A trans-ecosystem fishery: Environmental effects on the small-scale gillnet fishery along the Río de la Plata boundary

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ABSTRACT

To improve the understanding of the environmental processes affecting small-scale gillnet fisheries along neighboring waters of estuaries, we analyzed the main climatic forcing and the environmental conditions, the fishery landing spatial and temporal variation, including the relative importance of site, distance to coast, temperature and salinity in the structuring of landed species profile. Data were collected monthly in two sites along the adjacent south coast of the Río de la Plata between October 2009 and September 2010. The gillnet fishery was dominated by four species (*Cynoscion guatucupa*, *Micropogonias furnieri*, *Mustelus schmitti* and *Parona signata*) from a total of 38 species landed, which accounted for 98.6% of total landings. The fishing effort and landings by the fishery were largely conditioned by the availability of fish species in the fishing grounds resulting from the combination of the species reproductive behavior and the predominant environmental conditions. The highest abundances for some species occurred before (*M. furnieri*, *C. guatucupa*, *P. signata*) or during the reproductive period (*M. schmitti*, *Squatina guggenheim*), while in other species it was associated with favorable environmental conditions during cold months (*Squalus acanthias*, *Callorhinchus callorhynchus*, *Galeorhinus galeus*) or warm months (*Trichiurus lepturus*). The predominant seasonal environmental conditions along the coast were mainly determined by the location of Río de la Plata boundary, whose spatial extent was forced by the wind patterns and freshwater discharge. The strong environmental dependence means that the small-scale fishery is in fact a seasonal trans-ecosystem fishery. This attribute, together that shared the resources with the industrial fishery and the overlap of the fishery ground with essential habitat of sharks, make this kind of small-scale gillnet fishery particularly relevant to be included in the development of a coastal ecosystem-based management approach.

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1. Introduction

Climate and environmental changes are expected to affect the use of estuaries and coastal habitats by fish species, many of which are already considered vulnerable to ongoing climatic variability. The influence of climatic conditions is conspicuous in the recruitment success, migration, and dispersal of fishery resources toward/from fishing ground, which may have significant influences on the success of small-scale fisheries (Roessig et al., 2004; Brander, 2010; Gillander et al., 2011; Petitgas et al., 2013). The shifting distribution and migration patterns that will result from climate change are likely to disrupt the traditional fishing calendar and also the traditional fish sharing and access agreements to neighboring fisheries along an environmental gradient. This environmental restructuring, together with declining fish stocks, will lead to increasing vulnerability of fishing communities (Kalikoski et al., 2010) and probably to a variety of adaptive changes in the social system in response.

Such adaptive responses to marine ecosystem changes, typically include short (intensification of effort, diversification of fishing, migration, 'riding out the storm') or long time perspectives (political reform, restructuring, capacity building, community closure), and is likely to vary (or be constrained) by the capacities of a country (Perry et al., 2011). The susceptibility of fishing communities to climate and environmental change is a major issue for the

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governance of fisheries resources within a vulnerability approach and has a direct effect on human security, livelihoods and fishing rights (Kalikoski et al., 2010). Therefore, understanding the degree to which the environment influences small-scale fishery communities in the context of future climate change is crucial for the development of policies and operational rule that can maintain the livelihoods of these communities and their social-ecological systems.

Important small-scale or artisanal fisheries occur along the Río de la Plata (RdP), at the northern coast (Uruguay, Norbis, 1995, Acuña Plavan and Verocai, 2001; Puig, 2006, 2010; Segura and Milessi, 2008; Defeo et al., 2010) and southern coast (Argentina, Lasta et al., 2001, Lagos, 2001), which are exposed to low salinity extensions of the RdP plume. The RdP discharge, ~23,000 m^{3}s^{-1} of freshwater to the western South Atlantic shelf at 35° S (Jaime et al., 2002), results in a estuarine region that encompasses approximately 35,000 km^2 (Framiñan et al., 1999) and the meridional extension of the plume of low salinity extends northeastward (beyond 26° S) in fall–winter and southwestward (reaching 37° S, Punta Médanos, Fig. 1) in spring–summer as a result of the changes in the along-shore wind stress and freshwater discharge (Piola et al., 2005; Simionato et al., 2007; Jaureguizar et al., 2007). In shallower waters, the seasonal and inter-annual variation in RdP freshwater inputs modifies the spatial extents of estuarine conditions (along-shore salinity gradient) influencing the distributions of marine and estuarine fish species (*Prionotus punctatus* vs *Prionotus nudigula*, Jaureguizar et al., 2007) and their ontogenetic stages (*Cynoscion guatucupa*, Jaureguizar and Guerrero, 2009; Jaureguizar et al., 2006a; *Micropogonias furnieri*, Jaureguizar et al., 2003a), thereby affecting fish assemblage composition along the coast (Jaureguizar et al., 2003b, 2004, 2006b; García et al., 2010; Barletta et al., 2010). Therefore, RdP freshwater inputs can directly influence the availability of resources to settled small-scale fishers along the RdP and thus impact in the total landings.

The activity of RdP small-scale fisheries is usually conducted in inshore coastal waters (up to 1.5–5.5 km offshore), use small boats (wood, fibreglass, inflatable, semi-rigid) of less than 10GRT with outboard motors. The fishing trips normally occur during the day. In northern coast of RdP, a wider variety of fishing gears (gillnets, lines, hooks and trap) is used than in southern coast (normally gillnets). The main species caught mainly include white croaker (*Micropogonias furnieri*) and stripped weakfish (*Cynoscion guatucupa*) and, to a lesser extent, parona leatherjacket (*Parona signata*), brazilian codling (*Urophycis brasiliensis*) and patagonian smoothhound shark (*Mustelus schmitti*) (Lagos, 2001; Lasta et al., 2001; Defeo et al., 2010). The small-scale fishery exploits the same resource as the industrial fleet, which has strong spatial overlapping and produces a negative effect on the small-scale catches (Horta and Defeo, 2012). At the northern RdP coast (Uruguay) white croaker fishers show stronger (~60 km) intra-annual displacement (either sailing or carrying their boats) than along southern coast (Argentina). The northern fleet follows the migrations of *M. furnieri* to the coastal spawning areas (Defeo et al., 2010; Horta and Defeo, 2012) associated with the inner salinity front (Macchi and Christiansen, 1996; Jaureguizar et al., 2003a, 2008). Consequently, for non-migrant small-scale fisheries settled on the southern coast, it is expected that, due to environmental change, the spatial variation in the salinity patterns will disrupt the traditional availability of fish and the spatial access agreements, producing 'winners' and 'losers' along the environment gradient. This is a problem specific to small-scale fisheries on migratory trans-boundary stocks and it represents a special problem in fisheries management.

It is then important to understand the environmental influences on the harvest of small-scale fishing communities along the Río de la Plata gradient, for example Las Toninas (Faro San Antonio, 36°17′S) and Punta Médanos (36°53′S) (Fig. 1), to improve future management approaches. The main goals of this work were: 1) to analyze the variation of temperature and salinity distributions and
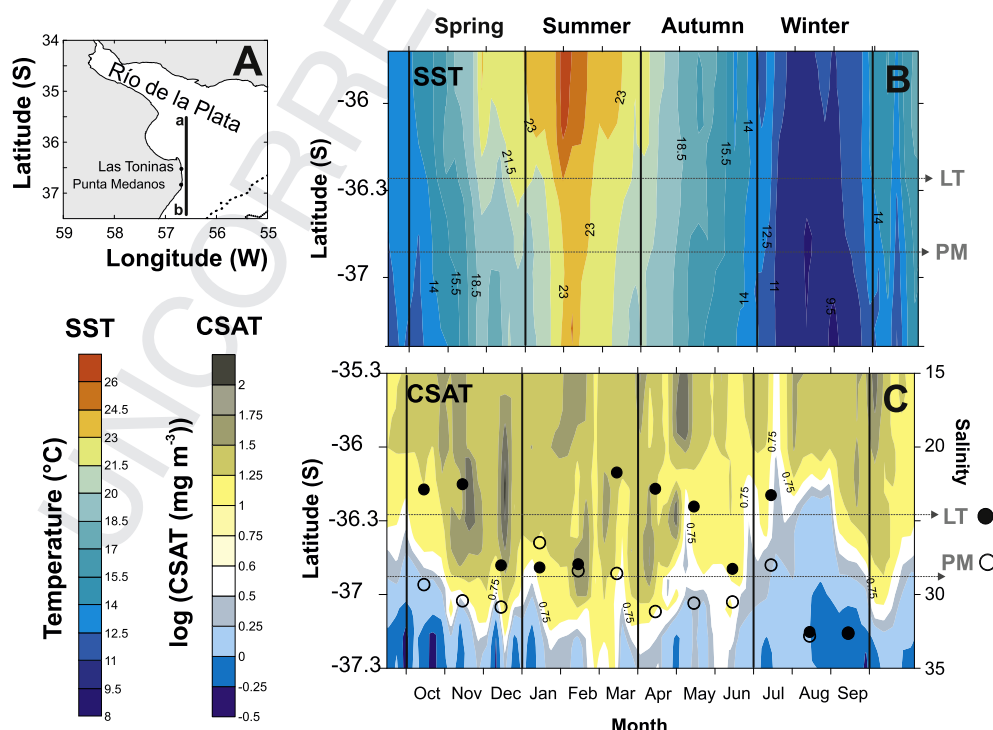

Fig. 1. A) Study area of the small-scale gillnet fishery of Río de la Plata, showing the sampling locations [sites Las Toninas (LT) and Punta Médanos (PM)] and location of the along-shore section (ab), B) Space–time plot of monthly sea surface temperature and C) monthly log (CSAT (mg m^{-3})) along section ab for the period of the study (2009–2010). The circles in C show the field salinity in the sampling location, Las Toninas (●) and Punta Médanos (○).

