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Understanding the dynamics of an enclosed trawl demersal fishery in Patagonia (Argentina): A holistic approach combining multiple data sources

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ABSTRACT

Understanding the dynamics of a fishery is a key ingredient to successful fishery management. The objective of this study was to improve the understanding of the dynamics of the trawl demersal fishery that operates in San Matías Gulf (Patagonia, Argentina). This system offers an opportunity to explore different issues of fishery dynamics and management because it is a simple system with a few well-characterised active vessels and a stock of Argentine hake (*Merluccius hubbsi*) that seems to have been well preserved since the beginning of the fishery in 1970. This study combined different sources of information to analyse the seasonality of landings, the link between catch and landing profiles, and the association between sea surface temperature and the spatio-temporal variability in catch profiles. The monthly species composition of the catch fell into three fishing seasons, each with a distinct landing profile. During warm months, *M. hubbsi* dominated the catch, and bottom trawl activity was concentrated in a thermal frontal zone. In winter, the fishing activity was more dispersed over the surface of the gulf, and yields were minimal. From August to October, the landings increased rapidly due to the catch of *Seriolella porosa*, and the distribution of the fishing effort was partially concentrated in the northeastern area of the gulf. The seasonal pattern observed would be related to the resource availability and the commercial opportunities. These factors were significant in determining what, when, and where to fish in the trawl demersal fishery of San Matías Gulf.

1. Introduction

One of the great challenges in ocean management is managing fish stocks and conserving the communities on which those stocks depend. The concerns of fisheries management extend beyond overfishing and include environmental, ecological, and biodiversity considerations (Grafton et al., 2008; Squires, 2009). In this context, analyses of fisheries dynamics and fisher behaviour have received widespread attention during the last decade (Salas and Gaertner, 2004; Branch et al., 2006; Davie and Lordan, 2011). The behaviour of fishermen has been increasingly included in the analysis of stock assessments and currently represents an essential issue in management recommendations. Models that ignore the fisher behaviour and fleet dynamics provide a fragmented vision of the impact that a fishery has on the ecosystem (Pelletier and Ferraris, 2000; Branch et al., 2006). This problem is particularly conspicuous in multispecies, multifleet fisheries, where more than one species is caught in the area, and different fleets simultaneously or sequentially exploit the same stocks. Because various species may be exploited at the same time, the fishery management of one stock influences the management of all other target and non-target stocks. Thus, for management advice in mixed fisheries, a fleet- or fishery-based approach is more appropriate than the conventional single-species approach (Holley and Marchal, 2004; Katsanevakis et al., 2010).

Integrated fishery management requires an understanding of the complexity that is introduced by multispecies and multifleet properties. The approach requires accurate knowledge of which

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species are consistently caught together, information about the fleet composition and flexibility, and a complete understanding of the way fisheries respond to management. These properties may vary depending on the season, areas, management measures, market conditions, and fisher behaviour (Marchal et al., 2006; Katsanevakis et al., 2010). In addition, the different fleets that operate in a fishery can generate technological externalities that should be considered as another factor that drives the fishery dynamics (Seijo et al., 1998).

Defining fishing tactics is the first step in analysing fleet dynamics. The term "fishing tactics" is used in the fisheries literature to describe the combination of fishing location, gear used, and one or several target species, and this term should reflect the fishing intention (Pelletier and Ferraris, 2000; Pech et al., 2001). Several methods based on uni- and multivariate procedures have been proposed to identify fishing tactics (Pelletier and Ferraris, 2000; Holley and Marchal, 2004; Castro et al., 2010). Most methods are based on the catch profile and assume that this profile reflects the fishing intention. However, Marchal (2008) provided two reasons why the fishing intention may not be reflected by the species composition: the catch profile is estimated from landings, so the discard fraction is ignored, and all species caught in the same fishery do not necessarily have the same temporal and spatial dynamics. This author also recognised that landing profiles are often the only source of information available to classify fishing tactics. In contrast, a full understanding would require tracking the activity of each fishing unit through the year in time and space; however, there are few studies addressing this issue (e.g., Fonseca et al., 2008; Katsanevakis et al., 2010). After characterising the fisheries, the next step is identifying groups of fishing vessels that share a similar activity pattern and/or technical features, i.e., participate in the same fisheries (Ulrich and Andersen, 2004).

In Argentine waters, fishing practices are diverse in terms of gear, target species, seasonality, and fishing areas. The main target species in the Argentine Economic Exclusive Zone (AEEZ) is the Argentine hake (*Merluccius hubbsi*), which is also the most important in economic terms. According to the FAO (2012), Argentina dominates global hake landings (0.4 million metric tonnes [t]). Two main stocks of *M. hubbsi* have been identified in the AEEZ (Ehrlich, 1998; Macchi et al., 2004), and both are considered overexploited (Aubone et al., 2004; Vaz-dos-Santos et al., 2010). A third stock, located within the San Matías Gulf (SMG, Fig. 1), constitutes an independent demographic unit (Sardella and Timi, 2004; González et al., 2007; Machado Schiaffino et al., 2011), with a population structure that seems to have been well preserved since the beginning of the fishery in 1970 (González et al., 2007; Ocampo Reinaldo, 2010).

Both industrial bottom trawl and artisanal midwater longline fleets conduct fishing activity in the SMG. Both fleets are well characterised in terms of gear, target species, and fishing grounds, and they are managed as two separate fishing units (González et al., 2007; Romero et al., 2010). The artisanal longliners operate in an area reserved exclusively for their activity (Fig. 1). This fleet consists of 40 and 50 vessels of less than 10 m in length with an average fishing effort of 3000–4000 hooks per day (González et al., 2007). The bottom trawl fleet is composed of approximately 10 industrial vessels longer than 18 m in length, which are allowed to operate only within the SMG (except in the artisanal exclusive zone). During the last decade, the total annual landings of the demersal fishery have fluctuated between 5000 and 15,000 t, of which 90% were trawl fleet landings (Millán, 2011).

From an oceanographic point of view, the SMG is a semi-enclosed basin with relatively isolated waters (Rivas and Beier, 1990; Gagliardini and Rivas, 2004). Studies performed in the last two decades have identified oceanographic phenomena and environmental patterns that appear to modulate ecological processes. The most important oceanographic feature is the formation of a thermohaline front that crosses the SMG near 41°50′S during the warmest months (Piola and Scasso, 1988; Gagliardini and Rivas, 2004). This frontal system divides the ecosystem into two distinct water masses: the northern, composed of relatively warmer and saltier water with strong vertical stratification; and the southern, characterised by cold and lower salinity water (Piola and Scasso, 1988). Recent studies (Williams et al., 2010) have identified some seasonal patterns of use in certain areas of the gulf by trawl vessels, and these patterns are hypothesised to follow the annual migrations of the fishing resources.

The SMG demersal fishery is well known in terms of landings, fleets, and gear and has been managed as a multispecies and mixed fishery (González et al., 2007; Romero et al., 2010). Biological and ecological information on the fishing resources and the associated communities is available, and the main oceanographic patterns have been recently characterised (Williams et al., 2010). Our new understanding of these factors and the existence of a healthy hake stock provide a unique opportunity to investigate the correlation among fishery dynamics, biological variables and environmental conditions. Therefore, the aim of this study is to improve the understanding of the dynamics of the SMG trawl fishery by assessing the fishing performance and practices using a holistic approach that combines different sources of information. Statistical data were combined with oceanographic and biological information to characterise the seasonality of landings, the link between catch and landing profiles, and the human responses to a changing environment.

2. Materials and methods

The research strategy included: (1) a description of the sources of information and data collection, (2) an analysis of seasonality based on catch and landing profiles, and (3) a compilation of oceanographic and fishery information to improve the understanding of fishery dynamics and human responses.

2.1. Data collection

The fishery data were obtained from two sources. The first data set was obtained from the Fishery Statistics compiled by the Fisheries Directorate (Millán, 2011) and consisted of information on the total weights of species landed by the trawl fleet each month from 2006 to 2008 (1030 fishing trips). Ranges, plots, and charts of the data were examined, and outliers that were obvious errors were removed. To analyse the landing profile, the species that composed the bottom trawl fishery landings in the study area were considered, bearing in mind that the less abundant species were recorded together in the official logbooks (Table 1).

