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Research Article

Fishing strategies and spatial dynamics of artisanal fisheries in the Uruguayan Atlantic coast

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ABSTRACT. Artisanal fisheries in Uruguay involve directly or indirectly more than 5000 people and constitute the main source of income in several coastal communities. However, and despite its economic and environmental importance, this activity is poorly documented. As such, this scarcity of information constrains the understanding and effective management of artisanal fisheries. This study aims to characterize different strategies of marine artisanal fisheries on the Uruguayan Atlantic coast and describe the spatial distribution of fishing effort. Based on a Principal Components Analysis we identified four fishing strategies targeting different species (mainly whitemouth croaker *Micropogonias furnieri*, narrownose smooth-hound shark *Mustelus* spp., angel shark *Squatina* spp. and Brazilian codling *Urophycis brasiliensis*), exhibiting different seasonal patterns and fishing gear usage. Finally, the above outlined strategies showed differences in spatial utilization of the fishing area. Our results provide a spatially explicit framework for the management of Uruguayan marine artisanal fisheries.

Keywords: artisanal fisheries, fishing strategies, management, spatial dynamic, catch composition, Uruguayan Atlantic coast.

Estrategias de pesca y dinámica espacial de las pesquerías artesanales en la costa atlántica uruguaya

RESUMEN. En Uruguay las pesquerías artesanales involucran, directa e indirectamente, a más de 5.000 personas, constituyendo la principal fuente de ingresos en varias comunidades costeras. Sin embargo, a pesar de su importancia económica y ambiental, dicha actividad está muy poco documentada. De esta forma, la falta de información restringe la comprensión y el manejo efectivo de las pesquerías artesanales en el país. Los objetivos de este trabajo son caracterizar las diferentes estrategias de la pesquería artesanal de la costa atlántica uruguaya y describir la distribución espacial de su esfuerzo pesquero. En base a un Análisis de Componentes Principales se identifican cuatro estrategias de pesca dirigidas a diferentes especies objetivo (principalmente corvina *Micropogonias furnieri*, gatuzo *Mustelus* spp., angelito *Squatina* spp. y brótola *Urophycis brasiliensis*), que presentan diferentes patrones estacionales y del tipo de arte utilizado. Finalmente, las estrategias anteriormente descritas muestran diferencias en el uso espacial de las áreas de pesca. Los resultados proporcionan un marco espacialmente explícito para el manejo de las pesquerías artesanales en la costa atlántica de Uruguay.

Palabras clave: pesquerías artesanales, estrategias de pesca, manejo, dinámica espacial, composición de la captura, costa atlántica de Uruguay.

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INTRODUCTION

Worldwide, fisheries capture approximately 90 million ton of fish per year and generate *ca.* 38 million of direct jobs (FAO, 2012), with artisanal fisheries being responsible for 45% of global landings and employing about 90% of direct labor of all the world fisheries (Berkes *et al*., 2001; FAO, 2012). In Uruguay, the artisanal fisheries census of 2007 recorded a total of 726 vessels for Río de la Plata Estuary and the Atlantic coast (AC hereafter; Puig *et al*., 2010). This activity involves directly or indirectly more than 5000 people and constitutes the main source of income of several coastal communities (GEO Uruguay, 2008; Defeo *et al*., 2009).

However, and despite its significant socio-economic and ecological importance, artisanal fishing is often neglected or poorly regulated by management agencies (Berkes *et al*., 2001; Puig, 2006; Defeo *et al*., 2009). Further, the main marine artisanal fisheries resources in Uruguay are fully exploited or show signs of overexploitation, calling for an urgent improvement in fisheries management (Defeo *et al*., 2009). This is, however, hindered by the scarcity of information on catch composition, fishing effort and spatial patterns of the artisanal fleet. In addition, Uruguayan coastal artisanal fishers utilize a not yet fully characterized diversity of fishing gear and operational strategies, according to targeted species, season and/or market opportunities. Insights on the complexity of this activity may result in an improvement of management schemes (Puig, 2006; Defeo *et al*., 2009).

