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Research Article

Effects of marine protected areas on fisheries: the case of São Paulo State, Brazil

Fernanda A. Rolim[1]& Antônio O. Ávila-da-Silva[2]
[1]São Paulo State University - UNESP, Biosciences Institute of Rio Claro, SP, Brazil
[2]Instituto de Pesca, Centro APTA do Pescado Marinho, Santos, São Paulo, Brazil
Corresponding author: Antônio O. Ávila-da-Silva (aolinto@pesca.sp.gov.br)

ABSTRACT. In 2008, the government of the São Paulo State, Brazil, established marine protected areas (MPAs) along its entire coast. Pair trawling was banned from most of these areas ever since. This study investigated how these MPAs influenced on pair trawling fleet's operational patterns and landings from 2005 to 2012 as well as on the other fleets dynamics. Landings of pair trawlers per unit effort remained stable, however, they had to look for farther fishing grounds and capture deeper and less profitable species, changing their landing composition and reducing income. Gillnet fleet, particularly, has intensified fishing in MPAs and showed an increase in catches of some species that was once targeted by pair trawlers. In this case, MPAs management acted more towards a territorial management, protecting artisanal fisheries, than in the protection of fisheries resources.

Keywords: industrial fisheries, marine spatial planning, ecosystem approach to fisheries management, fishery socio-economics, southwest Atlantic Ocean.

Efecto de las áreas marinas protegidas en las pesquerías: el caso del Estado de São Paulo, Brazil

RESUMEN. En 2008, el gobierno del Estado de São Paulo, Brasil, estableció áreas marinas protegidas (AMPs) en toda su costa. Desde entonces se prohibió la pesca de arrastre en pareja en la mayoría de estas áreas. Este estudio investigó como las AMPs influenciaron los patrones operativos y de desembarque entre 2005 y 2012, así como también otras dinámicas de la flota de arrastre en pareja. Los desembarques de buques de arrastre en pareja por unidad de esfuerzo se mantuvieron estables; sin embargo, tuvieron que buscar áreas de pesca más lejanas y capturar especies de mayor profundidad y menos rentables, lo que cambió la composición del desembarque y redujo los ingresos. En particular, la pesca con red de enmalle ha intensificado sus actividades en las AMPs, mostrando un aumento en la captura de ciertas especies que anteriormente fueron el objetivo de buques de arrastre en pareja. En este caso, la gestión de las AMPs se orientó hacia un manejo del territorio, protegiendo la pesca artesanal, más que hacia la protección de los recursos pesqueros.

Palabras clave: pesca industrial, planificación espacial marina, enfoque ecosistémico del manejo pesquero, socio-economía pesquera, Océano Atlántico Suroccidental.

INTRODUCTION

Concern about marine conservation has rapidly risen worldwide, mainly due to overfishing (Watson & Pauly, 2001; FAO, 2011) and the lack of efficiency of some management measures particularly difficult to apply and enforce (Lauck *et al.*, 1998; Roberts *et al.*, 2005; Wilen, 2006), such as total allowable catches (TAC) and fishing gear restrictions (Lauck *et al.*, 1998). Therewith, in order to revert this reality of overexploitation, more complex and potentially effective management strategies have been developed, for example, the establishment of marine protected areas (MPAs) (Gell & Roberts, 2003), the adoption of measures for the restoration of MPA's vicinities (Allison *et al.*, 1998) and even understanding and influencing changes in fishermen's behavior (Wilen, 2006).

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MPAs have been an important instrument to carry out conservation in some regions (Gell & Roberts, 2003). This management measure regulates ocean use in order to protect natural resources as well as historical and cultural features (Day *et al.*, 2012). MPAs are based on the precautionary principle, buffering against management miscalculation, lack of information and unusual conditions (FAO, 1996; Lauck *et al.*, 1998). Besides, MPAs can be considered as an application of the ecosystem approach to fisheries management, enabling a more holistic protection in which species, habitats ecosystem and ecological processes are also considered (Agardi, 1994; FAO, 1996; Diegues, 2008).

In Brazil, there are 59 national conservation units that include marine environments, covering 36,768 km^2. Another 43,617 km^2 are divided into 18 state marine conservation units. These MPAs are categorized differently according to the restriction level (Brazil, 2000).

In 2008, Brazil's largest MPAs were established on the coast of São Paulo State by the state government under the category of marine Environmental Protected Area (marine EPA) which are classified as protected areas for sustainable use and have been deployed in order to protect natural resources, regulating, ordering and ensuring their use. This management measure also aims at planning tourism, research and fishing activities, providing sustainable development of the region (São Paulo, 2008). This kind of MPA falls under category V of IUCN Protected Landscape/Seascape (Day *et al.*, 2012).

