasiliensis*) and the seabob shrimp (*Xiphopenaeus kroyeri*) (Ávila-da-Silva *et al.*, 2011, 2012). The species is also reported by fishermen in a category defined as 'mixture', which includes small individuals of species of commercial value and species of low commercial value.

Corrêa (2013) studied the catch composition of gillnet fishing in São Paulo and identified eight *métiers* (*i.e.*, groups of trips with own capture features and factors involved in fishery) three of which had whitemouth croaker as a relevant target species. Sustainability of their catches, however, has been uncertain because the south stock has been considered overexploited and the adoption of restrictions on fishing areas and seasons has been proposed to restore it to a biologically safe condition (Rossi-Wongtschowski *et al.*, 2009). The effective implementation of these and other management measures, however, is complex because multiple fisheries exploit the stock directly and indirectly in the southeastern Brazilian Bight, each of

them with potentially different levels of impact on the stock's structure and productivity.

In this context, this study aims to evaluate catch characteristics and trends of this species in different fishing *métiers* within two main fisheries, pair trawl and gillnet. Aspects of directed effort, seasonality, and depth of capture per *métier* were considered. Each *métier* represents a set of fishing tactics including fishing gear, operating standards and fishing area, and the resulting catch composition. The approach, based on typologies of fishing operations involves multivariate descriptive methods and classification techniques (Pelletier & Ferraris, 2000; Ulrich & Andersen, 2004).

MATERIALS AND METHODS

Pair trawl and gillnet fishing fleets operated along the distribution area of the whitemouth croaker southeastern and southern stock between latitudes 23° and 26°S (Fig. 1). Catch data were obtained from fishermen interviews, at 216 landing places, between 2008 and 2011 by the Fishery Monitoring Program of the São Paulo State Fisheries Institute. This program adopts the census method (FAO, 1999) to obtain fishing information through the application of structured interviews (Bunce *et al.*, 2000), answered in a voluntary manner by fishermen and skippers, at the moment of catch landing. Records of each fishing trip include information on species caught (common name and kg), fishing area and depth, type of fishing gear and fishing effort.

We used data from 23,450 gillnet fishing trips and 701 of pair trawling with reported catches of whitemouth croaker. Gillnet fishing trips were conducted by 512 vessels and pair trawl trips by 23 vessels. The pair trawl fleet comprises industrial vessels mostly 19 to 22 m-long and between 50 and 90 GT, with a great fishing power. As a general pattern, their trips last about 10 days and each day includes four tows of 4 h duration. Pair trawl nets have a horizontal mouth opening that can reach 55 m and a vertical opening of 6 m (Castro & Tutui, 2007). A minimum mesh size of 90 mm (stretched mesh) is allowed in the tunnel and cod-end (IBAMA, 1989).

The gillnet fleet is very diverse and mainly artisanal. Length of fishing boats usually range between 7 and 12 m and GT between 3 and 10, but a few larger (up to 24 m-long) boats can also be found. Sciaenid fish are caught with monofilament gillnet netting with different mesh sizes, usually ranging between 70 to 160 mm (stretched mesh). Multi-mesh gillnets are quite common. Specifically for whitemouth croaker mesh sizes from 70 to 130 mm are used (Queirolo *et al.*, 2016). These gillnets are typically 1.5-6 m high and 700-3,000 m long.