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their main environmental forcing (wind, freshwater discharge), 2) to identify and characterize the species composition of landings, their spatial and temporal variations, fishing effort and catch per unit effort (CPUE), and 3) to determine the relative importance of site, distance to coast, temperature and salinity in structuring the species composition of the landings over a 1 year period.

2. Materials and methods

Small-scale gillnet fishery landings were analyzed in Las Toninas and Punta Médanos (Fig. 1), two neighboring fishing communities at the southern boundary of the Río de la Plata. Monthly field sampling, each one extending for eight days, occurred during the period from October 2009 to September 2010. For each fisher trip, the species composition was sampled and the fishers were interviewed at the beach to obtain the main characteristics of fishing net (material, stretched mesh size), length of the net and catch time (in order to estimate the fishing effort), and also the distance from the shore (using GPS) where the fixed gillnet was soaked. The composition of the landings was identified to species and the total number of individuals by species was recorded. The average yield (CPUE) for each landed species was estimated as the number of fish landed by 100 m of gillnet during 24 h (Individuals/(100 m/24 h)).

The monthly variation in the main external forcing on environmental conditions (freshwater discharge, winds) and water conditions (temperature, salinity) along the coast were examined. The Río de la Plata monthly mean discharges were obtained from the Instituto Nacional del Agua y del Ambiente (INAA). We used Blended Sea Winds (BSW) from the National Climatic Data Center (NCDC; http://www.ncdc.noaa.gov/oa/rsad/air-sea/seawinds. html#data), in the Río de la Plata area spanning between 57° W and 55° W and between 37° S and 35° S. The BSW combine satellite wind observations with re-analyses and contain globally gridded, high resolution ocean surface vector winds on a global 0.25° grid with daily temporal resolution. The period used was from October 1st, 2009 to September 30th, 2010, and the wind direction is described according to meteorological convention (direction from which the wind comes). Winds were assembled into two groups considering the direction of the resulting flow into two groups, based on water circulation forced by local winds as described by Simionato et al. (2004): winds forcing an inflow or outflow of water into or from the estuary along the Argentine coast. The outflow of water (offshore and southward) results when the wind blows from directions between NNW (330°) and ESE (120°). The inflow of water (inshore and northward) occurs when the wind blows from directions between SSE (150°) and WNW (300°) (Simionato et al., 2004).

The water conditions (temperature and salinity) along the fishery grounds were examined with a space–time plot of daily satellite sea surface temperature (SST) and satellite-derived chlorophyll-a (CSAT) along a section through the RdP estuary (Fig. 1). The SST and CSAT isolines were obtained by inverse distance to a power interpolation onto a 0.1° lat grid. The SST and CSAT data were obtained from http://oceancolor.gsfc.nasa.gov (MODIS-Aqua Reprocessing R2013.0, provide by NASA Goddard Space Flight Center). We used MODIS daily 4-km Level 3 Standard Mapped Image (SMI). The CSAT data were used to estimate the southward extent of the Río de la Plata waters by relation with the salinity observed by Piola et al. (2008). The log (CSAT) range is associated with a sharp surface salinity transition across the offshore edge of the Río de la Plata plume from 28.5 to 32.5. Waters of surface salinity <31, derived from mixtures of Río de la Plata waters with continental shelf waters, are associated with log (CSAT) > 0.5 (Piola et al., 2008). During the field surveys, water samples at the beach were collected in Las Toninas and Punta Médanos (three by fishery

site) to estimate the salinity in the laboratory using an Autosal Guildline 8400B salinometer standardized with IAPSO standard seawater supplied by Ocean Scientific International Limited (OSIL) of the UK.

To characterize the seasonal activity of the small-scale gillnet fishery, different estimators of the fishing effort were considered (average number of fishermen, net length, catch time, and distance to the coast). A two-way analysis of variance (ANOVA), which considered the seasons as factors for classification and the different fishing effort estimators as predictor variables, was used to determine spatial and temporal differences among seasons. Different transformations were tried with the Bartlett test to verify the assumption of equal variances across samples required by the analysis of variance. In all trials the Bartlett test indicated significant heteroscedastic, therefore the ANOVA was applied using a $p = 0.01$ level of significance in order to maintain a greater control on the level of significance associated with the ANOVA. In the case of existing significant differences, comparisons a posteriori were done using the Scheffe's test.

To obtain a hierarchical structure of landed species, an Olmstead–Tukey diagram (Sokal and Rohlf, 1981) was used by season considering spring (October, November, December), summer (January, February, March), autumn (April, May, June), winter (July, August, September), and the annual landings. The dominant, frequent, rare and occasional species were determined from the relationship between the frequency of average occurrence of the species (number of times caught) and their CPUE (individuals/ (100 m/24 h)) $\log_{10}$ transformed.

The landed species by site (Las Toninas, Punta Médanos) and season were characterized using the similarity percentage procedure (SIMPER); species that on average contributed strongly to a site or season were quantified and ranked according to the method described by Clarke and Warwick (2001). To determine whether or not major shifts in the species composition of the landings occurred between sites or seasons, we used a non-parametric permutation-based one-way analysis of similarity (ANOSIM). Where appropriate, R-statistic values for pair-wise comparisons provided by ANOSIM were used to determine the dissimilarity between sites and seasons; values close to 1 indicate very different species composition, while values near zero show little difference. ANOSIM was used to test the null hypothesis that no changes in the species composition of the landings were observed between sites and seasons. In the cases in which a significant change was detected, we identified the species in the landings that were responsible for these differences. For each site and season we categorized target species as common or discriminators through the similarity percentage procedure (SIMPER, Clarke and Warwick, 2001). Species were considered common if they contributed to the top 50% of the average similarity within the site or season, whereas species were considered discriminators if they contributed to the top 90% of the dissimilarity between sites or seasons, and had a low ratio of average dissimilarity to its standard deviation.

To determine the influence of the fishing site, distance to the coast, temperature (SST) and salinity (across the relationship with CSAT, Piola et al., 2008) on the species composition of the landings we used a Multivariate Regression Tree analysis (MRT; Death 2002, Borcard et al., 2011). MRT is a multivariate method that can handle non-linear relationships between the response and explanatory variables or high-order interactions among explanatory variables (Death 2002; Borcard et al., 2011). The result of this analysis is a tree whose leaves (terminal groups of samples) are composed of subsets of sites chosen to minimize the within group sums of squares (Borcard et al., 2011). The selection of tree was done by cross-validation using '1se', that gives the best tree within one SE of the overall best. The predictive accuracy of the MRT was estimated

from the cross-validated relative error (CVRE, Borcard et al., 2011). As most species were occasional or rare, the MRT was developed using only the dominant and frequent species determined from the Olmstead−Tukey diagram (Table 1). ANOVA and MRT analyses were implemented using the *mvpart* and *labdsv* packages of the R statistical software (R Development Core Team, 2011).

3. Results

3.1. Environmental conditions

The sea surface temperature showed an annual cycle with maximum temperature (~24 °C) in summer, minimum in winter (~10 °C) and intermediate in the other seasons (spring and autumn). During the summer, SST also showed relatively small increases from the RdP estuary to the neighboring shelf region; as a consequence, the water temperature of Las Toninas and Punta Médanos showed weak differences (Fig. 1B). The salinity showed a cycle with higher values in winter (mean 31.27 ± 2.08), lower in autumn (mean 26.88 ± 3.61), and intermediate during spring (mean 28.52 ± 2.08) and summer (28.08 ± 2.75); in all seasons the salinity in Las Toninas was lower than in Punta Médanos (Fig. 1C). The salinity pattern obtained from samples collected on the beach is similar to the pattern obtained from the satellite-derived surface chlorophyll-*a* (CSAT) along the section over the study period. Note that the CSAT showed higher spatial and temporal variation than did the temperature along the same section (compare Fig. 1B and C). The space−time plot of log (CSAT) along the near-shore section indicate that the along coastal penetration of low salinity waters to fishing ground, is associated with log (CSAT) > 0.5 (CSAT > 3 mg m^{-3}), is maximum in austral summer and minimum in austral winter. The RdP southward penetration increased during spring, and the difference in salinity between the fishing localities (Las Toninas being lower than Punta Médanos) decreased as the season progressed. The high CSAT-low salinity water expansion was greatest in summer, with the result that both localities had similar and intermediate salinities. During winter, the RdP southward retreat was at its maximum and there was a northward penetration of high salinity waters (>31) into the fishing grounds, which was associated with log (CSAT) < 0.5 (CSAT > 3 mg m^{-3}) (Fig. 1C).