In order to enhance the quality of the information available to managers, it is critical to characterize the different fishing strategies, catch composition and spatio-temporal dynamics of these fisheries (Blaber *et al*., 2000; Salas & Gaertner, 2004; Tzanatos *et al*., 2005). However, knowledge on the dynamics of the Uruguayan coastal artisanal fisheries has been historically impeded by the high variety of fishing strategies deployed, the number of target species and the mobility of fishermen which shifts between different coastal areas according to the season (Norbis & Verocai, 2001; Spinetti *et al*., 2001; Franco-Trecu *et al*., 2009). Further, available data obtained by the National Direction of Aquatic Resources (DINARA) are sometimes incomplete due to the low return on catch reports and their unreliability (Delfino *et al*., 2006; Puig *et al*., 2010). Consequently, the precise characterization of fishing strategies and associated catch has been little developed so far. According to Delfino *et al*. (2006), few studies assessed variability, catch composition or landings for the artisanal fleet. Although recently Horta & Defeo (2012) reported CPUE (kg/boat/month) in a port basis estimated from monthly information on landings, there is no spatially explicit analysis of the fishing grounds used by Uruguayan artisanal fleet. Current available information on artisanal fishing effort is insufficient or inadequate for 76% of the species caught on the AC (Defeo *et al*., 2009). In this vein, it is necessary to take into consideration the spatial dynamics of the fishing fleet in order to improve the design of management measures, such as artisanal exclusive-use zones and spatio-temporal management windows (Defeo *et al*., 2009, 2011; Horta & Defeo, 2012).

In this context, and taking into consideration the pressing needs for the development of more effective management schemes, this paper aims to 1) characterize the different fishing strategies of the artisanal fisheries in the main ports of the Uruguayan Atlantic coast, and 2) report on the spatial distribution of fishing effort associated with each strategy.

MATERIALS AND METHODS

Study area

The study area is located in the southwestern Atlantic coast (Fig. 1). This region is dominated by the dynamic of the Brazil-Malvinas confluence, and the presence of coastal waters and freshwater discharge of the Río de la Plata Estuary. Wind regime, freshwater discharge and the seasonal migration of the confluence zone generates a high seasonal variation. Winter is characterized by the presence of subantarctic, cold and nutrient rich waters, while the summer is dominated by warm and nutrient poor subtropical waters (Piola *et al*., 2000; Ortega & Martínez, 2007). The confluence of these different waters generates one of the most productive aquatic systems in the world, used by many demersal fish for spawning and nursing (Jaureguizar *et al*., 2004), and sustains several artisanal and industrial fisheries (Guerrero *et al*., 1997; Lopes *et al*., 2006; Ortega & Martínez, 2007).

Artisanal fisheries of the Atlantic coast

Uruguayan AC marine artisanal fisheries (*i.e.*, defined as vessels with <10 Gross Registered Tonnage by DINARA) use almost exclusively gillnets and longlines. These fisheries operate between the coast and 15 nm offshore, in vessels from 4 to 10 m in length ($\bar{X}$ = 7.5 m), powered by outboard engines ($\bar{X}$ = 48 HP), with a small crew ($\bar{X}$ = 3 people) and low levels of technology and capital investment per fishermen (Puig, 2006; Puig *et al*., 2010; DINARA, 2012). Eleven artisanal ports are located in the Uruguayan AC, registering 82 artisanal fishing vessels (DINARA, 2012). Currently, La Paloma port is the most important with about 62% of total artisanal AC catches and about 30 (37%) artisanal fishing vessels (Defeo *et al*., 2009). Fishing vessels operating from this port are typically larger than the ones from other ports, with lengths up to *ca*. 10 m (Delfino *et al*., 2006). The gillnet panels used are 50 or 60 m long, from 1.8 to 5.0 m in height and the mesh sizes range from 11 to 40 cm, depending on the