The second data set was obtained from the regular reports of the Fishery Observer Programme (FOP) of Río Negro Province. This programme provided data about the monthly catch composition of the trawl demersal fishery. Fishing trips lasted from 3 to 6 days, and the number of hauls ranged from 2 to 5 per fishing day (haul duration ≈2–5 h). For each haul, observers collected a random sample from the unsorted catch (at least six 40 kg boxes) to evaluate the catch composition. The fish sampled were subsequently sorted, counted, and weighed by species. This routine was repeated for at least one haul per fishing day. The species composition of the samples was then raised to the fishery level to estimate the total catch using a ratio-estimator based on auxiliary variables that served as a proxy for fishing activity (Romero et al., 2010). Hake landings (ratio-estimator of total landings to landings sampled) were chosen to estimate the monthly catch. The fish sampled per species (f_{ibox}) were raised to the haul level f_{ht} by the ratio-estimator of total hake

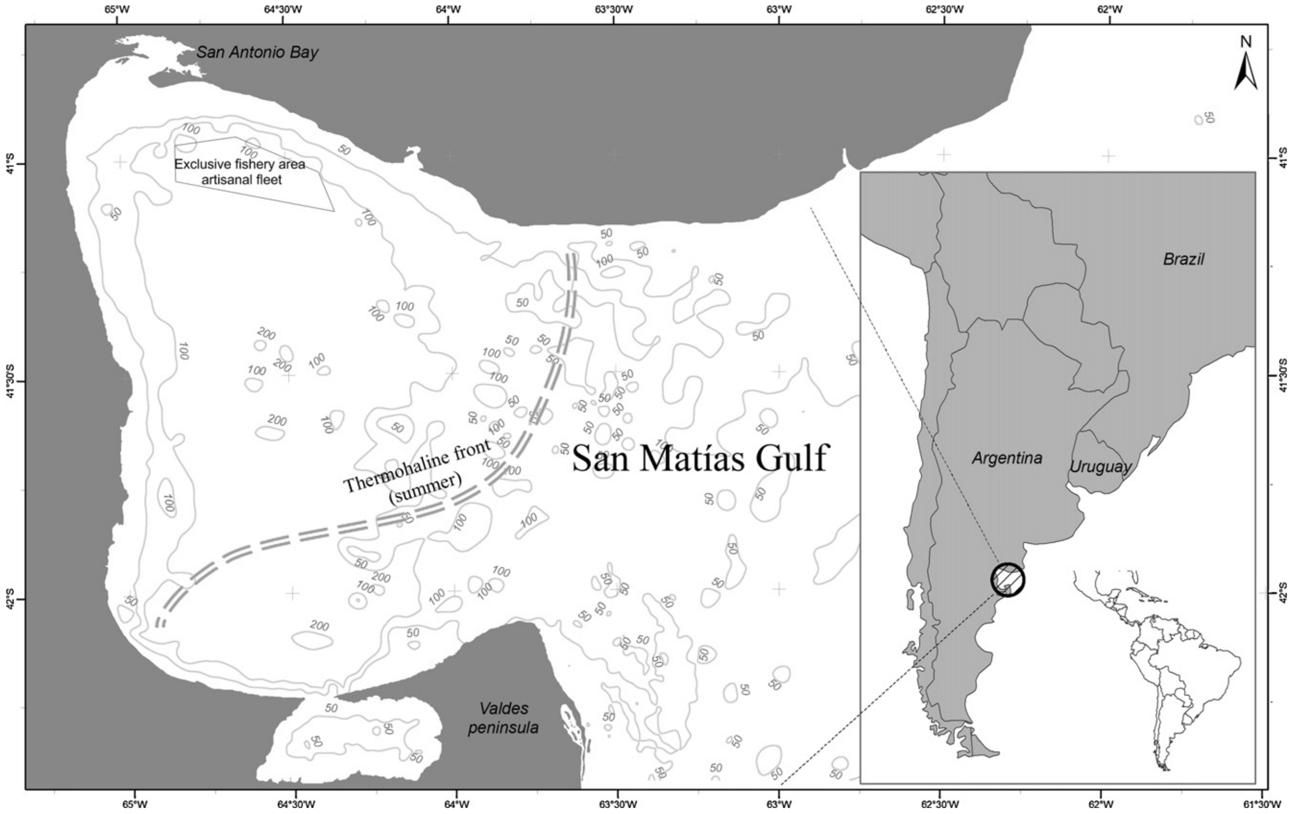

Fig. 1. Study area: San Matías Gulf, showing the seasonal thermohaline front and the polygon of the exclusive fishery area for the artisanal fleet.

landings (l_{ht}) to the hake landings sampled (l_{box}) according to the following equation (adapted from Romero et al., 2010):

$$f_{hti} = \frac{l_{ht}}{l_{box}} \cdot f_{ibox} \qquad (1)$$

The data set used to estimate the catch profile was pooled for 2006 and 2007 (Table 1). This period was selected for analysis because the FOP had the highest percentage of observer coverage during those years (2006 = 14 fishing trips; 2007 = 10 fishing trips).

2.2. Analysis of seasonality in the catch and landing profiles

To identify the seasonal pattern in the catch and landing profiles (i.e., relative species composition), both hierarchical clustering analysis and non-metric multidimensional scaling [nMDS] were applied to the log(x + 1)-transformed data on the relative weight of each species by year (to reduce the contribution of the most abundant species). A hierarchical clustering analysis was selected because the natural hierarchical structure in the data was reflected in the classification scheme. The ordination technique, nMDS, is itself a complex numerical algorithm, but it is conceptually simple. It makes few assumptions about the data set or the interrelationship of the samples, and the link between the final picture and the original data is relatively transparent and easy to explain (Clarke and Warwick, 2001). These methods were employed using the Bray–Curtis similarity index (Clifford and Steptlenson, 1975) because this index has a number of biologically desirable properties and is a particularly robust measure of ecological distance (Faith et al., 1987). Complete linkage was performed to link similar samples into clusters (Clarke and Warwick, 2001). Similarity percentage analysis (SIMPER) was also applied to identify the species that contributed most to each group (Clarke, 1993). This method is based on the analysis of Bray–Curtis (dis) similarity matrices that are derived from monthly species compositions. This procedure uses the standard deviation of the Bray–Curtis dissimilarity matrix attributed to a species for all pairs of species and compares it with the average contribution of a species to the dissimilarity. In addition, this method quantifies the average contribution of each species to the measure of dissimilarity between monthly groups (Clarke and Warwick, 2001). The analyses were performed separately for the catch and landing profiles, and the results were then compared to offer a first approximation of fisher behaviour.

After the seasonal pattern was described, the mean trophic level (mTL) of the trawl demersal catch for each month was estimated as an index of how the fishery may affect the flow of biomass across tropic levels in a year. The mTL for a given month j was estimated by multiplying the catch (Y_i) by the trophic level of an individual species/groups i and then taking a weighted mean (Pauly et al., 1998). That is,

$$\overline{TL_J} = \frac{\sum TL_i * Y_{ij}}{\sum Y_{ij}} \qquad (2)$$

where TL_j is the mean trophic level of catch in month j; Y_{ij} is the catch of species i in month j, and TL_i is the trophic level of species i. Trophic levels of each species were obtained from FishBase (Froese and Pauly, 2012), CephBase (Wood and Day, 2006), and Cortés (1999) (Table 1). When multiple species were grouped under a common name in the Fishery Statistics (e.g., flounder), we used the trophic information for the genus (i.e., *Paralichthys*) as the value for each species (i.e., *P. patagonicus* and *P. isosceles*, Table 1) and the mTLs of each species as the representative value for the species groups. The exploited species were separated according to their taxonomic group (mollusc, fish, or crustacean), size (small, medium, or large) and habit (pelagic, benthopelagic, or demersal).