The anomalies of RdP mean monthly discharge (m^{3}s^{-1}) showed positive values over the study period. Seasonally, the maximum mean discharge occurred in summer (43,300 m^{3}s^{-1}), followed by autumn (31,766 m^{3}s^{-1}), spring (29,400 m^{3}s^{-1}) and winter (22,166 m^{3}s^{-1}) (Fig. 2A). The wind pattern observed over the year showed a dominance of inflow winds (outflow winds) that produce inflows of brackish (marine) water to the fishing ground (estuary) along the coast, from October to March (spring−summer). From April to August (Autumn−Winter), there was a weak balance in the occurrence (~50%) among inflow and outflow winds (Fig. 2B). The monthly average wind speed of inflow and outflow winds showed inverse patterns. Inflow wind speeds increased from October to August [minimum in spring (average 5.08 m/s) and maximum in winter (average 7.11 m/s)], whereas the average outflow wind speed was maximum in spring and summer (average 6.04 and 6.86 m/s respectively) and minimum in autumn and winter months (average 5.82 and 5.43 m/s respectively) (Fig. 2B).

3.2. Fishing effort

A total of 243 samples of small-scale fishery catches were obtained between October 2009 and September 2010 exclusively using gillnets of nylon (0.60 mm) with stretched mesh ranging from 90 to 120 mm and 2 m high. The annual average number of fishermen considered in this study was 12 (Fig. 3), with a decrease from October to March (the minimum) followed by an increase to a peak of 25 in August. The average monthly soak time showed significant differences among all seasons ($p < 0.01$) with higher values (average $\pm$ SD) in summer (21.2 ± 4.5 h) and spring (17.8 ± 6.5 h), and lower values in autumn (12.6 ± 6.8 h) and winter (8.7 ± 8.1 h). During the course of the study, the average gillnet length (Fig. 3) did not show significant differences between autumn and winter ($p = 0.977$), but it was significantly different from the two warm seasons; there were significant differences as well between the warm seasons ($p < 0.01$). The minimum net length was used in summer (375 ± 181.1 m) and spring (511.6 ± 251.4 m), increased in winter (667.3 ± 330.1 m), and showed a maximum in autumn (691.6 ± 322 m). The shortest distance to the coast where the nets were soaked only changed significantly between spring (3443.12 ± 2048 m) and the rest of seasons ($p < 0.01$). Although the distance to the coast did not show significant differences between seasons, on average it was farthest in autumn (5106.7 ± 2197 m), intermediate in summer (4850.6 ± 1870 m) and winter (4447.1 ± 2534.3 m) and closest in spring (Fig. 3).

3.3. Faunal composition

A total of 111569 fish belonging to 38 species (13 Chondrichthyes and 25 Osteichthyes) and 26 families were sampled from the landings between 2009 and 2010. The Sciaenidae was the most important family, represented by 6 species, followed by Triakidae, Myliobatidae, Rajidae, Stromateidae, Paralichthyidae and Triglidae, each of which was represented by only 2 species. According to the Olmstead−Tukey (O-T) diagram, most species ($n = 29$) were rare (76.3%), five species were frequent (13.2%) and four species were dominant (10.5%) (Table 1, Fig. 4). The four dominant species were *Cynoscion guatucupa*, *Micropogonias furnieri*, *Mustelus schmitti* and *Parona signata*, which were present in more than 70.42% of all landings and represented 98.6% of total abundance for all landings (Fig. 4, Table 1).

The species caught showed different trends in CPUE and occurrence throughout the year, suggesting a seasonal pattern (Table 1, Fig. 5). Some species categorized as rare at the annual level were actually frequent in one or two seasons. *Squalus acanthias*, *Callorhinchus callorhynchus* and *Galeorhinus galeus* had higher yields and occurred during late winter (September), *Trichiurus lepturus* had its maximum CPUE and occurrence during summer and autumn, and *Stromateus brasiliensis* was occasional in spring and frequent in winter. The dominant and frequent species also showed annual trends in their landings with the maximum in one season, for example *Cynoscion guatucupa* and *Micropogonias furnieri* in winter, *Mustelus schmitti* in early spring, and *Squatina guggenheim* in autumn, or in two seasons such as *Parona signata* which had higher landings during winter and spring (Fig. 5).

3.3.1. Seasonal composition of landings

The seasonal yield showed significant differences (ANOSIM, $p < 0.05$) among most of the seasons, except during autumn when compared with spring and winter respectively. The seasonal yield showed an average similarity, between 56.18% and 64.97%, being higher during winter and spring (Table 2, SIMPER analysis). *Cynoscion guatucupa*, *Micropogonias furnieri*, *Parona signata*, and *Macrodon ancylodon* (during spring and summer), and *Mustelus schmitti* (in autumn and spring) mainly contributed to the higher average similitude in the yields for all seasons (Table 2). Although 70% of similitude was represented by almost the same species, the seasonal yield showed differences in their structure with different discriminator species (Table 3). The spring landings were discriminated by *Stromateus brasiliensis*, *Porichthys porosissimus* and *Mugil* sp., summer landings were discriminated by *M. ancylodon* and

Table 1

Seasonal average yield (Individual/(100 m/24 h)) and occurrence (OC) of species caught by the small-scale fishery along the boundary of Río de la Plata, indicating their class, family, estuarine use functional group (EUFG) suggested by Elliott et al. (2007) [estuarine (es), marine stragglers (ms), marine migrants (mm), anadromous (an)] and their category according to the Olmstead–Tukey (O-T C) diagram (D, dominant; F, frequent; R, rare; O, occasional).