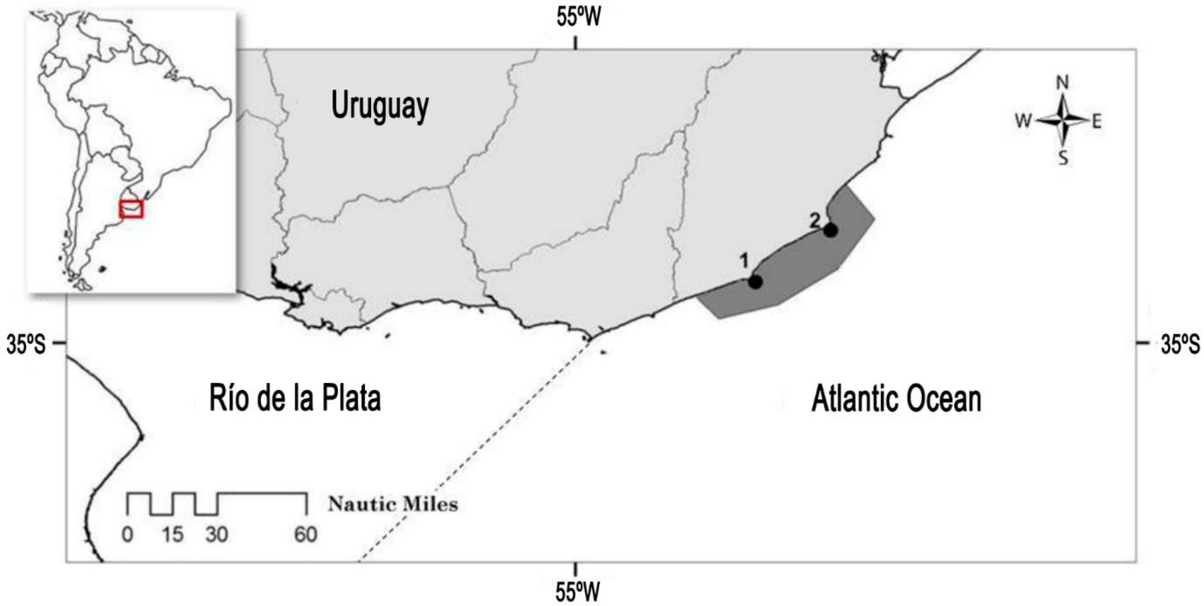

Figure 1. Study area. Fishing area (dark gray) of the main artisanal fleets in the Uruguayan Atlantic coast and location of the ports included in the present study (black dots). 1: La Paloma, 2: Cabo Polonio.

targeted species. Longlines consist of a main line 80 to 100 m long; with branch lines placed every one meter, each one containing a 5 cm hook.

These fisheries operate on a multispecies basis (*i.e.*, more than 20 species), targeting mainly narrownose smooth-hound shark *Mustelus* spp., tope shark *Galeorhinus galeus*, angel shark *Squatina* spp., rays *Sympterygia* spp., *Atlantoraja* spp. and *Rioraja agassizi*, whitemouth croaker *Micropogonias furnieri*, king weakfish *Macrodon atricauda*, stripped weakfish *Cynoscion guatucupa*, Argentine croaker *Umbrina canosai*, bluefish *Pomatomus saltatrix* and Brazilian codling *Urophycis brasiliensis* (Defeo *et al*., 2009; Franco-Trecu *et al*., 2009).

Data collection

A total of 21 fishermen, each fisherman was in charge of at least one vessel, operating from La Paloma and Cabo Polonio ports (Fig. 1) were visited on a monthly basis, between January 2006 and December 2009. A logbook was given to each fishermen, where they recorded, aided with GPS and echosounder, the following data for each fishing event: geographic position, bearing angle from port to fishing ground, distance to port and coast, depth, date, type and characteristics of fishing gear (nets or longlines, number and size of nets and longlines used), soaking time, and catch (kg of each species). Fishermen kept these logbooks in their homes or boats throughout the study period, which facilitated our access to the data. “Failed” fishing events (little or none catch) were excluded from the analysis because they do not represent a common event, as fishermen use repeated and brief soaks of few nets (3 or 4) to probe the fish abundance of the fishing spot and decide whether or not to set the gear.

These data were derived from a six year project (2004-2009) originally directed to evaluate incidental catches of the endangered franciscana dolphin *Pontoporia blainvillei*. During the first stages of the project we worked basically on trust building and pilot surveys to enhance onboard logbook filling. The systematic survey was developed with those fishermen who showed commitment with the logbook fulfillment and the project itself and implied not only monthly visits but also workshops to analyze data together and to discuss about fisheries. After this period, researchers, fishermen and their families created a strong bond based on mutual trust, a fact reflected in the quality and detail of the data included in the logbooks, rarely available to fisheries management agencies.