Table 1
Species or taxonomic groups listed in the periodic reports of the Fishery Observer Programme and/or reported in Fishery Statistics (commercial species are denoted with an asterisk) which were included in the seasonality analysis of landing and catch profile. Functional categories (FC): CB (Chondrichthyan Benthic), CD (Chondrichthyan Demersal), CP (Chondrichthyan Pelagic), C (Crustaceans), LD (Large Demersal), LP (Large Pelagic), MD (Medium Demersal), MP (Medium Pelagic), M (Molluscs), SD (Small Demersal), SP (Small Pelagic), SBP (Small Benthopelagic). TL: trophic level.

Common name	Scientific name	FC	TL
Argentine seabass*	*Acanthistius patachonicus*	MD	4.01
Elephant fish*	*Callorhinchus callorhynchus*	CD	3.23
Castañeta*	*Nemadactylus bergi*	MD	3.18
School shark*	*Galeorhinus galeus*	CD	4.21
Pink cusk-eel*	*Genypterus blacodes*	LD	4.34
Argentine short-fin squid*	*Illex argentinus*	M	3.20
Hoki*	*Macruronus magellanicus*	LD	3.93
Argentine hake*	*Merluccius hubbsi*	LD	4.23
Smooth-hound shark*	*Mustelus schmitti*	CD	3.59
Flounders*	*Paralichthys* spp., *Xystreurys rasile*	MD	3.44
Parona leatherjack*	*Parona signata*	MP	3.40
Argentine sandperch*	*Pseudopercis semifasciata*	LD	3.88
Silver warehou*	*Seriolella porosa*	MP	3.40
Angular angel shark*	*Squatina guggenheim*	CD	4.39
Horsefish	*Congiopodus peruvianus*	SBP	3.27
Cocherito	*Dules auriga*	SBP	3.59
Rays	*Dipturus chilensis, Atlantoraja platana, Psammobatis lentiginosa*	CB	3.95
Argentine anchovy	*Engraulis anchoita*	SP	2.51
Octopus	*Enteroctopus megalocyathus, Eledone massyae*	M	3.20
Squids	*Loligo gahi, L. sanpaulensis*	M	3.20
Whitemouth croaker	*Micropogonias furnieri*	MD	3.26
Argentine goatfish	*Mullus argentinae*	SD	3.45
Southern eagle ray	*Milyobatis* spp.	CB	3.27
Broadnose sevengill shark	*Notorhynchus cepedianus*	CD	4.60
Red Porgy	*Pagrus pagrus*	SBP	3.65
Brazilian flathead	*Percophis brasiliensis*	MD	4.33
Crab	*Platyxanthus* sp., *Ovalipes trimaculatus*	C	2.52
Pejesapo	*Porichthys porosissimus*	SD	3.73
Red searobin	*Prionotus nudigula*	SD	4.20
Banded cusk eel	*Raneya brasiliensis*	SD	3.57
Tadpole codling	*Salilota australis*	MD	4.43
Patagonian redfish	*Sebastes oculatus*	MD	3.62
Picked dogfish	*Squalus acanthias*	CD	4.30
Southwest Atlantic butterfish	*Stromateus brasiliensis*	MP	3.40

2.3. Association between the seasonal pattern, fishing location, and environmental conditions

The seasonal patterns of the catch and landing profiles were analysed with respect to the spatial dynamics of the trawl fleet. Then, the temporal and spatial variability of the fleet was related to oceanographic information to integrate different points of view on the dynamics of the system. One interesting issue in this analysis is the potential to link information from different sources, in this case data from Fishery Statistics (landing profile) and the FOP (catch profile) with information obtained through the use of satellite technology (climatological maps made from satellite-derived environmental data and fishing operations recorded by a vessel monitoring system (VMS)).

The sea surface temperature (SST) was the environmental variable considered to best describe the oceanographic patterns and processes of the SMG because the distributions of several fish species are associated with thermal structure and specific thermal conditions (Perrota et al., 2001; Alemany et al., 2009; González et al., 2010). In addition, the SST has already been used to describe important seasonal changes in this gulf (Williams et al., 2010, 2012). Data from the Daily Level 1B local area coverage (LAC) AVHRR, which is on board the NOAA-N polar orbiting satellites, were acquired through the Argentine National Commission of Space Activities (CONAE) for the period 2006–2008. Relatively cloud-free AVHRR scenes were processed by applying the Multichannel Sea Surface Temperature (MCSST) algorithms (McClain et al., 1985) and were further processed using Erdas Imagine 8.7 software. The SST products were mapped to a WGS 84 reference system (datum WGS84, ellipsoid WGS84) on the cartographic Transverse Mercator projection (zone 4) at 1100 m of spatial resolution at nadir and co-registered with respect to a reference landmark. Land and cloudy pixels were flagged to zero and not considered for the computations. Monthly composite images were obtained by averaging the temperature of the corresponding five-day SST composites at each pixel, and seasonal variability was examined by creating seasonal composites from monthly climatological images (2006–2008).

The dynamics of the trawl fleet were characterised in terms of the spatial distribution of effort (location of hauls). The source of data was the VMS known as SIMPO (González et al., 2004) for the period 2006–2008. The VMS provided real-time data of vessel location, bearing, and speed (approximately every 90 min) from on board Inmarsat D+ satellite transceivers. Criteria of speed were used to select the VMS records that corresponded to fishing activity (all speeds less than 2.5 knots and higher than 4.0 knots were excluded because they were not associated with fishing activity). All data were inspected to remove additional invalid records (e.g., speed records in the range of fishing activity but linked with adverse weather conditions or arrival at port).

Fishing activity maps were obtained by calculating the density of the filtered location data on a 1000 m grid. The plots were then mapped as topographic representations using the same reference system as the environmental data, with Z giving the density of vessel location per unit area on a 1000 m grid. The data were grouped according to the results obtained from the multivariate analysis of landing profiles (pooled by monthly groups from 2006 to 2008). The haul density distributions were then compared between monthly groups to examine seasonal patterns using the Kolmogorov–Smirnov test for two independent samples. Afterwards, a multivariate Partial Mantel test was performed for each dataset to evaluate the association between SST and the fishing activity maps (Euclidean distance, 999 permutations, Bonferroni's corrected $\alpha = 0.017$). Mantel's test consists of a partial regression on three distance matrices: hauls density dissimilarity, SST dissimilarity, and geographic distance (Smouse et al., 1986; Legendre and Fortin, 1989) per monthly group (MG). This test is similar to a partial correlation coefficient and can account for the spatial position of sampling points, allowing us to evaluate whether the distribution of haul densities along the sampling area is independent of the values of SST. The analyses were conducted using the R software environment (http://www.R-project.org/).

3. Results

3.1. Catch and landing composition

During 2006 and 2007, 297 fishing hauls (sampling coverage: 2006 = 5.59%, $N = 167$; 2007 = 3.61%, $N = 130$) were sampled by the FOP to assess the catch composition of the trawl demersal fleet that operates in SMG waters (total fish sampled: 48,040 individuals). Thirty-four taxonomic groups were identified in the catch (Table 1). When classification at the species level was not possible, species were pooled by their taxonomic proximity. Fish, with 30 taxonomic groups recognised, were the dominant group, followed by molluscs and crustaceans. Other taxa, including annelids, tunicates, and cnidarians, were also mentioned in the FOP reports but with low frequencies of occurrence.

Table 2
Monthly groups identified from cluster analysis in the catch and landing profiles (similarity level: 75%).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Catch (2006-2007)	I	I	I	I	I	II	II	III	III	I	I	I
Landing (2006)	I	I	I	I	II	II	II	III	III	I	I	I
Landing (2007)	I	I	I	I	II	II	II	III	III	III	I	I
Landing (2008)	I	I	I	I	II	II	II	III	III	III	I	I

Monthly group: ■ – I, ▨ – II, □ – III.