| Class	Family	Specie	EUFG	Spring			Summer			Autumn			Winter			Annual		
				Yield	OC	O-T C	Yield	OC	O-T C	Yield	OC	O-T C	Yield	OC	O-T C	Yield	OC	O-T C
Chondrichthyes																		
	Callorhinchidae	Callorhinchus callorhynchus(Linnaeus, 1758)	ms	0.044	11.39	R				0.004	2.78	R	0.240	26.76	F	0.086	12.08	R
	Hexanchidae	Notorynchus cepedianus (Péron, 1807)	ms	0.138	24.05	F	0.023	9.26	R	0.107	16.67	R	0.028	8.45	R	0.075	15.00	R
	Myliobatidae	Myliobatis goodei Garman, 1885	mm	0.027	5.06	R	0.020	5.56	R	0.034	8.33	R	0.008	1.41	R	0.021	4.58	R
		Myliobatis spp.	mm							0.011	5.56	R	0.009	4.23	R	0.004	2.08	R
	Narcinidae	Discopyge tschudii Heckel, 1846											0.011	1.41	R	0.003	0.42	R
	Odontaspididae	Carcharias taurus Rafinesque, 1810	ms				0.008	3.70	R				0.002	1.41	R	0.002	1.25	R
	Rajidae	Atlantoraja castelnaui (Miranda Ribeiro, 1907)	ms	0.024	5.06	R							0.010	2.82	R	0.011	2.50	R
		Sympterygia bonapartii Müller & Henle, 1841	mm	0.005	3.80	R										0.002	1.25	R
	Rhinobatidae	Rhinobatos horkelii Müller & Henle, 1841	ms	0.003	1.27	R										0.001	0.42	R
	Squalidae	Squalus acanthias Linné, 1758	ms	0.630	10.13	R	0.004	1.85	R	0.384	16.67	R	1.309	36.62	F	0.653	17.08	R
	Squatinidae	Squatina guggenheim Marini, 1936	mm	0.569	73.42	F	0.565	66.67	F	1.714	77.78	F	0.104	19.72	F	0.602	56.67	F
	Triakidae	Galeorhinus galeus De Buen 1950	ms	0.071	13.92	R							0.437	21.13	F	0.153	10.83	R
		Mustelus schmitti Springer, 1939	mm	12.579	91.14	D	3.780	64.81	D	42.995	97.22	D	27.858	38.03	D	19.682	70.42	D
Osteichthyes																		
	Ariidae	Genidens barbus (Lacépede, 1803)	an	0.185	25.32	F	0.404	37.04	F	0.106	22.22	R				0.168	20.00	F
	Batrachoididae	Porichthys porosissimus (Valenciennes, 1837)	ms	0.562	3.80	R				0.115	13.89	R	0.698	18.31	F	0.409	8.75	R
	Carangidae	Parona signata (Jenyns, 1842)	mm	9.989	73.42	D	4.853	83.33	D	5.307	75.00	D	14.011	63.38	F	9.321	72.92	D
	Cheilodactylidae	Nemadactylus bergi (Norman, 1937)	ms							0.031	5.56	R	0.000	0.00		0.005	0.83	R
	Clupeidae	Brevoortia aurea (Agassiz, 1829)	es	0.106	10.13	R	0.209	20.37	F	0.465	19.44	R	1.017	14.08	R	0.452	15.00	R
	Congridae	Conger orbignyanus Valenciennes, 1847	ms	0.021	3.80	R	0.009	3.70	R	0.014	5.56	R				0.011	2.92	R
	Engarulidae	Lycengraulis grossidens (Agassiz, 1829)	an				0.006	1.85	R							0.001	0.42	R
	Mugilidae	Mugil platanus Günther, 1880	es	0.146	17.72	R	0.016	3.70	R							0.052	6.67	R
	Paralichthyidae	Paralichthys orbignyanus (Valenciennes, 1939)	es				0.011	3.70	R	0.010	2.78	R				0.004	1.25	R
		Paralichthys patagonicus Jordan, 1889	mm	0.003	1.27	R										0.001	0.42	R
	Percophidae	Percophis brasiliensis Quoy and Gaimard, 1824	ms	0.011	2.53	R	0.002	1.85	R	0.009	5.56	R	0.033	7.04	R	0.015	4.17	R
	Phycidae	Urophycis brasiliensis (Kaup, 1858)	ms	1.379	59.49	F	0.945	62.96	F	0.518	47.22	F	0.056	12.68	R	0.761	44.58	F
	Pomatomidae	Pomatomus saltatrix (Linné, 1758)	ms	0.017	7.59	R	0.019	1.85	R	5.883	52.78	D	0.202	8.45	R	0.952	13.33	R
	Sciaenidae	Cynoscion guatucupa (Cuvier, 1830)	mm	75.918	97.47	D	31.343	90.74	D	41.648	97.22	D	517.834	98.59	D	191.482	96.25	D
		Macrodon ancylodon Schneider, 1801	es	1.314	45.57	F	1.294	50.00	F	1.295	38.89	F				0.918	32.08	F
		Menticirrhus americanus (Linné, 1758)	es	0.039	11.39	R	0.049	11.11	R	0.137	19.44	R	0.023	2.82	R	0.051	10.00	R
		Micropogonias furnieri (Desmarrest, 1823)	es	30.597	97.47	D	12.995	96.30	D	32.727	97.22	D	186.285	90.14	D	73.014	95.00	D
		Paralonchurus brasiliensis (Steindachner, 1875)	es	0.002	1.27	R							0.000	0.00		0.001	0.42	R
		Umbrina canosai Berg, 1895	ms	0.734	22.78	F	0.137	12.96	R	2.370	36.11	F	9.394	45.07	F	3.407	29.17	F
		Acanthistius brasilianus (Valenciennes, 1828)	ms							0.056	8.33	R				0.008	1.25	R
	Stromateidae	Peprilus paru (Linné, 1758)	ms	0.003	1.27	R				0.017	2.78	R	0.000	0.00		0.003	0.83	R
		Stromateus brasiliensis (Fowler, 1906)	mm	4.420	10.13	O	0.002	1.85	R	1.579	13.89	R	1.702	22.54	F	2.196	12.50	R
	Trichiuridae	Trichiurus lepturus Linné, 1758	ms				0.185	40.74	F	0.328	27.78	F				0.091	13.33	R
	Triglidae	Prionotus nudigula Ginsburg, 1950	ms							0.568	16.67	R				0.085	2.50	R
		Prionotus punctatus (Cuvier 1829)	mm	0.060	10.13	R	0.033	5.56	R	0.044	8.33	R	0.311	8.45	R	0.126	8.33	R
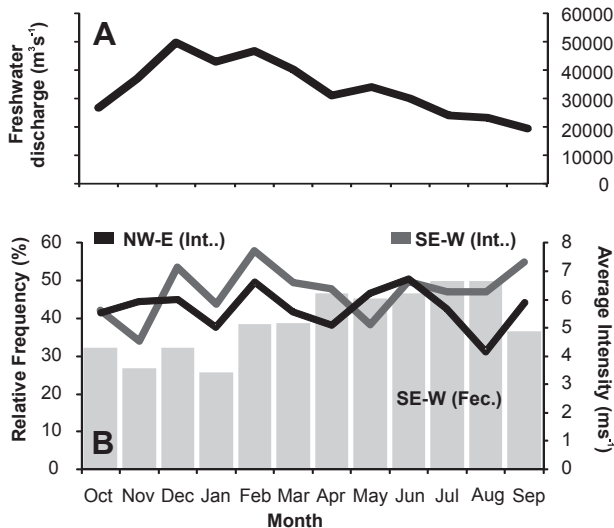
Fig. 2. A) Río de la Plata (RdP) monthly mean freshwater discharges. B) Climatological frequency and wind stress fields derived from monthly mean Blended Sea Winds (BSW, National Climatic Data Center), for Río de la Plata area (57°–55° W, 37°–35° S), clustered in winds forcing an inflow [SSE (150°) − WNW (300°)] or outflow [NNW (330°) − ESE (120°)] of water from the Río de la Plata (see Simionato et al., 2004). Bar plot represents the monthly average wind speed.

Genidens barbus, autumn landings by *M. schmitti*, *Pomatomus saltatrix* and *Trichiurus lepturus*, and winter landings by *C. guatucupa*, *M. furnieri*, *Umbrina canosai*, *P. signata*, *Squalus acanthias*, *Prionotus punctatus* and *Callorhinchus callorhynchus* (Table 3).

3.3.2. Spatial composition

The species composition of landings showed significant differences between sites (ANOSIM, $p = 0.007$). Species composition at Las Toninas showed an average similitude of 56.7%, with the species that contributed the most to the similitude of catch landing

composition being *Micropogonias furnieri*, *Cynoscion guatucupa* and *Parona signata*. The Punta Médanos landing species composition showed a little higher similitude (59.6%), with *M. furnieri*, *C. guatucupa*, *P. signata*, *Mustelus schmitti* contributing most to the average similitude (Table 2). The main differences among the species composition of the landings between sites (90% dissimilitude) were determined by higher landings of *Macrodon ancylodon*, *Urophycis brasiliensis*, *Genidens barbus* and *Trichiurus lepturus* in Las Toninas, and *C. guatucupa*, *M. schmitti*, *Stromateus brasiliensis*, *M. furnieri*, *Umbrina canosai*, *P. signata*, *Squalus acanthias*, *Brevoortia aurea*, *Squatina guggenheim*, *Pomatomus saltatrix*, *Porichthys porosissimus* and *Prionotus punctatus* in Punta Médanos (SIMPER, Fig. 6).

3.4. Environmental influence on the species composition of the landings

The Multivariate Regression Tree analysis (MRT) of the CPUE data set produced a tree with five leaves (Fig. 7); each of the four splits had different predictor variable. The overall fit of the MRT, defined by the relative error, was 30.83%, and the MRT predictive accuracy, estimated from the cross-validated relative error (CVRE), was 23.12%. The first split explained 18.78% of the variance, the second split 4.88%, and third and fourth split explained the 4.27% and 2.88% of variance.

The groups from the MRT revealed a strong environmental influence in the small-scale fishery yields, which first split the temperature <11.4 °C. The differences between the groups for this branch are mainly based on the higher abundances of *Cynoscion guatucupa*, *Micropogonias furnieri* and *Umbrina canosai* in colder waters. The group corresponding to warm waters (≥11.4 °C) was further split by the landing site. This split was explained by higher abundances of *C. guatucupa*, *Mustelus schmitti* and *Parona signata* in Punta Médanos and by higher abundances of *Macrodon ancylodon* and *Urophycis brasiliensis* in Las Toninas. Additionally, Punta Médanos landings were first split in temperatures <18.3 °C, based on the predominance of *M. schmitti* and *U. canosai*, and the warm waters after were split by the salinity. The landing during the salty
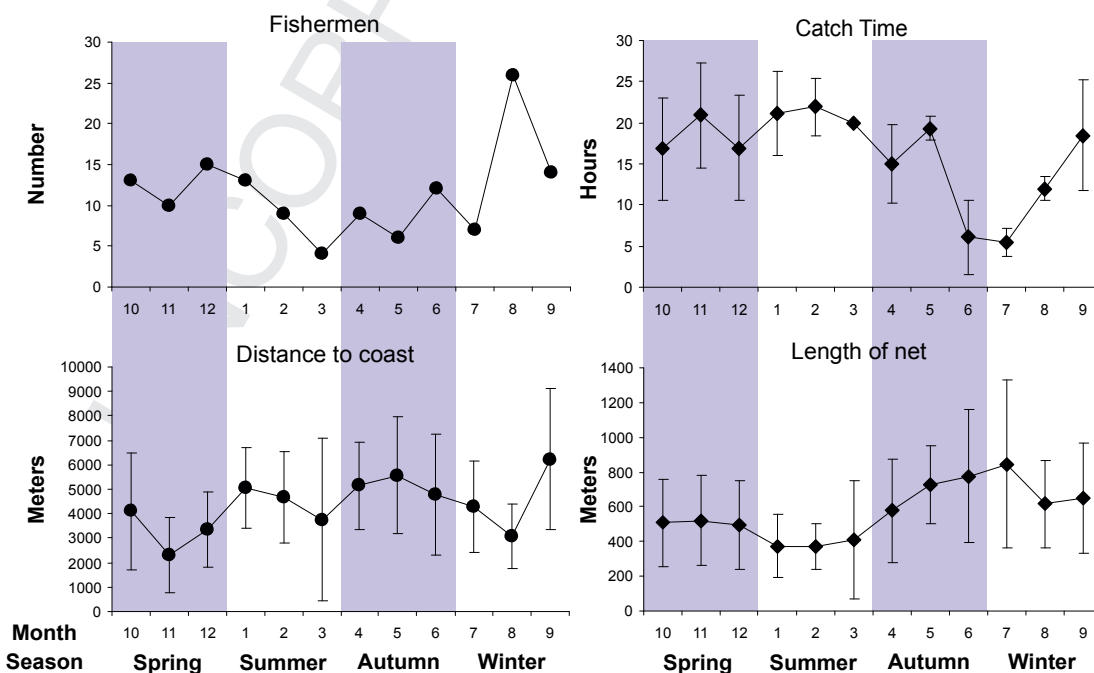