Data analysis

Identification of fishing strategies

In this study, a fishing strategy is considered as a type of fishing actions based on targeted species and fishing gear and its use. Based on field observations and previous knowledge, gillnets were grouped according to their mesh size (knot distance) into three categories: "small mesh gillnet" (11 to 12 cm), “medium mesh gillnet" (13 to 18 cm) and "large mesh gillnet" (more than 19 cm). Identification of the different fishing strategies was based on the associations between types of fishing gear and catch composition. We performed a Principal Component Analysis (PCA) (Clarke & Warwick, 1994) on a matrix which entries were centered using catches per species (rows) for every fishing gear combination (variables). Variable contributions to each principal component and species scores on each component determined gear and catch associations, finally classified into fishing strategies.

Further, for each fishing strategy thus recognized by the PCA, we analyzed temporal (monthly pooled) patterns of a) total number of nets or longlines used and b) total soaking time (hours). This allowed the temporal characterization of the fishing strategies. This analysis was performed with the princomp function of the free software R (R Development Core Team, 2011).

Spatial distribution of fishing strategies

The spatial distribution of the effort of each fishing strategy identified was represented using the spatial interpolation tool (Kriging) of ArcMap 9.2 software. This tool generates a continuous softened representation of fishing effort as the number of events per quadrant of 0.025 decimal degrees.

RESULTS

Fishing gear usage

Participation of fishermen throughout this study generated a database of 3256 fishing events. We identified the use of 10 gear or gear combinations: small mesh gillnet (57%), longline (17%), large mesh gillnet (16%), medium mesh gillnet (3%), medium and large mesh gillnet (2%), small mesh gillnet and longline (2%), medium mesh gillnet and longline (1%), large mesh gillnet and longline (1%), and medium, large mesh and longline and small and large mesh represented less than 1% each (Table 1a).

Catch description

A total of 26 fish species were caught during the study period (Table 1b). Some species were grouped due to their very low overall representation or to reflect fishermen categorization, resulting in 14 categories. Most representative species were narrownose smooth-hound shark, whitemouth croaker, angel shark, argentine croaker, Brazilian codling, stripped weakfish, tope shark, bluefish, flounder and leatherjack. The remaining represented less than 0.5% each, and were grouped into the categories "Other bony fishes" or "Other elasmobranchs".

Identifying fishing strategies

The PCA allowed the reduction from 10 variables (fishing gear or combinations) to three components, which accounted for 99.9% of the variance of the data set (Fig. 2). The first component was highly correlated with the use of small mesh gillnets -component loading of 0.999- and explained 94.5% of the total variance (Fig. 2a). Species associated with the use of small mesh gillnets (*i.e.*, with highest scores on the first component) was represented mainly by narrownose smooth-hound shark and whitemouth croaker. The second component explained 4.2% of the total variance and was highly correlated with the use of large mesh gillnets - component loading of 0.993 (Fig. 2a). Capture associated with large mesh gillnets was related mainly with angel shark. Even though the third component accounted for only 1.3% of the variance of the data set, it was still considered due to its relevance, as it was the only one strongly associated with the use of longlines-component loading of 0.994 (Fig. 2b). Catch associated with longlines was composed mainly by Brazilian codling, followed by narrownose smooth-hound shark.

As described above, the PCA allowed the identification of three main fishing gear-species associations (*i.e.*, small mesh gillnet, narrownose smooth-hound shark and whitemouth croaker; large mesh gillnet and angel shark; and longline and Brazilian codling). Based on operational differences regarding narrownose smooth-hound shark and whitemouth croaker fishing (*i.e.*, the former is found via brief "test" soakings, while the latter is located using an echosounder device) we classified these two associations as separate fishing strategies.

Thus, the following four fishing strategies were identified: "large mesh fishing" (mainly targeting angel shark), "longline fishing" (mainly targeting Brazilian codling), "croaker fishing" (small mesh gillnets targeting whitemouth croaker) and "shark fishing" (small mesh gillnets targeting narrownose smooth-hound shark).

Temporal dynamics of fishing strategies

Fishing strategies identified by the PCA showed differential monthly effort distribution throughout the study period (Fig. 3). Based on the nº of gear used (relative to maximum value), the fishing effort was higher from November to February for large mesh fishing, from October to March for the longline fishing, and from April to November for the shark fishing. Croaker fishing showed a multimodal irregular pattern on its temporal effort distribution during winter and autumn, with very low to no effort during spring and summer (September through January). Regarding monthly soaking time distribution (relative to maximum

Table 1. a) Registered fishing gear used, b) species caught by the artisanal fleet during the study period. Some species were grouped due to their very low overall representation or to reflect fishermen categorization. Overall percentage of total landing weight is shown.