The comparison between caught and landed species indicates that only 15 taxonomic groups have commercial importance and are traditionally listed in the Fishery Statistics. The commercial species include teleost fishes, sharks, rays, and squids with demersal or benthic habits. Some other species are landed by the trawl demersal fleet but have always been reported together in logbooks (denoted as "assorted fish"), and there is no formal information about their taxonomic identity. The highest percentage likely corresponds to rays (*Dipturus chilensis, Atlantoraja platana*, and *Psammobatis lentiginosa*) because they have traditionally been listed in the Fishery Statistics in conjunction with other less abundant but commercially important species such as the Brazilian flathead (*Percophis brasiliensis*); the Southwest Atlantic butterfish (*Stromateus brasiliensis*); and some species of squids (*Loligo gahi, L. sanpaulensis*), octopus (*Enteroctopus megalocyathus* and *Eledone massyae*), and sharks (*Squalus acanthias* and *Notorynchus cepedianus*).

The Argentine hake (*M. hubbsi*) was the main species caught and landed by the trawl demersal fleet. During the last decade, its landings have fluctuated between 4000 and 8000 t. Although *M. hubbsi* was the only target species throughout the history of the fishery in the gulf, the diversity of the landings has clearly increased in recent years (Romero et al., 2010).

3.2. *Seasonal pattern in the catch and landing profiles*

The monthly percentage composition of catch and landings showed a pattern throughout the year, following a similar trend for each year of the study period (Fig. 2). *M. hubbsi* was landed every month. It was the most important species caught in summer (December–March) and less important in winter and spring (May–October). The silver warehou (*Seriolella porosa*) could be considered as the second target species of the fishery because this species was intentionally fished from August to October. The pattern of non-target but commercial species was the inverse of that described for hake, with greater importance during the cold months (May–July) ("Others" Fig. 2).

Three main monthly groups were delineated at a high similarity level (75%) by the hierarchical cluster analysis of catch and landing profiles (Table 2). The nMDS showed a low stress, varying between 0.01 and 0.09, which was sufficient to provide a useful representation of the data. In two dimensions, the nMDS gave the same sample distribution as the cluster analysis (Table 2 and Fig. 3). The agreement in the results of these two methods confirms the ability of the monthly groups to define a clear seasonal pattern in catch and landing compositions from 2006 to 2008 (Fig. 3). It is also important to highlight the correspondence between the seasonal patterns in the catch and landing profiles; each has three well-discriminated groups.

The monthly groups in the catch profile ranged in similarity between 84.3% and 89.0%, while the monthly groups in the landing profile showed a similarity range between 72.4% and 95.0% (SIMPER, Table 3). In both cases, the monthly groups were characterised by several common and diagnostic species (SIMPER, Table 4).

Table 3
Average similarities among months composing each group (landing or catch) are shown in the diagonal. The percentages of dissimilarity between monthly groups (MG) are listed in the subdiagonals (SIMPER procedure).

	MG	I	II	III
Catch				
2006–2007				
	I	84.33		
	II	15.41	89.40	
	III	50.81	44.72	89.00
Landing				
2006	I	92.57		
	II	25.55	87.61	
	III	64.05	61.22	89.71
2007	I	95.04		
	II	22.57	83.06	
	III	32.37	30.12	72.44
2008	I	88.45		
	II	21.25	86.64	
	III	35.71	30.42	77.69

Table 4
Contributions (%) of each species (or taxonomic group) to the similarity within time blocks (SIMPER procedure). Cumulative percentage of landing/catch contributions: 90%. The cumulative percentages of 75% are shown in bold type.

	Species	I	II	III
Catch				
2006–2007	*Merluccius hubbsi*	**89.05**	**85.60**	**43.73**
	Flounders	5.41	3.62	
	Stromateus brasiliensis		4.34	13.33
	Seriolella porosa			**36.02**
Landing				
2006	*Merluccius hubbsi*	**87.36**	**65.85**	**21.54**
	Callorhinchus callorhynchus	5.63	**12.92**	6.26
	Assorted fish		8.29	
	Flounders		4.85	
	Seriolella porosa			**64.03**
2007	*Merluccius hubbsi*	**90.14**	**69.78**	**65.97**
	Callorhinchus callorhynchus		**8.96**	3.80
	Assorted fish		5.58	4.94
	Flounders		4.86	
	Seriolella porosa			**16.68**
	Galeorhinus galeus		2.88	
2008	*Merluccius hubbsi*	**87.56**	**69.55**	**55.28**
	Callorhinchus callorhynchus	6.07	**11.67**	**4.71**
	Assorted fish		7.03	15.81
	Flounders		4.06	
	Seriolella porosa			**18.20**

Monthly Group I (MG I) was fished mainly in the warmest period of the year, from November to April, although the period was slightly longer in the catch profile, extending from October to May (Table 2). *M. hubbsi* was the species that contributed most

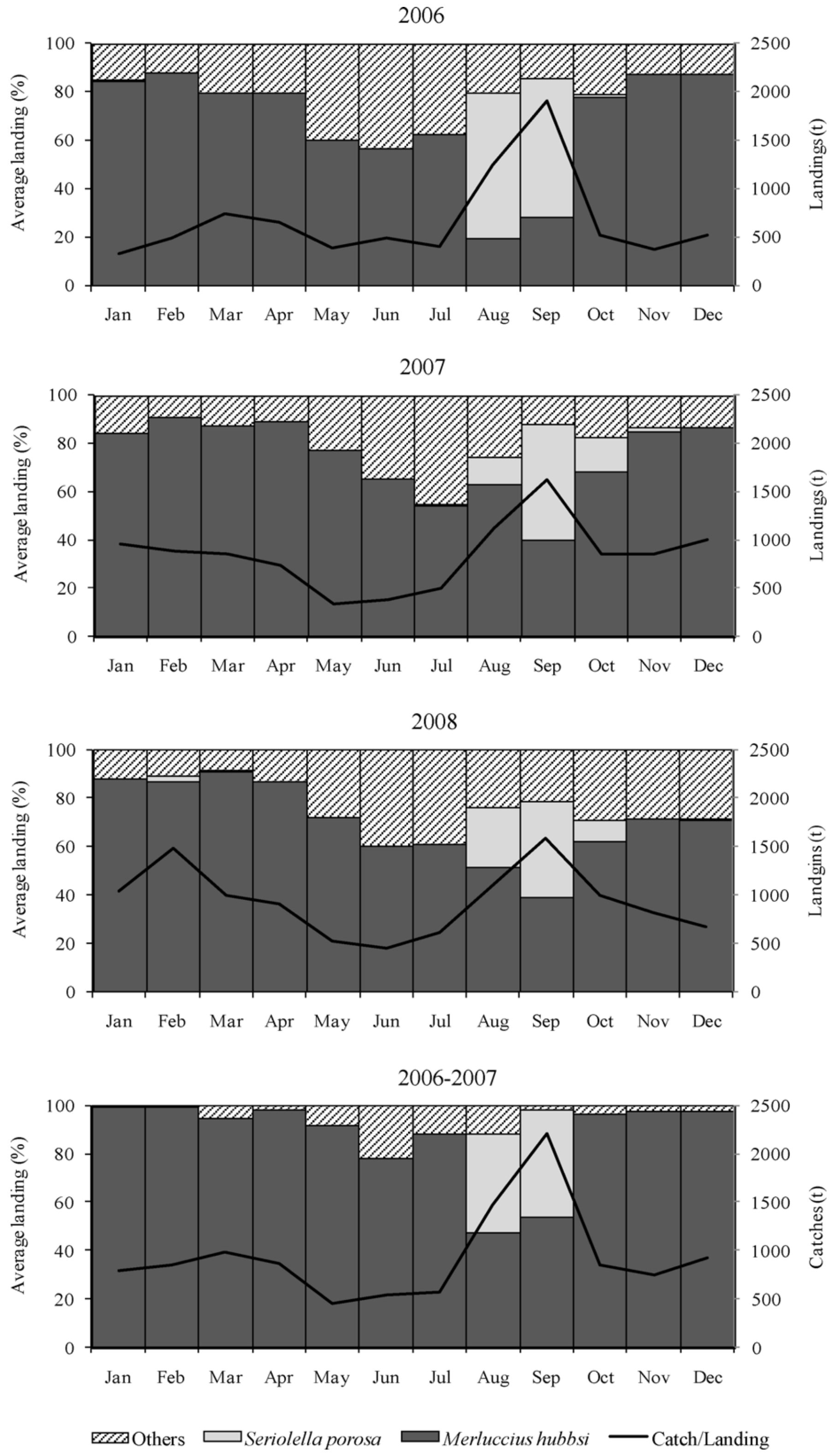

Fig. 2. Monthly percentage composition of landings (2006–2008) and catches (2006–2007) of the trawl demersal fleet that operates in San Matías Gulf. The target species (the Argentine hake *Merluccius hubbsi* and the silver warehou *Seriolella porosa*) were discriminated individually while the remaining ones are shown together denoted as "Others". The solid line shows the total landings/catches per month (catches were weighted for 2006 and 2007 because the FOP, during those years, reached the highest percentage of coverage of catch).

to the similarity between the catch and landing compositions (87.6–90.1%, Table 4).