Marine EPAs along the coast of São Paulo were established by three decrees, one for each region of the coast - northern, central and southern. Commercial and recreational fishing were allowed in most of the EPAs including artisanal bottom trawl and artisanal gillnets. A ban, however, was established on scuba-assisted spear fishing and pair trawling, one of the main gears used to explore demersal fishing resources. None of these measures derived from or were accompanied by stock-driven protection measures (São Paulo, 2008).

Pair trawling is an industrial fishing technique to capture coastal demersal fish. It is characterized by the use of two boats towing one single trawl net over the seafloor with 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 is allowed in the tunnel and cod-end (Brazil, 1989).

Despite usually applied regulations, pair trawl fishery has been discussed worldwide because of impacts on the population of target species as well as on populations of species incidentally caught, in benthic organisms and on their habitats (McConnaughey *et al.*, 2000; Kaiser *et al.*, 2002; FAO, 2009). It is characterized by the use of a low selectivity gear and by the high bycatch rate for capturing non-commercial organisms or juveniles of commercial species without market value.

This fishing technique has a high catch power and conflicts with artisanal fisheries by competing for both demersal fishing resources and the use of maritime space (Castro & Tutui, 2007; Seckendorff & Azevedo, 2007). In Brazil there are no minimum catch or landing size restrictions for any species exploited by this fishery. Nevertheless, pair trawl remains one of the most important industrial fisheries in São Paulo State and the only that used to frequently operate inside the marine EPAs. Its participation has been relevant for both local market fish supply and fisheries economy.

In southwestern Brazil between 1995 and 2000 the pair trawl fleet operated at depths up to 70 m but most of often between 20 and 25 m. They captured mainly Sciaenidae fish species such as whitemouth croaker (*Micropogonias furnieri*), southern king weakfish (*Macrodon atricauda*) and Jamaica weakfish (*Cynoscion jamaicensis*), as well as grey triggerfish (*Balistes capriscus*), several species of catfish (Ariidae), flounders (Paralichthyidae), sharks (Selachii) and rays (Batoidea) (Castro *et al.*, 2007).

In recent years fishermen and owners of pair trawlers have claimed that the ban inside the EPAs is hindering their activity due economic losses. Dissatisfaction of the fishermen was also justified by the fact that the ban was a top-down decision, not properly discussed in representative fora (*e.g.*, the Councils of marine EPAs).

When established in strategic preservation areas, MPAs have proved rather effective (Gell & Roberts, 2003; Roberts *et al.*, 2005), generating environmental improvements and benefits to fishermen, providing breeding and/or refuge to fish populations, increasing the possibility of biomass export (*i.e.*, spillover) and increasing fish production in surrounding area (McClanahan & Mangi, 2000). In São Paulo coast, however, obtaining such benefits may be uncertain because fishing restrictions have focused on a single fishing gear whereas others have continued to exploit demersal resources within the marine EPAs. Such limitation may hamper the conservation purposes, particularly, of MPAs in tropical areas, which tend to host multi-species and multi-fleet exploitation regimes.

In this context, the present study intended to determine the initial effects of the establishment of the São Paulo marine EPA in various aspects of pair trawl fishing such as physical characteristics of vessels, operating standards, operation area and fishing effort.

Changes in catch composition and economic yield were also analyzed. The impact of EPAs on the total catch of some key species for pair trawlers was further assessed by analyzing landings patterns of these species in other fleets.

MATERIALS AND METHODS

Study area

The study area covered the southwestern Atlantic from Rio de Janeiro (23°S) to Santa Catarina (27°S) up to isobaths of 70 m, where the pair trawlers that land at São Paulo fishing ports have traditionally operated (Fig. 1).

The marine EPAs cover approximately 11,300 km^2 and were established in three regions: North coast, Central coast and South coast. Pair trawling was banned from the entire North and South EPAs, and from shallow areas (<23.6 m depth) off the Central coast (São Paulo, 2008) (Fig. 1).

Data set

The data on fisheries used in this study came from the São Paulo State Fisheries Institute Monitoring Program (PMAP) database, which was obtained by the census method through interviews with fishermen on the occasion of landings (Ávila-da-Silva *et al.*, 1999) between the years 2005 and 2012. It comprised all fishing operations of vessels that land their catches in São Paulo fishing ports. Fishing operations of vessels from other states in the study area tend to be rare and could be considered negligible.

This data set contained information on individual fishing trips, that included: departure and arrival dates, number of effective fishing days, location and depth of fishing operations, catch data (kg) and average ex-vessel prices (US$ per kg) of the landed species. Additional information on the physical characteristics of vessels was obtained from PMAP and from the Fishing General Register (Brazil, 2014).