Fig. 3. Monthly trends of the estimators for fishing effort of a small-scale gillnet marine fishery from Río de la Plata (Argentina). The numbers on the *x* axis represent months.
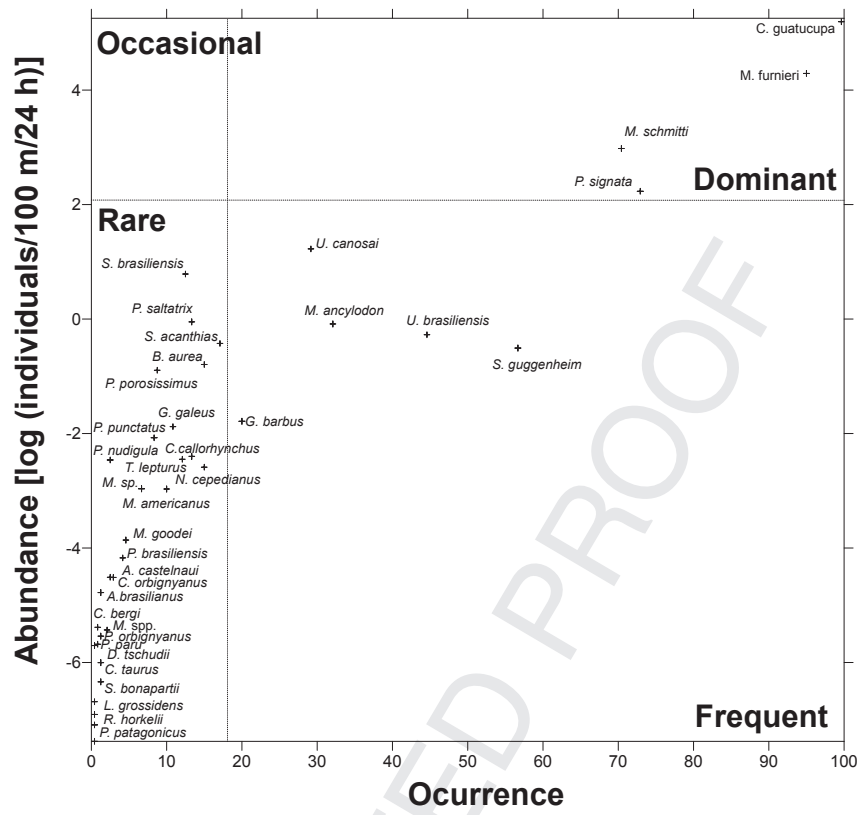
Fig. 4. Olmstead–Tukey diagram showing the relationship between frequency and abundance of the species landed in the small-scale fishery of Río de la Plata between 2009 and 2010. The black lines correspond to the mean abundance (vertical) and occurrence (horizontal), and are used to define the occasional, dominant, rare and frequent species. Species names are defined in Table 1.

waters (Log (CSAT) < 1.022) were predominated by *Squatina guggenheim* and *Genidens barbus,* and during the dominance of brackish (Log (CSAT) ≥ 1.022) waters by *P. signata*, *M. furnieri*, and *U. brasiliensis*.

4. Discussion

This study has shown that the small-scale gillnet fishery along the southern boundary of Río de la Plata (RdP) is based on a few species and that the variability in the fishery landings suggest that certain species become more or less catchable by the gillnet over the course of the year. The fishing effort and resource use by the small-scale gillnet fishery appears to be conditioned by the availability of resources in the fishing grounds. This, in turn, results from the combination of the species reproductive behavior and the predominant environmental conditions mainly determined by the location of RdP boundary, whose spatial extent is mainly forced by the wind patterns and freshwater discharge. Most of the landed species were rare (76.3%), with five species frequent (13.2%) and only four species were dominant (*Cynoscion guatucupa*, *Micropogonias furnieri*, *Mustelus schmitti* and *Parona signata*) accounting for 98.6% of total landings. These species are identified as the most typical species of the RdP estuarine and inner coastal assemblages of Argentina (Jaureguizar et al., 2006b), and belong to the varied coastal fishing group (depths less than 50 m) which is shared with the industrial trawl fishery. The increase in fishing effort (length of net/h) during winter months and the inverse relationship observed between catch time and length of soaked gillnet, taking into account that the fishing area and the net characteristics were constant throughout the year, indicates that this trend may be associated with the relative abundance of fish. During the winter, the season with the highest average yield (761.58 Individual/(100 m/24 h)), the fishermen soaked gillnets for a shorter time but used longer nets. In contrast, when the CPUE decreased and reached the lowest values during summer (56.91 Individual/(100 m/24 h)), the fishermen preferred to soak their gillnets for longer but using shorter nets.

The RdP small-scale gillnet fishery showed a multispecific nature which is different from the gillnet fishery developed in San Blas Bay (40°36′ S 62°08′ W), southern coastal area, which is monospecific and active mainly from October to December (Llompart, 2011). Although both fisheries captured the same coastal fish assemblage (Jaureguizar et al., 2006b; Llompart et al., 2013) and used the same net (90–120 mm), the RdP gillnet fishery landings were mostly based on *Cynoscion guatucupa*, *Micropogonias furnieri*, *Mustelus schmitti* and *Parona signata*, which represented ~93% of spring landings composition, while in the San Blass gillnet fishery 96% of spring landings consisted of *M. schmitti*. This difference can be related to the high aggregation of this small shark during its mating and reproduction time, when adults enter the bay during spring and remain until the summer (Colautti et al., 2010). The RdP gillnet fishery also showed significant decadal differences in the species composition of the landings. During the course of the present study (2009–2010) more species were landed ($n = 38$) than was recorded in 1999 ($n = 14$; Lagos, 2001). The species that contributed the most to the small-scale landings during 1999 (Lagos, 2001) were the same as the ones observed in this study; however, the species composition of the landings showed strong differences. The small-scale landings mainly consisted of *M. furnieri* and *P. signata* in 1999, while in 2009–2010 the main species landed
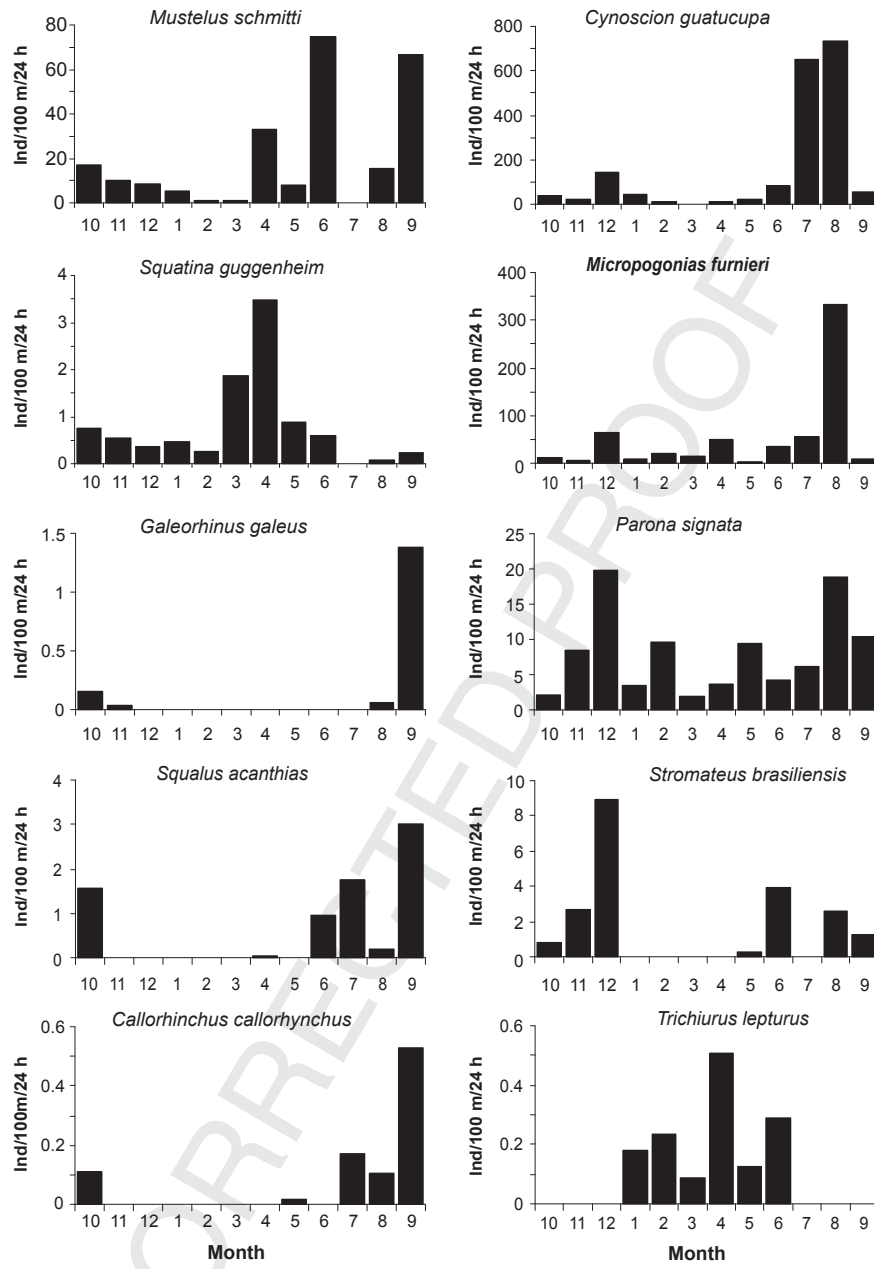
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Fig. 5. Monthly yield (Ind/(100 m/24 h)) of some species landed in the small-scale gillnet fishery of Río de la Plata. Note the different scales of CPUE (y) axis. The numbers on the x axis represent months.