Monthly Group II (MG II) covered the coldest period of the year, from May to July in the landing profile and June and July in the catch profile (Table 2). Compared with the rest of the year, landings were most diverse in this period, and several species contributed to the 90% similarity among months. *M. hubbsi*, flounders (*P. patagonicus*, *P. isosceles*, and *X. rasile*), the Southwest Atlantic butterfish

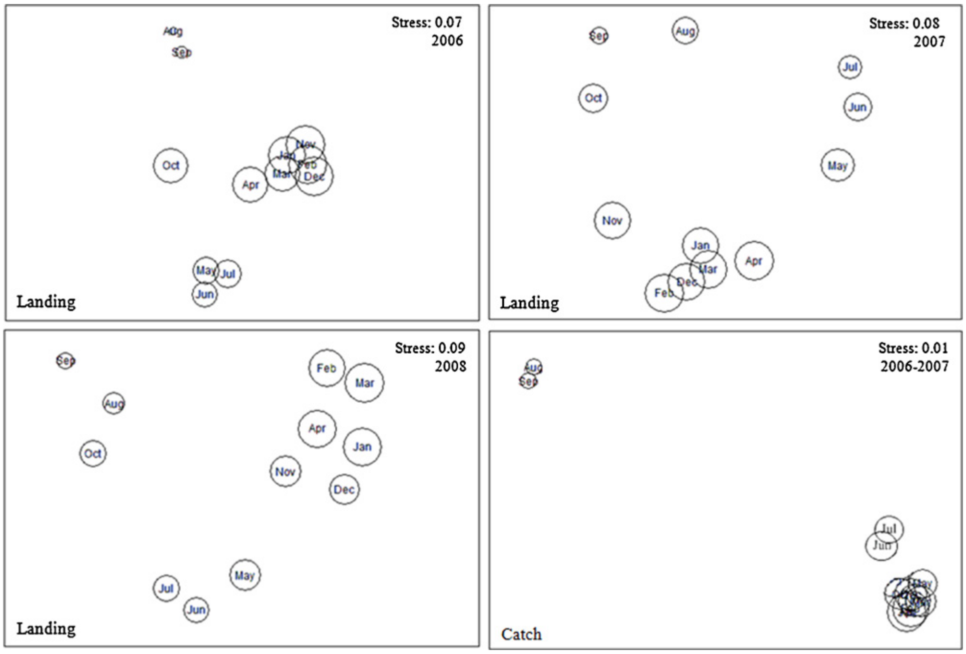

Fig. 3. nMDS (non-metric multidimensional scaling) two-dimensional diagram showing the resulting time blocks. The bubble size indicates the contribution of the Argentine hake (*Merluccius hubbsi*) to catches/landings of each month.

(*S. brasiliensis*), the Elephant fish (*Callorhinchus callorhynchus*), and "assorted fish" were the most common species (Table 4). The total landings per month in this monthly group were lower than the landings from the other seasons (Fig. 2).

Monthly Group III (MG III) was defined by the period from August to October in the landing profiles from 2007 and 2008 but comprised only August and September in the catch and landing profiles in 2006 (Table 2). This time period was mainly typified by large contributions from *M. hubbsi* and the silver warehou (*S. porosa*). The latter was only caught and landed during this monthly group (Table 4). *S. porosa* was mostly highly represented in the 2006 landings and accounted for 50% of the total landed catch. During this period, the trawl demersal fleet recorded a peak in total annual landings (Fig. 2).

The percentages of dissimilarity between monthly groups are listed in Table 3. The highest percentage was recorded when comparing MG I and MG II and ranged between 15.4% and 25.5%.

The trend in the m*TL* of the catch throughout the year showed a pattern clearly associated with the results of the multivariate analysis (Fig. 4). During MG I and II, the m*TL* of the catch varied between 4.0 and 4.2 due to the prevalence of *M. hubbsi*, a species with a relatively high trophic level (Table 1). In MG III, the presence of *S. porosa* (a medium pelagic species, trophic level: 3.4) in catch led to a reduction in the m*TL*, which reached values between 3.7 and 3.8 (Fig. 4).

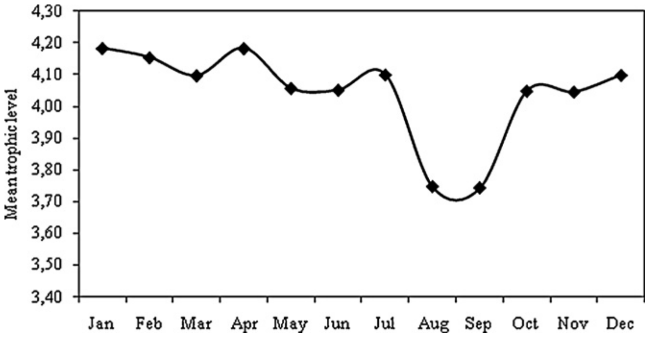

Fig. 4. Mean trophic level (m*TL*) of the catch of the trawl demersal fleet throughout the year, weighted for the period 2006–2007.

3.3. Associations among the seasonal pattern, fishing location, and environmental conditions

The fishing activity density maps (haul records km^{-2}) for the three monthly groups are shown in Fig. 5a. During MG I, the bottom trawl activity was concentrated in the southern and southeastern zones of the SMG. From May to July (MG II), the fishing activity was more evenly spread over the surface of the gulf, with a low haul density in the southern area. In MG III, fishing hauls were concentrated in the northern and southwestern region (Fig. 5a). The absolute frequency of haul records was different for each monthly group when plotted as a function of location (Fig. 5b). The comparison of the haul density maps showed significant differences between seasons (MG I–MG II, $D_{\max}$: 0.4478, KS: 0.0216; MG II–MG III, $D_{\max}$: 0.1468, KS: 0.0279; MG I–MG III, $D_{\max}$: 0.4952, KS: 0.0240; *N*: 9691; $P < 0.0001$).

Seasonal composites were produced according to the results of the multivariate analysis (Fig. 5c). The fleet activity in summer (MG I) was mostly between the 18.0 °C and 19.5 °C isotherms (Fig. 5c), corresponding with the frontal zone. The results of the Partial Mantel test confirm that there was an association between SST and fishing density in this season (Table 5). During the cold period (MG II and III), the fishing activity was conducted in a more homogeneous environment in relation to SST (Fig. 5c), and an association between these variables was not detected by the Partial

Table 5
Results of the Partial Mantel test (Euclidean distance, 999 permutations, Pearson's correlation, Bonferroni's corrected $\alpha = 0.017$). The variables used to calculate the first and second distance matrix were SST and the "absolute frequency of fishing records". The third distance matrix used was based in the geographical position of each pixel. Significant tests are shown in bold and *p* values between parentheses.