a) Fishing gear (or combination)	Overall percentage
Small mesh gillnet (S)	57%
Longline (Lg)	17%
Large mesh gillnet (L)	16%
Medium mesh gillnet (M)	3%
M + L	2%
S + Lg	2%
M + Lg	1%
L + Lg	1%
M + L + Lg	<1%
S + L	<1%
b) Species registered	**Overall percentage**
Narrownose smooth-hound shark (*Mustelus* spp.)	40%
Whitemouth croaker (*Micropogonias furnieri*)	25%
Angel shark (*Squatina guggenheim, S. occulta* and *S. argentina* according to Domingo *et al*. (2008)	11%
Argentine croaker (*Umbrina canosai*)	6%
Brazilian codling (*Urophycis brasiliensis*)	5%
Stripped weakfish (*Cynoscion guatucupa*)	3%
Tope shark (*Galeorhinus galeus*)	2%
Bluefish (*Pomatomus saltatrix*)	2%
“Mix 1” (Brazilian codling and flounder, *Paralichthys* spp.)	2%
“Mix 2” (Stripped weakfish and whitemouth croaker)	1%
Flounder (*Paralichthys* spp.)	1%
Leatherjack (*Parona signata*)	1%
"Other bony fishes": white and guri sea catfish (*Genidens spp.*), Argentine hake (*Merluccius hubbsi*), South American silver porgy (*Diplodus argenteus*), black drum (*Pogonias cromis*), wreckfish (*Polyprion americanus*), Brazilian menhaden (*Brevoortia aurea*) and southern kingcroaker (*Menticirrhus americanus*).	<1%
"Other elasmobranchs": dogfish (*squalus* spp.), sand tiger shark (*Carcharias taurus*), hammerhead sharks (*Sphyrna* spp.), narrowmouthed catshark (*notorhynchus cepedianus*), southern eagle fish (*Myliobatis* spp.) and “skates” (*Sympterygia* spp., *Atlantoraja castelnaui*, *Rioraja agassisi*, according to Defeo *et al*. (2009)).	<1%

mum value), it was only possible to differentiate a clear pattern for large mesh fishing effort distribution, which supported the observations outlined above.

Spatial distribution of fishing strategies

Among the 3256 fishing events analyzed, 69% were reported with geographic location. Fifty two percent of these were recorded by fishermen with GPS, 33% were calculated from information of vessel bearing and distance to port (measured with on board GPS), while 15% were obtained from a map based on information on the bearing angle, distance from shore and depth. The accuracy of the calculated locations was considered good enough given the spatial scale of our analysis. The distribution of the four strategies recognized showed a differential use of the Uruguayan

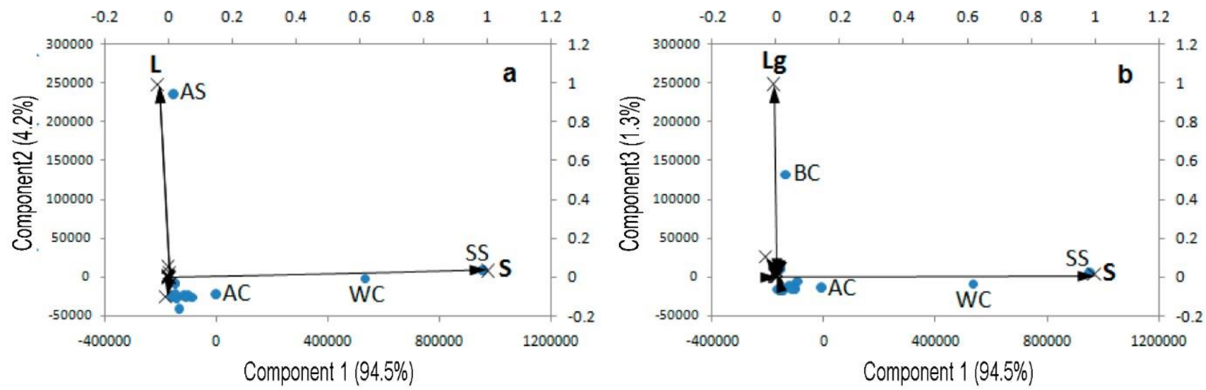

Figure 2. Biplot of the Principal Component Analysis showing associations between species and each fishing gear or combination (variables): a) components 1 and 2, b) components 1 and 3. Total variance percentage explained by each component is shown in parentheses. Component variables (*i.e.*, gear combinations, top and right axes) are represented with a line from origin and a cross: S: small mesh nets, L: large mesh nets, Lg: longlines. Species (bottom and left axes) are represented by blue dots: SS: narrownose smooth-hound shark, AS: angel shark, WC: whitemouth croaker, BC: Brazilian codling, AC: Argentine croaker. Remaining species and gear combinations are not shown due to high overlapping.