Data analysis

Fishing trip data were grouped by year (2005 to 2012) and period. Two periods were considered: before the creation of marine EPAs (BEPA) comprising the years 2005-2008 and after the creation (AEPA) including 2010 to 2012. The trips from 2009 were not considered in the comparative analysis between periods, as it was a year of transition.

For the pair trawl fleet, each pair of fishing boats was treated as a single 'production unit' since they operated together and their fishing efforts were pooled. 'Days at sea' included all the fishing trip period. 'Fishing days' were considered the days during a fishing trip when pair-trawling effectively occurred. Changes in the structure of the pair trawl catches were assessed using landings (kg) per days at sea as a relative index of abundance (landings per unit effort, LPUE) for 11 'fish categories' that most contributed to the economic income for this fishery in the period. These categories are reported and commercialized by the interviewed skippers and vessel-owners, and each of them may comprise more than one species. The selected fish categories accounted for 84.3% of total income and for 76.8% of the total weight reported by all vessels during the study periods. Days at the sea were used to calculate LPUE because one day of navigation has a cost that should be considered in this analysis.

The selected species are listed as follows: catfishes (Ariidae), kingcroaker (*Menticirrhus* spp.), whitemouth croaker (*Micropogonias furnieri*), largehead hairtail (*Trichiurus lepturus*), Jamaica weakfish (*Cynoscion jamaicencis*), flounders (Paralichthyidae), acoupa weakfish (*Cynoscion acoupa*), smooth weakfish (*Cynoscion leiarchus*), green weakfish (*Cynoscion virescens*), southern king weakfish (*Macrodon atricauda*) and grey triggerfish (*Balistes capriscus*).

The economic performance of pair trawl fishery was analyzed by the gross value raised from fish sales per trip and per day at sea. The values were standardized in relation to December of 2012 through the Broad Producer Price Index by the Getulio Vargas Foundation (FGV) to enable comparison of values over the years without the effect of inflation.

All variables analyzed were evaluated for normality by the Shapiro-Wilk (Legendre & Legendre, 1998) and for homoscedasticity by the Bartlett test (Zar, 2009). Kruskal-Wallis test (Siegel & Castellan, 1988) was used to assess the statistical significance of the differences observed in physical (engine power - HP, length - m and gross tonnage - GT) and operational (effective fishing days and days at sea) standards among years (2005 to 2012). LPUE of selected species and the economic performance of trips were also analyzed. In the case of significant changes, Mann-Whitney test was used as a *post-hoc* test to verify the difference between periods (Before and After the marine EPA).

To assess changes in fishing areas, it was calculated for both BEPA and AEPA the total effort, in 'fishing days', conducted by pair trawlers within statistical squares of 10 nm side. The significance of changes in depth and distance from the shore off São Paulo coast between the periods were also evaluated with Mann-Whitney test. For fish categories that showed significant catch changes between the periods, trends over time with monthly LPUE values were estimated through time series analysis.

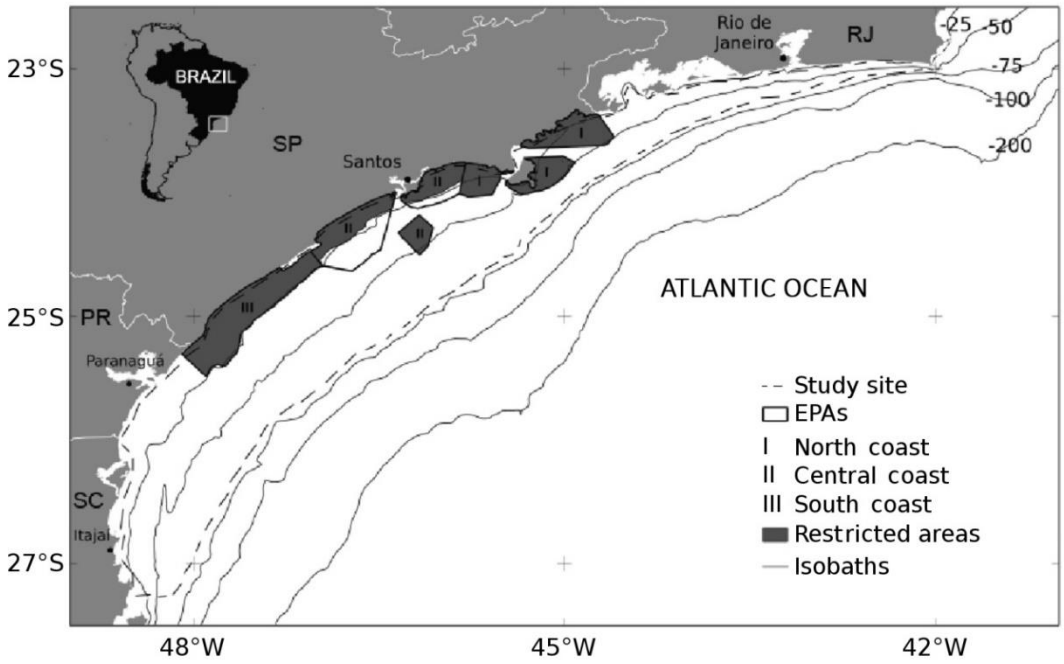

Figure 1. Map of the study area with the division of the marine Environmental Protected Areas (marine EPAs), restricted area to pair trawl fisheries and isobaths. RJ: Rio de Janeiro, SP: São Paulo, PR: Paraná, SC: Santa Catarina.