was *C. guatucupa*, which represented 55% (summer), 30% (autumn), 68% (winter) and 54% (spring) of total seasonal landings. *Micropogonias furnieri* and *P. signata* showed an important decline in their contributions to the total landings after 10 years. The contribution of *M. furnieri* declined from 64% to 22% in summer, from 46% to 24% in autumn, from 28% to 23% in winter, and from 64% to 22% in spring. Furthermore, *P. signata* showed a similar pattern, falling from 17% to 8.5% in summer, from 44% to 3.8% in autumn, and from 51% to 1.8% in winter. The decadal differences in the landing profiles are likely to be associated with strong declines in all traditional fishery resources (*i.e. M. furnieri*, *C. guatucupa*, *M. schmitti*) as a result of the fishing down marine food webs process in the Argentinean–Uruguayan Common Fishing Zone (Milessi et al., 2005; Jaureguizar and Milessi, 2008). The main coastal fishery resource, *M. furnieri*, is targeted by different fisheries (artisanal,

coastal and shelf) and the available information indicates that it is in a critical state (Carozza et al., 2004; Carozza, 2010), overexploited (Vasconcellos and Haimovichi, 2006), or fully exploited at a higher level than its biological potential (Carozza and Rey, 2010). Similar differences were observed in the 1990s for the artisanal fishery in the Bahia Blanca estuary (39° S), south of Buenos Aires province (López Cazorla et al., 2014), where the catches of *C. guatucupa* dropped from 50% of total annual landings in the early 1990s to 15% at the end of the 1990s. This fishery subsequently collapsed between 2000 and 2004, possibly as a result of overfishing by the industrial trawling fleet in the El Rincon area. The decreasing catch of the main fished species together with the decreasing options to diversify catches could be the cause of the observed reduction in the landings by-catch, because of the need to increase income from the traditional fisheries products and maintain fishing activities.

Table 2
Contribution (%) of common species (90% similitude, defined by SIMPER analysis) to seasonal yields and fishing sites of small-scale fishery along the boundary of Río de la Plata. SP indicate the average similitude (AS) of yield by season. Values in bold indicate the species that contributed to top 70% of similitude.

Specie	Spring AS: 64.97	Summer AS: 60.74	Autumn AS: 56.18	Winter AS: 61.45
Brevoortia aurea	1.8	2.57	2.56	0.25
Cynoscion guatucupa	**23.21**	**17.73**	**19.38**	**38.45**
Genidens barbus	1.31	3.68	1.81	<0.1
Macrodon ancylodon	**5.71**	**13.85**	5.5	<0.1
Micropogonias furnieri	**17.97**	**27.19**	**19.33**	**25.52**
Mugil sp.	2.51	<0.1	<0.1	<0.1
Mustelus schmitti	**14.36**	9.25	**15.16**	2.78
Parona signata	**11.34**	**12.54**	**17.8**	**15.48**
Squatina guggenheim	3.69	3.22	7.03	0.19
Stromateus brasiliensis	5.05	<0.1	0.35	0.97
Trichiurus lepturus		3.25	1.89	<0.1
Umbrina canosai	2.55	0.91	1.5	10.28
Urophycis brasiliensis	4.87	4.36	3.68	0.13

Specie	Las Toninas AS: 56.70	Punta Médanos AS: 59.04
Micropogonias furnieri	**27.52**	20.27
Cynoscion guatucupa	**25.73**	**22.65**
Parona signata	**17.54**	13.22
Macrodon ancylodon	7.35	3.24
Mustelus schmitti	5.95	**15.6**
Urophycis brasiliensis	4.31	2.33
Squatina guggenheim	2.92	3.42
Stromateus brasiliensis	<0.1	4.15
Umbrina canosai	<0.1	5.81

However, the recent collapse in the *C. guatucupa* artisanal fishery (López Cazorla et al., 2014) together with the increasing industrial fishing effort (double the number of vessels and quadruple the fishing hours compared with the 1990s) targeting *C. guatucupa* in the Rio de la Plata area (Ruarte et al., 2000) puts at risk the future of this small-scale gillnet fishery based on *C. guatucupa*.

Considering the estuarine use functional group suggested by Elliott et al. (2007), the species composition of the landings reflects the influence of brackish water on the small-scale fishery, where 18% of species were estuarine and the rest were marine migrants (26%), marine stragglers (50%) or anadromous (4%). In all functional groups, the species classified as rare (low abundance and occurrence) were predominant and they are mostly batoidea (*Atlantoraja. castelnaui*, *Sympterigia bonapartii*, *Rhinobatos horkelii*, *Myliobatis goodie*, *Myliobatis* spp., *Discopyge tschudii*), large sharks (*Carcharias taurus*), flatfish (*Paralichthys patagonicus*, *Paralichthys orbignyanus*) and cylindrical fish (*Conger orbignyanus*, *Percophis brasiliensis*). Several authors distinguished the presence of these species in the shallow coastal waters (<25 m depth), which are used as nursery, mating (Mabragaña et al., 2002; Massa et al., 2004; Colonello et al., 2007) or spawning areas (Macchi and Acha, 1998; Militelli and Macchi, 2006; Rodrigues et al., 2007; Militelli, 2011). The low abundance and occurrence of these rare species in the small-scale landings could be associated with the low catchability of bottom gillnets when used for these kinds of species. In the artisanal elasmobranch fishery of Sonora (Mexico), Bizzarro et al. (2009) denoted an important landing of batoids (*Rhinobatos productus*, *Dasyatis dipterura*, *Gymnura* spp. and *Rhinoptera steindachneri*) using gillnets with mesh size from 8.9 to 33.0 cm. Therefore, the smaller mesh size used in the artisanal fishery in the study area considered here (90–120 mm) could explain the low susceptibility of large rays and skates.

The fishing grounds of this small-scale gillnet fishery coincide with the RdP boundary between the estuarine and marine systems where the 30 isohaline intersects the bottom (Guerrero et al., 1997b; Framiñan et al., 1999), and represents the boundary for marine species intrusions into the estuary (Jaureguizar et al., 2003b, 2006b, 2007; García et al., 2010; Barletta et al., 2010). Similar results were observed at Chesapeake Bay and Delaware Bay (Bulger et al., 1993; Able et al., 2001), where the 25–27 isohaline was identified as the edge of the brackish water for the strictly marine species. The location of the salinity front differs on average 100 km along the Argentine coast between winter (~36° S) and spring (~37° S) (Jaureguizar et al., 2007), associated with the combined influence of the seasonal distribution of shelf water masses in the Southwestern Atlantic Coastal System and the discharge pattern of RdP, which is coupled to the wind seasonality and regulated by the bathymetry and the Coriolis force (Lucas et al., 2005). Within each season, the location of the front is also strongly associated with the blended influence of synoptic wind stress and freshwater discharge (Jaureguizar et al., 2007). During spring, the minimum southward intrusion of RdP into the coastal system (36° 42′ S, near Las Toninas) occurred when outflow wind stress was weak (4.8 m/s, from 120° to 85°) and freshwater discharge was low (~19,000 m^3s^{-1}); the intrusion was maximum (37° 36′ S, covering the fishing ground) when the freshwater discharge was higher (~22,000 m^3s^{-1}). Under similar freshwater discharge, the along-shore wind stress associated with opposite wind conditions drove an intermediate intrusion (37° 18′ S) of RdP into the coastal system (Jaureguizar et al., 2007). This seasonal movement of the salinity front, which constitutes the boundary between the estuarine and marine systems, mean that the small-scale gillnet fishery is in fact a trans-ecosystem fishery.