Season	MG1	MG2	MG3
Mantel statistic *r*	**0.1317**	−0.04938	−0.04646
p	0.001	1	1

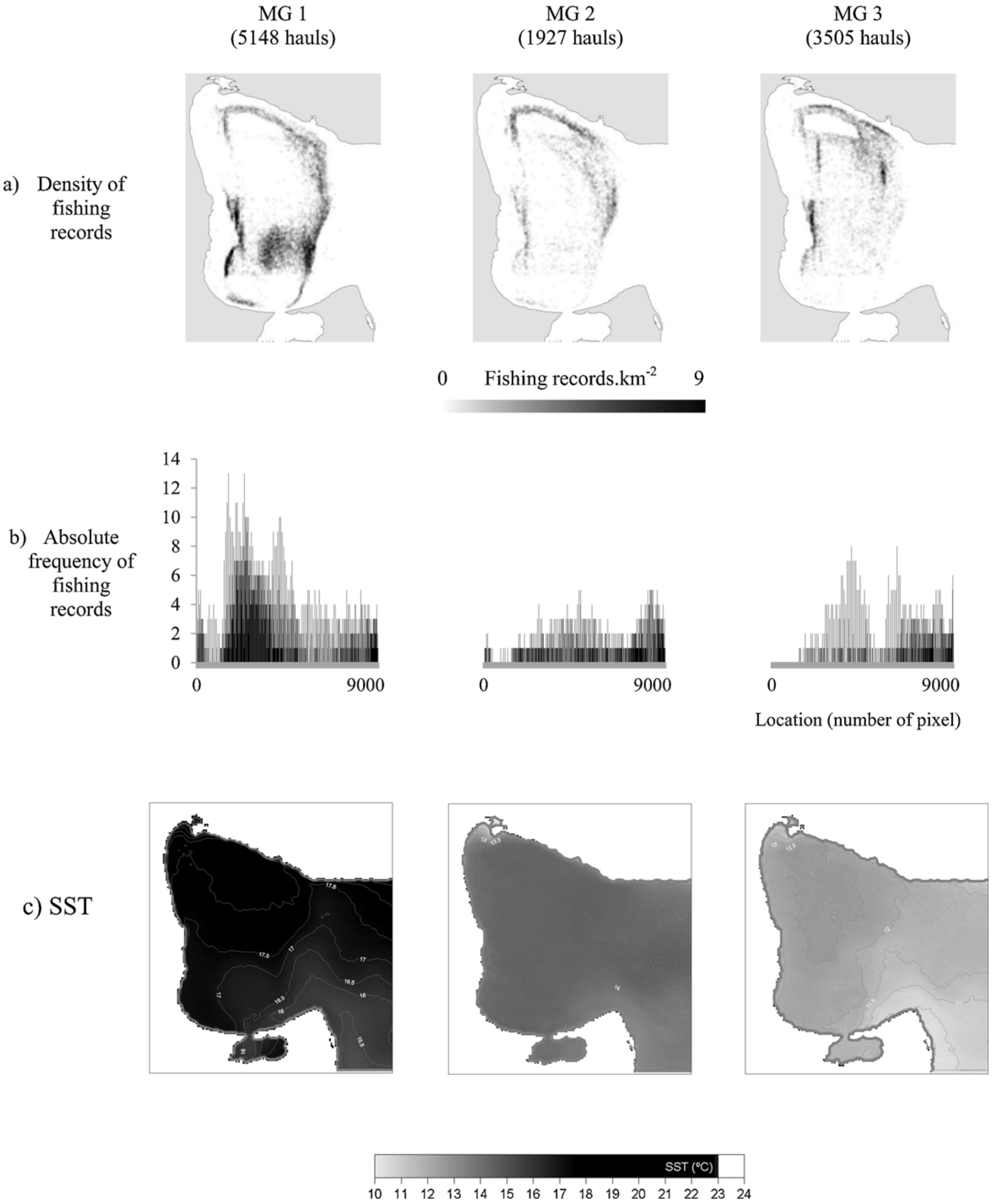

Fig. 5. Reference seasonal climatological maps (2004–2007) for each season identified by the multivariate analysis. (a) Fishing density maps (hauls records km^{-2}) for each monthly group (2006–2008). (b) Distribution of absolute frequency of fishing records in relation to location. (c) NOAA/AVHRR Sea Surface Temperature (SST, °C).

Mantel test (Table 5). The fleet dispersed when the thermal front disappeared.

4. Discussion

There is general agreement that managing fisheries is managing people. Therefore, a key ingredient to successful fisheries management is a clear understanding of fishermen behaviour and their incentives, through the aggregated behaviour of fishing fleets (Hilborn, 2007). Improving the knowledge of fishing fleet dynamics is crucial to change from single species to fishery/fleet-based advice and to advance towards biological and social sustainability and higher economic profitability (Vinther et al., 2004; Hilborn, 2007).

In this study, information on fishing fleet activity and satellite-derived SST data were combined to examine the seasonal dynamics of the SMG trawl fleet. Data about fishing activity were obtained from the Fishery Statistics and the periodic reports of the onboard observer programme (FOP). In addition, remote sensing and VMS technologies allowed us to gather environmental information together with the spatio-temporal distribution of the fishing effort and catch composition. Therefore, in a system where scientific data are not abundant, this study focused on combining information from different sources as a useful tool to move towards a better understanding of the system dynamics.

The SMG trawl fleet is a typical mixed-species fishery that exploits a diversity of species (almost 50), but only a few species account for 95% of the total catch. The main target species is *M. hubbsi*, which represents 80–90% of the landings in summer but ranges only between 30% and 60% during the cold period. Although the fleet intention is primarily directed to target *M. hubbsi*, there are several other species with commercial importance, including teleost fishes, sharks, rays, and cephalopods such as squids and octopus. Among these species, the silver warehou (*S. porosa*) was the second most important target species. Some vessels shifted their fishing intention to catch *S. porosa* during certain months of the year.

The analysis of the catch profile and catch composition highlighted three interesting issues. First, commercial species (target and non-target) accounted for 90.5% of the total catch. This distribution indicates that the discard practices generated by selecting certain species were relatively few, although it does not mean that discarding practices by length selection was similarly uncommon. Romero et al. (2010) reported that discards of juvenile hake were relatively high (near 30% of the total catch) and have increased over the last 20 years. Secondly, a seasonal correspondence between the catch and landing profiles was observed. Therefore, bearing in mind the discard fraction, the landing profile may reflect the fisher's intentions and could serve as a good proxy to the relative abundance and distribution of species. This information is particularly useful when the operating cost to support an onboard observer programme is high, and landings are used instead for stock assessments. Thirdly, analysing the m*TL* of the catch as part of a more comprehensive study of the fishery behaviour may elucidate how changes in resource availability, the environment, and/or fishing intention can affect the community and the food web throughout the year. Because *S. porosa* has been registered in landings since 1998 (Romero et al., 2010; Ocampo Reinaldo et al., 2012), an analysis of the m*TL* trend over the years is needed to determine whether the fleet is "fishing down marine food web" (Pauly et al., 1998) or "fishing through marine food webs" (Essington et al., 2006).

The changes in the spatial allocation of the fishing effort reflect changes in fisher behaviour. The decision on what, when, and where to fish depends on numerous factors, including recent yield patterns, the income earned from a particular species, the skipper's empirical knowledge, the availability of resources (which might be seasonal), the distance to fishing grounds, weather conditions, and fisheries management regulations (Pelletier and Ferraris, 2000; Christensen and Raakjær, 2006; Marchal, 2008). In the SMG, there were significant differences in the distribution of the fishing effort between monthly groups. During the warm season (MG I), the trawl fleet fished for hake near the thermal front, with high yields. From May to July, the fishing effort and yields were reduced to minimum levels (Williams et al., 2010), although, during MG III, the landings increased rapidly due to the catch of *S. porosa*. In this ecosystem, the seasonal variation in resource availability (mainly, targeted species) would be an important factor to determine the fleet dynamics.