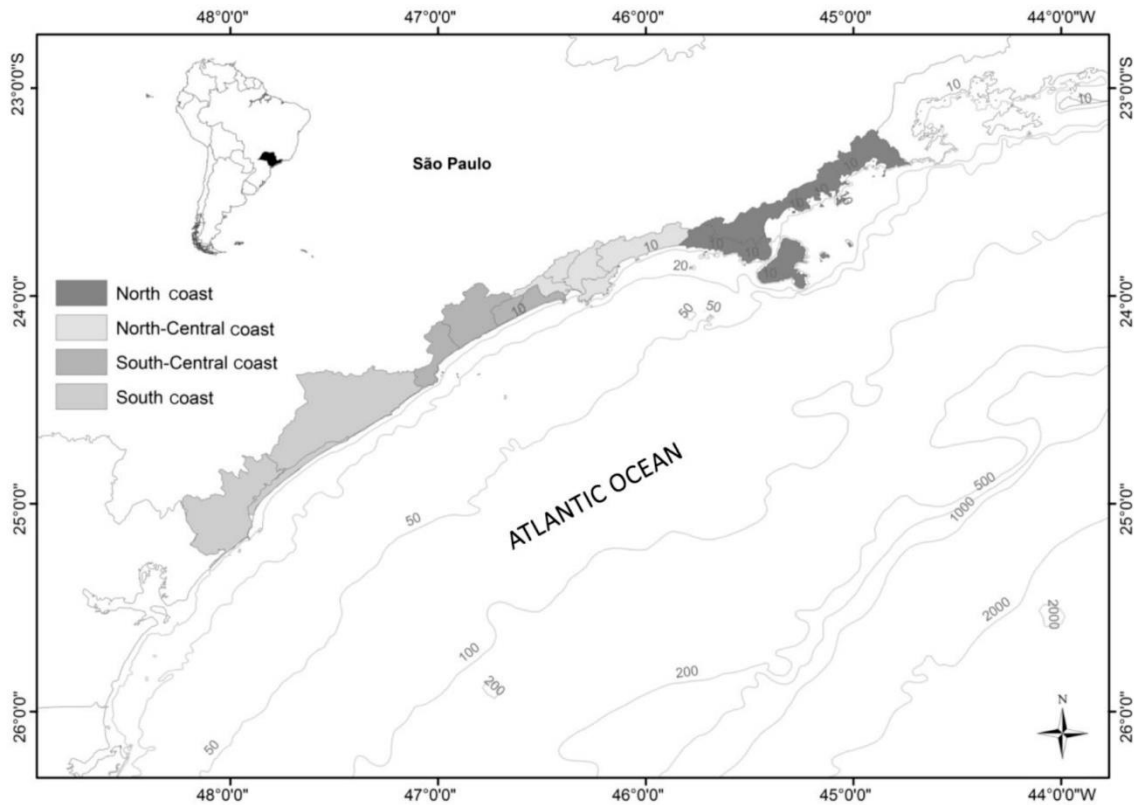


Figure 1. Map of the study area, highlighting the north, center and south coasts of São Paulo State.

Gillnet fishing trips were divided into *métiers*: Croaker (8,038 trips), Mixed fishes (9,508) and Weakfish (5,904), according to Corrêa (2013). The *métier* Croaker had whitemouth croaker as the main species caught, mainly during the second and third quarters (autumn and winter), and along the entire coast of São Paulo State. These operations use multi-mesh gillnets with mesh sizes from 100 to 180 mm.

Mixed fishes *métier* also had whitemouth croaker as the main catch component but other species such as leatherjacket (*Oligoplites* spp.), kingcroaker (*Menticirrhus americanus*) and Jamaica weakfish (*Cynoscion jamaicensis*) played an important role in the composition of the landings. Mesh sizes from 60 to 200 mm were used during these trips which were more frequent in the northern coast of São Paulo. The *métier* Weakfish had the southern king weakfish (*Macrodon atricauda*) as the main target but kingcroaker, whitemouth croaker and shorthead drum (*Larimus breviceps*) were also frequent in the landings. The trips classified in this *métier* covered the central and southern coast of São Paulo and used typically gillnets with mesh sizes of 60, 70, 80 and 90 mm (Corrêa, 2013).

In this study we considered as fishing modalities the gillnet *métiers* Croaker, Mixed fishes and Weakfish, and the Pair trawl.

We applied the Biseau method (1998) to identify the degree of fishing effort directed to whitemouth croaker in each fishing modality. The degree of directed effort is determined from an analysis of the composition of landings of each fishing trip, categorized as to whether it targets a given species or not (Biseau, 1998).

We determined the bathymetric operation range of each modality from information on maximum depth of operation reported per trip. To identify operational patterns of the fleets we considered the first, second and third quartiles of depth per month, as well as non-outlier minimum and maximum. This calculation was based on a boxplot diagram (Chambers *et al.*, 1983).