AC as fishing grounds (Fig. 4). Large mesh fishing events (Fig. 4a) and shark fishing events (Fig. 4b) were equally distributed around and to the southwest of La Paloma port. While the former also presented a high concentration in the coast around Cabo Polonio port, the latter strategy showed a second "hotspot" located 12 nm to the southwest off that port. Croaker fishing (Fig. 4c) and longline fishing events (Fig. 4d) showed clear trends on their spatial distribution, being directed mostly westward La Paloma port.

DISCUSSION

The present work characterizes artisanal fishing strategies in the Uruguayan Atlantic coast, showing a high intra-annual variability in strategies used and species captured. The strong relationship between fishing gear categories and PCA components allowed a sound differentiation of four fishing strategies, whereas spatial analysis showed differences in their usage along the fishing area. Based on these two aspects and qualitative field information, we characterize each fishing strategy identified for La Paloma's and Cabo Polonio's artisanal fisheries.

Large mesh fishing strategy occurred mainly during summer (between October and February) and was directed mainly to angel shark. Spatial distribution of fishing events was concentrated around La Paloma and Cabo Polonio ports. As registered during field visits, when using this strategy fishermen select the fishing grounds based on local knowledge and short term previous experience, soaking the nets between 24 to 92 h. Shark fishing targeting narrownose smooth-hound shark occurred mostly between April to October around La Paloma port and 12 nm from Cabo Polonio port, which could be suggesting an area of high abundance of sharks during that period. In this strategy, soaking place is decided based on short trials, consisting of repeated 15 min soaks of few nets, to locate the shoals. Croaker fishing, targeting whitemouth croaker, occu-rred during autumn and winter (February to August). This trend is consistent with the reported whitemouth croaker migratory and reproductive events (Jaureguizar *et al*., 2003; Norbis & Verocai, 2005). Most of these fishing events were concentrated to the west of La Paloma port (Fig. 4c). This strategy is based on the use of an echosounder to locate specific shoals. Once located, nets are soaked for a short period, generally less than an hour, enough for the fish to get entangled. *Longline fishing* was mainly related to the extraction of Brazilian codling, and occurred on summer (October to February). Regarding its spatial distribution, a higher concentration of fishing events was observed on the west side of La Paloma port (Fig. 4d). In this strategy, longlines are soaked right above the shoal, and settled for periods that generally do not exceed 7 h and last in average 3 h.

Our results suggest that, at least regarding the biological system, these fisheries deserve more attention from management agencies. First, the diversity of fishing strategies characterized adds complexity to this multispecies system, thus posing new management challenges (Berkes *et al*., 2001). This may be exacerbated by the recognized interdepen-dencies between these and industrial fisheries. The four strategies here depicted share their main targeted species sequentially, and often spatially, with industrial