The seven species that most contributed to the income of pair trawl fleet in the period 2008-2012 were selected for a multi-fleet analysis. Landing data of these species from trips of other fleets that operated within the marine EPA were grouped by year and fishing gear and their trends compared to the variation observed in the pair trawl fleet. Gillnetters, which actually use a wide variety of net types, were treated as one single fleet. Less important fleets in the area, such as purse seine, bottom and surface longline, trawl and some artisanal fisheries were also grouped as "Others". Off the coast of São Paulo purse seiners commonly catch sardines and other small pelagic fish, longliners target dolphin fish (*Coryphaena hippurus*), namorado sandperch (*Pseudopercis numida*) and tilefish (*Lopholatilus villarii*), and artisanal trawlers aim at seabob shrimp (*Xiphopenaeus kroyeri*). An additional analysis of effort was conducted for the gillnet fleet, given its relevant landings of the selected categories.

All analyses were performed using the statistical package R (R Core Team, 2013), adding the pgirmess package (Giraudoux, 2013).

RESULTS

In the analyzed period, 44 vessels operated composing 25 different pair trawlers. These production units made jointly 1,296 trips in total, landing a catch of 32,550 ton with an estimated value of R$112.1 million (Brazilian reais) or approximately US$30.7 million considering an exchange rate of 3.65 R$ per 1 US$ (Table 1).

All variables followed a non-normal and heteroscedastic distribution ($P < 0.05$) and the nonparametric methods were, thus, selected for analysis.

No significant difference in the physical characteristics of vessels was observed over the years (HP: $P = 0.7$, length: $P = 0.8$ and AB: $P = 0.9$). The engine power ranged from 150 to 420 hp with a median of 290 hp. The vessel's lengths varied from 9.5 to 23.6 m with a median of 20.2 and the GT remained between 13.7 and 93.9 with a median of 61.0.

Indicators of activity as number of trips, number of days at sea and number of fishing day per year fell steeply between periods ($P < 0.01$). Their mean numbers had suffered reduction of almost 30% between the periods. As a result, losses were also observed in landings (28%) and total income (36%) (Table 1).

The duration of trips varied significantly between the years 2005-2012 ($P = 0.007$), however, no significant difference was observed between the BEPA and APEA periods ($P = 0.5$). Fishing trips were 1 to 23 days-long, with a median of 11 days. Fishing days per trip did not differ significantly between years ($P = 0.05$). Fishing days during a fishing trip varied between 1 and 19, with a median of 10 days.

Table 1. Summary of the pair trawler fishing activity in São Paulo. BEPA: period before the establishment of marine Environmental Protected Areas. AEPA: period after the establishment of marine Environmental Protected Areas.

	Year	Vessels	Pairs of vessels	Trips	Days at sea	Fishing days	Landings (ton)	Income (US$ millions)
BEPA	2005	32	17	228	2,702	2,185	5,478.3	5.39
	2006	35	19	208	2,434	1,944	5,140.4	5.26
	2007	28	15	207	2,272	1,893	5,418.4	5.47
	2008	28	14	203	2,328	1,901	5,072.4	4.60
AEPA	2010	22	14	159	1,774	1,456	4,186.9	3.86
	2011	18	11	157	1,859	1,523	4,004.8	3.33
	2012	16	8	134	1,643	1,367	3,251.8	2.80