To assess seasonality of whitemouth croaker capture per fishing modality, we standardized the monthly catches by mean values and standard deviations (Borcard *et al.*, 2011). This standardization method was applied to reduce the effect of the difference in magnitude of catch values between fleets by scaling catch data to zero mean and unit variance. Despite some punctual events, based on available data

and field observations, we assumed that there were no relevant variations of fishing effort and catchability within each modality during period analyzed.

An autocorrelation analysis was used to determine the existence of seasonal or cyclical patterns in the different modalities. This analysis measures the association between a particular series and itself at the initial time (t_0) and at different time lags ($t+k$). The cross-correlation analysis was used to measure the association between different time series. The analysis verifies the degree of linear association between two series with time lag. Autocorrelation and cross-correlation were measured through the Pearson correlation coefficient (r) calculated to quantify the association between variables (Zuur *et al.*, 2007). We conducted statistical analyses with the software R (R Core Team, 2013).

RESULTS

The Biseau method showed the relative importance of whitemouth croaker for the different modalities. In *métier* Weakfish, 50% of the total catches was obtained from travels in which whitemouth croaker did not represent more than 20% of total captures. For *métier* Mixed fishes and Pair trawl, 50% of the total catches refers to trips in which whitemouth croaker comprised 30-35% of the catches. In *métier* Croaker, 50% of the total landed was obtained from trips in which the whitemouth croaker represented at least 90% of the total. From this graph analysis (Fig. 2), whitemouth croaker in *métier* Weakfish was considered a by-catch species. In *métiers* Mixed fishes and Pair trawl the species was a target and in *métier* Croaker, it was a “massive target” (*sensu* Biseau, 1998). As a result, *métiers* Croaker and Pair trawl presented the highest values of capture (>50 ton) (Fig. 3).

Gillnet fishing trips of *métiers* Weakfish and Mixed fishes occurred throughout the year within the depth range of 10-20 m. The trips of *métier* Croaker occurred mainly between 10-25 m isobaths except from April to August when these trips occurred in areas down to 75 m deep. Throughout the year, the trips carried out by pair trawlers occurred between 25-35 m depth; however, between May and July, these trips reached 75 m deep.

The analysis of standardized time series showed a seasonal trend and variation over the years (Fig. 4). The *métiers* that represented gillnet fisheries had their peaks of whitemouth croaker capture mainly between May and July, while catches of the species with pair trawl had two annual peaks between March and May and between August and November.

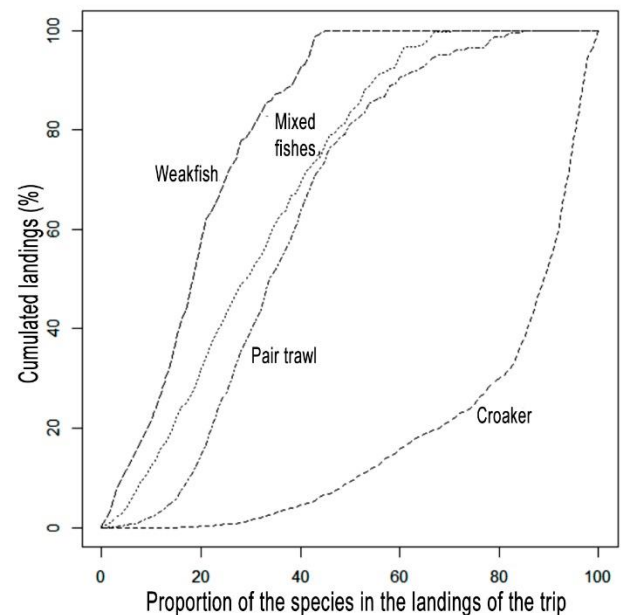


Figure 2. Directed effort analysis of Gillnet *métiers* Croaker, Weakfish and Mixed fishes and Pair trawl by the Biseau method (1998).