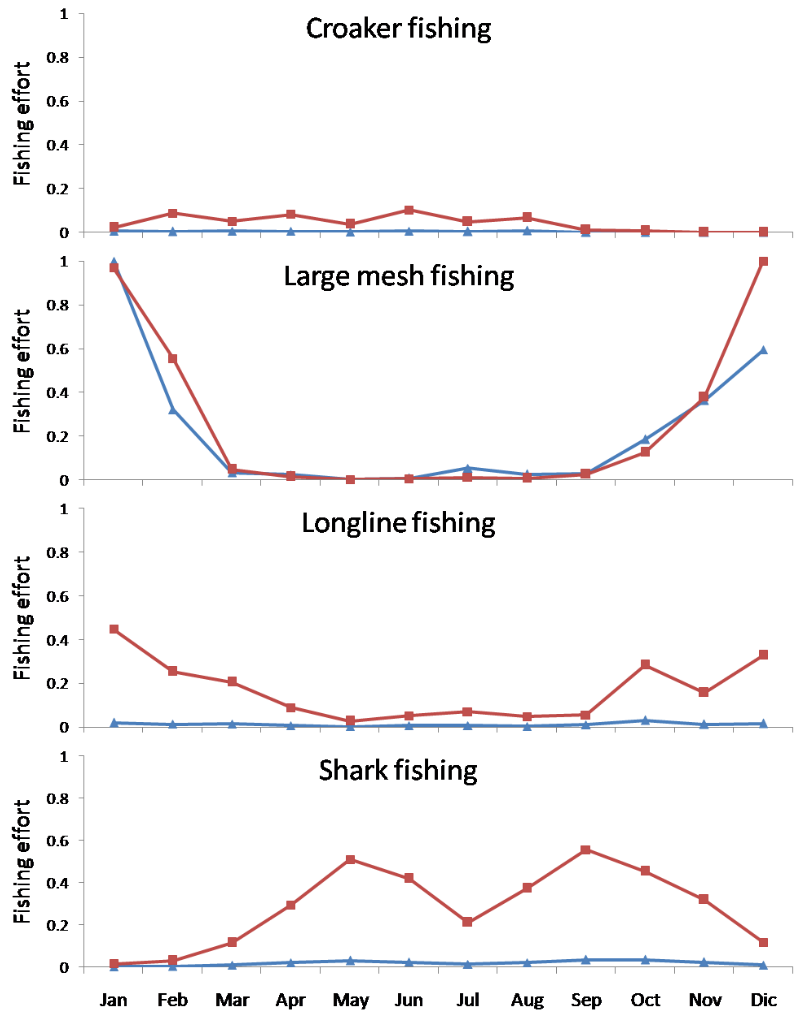

Figure 3. Intra-annual dynamics of fishing effort for each identified strategy, measured as number of gear used (red squares) and as total soaking time (blue triangles). Values of the two categories were divided by their respective overall maximum for comparison purposes while preserving original relationships.

fisheries, broadening the influence of the artisanal sector (Defeo *et al*., 2009; Horta & Defeo, 2012). Second, our results pointed out the importance of resource conservation planning at this small-scale level. According to the resource exploitation status described by Defeo *et al*. (2009), 28% and 43% of total landings reported here correspond to fully-exploited and over-exploited species, respectively. These include angel sharks and narrownose smooth-hound shark, classified as Endangered by the IUCN (Massa *et al*., 2005; Vooren & Chiaramonte, 2006; Chiaramonte & Vooren, 2007) and tope shark, classified as Vulnerable (Walker *et al*., 2006). Moreover, these aspects are of regional relevance, as most of these species are also exploited by the neighboring countries Argentina and Brazil (Nion, 2010), making conservation a more challenging goal, especially when the understanding of each fishery is limited.

Finally, spatial distribution of fishing effort showed to be highly convergent with Cabo Polonio and Rocha Lagoon protected areas (Fig. 4). Disentangling operational and spatial patterns for these fisheries is a critical step towards protected area co-management (Berkes *et al*., 2001; Hilborn *et al*., 2004). Further, this kind of information may facilitate the understanding of population dynamics of species with conservation priorities such as angel sharks, narrownose smooth-hound shark and tope shark.

In this scenario, the present work should support the generation of local and regionally relevant management tools, favoring the comprehension of the fishery system and the proper definition of management units, which should include operational, spatial and temporal patterns of fishermen activities (Berkes *et al*., 2001). In this vein, this work allows the development of differen-