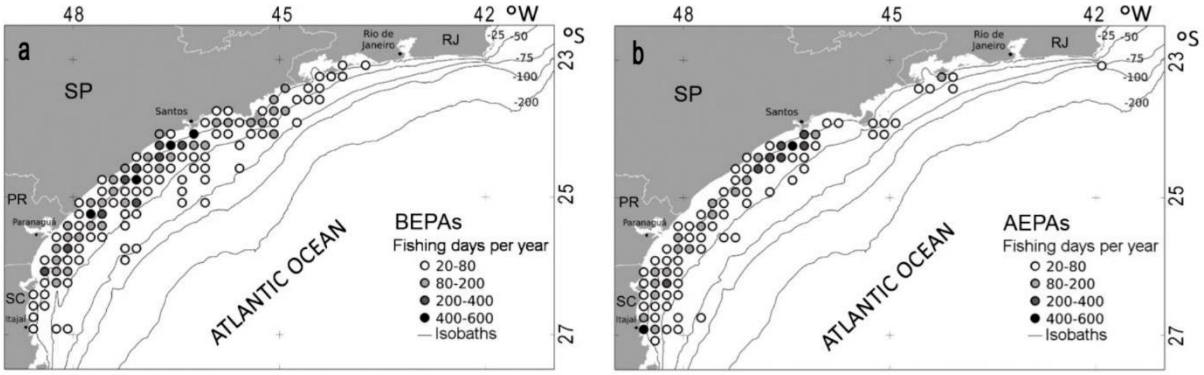

Figure 2. Spatial variation of fishing days by year. a) Before the marine Environmental Protected Areas (BEPA), b) after the marine Environmental Protected Areas (AEPA) for statistical square 10 minutes latitude/longitude. RJ: Rio de Janeiro, SP: São Paulo, PR: Paraná, SC: Santa Catarina.

After the establishment of the marine EPAs, the fleet significantly moved to deeper ($P < 2.2x10^{-16}$) and more distant ($P < 2.2x10^{-16}$) fishing grounds off São Paulo coast and also to coastal areas of other Brazilian states, mainly Santa Catarina where pair trawling is allowed at shallower depths. There was a concentration of fishing next to the regions of Santos and Itajaí fishing ports (Fig. 2).

From the 89 fish categories landed during the entire study period, the main 11 cited above were considered for analysis. Of these, only whitemouth croaker, largehead hairtail, Jamaica weakfish, flounders and catfishes showed no significant difference in the LPUE values among the years, with *P*-values of 0.061, 0.222, 0.325, 0.545 and 0,131 respectively. All other categories showed significant differences in LPUE by year and period. Nevertheless total LPUE values did not vary significantly between BEPA and AEPA (Table 2).

Figure 3 shows monthly values of LPUE for fish categories that presented significant differences between the BEPA and AEPA periods. Grey triggerfish was the only species to show an increase after the management measure was established. Kingcroaker, green weakfish and southern king weakfish had a major decrease after the implementation of EPAs. Acoupa and smooth weakfishes had presented decline since before 2008.

Table 3 shows the participation of the main fish categories in different periods as well as their economic importance. Whitemouth croaker and Jamaica weakfish were the categories that mostly contributed to the fleet income. These categories, along with the southern king weakfish and kingcroaker, accounted for 67.6% of income in the period before marine EPA and 74.5% after marine EPA. Whitemouth croaker was the species with the highest increase in participation while acoupa weakfish showed the highest decrease.

The economic output per pair trawl fishing trip showed significant differences over the years ($P = 4.91x10^{-5}$) and between periods ($P = 4.41x10^{-4}$), with a decrease in income. The BEPA period values ranged from US$632.95 to US$74,936.84 with a median of US$23,494.92. At AEPA period, the minimum value was US$2,147.66, maximum US$75,988.66 with a median of US$20,997.07. Landings per day at sea (LPUE) also varied significantly over the years ($P = 2.23\ 10^{-12}$) and also decreased between the periods ($P =$

Table 2. Mann-Whitney test of landings (kg) per unit effort (days at sea) between the periods for those categories that showed significant difference of LPUE over the years. BEPA: value of the medians Before the Marine Environmental Protected Areas; AEPA: median values After the Marine Environmental Protected Areas; U: test statistic; ns: not significant; s: significant.

Categories	BEPA	AEPA	Variation (%)	U	*P*	
Kingcroaker	176.8	146.0	-17.4%	49,456.0	$5.05\ 10^{-5}$	s
Acoupa weakfish	0.0	0.0	-	488.0	$9.93\ 10^{-4}$	s
Smooth weakfish	40.6	18.4	-54.7%	24,586.5	$1.02\ 10^{-5}$	s
Green weakfish	11.8	4.4	-62.7%	16,054.5	$2.74\ 10^{-5}$	s
Southern king weakfish	54.2	28.7	-47.2%	30,264.5	$3.51\ 10^{-12}$	s
Grey triggerfish	21.4	34.0	+58.9%	24,249.5	$2.51\ 10^{-3}$	s
Total	2,299.8	2,326.8	+1.2%	184,201.0	$6.32\ 10^{-1}$	ns