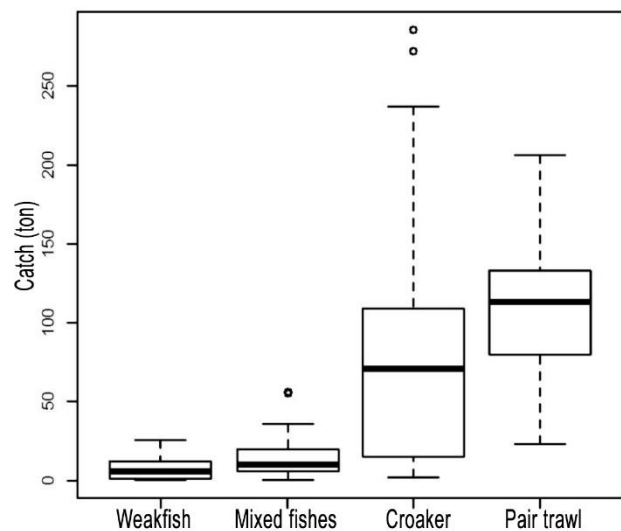


Figure 3. Boxplot of monthly whitemouth croaker catches (ton) of gillnet in *métiers* Weakfish, Mixed fishes, Croaker and in *métier* Pair trawl between 2008 and 2011.

The *métier* Mixed fishes had the lowest values of catches in 2008 and 2010 and the highest ones in 2009 and 2011, with a strong upward trend in later years. Seasonal component of catches showed two capture peaks, one in July and another in September (Fig. 5) and its autocorrelation showed a negative correlation of capture in a one-year lag (Fig. 6).

The capture of Whitemouth croaker in *métier* Weakfish remained stable during the four years studied, except in 2009, when there was a drop in capture of the