Williams et al. (2010) and Ocampo Reinaldo et al. (2012) studied the association between the oceanographic conditions in SMG and the distribution and biological features of *M. hubbsi*. During summer, the thermal front increases the vertical mixing of water in the southern area, resulting in higher primary productivity (Williams et al., 2010). In biological terms, the appearance of the thermal front is concurrent with the peak of hake spawning, followed by a period when adults feed actively (Hart, 1946, *sensu* Podestá, 1990; Ocampo Reinaldo et al., 2011). This synchrony between high primary productivity and active feeding may cause the dense hake schools that have been reported in the frontal zone (Williams et al., 2010; Ocampo Reinaldo et al., 2012). Despite the long distance to port (located in San Antonio Bay, see Fig. 1), fishers have traditionally operated on these schools, motivated by high yields. This behaviour is clear in the maps of fishing activity. In autumn, the lack of vertical stratification may encourage the hake to disperse through the water column in search of food (Ocampo Reinaldo et al., 2011, 2012). The low hake yields may encourage captains to seek better catch in coastal sectors, where there may be greater species diversity.

The biology of *S. porosa* has been poorly studied in the SMG, and the causes of its seasonal occurrence remain unknown. Perier and Di Giácomo (2002) analysed the catch of *S. porosa* over four seasonal surveys and reported dense reproductive schools during August and September in the northern area of the gulf. Fishers are now taking advantage of this seasonal resource, given its high availability and commercial opportunities. This change in fishing intention has resulted in additional working hours because hake is fished during daylight hours but *S. porosa* is caught at night (Romero, 2010). However, the average duration of fishing trips during winter has been reduced from 6 to 1.5 days because of the *S. porosa* harvest.

The spatio-temporal variability in fleet behaviour of the SMG trawl fishery has implications for fishery economics and consequently for fishery management. Analysing and modelling the fishing activities with reference to fishing location and seasonality is necessary to quantitatively assess the consequences of alternative management measures on stock dynamics and fisher behaviour in a context of uncertainty (Pelletier and Ferraris, 2000). In a system where change is the rule, fishers must deal not only with spatio-temporal variations in resource availability but also with rising fuel costs, fluctuating stock levels, regulations, and market conditions (Fulton et al., 2011; Tidd et al., 2012).

In summary, the implementation of a holistic approach that combines information from different sources allowed us to improve the knowledge about the dynamics and behaviour of the trawl demersal fleet that operates in the SMG. Our results suggest that the resource availability and commercial opportunities are significant factors in determining what, when, and where to fish. These findings agree with results from the Argentine Continental Shelf, where seasonality in landings of demersal species was primarily correlated with the migratory cycle of the target species and market demands (Fernández Aráoz et al., 2005).

This study provides new information that can be used to identify other drivers (e.g., commercial opportunities, regional and large-scale economic dynamics) that also determine fisher behaviour. Future research and fishery management decisions should attempt to take advantage of some features of the system, such as the presence of a healthy hake stock, a semi-enclosed ecosystem, and a simple fishery model with a well-known fleet, to ensure the sustainability of the SMG ecosystem.

References

Alemany, D., Acha, E.M., Iribarne, O., 2009. The relationship between marine fronts and fish biodiversity in the Patagonian Shelf Large Marine Ecosystem. J. Biogeogr. 36, 2111–2124.

Aubone, A., Bezzi, S.I., Cañete, G., Castrucci, R., Dato, C., Irusta, G., Madirolas, A., Pérez, M., Renzi, M., Santos, B., Simonazzi, M., Villarino, M.F., 2004. Evaluación y sugerencias de manejo del recurso merluza (*Merluccius hubbsi*). La situación hasta 1999. In: Sánchez, R.P., Bezzi, S.I. (Eds.), El Mar Argentino y sus recursos pesqueros. Tomo 4. Los peces marinos de interés pesquero. Caracterización biológica y evaluación del estado de explotación. Instituto de Investigación y Desarrollo Pesquero, Mar del Plata, pp. 207–235.

Branch, T.A., Hilborn, R., Haynie, A.C., Fay, G., Flynn, L., Griffiths, J., Marshall, K.N., Randall, J.K., Scheuerell, J.M., Ward, E.J., Young, M., 2006. Fleet dynamics and fishermen behavior: lessons for fisheries managers. Can. J. Fish. Aquat. Sci. 63, 1647–1668.

Castro, J., Punzón, A., Pierce, G.J., Marín, M., Abad, E., 2010. Identification of métiers of the Northern Spanish coastal bottom pair trawl fleet by using the partitioning method CLARA. Fish. Res. 102, 184–190.

Clarke, K.R., Warwick, R.M., 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, 2nd edition. Plymouth, UK, Primer-E Ltd.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18, 117–143.

Clifford, H.T., Steptlenson, W., 1975. An Introduction to Numerical Classification. Academic Press, New York-San Francisco-London.

Cortés, E., 1999. Standardized diet compositions and trophic levels of sharks. ICES J. Mar. Sci. 56, 707–717.

Christensen, A-S., Raakjær, J., 2006. Fishermen's tactical and strategic decisions: a case study of Danish demersal fisheries. Fish. Res. 81, 258–267.

Davie, S., Lordan, C., 2011. Definition, dynamics and stability of métiers in the Irish otter trawl fleet. Fish. Res. 111, 145–158.

Ehrlich, M.D., 1998. Los primeros estadios de vida de la merluza *Merluccius hubbsi* Marini 1933, como aporte al conocimiento de su reclutamiento y estructura poblacional. Doctoral Tesis. Universidad de Buenos Aires, Argentina.

Essington, T.E., Beaudreau, A.H., Wiedenmann, J., 2006. Fishing through marine food webs. Proc. Natl. Acad. Sci. U.S.A. 103, 3171–3175.

Faith, D.P., Minchin, P.R., Belbin, L., 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetation 69, 57–68.

FAO Fisheries and Aquaculture Information and Statistics Service, 2012. Total fishery production 1950–2009. FISHSTAT Plus – Universal software for fishery statistical time series. Food and Agriculture Organization of the United Nations. Available: http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp (April 2012).

Fernández Aráoz, N., Jaureguizar, A.J., Lagos, N., 2005. Patrón estacional de la composición íctica de las capturas desembarcadas por la flota nacional durante 1998–2004. Ecosistema Costero Marino (35–41°). INIDEP Inf. Tec. 51, 1–10.

Fonseca, T., Camposa, A., Afonso-Dias, M., Fonseca, P., Pereira, J., 2008. Trawling for cephalopods off the Portuguese coast—fleet dynamics and landings composition. Fish. Res. 92, 180–188.

Froese, R., Pauly, D. (Eds.), 2012. FishBase 2012: Concepts, Design and Data Sources. ICLARM, Los Baños, Laguna, Philippines.

Fulton, E.A., Smith, A.D.M., Smith, D.C., van Putten, I.E., 2011. Human behaviour: the key source of uncertainty in fisheries management. Fish Fish. 12, 2–17.

Gagliardini, D.A., Rivas, A.L., 2004. Environmental characteristics of San Matías Gulf obtained from LANDSAT-TM and ETM+ DATA. Gayana 68, 186–193.

González, R., Gaspar, C., Curtolo, L., Sangiuliano, I., Osovnikar, P., Borsetta, N., 2004. Fishery and Oceanographic Monitoring System (FOMS): a new technological tool based on remote sensing, with application in ecosystem management of coastal fisheries in Patagonia. Gayana 68, 234–238.

González, R., Narvarte, M., Caille, G.M., 2007. An assessment of the sustainability of the hake *Merluccius hubbsi* artisanal fishery in San Matías Gulf, Patagonia, Argentina. Fish. Res. 87, 58–67.

González, R., Ocampo Reinaldo, M., Schneider, C., Romero, M.A., Maggioni, M., Williams, G., Cabrera, G., Narvarte, M., Gagliardini, A., 2010. Correlating SST Satellite Data to the Spatial Distribution of Spawning Aggregations of Argentine Hake (*Merluccius hubbsi*) in San Matías Gulf, Patagonia, Argentina. In: JRC Scientific and Technical Reports – Proceeding Oceans from Space Venice 2010, JRC 57986, pp. 103–104.

Grafton, R.Q., Hilborn, R., Ridgeway, L., Squires, D., Williams, M., Garcia, S., Groves, T., Joseph, J., Kelleher, K., Kompas, T., Libecap, G., Lundin, C.-G., Makino, M., Matthiasson, T., McLoughlin, R., Parma, A., San Martin, G., Satia, B., Schmidt, C.-C., Tait, M., Zhang, L., 2008. Positioning fisheries in a changing world. Mar. Policy 32, 630–634.