During the study period, the environmental conditions were characteristic of El Niño Southern Oscillation (ENSO) event. The ENSO warm phase (El Niño) from austral winter (June–August) 2009 to austral autumn (March–May) 2010 was moderate (Wang et al., 2012). El Niño episodes produce excess precipitation in southern Brazil, Uruguay and northeast Argentina which directly affects runoff and stream flow in the major rivers of the region (Mechoso and Perez-Iribarren, 1992). This event would explain the higher than mean [RdP mean = 24,000 m^3s^{-1} (Jaime et al., 2002), RdP Q_3 = 28,000 m^3s^{-1} (Guerrero et al., 2010)] freshwater discharge, with maximum discharge in December (49,800 m^3s^{-1}), that produced the observed fresher water and warmer temperatures throughout the year. This variation coincided with the change of salinity and temperature observed under Low/Normal/High freshwater discharge of RdP (Guerrero et al., 2010). Although the temperature showed a pronounced seasonal cycle, typical of temperate regions, it was warmer than the seasonal mean obtained over the long term for this coastal region (Guerrero et al., 1997a, 2010). The waters showed temperatures higher than 21 °C in summer (mean 21.21 °C, Guerrero et al., 1997a) and 11 °C in winter (mean 9 °C, Guerrero et al., 1997a). The observed seasonal salinity pattern coincided with the salinity cycle denoted for this coastal region (Guerrero et al., 1997a, 2010), with maximum southward brackish water extent in summer and minimum in winter as reflect by the CSAT pattern (Fig. 1). The nearshore salinity values mostly reflect that influence, where the lowest salinities occurred in autumn (26.88 ± 3.61), intermediate in spring (28.52 ± 3.3) and summer (28.08 ± 2.75), and the highest in winter (31.27 ± 2.08). However, the summer salinity field value did not reflect the CSAT pattern. The higher than expected salinity from the sample collected at the beach may have been due to higher evaporation in the shallow (<1 m) than in deeper waters. The wind pattern observed throughout the year, which showed a weak balance in the occurrence (~50%) among inflow and outflow winds (Fig. 2B), coincided with the general wind pattern described by several authors for RdP (Guerrero et al., 1997a,b; Simionato et al., 2004; Lucas et al., 2005). Therefore, under the normal wind conditions observed during this study, the higher RdP discharge intensified the warm

Table 3

Discriminate species (90% of dissimilitude) determined by SIMPER analysis for seasonal yield of small-scale fishery along the boundary of Río de la Plata. (Species in bold are manly diagnostic of season of top column).

	Spring	Summer	Autumn	Winter
Spring		**Macrodon ancylodon** *Brevoortia aurea* **Genidens barbus** *Trichiurus lepturus*	**Mustelus schmitti** *Umbrina canosai* *Macrodon ancylodon* **Pomatomus saltatrix** *Brevoortia aurea* *Squatina guggenheim* **Trichiurus lepturus** *Genidens barbus*	**Cynoscion guatucupa** **Micropogonias furnieri** **Umbrina canosai** **Parona signata** **Squalus acanthias** *Brevoortia aurea* **Prionotus punctatus** **Callorhinchus callorhynchus** *Galeorhinus galeus*
Summer	**Stromateus brasiliensis** *Cynoscion guatucupa* *Mustelus schmitti* *Parona signata* *Micropogonias furnieri* *Umbrina canosai* *Urophycis brasiliensis* *Squalus acanthias* **Porichthys porosissimus** **Mugil** sp. *Squatina guggenheim* *Prionotus punctatus* *Myliobatis goodei*		**Mustelus schmitti** *Cynoscion guatucupa* *Micropogonias furnieri* *Parona signata* **Pomatomus saltatrix** *Umbrina canosai* *Squatina guggenheim* *Brevoortia aurea* *Stromateus brasiliensis* **Trichiurus lepturus** *Menticirrhus americanus*	**Cynoscion guatucupa** *Mustelus schmitti* **Umbrina canosai** **Micropogonias furnieri** **Parona signata** **Squalus acanthias** *Stromateus brasiliensis* *Porichthys porosissimus* **Callorhinchus callorhynchus** **Prionotus punctatus**
Autumn	**Stromateus brasiliensis** *Cynoscion guatucupa* *Micropogonias furnieri* *Parona signata* *Squalus acanthias* *Urophycis brasiliensis* **Porichthys porosissimus** **Mugil** sp. *Prionotus punctatus*	**Macrodon ancylodon** *Urophycis brasiliensis* **Genidens barbus**		**Cynoscion guatucupa** **Micropogonias furnieri** **Umbrina canosai** **Parona signata** *Stromateus brasiliensis* **Squalus acanthias** *Porichthys porosissimus* **Callorhinchus callorhynchus** **Prionotus punctatus**
Winter	*Mustelus schmitti* **Stromateus brasiliensis** *Macrodon ancylodon* *Urophycis brasiliensis* **Porichthys porosissimus** **Mugil** sp. *Squatina guggenheim*	**Macrodon ancylodon** *Brevoortia aurea* *Urophycis brasiliensis* **Genidens barbus** *Squatina guggenheim*	**Mustelus schmitti** *Macrodon ancylodon* *Squatina guggenheim* **Pomatomus saltatrix** *Brevoortia aurea* *Urophycis brasiliensis* **Trichiurus lepturus**	

(spring-summer) conditions with longer and greater southward spatial coverage of brackish water, which intensified the trans-ecosystem fishery.

The predominant environmental conditions along the fishing grounds would affect the fishing calendar. Kalikoski et al. (2010)
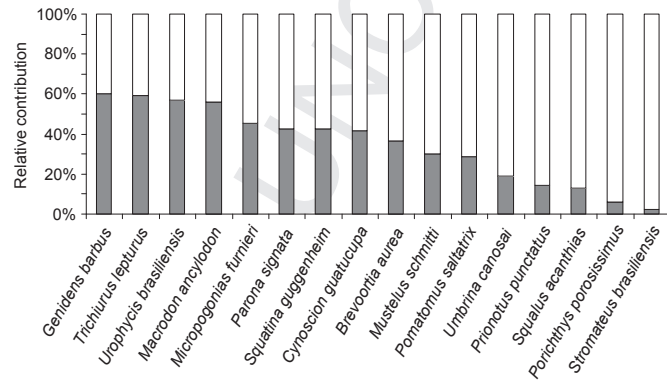

Fig. 6. Relative contributions of discriminate species (SIMPER analysis) of Las Toninas (grey) and Punta Médanos (white) artisanal fishery yield.

noted that the artisanal fishing calendar in the estuary of Patos Lagoon (Brasil) is, according to fishers, strongly affected by the strength of the intrusion of salt water and the rainfall regime. However, studies in the southwest Atlantic coastal system, *e.g.* San Blas Bay (Llompart et al., 2013) and marine coastal areas of Brazil (Pinheiro et al., 2009) found that the temporal variation in fish assemblages was mainly related to reproductive activities. Since the temporal pattern of fish species behavior in for a coastal region is influenced by both physical and biological conditions, it follows that these conditions must also influence the fishing calendar. The highest CPUE of some species occurs before (*Micropogonias furnieri, Cynoscion guatucupa, Parona signata*) or during (*Mustelus schmitti, Squatina guggenheim*) the reproductive period, whereas in other species it appears to be associated with favorable environmental conditions during cold months (*Squalus acanthias, Callorhinchus callorhynchus, Galeorhinus galeus*) or warm months (*Trichiurus lepturus*). Therefore, the blend of the species reproductive behavior and the influence of water mass movements, forced by regional-scale processes, would explain the pattern in the landings species composition observed in the RdP small-scale gillnet fishery.