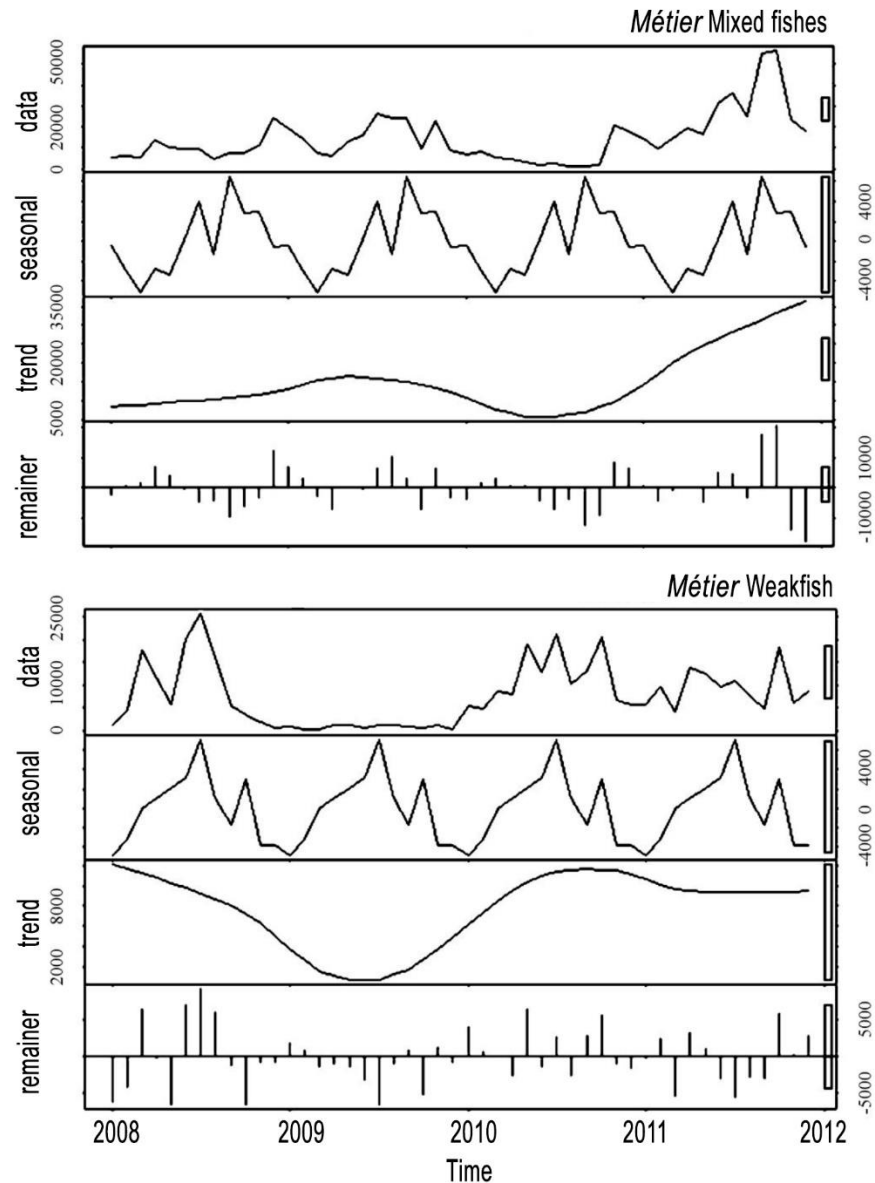


Figure 4. Decomposition of whitemouth croaker catch time series by gillnet fishing in *métiers* Mixed fishes and Weakfish.

species. The seasonal component showed two capture peaks, one in July and one in October and the autocorrelation indicated weak negative correlation after one year and four months.

Métier Croaker had the largest catches in 2008 and 2010 and a downward trend that became more pronounced in 2011. The seasonal component showed a capture peak in July with a drop until February, when values resumed increasing. Time lag showed a strong annual cycle with negative correlation after six and eighteen months and positive correlation after one and two years.

Data on capture of pair trawlers remained nearly constant over the four years studied but with a decreasing tendency that turned more visible after 2011. The annual cycle presented two capture peaks, a smaller peak between March and May and a larger peak in October. The autocorrelation function showed a negative correlation after three and nine months and the correlation became positive after one year.

The cross-correlation analysis showed a strong association between the series of *métiers* Croaker and Weakfish (0.64). No other series had correlation greater than 0.22 (Table 1).