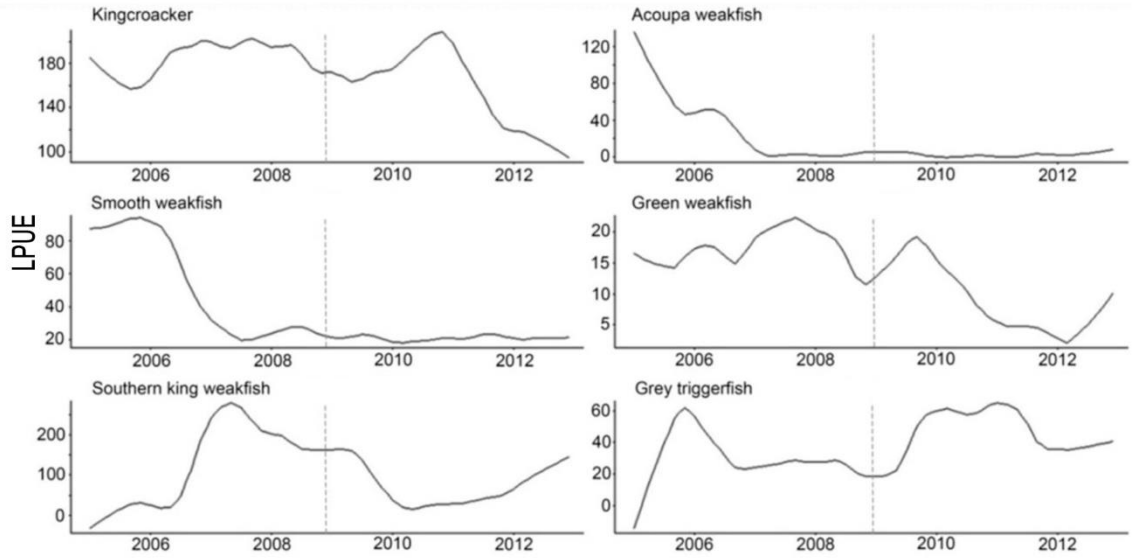

Figure 3. Monthly values of pair trawler landings (kg) per unit effort (days at sea) (LPUE) of the categories that presented significant differences between the periods before and after the marine Environmental Protected Areas (EPA). Dashed vertical line represents the creation of EPA.

$3.41x10^{-5}$). The minimum value found for BEPA was US$221.23 and the maximum was US$9,982.76 with a median of US$ 2,238.64. For AEPA, the minimum was US$238.62, the maximum US$6,515.30 and median US$1,933.17. Differences in income per fishing day were also found to be significant between years ($P = 4.54x10^{-12}$) and periods ($P = 3.60x10^{-6}$). During BEPA, the median income was US$2,488.59, the minimum of US$241.33 and maximum US$9,982.76. In the AEPA period, the median was of US$2,133.42, ranging from US$715.88 to US$ 7,966.99.

The multi-fleet analysis of fish categories that most contributed to the income of the pair trawlers revealed that this fleet had relative high values of coefficient of variation and a negative trend for six out of the seven selected categories (Fig. 4; Table 4). Gillnet landings increased in different scales for all categories, even those that exhibited an overall decreasing tendency. For this fishery there was predominance of catches of acoupa weakfish, southern king weakfish, king croaker and green weakfish.

Double-rig trawlers increased their catch of southern king weakfish and acoupa weakfish. Fleets grouped in the category "other" showed an increase primarily in landings of whitemouth croaker, king croaker and southern king weakfish and a decrease of Jamaica weakfish (Fig. 4; Table 4). This same fishery category accounted for a pronounced increase in green weakfish landings after the establishment of marine EPA with a sharp decrease in the following year.

Total landings of whitemouth croaker, Jamaica weakfish and smooth weakfish in all trips inside the protected area showed downward trends. Total landings of kingcroaker and green weakfish did not show a pro-

Table 3. Relative contribution of the different fish categories in landings (% L) in economic output (% $) and frequency of occurrence (FO%) in the periods Before the Marine Environmental Protected Areas (BEPA) and After the Marine Environmental Protected Areas (AEPA).

Categories	BEPA			AEPA		
	%L	%$	%FO	%L	%$	%FO
Whitemouth croaker	29.0	33.5	96.6	29.6	43.9	96.9
Jamaica weakfish	26.2	12.5	88.4	25.0	15.9	96.9
Kingcroaker	8.4	9.6	82.0	7.1	8.0	92.9
Southern king weakfish	5.3	12.0	49.4	2.3	6.7	47.8
Smooth weakfish	2.3	4.5	49.6	1.0	2.9	53.8
Largehead hairtail	2.1	1.5	66.3	2.8	2.3	90.4
Acoupa weakfish	1.5	6.3	16.2	0.0	0.2	1.3
Grey triggerfish	1.4	1.3	49.8	2.3	2.4	81.1
Catfishes	1.4	1.7	46.8	1.3	1.9	61.1
Green weakfish	0.8	2.6	40.2	0.3	1.4	30.9
Flounders	0.4	1.7	35.8	0.5	2.3	53.3
Totals	78.8	87.2	-	72.2	87.9	-