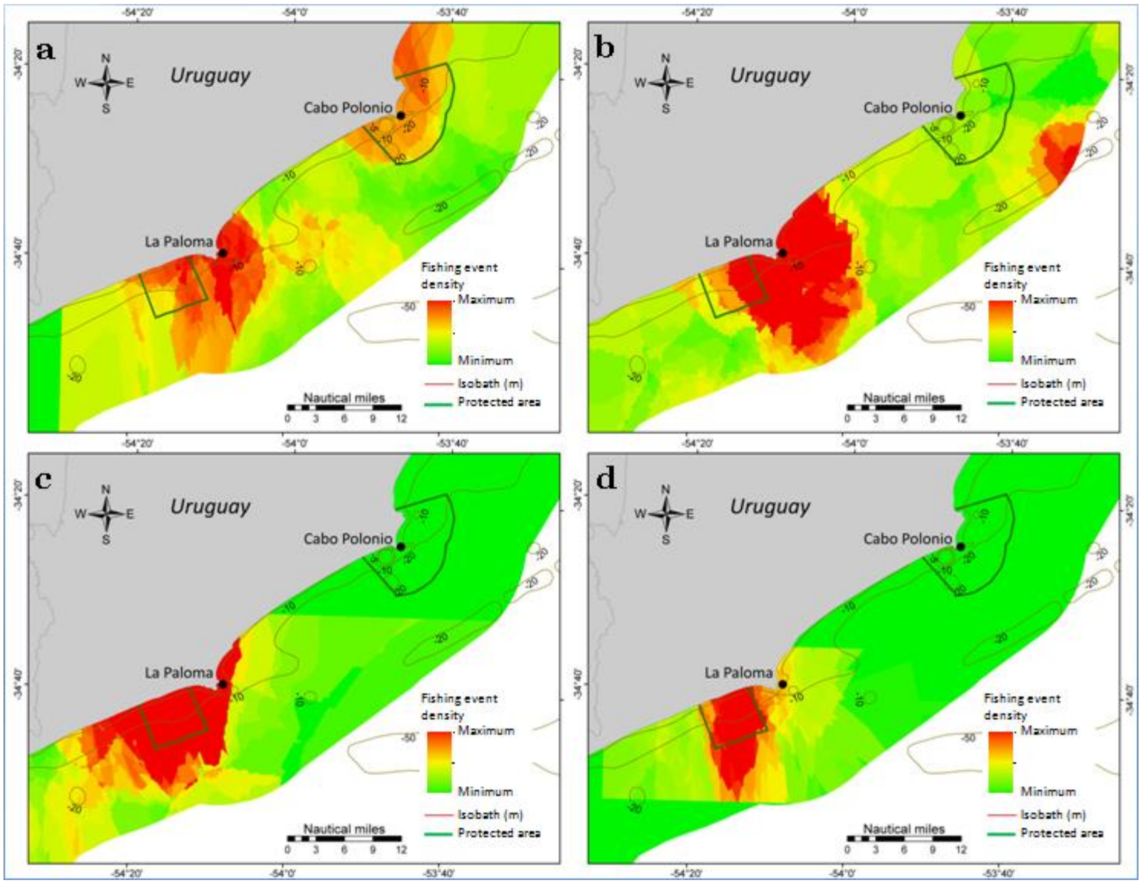

Figure 4. Spatial representation (Kriging) of the fishing effort, *i.e.* total number of fishing events for the study period, for the strategies: a) large mesh fishing, b) shark fishing, c) croaker fishing, d) longline fishing. The outer limit is given by 15 nm line. In each case, extreme colors were set to fit maximum and minimum interpolated values; therefore, absolute values of fishing effort are represented in different scales among fishing strategies (see text for details).

tial regulatory measures for each strategy and/or season, of high relevance in multispecies systems (Hilborn *et al*., 2004). As an example, if a management objective is to reduce narrownose smooth-hound shark mortality (*e.g.*, CTMFM, 2013), there would be no need to spend resources monitoring the number of large mesh gillnets on boats, nor to limit the number of small mesh gillnets on summer. As repeatedly observed by our group during the study period, this kind of inefficient regulatory measures negatively affects fishermen and their relationship with state agencies, probably making more difficult the proper implementation of the measure (as suggested by Salas & Gaertner, 2004).

Further, in line with the broadly recognized global pattern, Uruguayan artisanal fisheries management is in need of more and better data sources (Defeo *et al*., 2009). Results presented here promote the involvement of fishermen as data collectors as well as the use of official data sources from these fisheries, such as reported landings and fishing effort (*e.g.*, Branch *et al*., 2006). If this kind of information is to be used, it is of utmost importance to understand the basic operational functioning of the fishery. As an example, in the context of Maximum Sustainable Yield (MSY) assessments, knowledge on which strategy will better inform about the dynamics of a certain species population is crucial, as reported Catch per Unit of Effort used to calculate MSY should not include fishing effort not directed to that species.

To conclude, we stress that in the context of co-management and sustainable production of artisanal fisheries it is critical to develop this level of detailed knowledge of the targeted socio-ecological system, as well as to establish two-way interactions between involved stakeholders and managers (Puig *et al*., 2010; Gutiérrez *et al*., 2011; FAO, 2012; Trimble & Berkes, 2013).

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