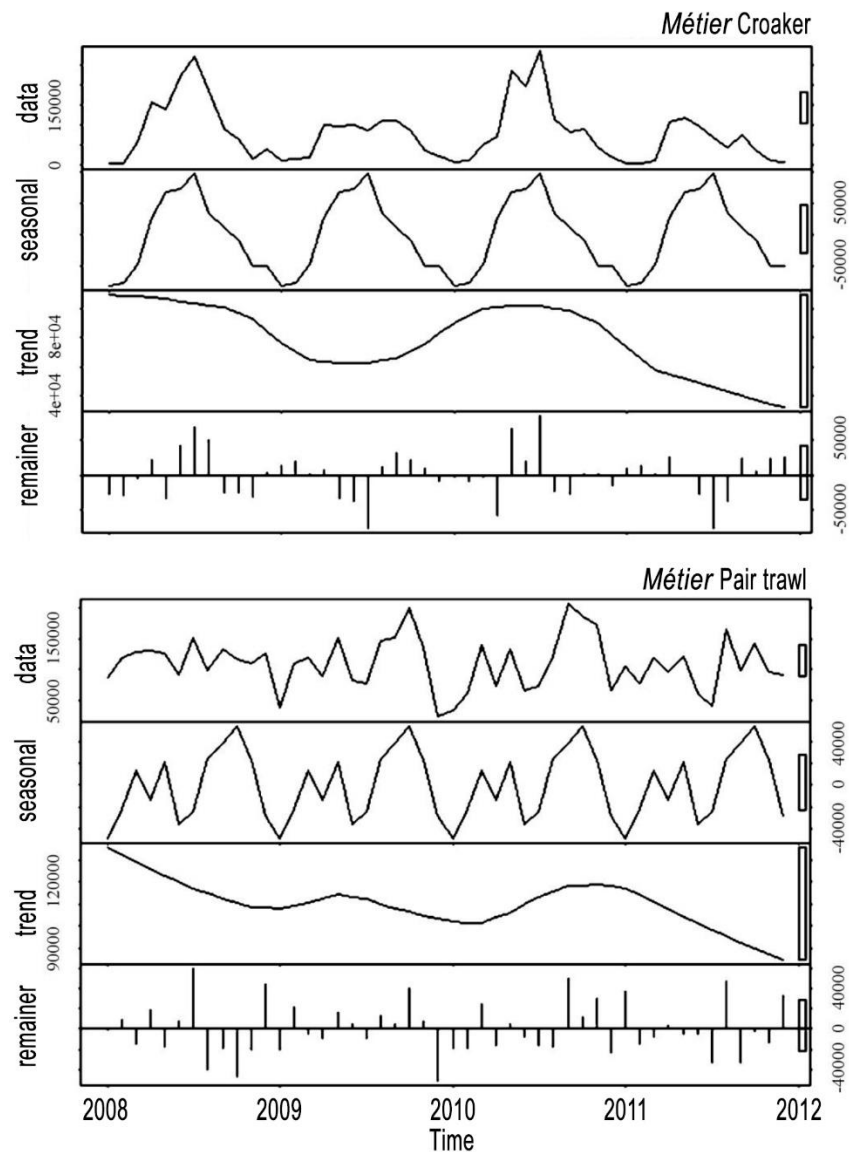


Figure 5. Decomposition of whitemouth croaker catch time series by gillnet fishing in *métiers* Croaker and Pair trawl.

DISCUSSION

The directed effort analyses for whitemouth croaker, in the various gillnet *métiers* and pair trawl showed the relative importance of the species for each of these fisheries. Whitemouth croaker was considered a by-catch species in *métier* Weakfish, whose main species caught was the *Macrodon atricauda*, followed by category “mixture” and *Menticirrhus americanus* (Corrêa, 2013). In *métiers* Mixed fishes and Pair trawl, whitemouth croaker was considered an intermediary (by-catch/target) and a target species, respectively. Despite the similarity in directed effort for species in these two fishing modalities, the magnitude of the catch per trip is distinct since pair trawl is an industrial fleet with great fishing power (Valentini & Pezzuto, 2006)

and *métier* Mixed fishes refers to a typically more coastal artisanal gillnet fishing (Corrêa, 2013). Another important factor is the selectivity of the two modalities, according to Souza *et al.* (2007), capture of whitemouth croaker by pair trawl is less selective when compared to catches with gillnets. Mortality impinged by gillnets is usually concentrated within a relatively narrow range of sizes (Queirolo *et al.*, 2016). In *métier* Croaker, the species was considered a massive target, which means that in the trips of this group a fishing tactic aimed specifically at whitemouth croaker was applied and the participation of this species in the landings becomes are much higher than the other species. In this group, whitemouth croaker contributed to 91.4% of the total catch (Corrêa, 2013).

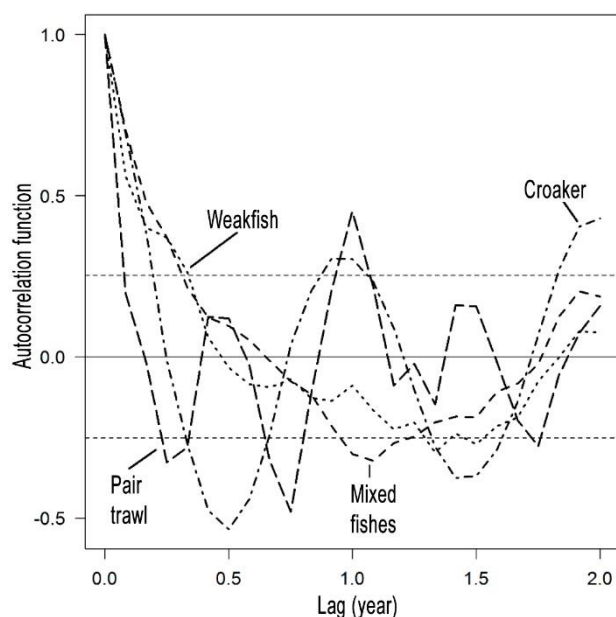


Figure 6. Autocorrelation of *métiers* representing gillnet fisheries of croaker, Mixed fishes and weakfish and the pair trawl fisheries.

Catches of *métiers* Weakfish, croaker and pair trawl, displayed a trend of stability or reduction (Fig. 4). However, it contrasted with *métier* Mixed fishes where there was an increasing catch trend. The increase in capture of whitemouth croaker in this *métier* was probably due to catches of other vessels that do not have license to capture this species, most likely purse seiners. Ordinance No. 43 of IBAMA September 24, 2007 (IBAMA, 2007), prohibits capture of whitemouth croaker by purse seiners, nevertheless, it is possible that they have continued to capture the species, transferring it to gillnetters. This practice seemed to be common on the northern coast of São Paulo State, the region with most fishing trips that characterized this *métier* (Corrêa, 2013). The impact of this illegal activity on this fish stock can be significant, since among the fishing gears for capture of the species, purse seiners and pair trawlers are the least selective (Souza, 2007).