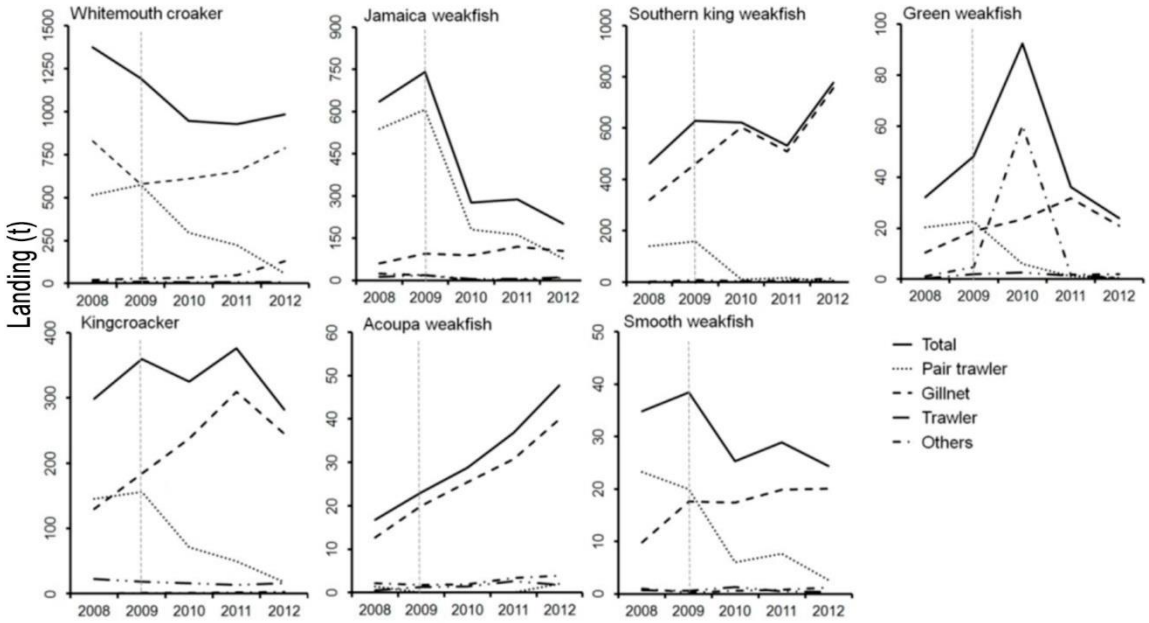

Figure 4. Landings (ton) of trips conducted within the Marine Environmental Protected Areas (EPA) between 2008 and 2012. Selected fish categories were those with the highest contribution to the income of the pair trawl fleet. Dashed vertical line represents the creation of EPA.

nounced tendency in the period. Acoupa weakfish and southern king weakfish showed an increase in total landings values (Fig. 4).

DISCUSSION

Some studies argue that effective conservation of the marine environment is only possible through the implementation of marine reserves that are off limits to fishing (Roberts *et al.*, 2005). Therefore, the American Association for the Advance of Science recommended prohibition of all fishing activities in 20% of seas by the year 2020. This recommendation was approved by the Durban agreement, at the V IUCN World Parks Congress in 2003, in which Brazil was present. The Marine Protected Areas (MPAs) created in São Paulo, however, only partially complies with these recommendations because they are not entirely no take zones.

After the restriction in the operation area the pair trawl fleet was driven to a change in its dynamics.

Table 4. Coefficients of variation (CV) and the Spearman correlation coefficients (s) for the landings of trips performed within the Marine Environmental Protected Areas (EPA) between 2008 and 2012. Selected fish categories were those with the highest contribution to the income of the pair trawl fleet.

	Kingcroacker		Whitemouth croacker		Jamaica weakfish		Acoupa weakfish		Smooth weakfish		Green weakfish		Southern king weakfish	
	CV	s	CV	s	CV	s	CV	s	CV	s	CV	s	CV	s
Trawl	19.4	-0.7	8.7	-0.5	55.7	-0.5	52.0	0.9	50.4	-0.7	67.1	0.1	67.1	0.9
Gillnet	30.6	0.9	16.0	0.0	23.4	0.8	40.2	1.0	24.6	0.9	36.5	0.7	30.7	0.9
Pair trawl	68.5	-0.9	63.9	-0.9	77.1	-0.9	141.1	0.2	76.4	-0.9	105.6	-0.9	118.0	-0.8
Other	63.0	0.9	86.4	1.0	90.8	-0.6	37.2	0.7	47.8	0.4	185.2	0.2	76.8	0.7
Total	12.0	-0.1	17.8	-0.7	56.6	-0.8	39.4	1.0	20.0	-0.8	58.3	-0.3	19.5	0.6