Hart, T.J., 1946. Report on trawling surveys on the Patagonian continental shelf. Discov. Rep. 23, 227–408.

Hilborn, R., 2007. Managing fisheries is managing people: what has been learned? Fish Fish. 8, 285–296.

Holley, J.-F., Marchal, P., 2004. Fishing strategy development under changing conditions: examples from the French offshore fleet fishing in the North Atlantic. ICES J. Mar. Sci. 61, 1410–1431.

Katsanevakis, S., Maravelias, C.D., Kell, L.T., 2010. Landings profiles and potential métiers in Greek set longliners. ICES J. Mar. Sci. 67, 646–656.

Legendre, I.P., Fortin, M-J., 1989. Spatial pattern and ecological analysis. Vegetation 80, 107–138.

Macchi, C.J., Pájaro, M., Ehrlich, M., 2004. Seasonal egg production pattern of the Patagonian stock of Argentine hake (*Merluccius hubbsi*). Fish. Res. 67, 25–38.

Machado Schiaffino, G., Juanes, F., Garcia-Vazquez, E., 2011. Identifying unique populations in long-dispersal marine species: Gulfs as priority conservation areas. Biol. Conserv. 144, 330–338.

Marchal, P., 2008. A comparative analysis of métiers and catch profiles for some French demersal and pelagic fleets. ICES J. Mar. Sci. 65, 674–686.

Marchal, P., Andersen, B., Bromley, D., Iriondo, A., Mahévas, S., Quirijns, F., Rackham, B., Santurtún, M., Tien, N., Ulrich, C., 2006. Improving the definition of fishing effort for important European fleets by accounting for the skipper effect. Can. J. Fish. Aquat. Sci. 63, 510–533.

McClain, E.P., Pichel, W.G., Walton, C.C., 1985. Comparative performance of AVHRR-based multichannel sea surface temperature. J. Geophys. Res., 11587–11601.

Millán, D., 2011. Anuario de Estadísticas Pesqueras de la Provincia de Río Negro. Departamento Policía de Pesca, Dirección de Pesca, Reporte 2007. San Antonio Oeste.

Ocampo Reinaldo, M., 2010. Evaluación pesquera integral de la merluza común (*Merluccius hubbsi* Marini, 1933) del Golfo San Matías y efectos de la explotación de esta especie sobre otros componentes de la trama trófica. Doctoral Tesis, Universidad Nacional de Córdoba, Argentina.

Ocampo Reinaldo, M., González, R.A.C., Romero, M.A., 2011. Feeding strategy and cannibalism of the Argentine hake *Merluccius hubbsi* Marini 1933. J. Fish Biol. 79, 1795–1814.

Ocampo Reinaldo, M., González, R.A.C., Williams, G., Storero, L.P., Romero, M.A., Narvarte, Narvarte, M., Gagliardini, D.A., 2012. Spatial patterns of the Argentine hake *Merluccius hubbsi* and oceanographic processes in a semi-enclosed Patagonian ecosystem. Mar. Biol. Res., http://dx.doi.org/10.1080/17451000.2012.739700, in press.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998. Fishing down marine foods webs. Science 279, 860–863.

Pech, N., Samba, A., Drapeau, L., Sabatier, R., Laloe, F., 2001. Fitting a model of flexible multifleet-multispecies fisheries to Senegalese artisanal fishery data. Aquat. Living Resour. 14, 81–98.

Pelletier, D., Ferraris, J., 2000. A multivariate approach for defining fishing tactics from commercial catch and effort data. Can. J. Fish. Aquat. Sci. 57, 51–65.

Perier, M.R., Di Giácomo, E.E., 2002. El savorín *Seriolella porosa* como un recurso estacional en el Golfo San Matías, República Argentina. INIDEP Revista de Investigación y Desarrollo Pesquero 15, 15–26.

Perrota, R.G., Viñas, M.D., Hernández, D., Tringali, L.S., 2001. Temperature conditions in the argentine mackerel (*Scomber japonicus*) fishing ground: implications for fishery management. Fish. Oceanogr. 10, 275–283.

Piola, A.R., Scasso, L.M., 1988. Circulación en el Golfo San Matías. Geoacta 15, 33–51.

Podestá, G.P., 1990. Migratory pattern of Argentine hake;1; *Merluccius hubbsi* and oceanic processes in the southwestern Atlantic Ocean. Fish. Bull. 88, 167–177.

Rivas, A.L., Beier, E.J., 1990. Temperature and salinity fields in the Northpatagonic Gulfs. Oceanol. Acta 13, 15–20.

Romero, M.A., 2010. Rol de los mamíferos marinos en el contexto de la trama trófica del Golfo San Matías e interacciones con las pesquerías demersales. Doctoral Tesis, Universidad Nacional del Comahue, Argentina.

Romero, M.A., González, R.A., Ocampo Reinaldo, M., 2010. When conventional fisheries management measures are not effective to reduce the catch and discard of juvenile fish: a case study of Argentine hake trawl fishery in San Matías Gulf (Patagonia, Argentina). N. Am. J. Fish. Manage. 30, 702–712.

Salas, S., Gaertner, D., 2004. The behavioral dynamics of fishers: management implications. Fish Fish. 5, 153–167.

Sardella, N., Timi, J., 2004. Parasites of Argentine hake in the Argentine Sea: population and infracommunity structure as evidence for host stock discrimination. J. Fish Biol. 65, 1472–1488.

Seijo, J.C., Defeo, O., Salas, S., 1998. Fisheries Bio-economics: Theory, Modelling and Management. FAO Tech. Fish. Doc. No. 368. Rome, Italy, 108 p.

Smouse, P.E., Long, J.C., Sokal, R.R., 1986. Multiple regression and correlation extensions of the mantel test of matrix correspondence. Syst. Zool. 35, 627–632.

Squires, D., 2009. Opportunities in social science research. In: Beamish, R.J., Rothschild, B.J. (Eds.), The Future of Fisheries Science in North America. Fish Fish. Series, vol. 31. Springer Science, New York, USA (chapter 32).

Tidd, A.N., Hutton, T., Kell, L.T., Blanchardd, J.L., 2012. Dynamic prediction of effort reallocation in mixed fisheries. Fish. Res. 125–126, 243–253.

Ulrich, C., Andersen, B.S., 2004. Dynamics of fisheries, and the flexibility of vessel activity in Denmark between 1989 and 2001. ICES J. Mar. Sci. 61, 308–322.

Vaz-dos-Santos, A.M., Rossi-Wongtschowski, C.L.D.B., de Figueiredo, J.L., Ávila-da-Silva, A.O., 2010. Threatened fish of the world: *Merluccius hubbsi* Marini, 1933 (Merlucciidae). Environ. Biol. Fish. 87, 349–350.

Vinther, M., Reeves, S.A., Patterson, K.R., 2004. From single-species advice to mixed-species management: taking the next step. ICES J. Mar. Sci. 61, 1398–1409.

Williams, G., Sapoznik, M., Ocampo Reinaldo, M., Solis, M., Narvarte, M., González, R., Esteves, J.L., Gagliardini, D., 2010. TM/ETM, AVHRR and SeaWiFS sensor studies in San Matías Gulf (Patagonia, Argentina): relationship with fishing activity and oceanographic surveys data. Int. J. Remote Sens. 31, 4531–4542.

Williams, G.N., Dogliotti, A.I., Zaidman, P., Solis, M., Narvarte, M., González, R.C., Esteves, J.L., Gagliardini, D.A., 2012. Assessment of remotely-sensed sea-surface temperature and chlorophyll-a concentration in San Matías Gulf (Patagonia, Argentina). Continent. Shelf Res., http://dx.doi.org/10.1016/j.csr.2012.08.014, in press.

Wood, J.B., Day, C.L., 2006. CephBase. A database-driven web site on all living cephalopods (octopus, squid, cuttlefish and nautilus) [online]. Available from: www.cephbase.utmb.edu (accessed 15.11.06).