We identified two sudden drops in catches of whitemouth croaker. One in 2009 for *métier* Weakfish and another in 2010 for Mixed fishes. The reduction in these *métiers* may be related to the migration of fishermen to other *métiers*. Studies conducted by Mendonça & Miranda (2008) and Alves *et al.* (2009) showed that fishermen alternate their catches and consequently the related variables according to the economic interest.

Gillnetters operated mainly within the 10–20 m depth range, while pair trawlers operated around the 30 m isobath. In winter, the pair trawl and medium-scale gillnet fleets, represented by *métier* Croaker (Corrêa,

Table 1. Cross-correlation between *métiers* Mixed fishes, Weakfish, Croaker and Pair trawl.

	Mixed fishes	Weakfish	Croaker	Pair trawl
Mixed fishes	1.00	-0.13	-0.22	-0.05
Weakfish	-0.13	1.00	0.64	0.14
Croaker	-0.22	0.64	1.00	0.14
Pair trawl	-0.05	0.14	0.14	1.00

2013), and performed operations in greater depths. This movement of fleets can be associated with the dynamics of water masses and reproductive characteristics of the species. Juvenile individuals remain near lagoons and estuarine areas, which are adequate environments for feeding and growth of the species (Vazzoler, 1975; Menezes & Figueiredo, 1980). Adults are distributed in the continental shelf, moving seaward to spawn (Vazzoler, 1991; Vazzoler *et al.*, 1999).

Trips in coastal areas observed in *métiers* Weakfish, Mixed fishes, and Croaker recorded catches of whitemouth croaker throughout the year. This continuous capture of the species is attributed to its long reproductive period (Vazzoler *et al.*, 1999).

In summer, oceanographic processes such as wind-driven upwelling provide an important nutrient supply to the nutrient-poor waters of the continental shelf, promoting concentration of fish species and increased fishery productivity (Silveira *et al.*, 2000; Castro *et al.*, 2006). During this period, winds blow mostly east northeastward, favoring the resurgence of nutrient-rich of South Atlantic Central Water (SACW) on the Southeastern Brazilian Bight (Castro *et al.*, 2006). Another process that contributes to SACW penetration is the meandering of Brazil's current, described by Campos *et al.* (1995). In winter, winds are unfavorable to this process and SACW retracts to the external area of the continental shelf (Castro *et al.*, 2006). At this time, adult fish take advantage of the temperature increase to move away from the coastal region to spawn. Thus, vessels with greater autonomy may direct their effort to these areas.

This fleet dynamics was observed between April and August in *métier* Croaker. Some fishing vessels use their greater autonomy to operate in greater depths, between 50 and 75 m, aiming at whitemouth croaker spawning concentrations, which are more pronounced in August and less intense in December (Carneiro *et al.*, 2005). Pair trawl also operated in this depth range, however, between May and July.

CONCLUSIONS

The different fishing modalities that regularly exploit the whitemouth croaker operated in distinct bathy-

metric ranges, but with some overlap. These modalities direct their fishing effort differently and gillnetting is the main method of whitemouth croaker exploitation off São Paulo State. Seasonality of whitemouth croaker captures followed two patterns; gillnet fisheries had their peaks of capture mainly between May and July, while pair trawl catches had two annual peaks between March and May and another between August and November. This seasonal variation is possibly related to the migration pattern of the species, in association with the physical and operational characteristics of fishing vessels.

This study contributes to the understanding of catch dynamics of the whitemouth croaker by gillnet and pair trawl fisheries. Despite the importance of the species for such fishing operations, these remain essentially multi-specific and therefore evaluating the capture of species within *métiers*, may prove a more comprehensive approach. When required, the management of multi-specific fisheries should incorporate the typology of specific *métiers* in order to regulate the mortality of one or a group of species.

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