Physical characteristics of the vessels remained relatively homogeneous throughout the period analyzed because almost the same vessels were kept in activity over the years. However, the area covered by this fleet has spread off the coast, reaching farther and deeper fishing grounds where the most valuable species were not so abundant. The fleet also concentrated its effort in traditional fishing grounds nearby Santos and Itajaí, where pair trawling is allowed, in order to keep elevated catches of key species. This concentration may also reflect the proximity to the landing ports, which reduces travel costs (Graça-Lopes *et al.*, 2002), but may locally increase the impact on exploited stocks. Kaiser *et al.* (2002), for instance, noted that trawl fleets distribution in the form of patches is relatively common and the establishment of MPAs can augment this behavior. Consequently, certain areas are sorely towed, probably harming more intensively the resources than when effort distribution is more homogeneous.

In the period analyzed, the fleet showed a decrease of economic performance. The reduction in activity occurred in both number of trips and days at sea per year. The decrease of economic output per fishing day was also significant and related to decreased capture of profitable species after the MPAs establishment. Although small, the change in income is economically significant for this fishery, since it was already operating at a limited economic performance in the past decades (Castro *et al.*, 2001). Furthermore, moving to farther fishing grounds imply in possible increase of fuel consumption and other costs.

After the implementation of MPAs, the fleet suffered from reduced participation of coastal species in the catch composition such as green weakfish, southern king weakfish and kingcroaker. This decrease led the fleet to search for valuable species off the coast of other states, as these fish categories greatly contribute to their economic performance.

The grey triggerfish LPUE values increased significantly between the two periods. This species has a relatively large distribution range (Aiken, 1983; Haimovici *et al.*, 1996; Fischer *et al.*, 2011) and is traditionally captured by several fishing fleets along the Brazilian coast (Vianna *et al.*, 2007; Souza & Ávila-da-Silva, 2010) with important annual catch variations. In 1999, pair trawlers reached record levels landing 1,448 ton of grey triggerfish in São Paulo (Instituto de Pesca, 2016). The increase in catches observed in the years 2010-2011 is probably a result of both natural variation of abundance and also the need of the fleet to offset the loss of important species.

In general, total catches of kingcroaker, acoupa weakfish and southern king weakfish within the restricted area have increased in comparison to the period when pair trawling was allowed probably because the removal of this fleet opened opportunities for other fleets. That also implies that stocks may have not benefited from the MPAs protection because an increase in both effort and landings were observed. Southern king weakfish is already in the national list of overexploited fish species or in danger of overexploitation (Brazil, 2004). Some fish categories such as kingcroaker, smooth weakfish and green weakfish also showed a transfer of catches from pair trawlers to other fleets, especially to gillnetters, followed by exploitation augmentation. This reaffirms the need for future regulation of gillnet fishing aiming at the effective conservation of target species.

In the sea off the coast of São Paulo there was a substantial overlapping of industrial pair trawlers and artisanal gillnetters fishing areas and this justified the ban of the first fleet. Pair trawl is considered an industrial large-scale fishery and was accused of being responsible for reducing the fishing area of other smaller coastal fishing fleets, which claimed to have lesser fishing capacity and navigation power. Such conflicts between passive and active fishing gears are well documented in the literature (Blyth *et al.*, 2002). Until now, the restriction to fish was addressed only to pair trawlers and this caused discontentment to those

engaged in this fishery. This was due especially because there is a perception that fishes were not protected and that the access to resources should be granted to all. This situation is not desirable for a sound management since the engagement of stakeholders is necessary for the effective establishment of the MPAs and considered an important element for the adoption of an ecosystem approach (Jones, 2001).

According to Baelde (2005), the purpose of an MPA should be clearly stated as well as the benefits to be expected. The goal can be to keep fishing profitable or preserve biodiversity in the area. MPAs established in São Paulo aimed to protect, manage and ensure the rational use of environmental resources in the region. It is necessary, therefore, to highlight the benefits to fisheries and to fish population structure in the years following their creation. MPAs also could provide a process of adaptive management where fishing monitoring supports the effectiveness assessment of management plans.

CONCLUSIONS

The pair trawl fishing fleet of São Paulo state underwent changes in its dynamics, mainly regarding the spatial allocation of effort after the implementation of MPAs. This was a consequence of the profit reduction owing to the decrease in valuable catches and the need for searching new fishing grounds. Nonetheless, other fleets that remained in the area increased their fishing efforts and landings. This picture leads to the conclusion that the MPA management acted more towards a territorial management, protecting artisanal fisheries, than in the protection of fisheries resources. To achieve the objective of ensuring the rational use of environmental resources, MPAs administrations should monitor carefully changes in abundance of catches and continue with the regulatory process of the use of their territory in a participatory way and based, whenever possible, on reliable data.

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