The first group of species (*Micropogonias furnieri, Cynoscion guatucupa, Parona signata*) has the reproductive period from November to March (Austral spring–summer) (Macchi and Christiansen, 1996; Militelli, 2007), and during this time the individuals move to spawning grounds adjacent to the small-scale
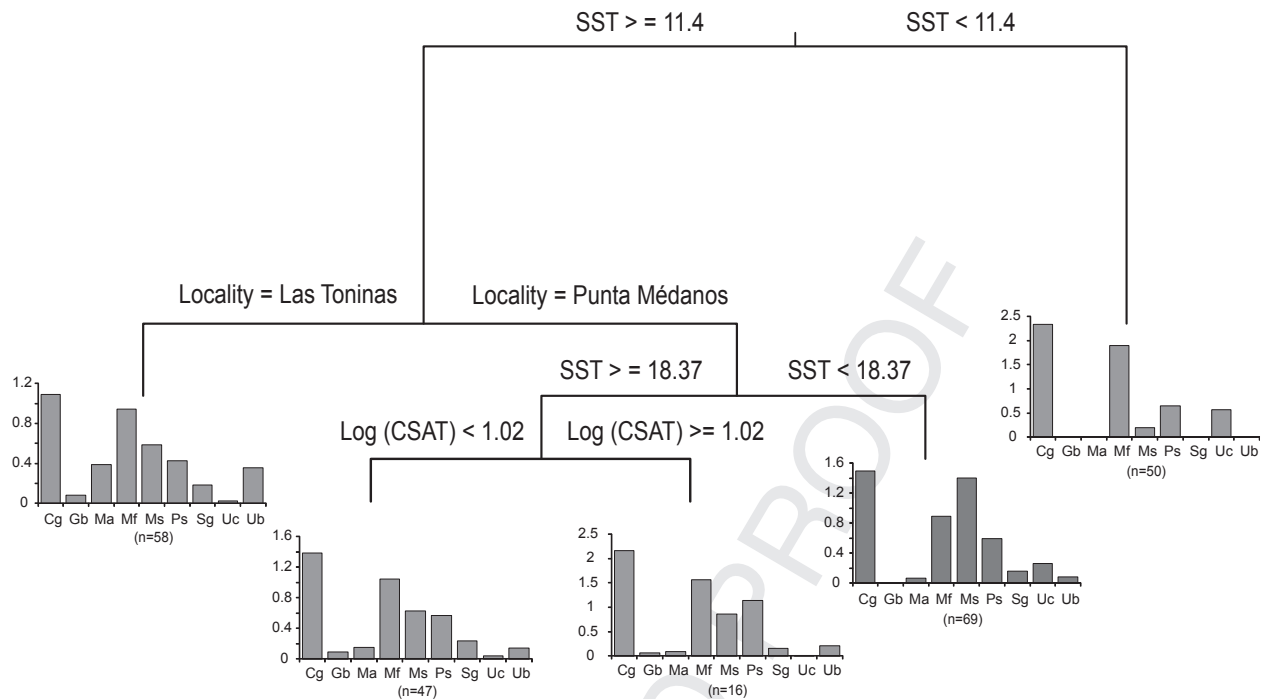
Fig. 7. Multivariate regression tree for Las Toninas and Punta Médanos small-scale fishery landings data. Bars indicate the $\log_{10}(x+1)$, where x are the average abundances of each species within a leaf. The numbers of samples within a leave are shown in parentheses. Species labels are as follows: *Cynoscion guatucupa* (Cg), *Genidens barbus* (Gb), *Macrodon ancylodon* (Ma), *Micropogonias furnieri* (Mf), *Mustelus schmitti* (Ms), *Parona signata* (Ps), *Squatina guggenheim* (Sg), *Umbrina canosai* (Uc) and *Urophycis brasiliensis* (Ub). Explanatory variables: Las Toninas (LT), Punta Médanos (PM), Sea surface Temperature (SST), and Logarithm of Satellite-derived chlorophyll-a (log (CSAT)).

fishery fishing ground, which is associated with salinity fronts of RdP (inner front in the case of *M. furnieri* or outer fronts in the case of *C. guatucupa* and *P. signata*) (Macchi, 1997; Jaureguizar et al., 2003a, 2008; Militelli, 2007). In the second group of species, mainly chondrichthyes, the adults inhabit offshore waters (>50 m depth) during the non-reproductive season (winter) and they migrate into nearshore waters during the reproductive season (spring, *Mustelus schmitti*; autumn, *Squatina guggenheim*) (Massa et al., 2004; Colonello et al., 2007; Pereyra et al, 2008; Vögler et al., 2008; Cortés, 2012). For those species associated with cold waters (*Squalus acanthias*, *Callorhinchus callorhynchus*, *Galeorhinus galeus*) or warm waters (*Trichiurus lepturus*), the seasonal variation in their abundance is likely to be related to water mass movements forced by regional-scale processes in the South Atlantic Costal System (34°–41° S, SACS) (Guerrero et al., 1997b; Palma et al., 2004; Lucas et al., 2005). During the winter, under a near-balance effect of onshore and offshore winds in the area (Fig. 2), the surface waters of the RdP present a north-northeast drift along the Uruguayan and southern Brazil coasts and there is a southern penetration of shelf waters into the estuary (Guerrero et al., 1997b). This environmental condition, where cool and high salinity waters cover a greater area of the SACS (Fig. 1A,B) and both fishery sites (Las Toninas and Punta Médanos) have similar landing composition and are under the influence of the same water mass (SST <11.5 °C, Fig. 7), allows a northern and wider distribution of *S. acanthias*, *C. callorhynchus* and *G. galeus*, as observed in *Discopyge tschudii* (Cortés et al., 2011) forcing even a winter intrusion (*S. acanthias*, *G. galeus* and *D. tschudii*) into the Río de la Plata (Jaureguizar et al., 2004). As the warm season progresses in the SACS, the RdP coastal system starts to be under the influence of more frequent northeast and easterly winds (Fig. 2) that force a southward drift of coastal waters, generating a freshwater flow along the Argentine coast south of RdP (Guerrero et al., 1997b; Simionato et al., 2001) while on a regional scale the relaxation of the Patagonian gyre generates

the formation of a southward coastal flow of shelf waters (Palma et al., 2004). The low salinity conditions in the small-scale fishery ground are therefore forced by a combination of the two processes and produces a reduction in the northern flow of cool and high salinity waters (Fig. 1A,B), thus restricting the northern distribution of cold shelf species (*e.g.* Cortés et al., 2011) and allowing a southern distribution of warm water species (*T. lepturus*). *Trichiurus lepturus* is a cosmopolitan species being among the more abundant benthopelagic teleosts of the continental shelf of southern Brazil (Haimovici, 1997). Its high densities in the RdP are associated with the penetration of subtropical continental water masses during warm periods forced by the southward flow of southern Brazil waters (Jaureguizar et al., 2004).

During the warm time (SST >11.5 °C), the first differentiation by fishing location and the later separations of Punta Médanos related to temperature and salinity consecutively reflects the increasing extension of RdP water on the small-scale fishery area (Fig. 1). With the exception of the winter season, Las Toninas is always under the influence of RdP waters and this is reflected in the landings composition, which is dominated by estuarine (*Macrodon ancylodon*) and marine migrant species (*Urophycis brasiliensis*). In Punta Médanos, during transition month (11.5 < SST < 18.3 °C) the RdP influence is limited (Log (CSAT < 1, Fig. 1B) and the landings composition is dominated by marine species and specially by *Mustelus schmitti*, a species that use this area as nursery and breeding grounds during early spring. The growth of southern extension of RdP forced the dominance of brackish water (log (CSAT) > 1, Fig. 1A,B) in Punta Médanos during the warmer time, and influenced the change in the landing composition, becoming it more similar to Las Toninas (higher CPUE of *M. ancylodon*, *U. brasiliensis*, *Micropogonias furnieri*). The later restriction of RdP the intrusion during the wamer season allow the dominance of salty water (Log (CSAT) < 1) and the landing species composition was characterized by the highest CPUE of *Squatina guggenheim* that

use this area as nursery and breeding grounds during early autumn (Colonello et al., 2007; Vögler et al., 2008; Cortés, 2012).

This study shows that the fishing effort of the small-scale gillnet fishery under the influence of brackish waters from RdP mostly operates on resources shared with industrial fisheries, defining sequential fisheries. The small-scale fishery is dependent on the availability of local resources that are mainly determined by a combination of environmental conditions and fish reproductive behavior. Also, the results provide evidence for the spatial overlap between the small-scale gillnet marine fishery and an area that is an essential habitat for shark species. The sharks use the inshore area of Cabo San Antonio (closer to Las Toninas) as parturition and breeding areas (Massa et al., 2004; Córtes and Jaureguizar, 2009; Cortés et al., 2011). Lyons et al. (2013) studied the gillnet fishery interactions with juvenile white shark in Southern California and proposed two main options to reduce the potential impact from overlap between the shark habitat and areas of high fishing effort, reduce significantly the effort and shift effort to areas less used by young sharks, or, considering the high survival of sharks released from gillnets, the impact may be lessened with shorter net soak durations.

Considerations that are important in fisheries management include the conservation of fisheries resources, the protection of fish habitats, and the allocation of fisheries resources to fishermen. The RdP small-scale gillnet fishery has three main attributes: a) resources shared with the industrial fishery, b) overlap with essential habitat of sharks, and c) the strong environmental dependence that makes the small-scale fishery a seasonal trans-ecosystem fishery. These features make this small-scale gillnet fishery particularly relevant to be included in the development of a coastal ecosystem-based management approach. Marine protected areas, special attention to the management of small shark species, the concession of territorial rights for fishing (based on environmental conditions) to organized fishing communities in conjunction with co-management policies could set the bases for management of these kinds of small-scale fisheries as suggested for Uruguayan waters (Defeo et al., 2009).

Uncited references

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ecss.2014.11.003.

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