

Interaction between southern sea lions *Otaria flavescens* and jack mackerel *Trachurus symmetricus* commercial fishery off Central Chile: a geostatistical approach

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ABSTRACT: A spatial description of the operational interaction between southern sea lions and jack mackerel fishing fleet off Central Chile is presented. The descriptive analysis showed a similar spatial trend for the number of sea lions per haul and catch per haul, both increasing in the SE direction, and decreasing in the NW direction. The number of sea lions was positively correlated with catches at intermediate distances from land, while negatively correlated with the number of fishing vessels at the greatest distance from the land. The geostatistical analyses corroborate the trends found during the descriptive analysis: 2 nuclei of high abundance of sea lions were found, which spatially overlapped 2 nuclei of high jack mackerel catches; nuclei that we proposed here as hot-spots for this interaction. Both hot-spots were located on the continental slope and over the deep ocean bed. No spatial relation was found between the number of sea lions and the number of fishing vessels. Thus, it is proposed that the area enclosed between 38–40° S and 74–75° 30' W constitutes the sector of higher interaction between the southern sea lions and jack mackerel industrial fishing fleet.

KEY WORDS: *Otaria flavescens* · *Trachurus symmetricus* · Commercial fishery · Interaction · Geostatistics · Central Chile

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INTRODUCTION

Coastal otariids are considered as generalist predators, located at high levels in trophic webs (FAO 1977, Beverton 1985), and participants in several interactions that involve the fishing sector (Wickens 1995). These interactions can be understood, in a broad sense, to be due to the concentration of fishing activities in coastal ecosystems, where fishing grounds overlap with otariids' feeding grounds, resulting in conflicts during the fishing operations and/or the occurrence of potential conflicts derived from changes in the common resources/prey (Shima et al. 2000), e.g. the removal of resources that constitute prey for the marine mammals (Jennings & Kaiser 1998).

The southern sea lion *Otaria flavescens* occurs along the entire Chilean coast. According to the most recent

estimates on population size, about 100 000 individuals inhabit Chilean waters (Sielfeld et al. 1997, Aguayo-Lobo et al. 1998, Oporto et al. 1999). Off Central Chile, the 3 most important prey items in the diet of sea lion are the whiptail hake *Macruronus magellanicus*, the cusk eels *Genypterus* spp. and the jack mackerel *Trachurus symmetricus* (George-Nascimento et al. 1985).

Pinnipeds may interact with fisheries during fishing operations (operational interaction), besides the biological interaction that results from sharing the same prey. The operational interaction results in various outcomes for both the pinnipeds and the fishery, mostly causing negative impacts upon one or both parties (e.g. Shaughnessy 1985, Wickens et al. 1992, Wickens 1995, Bjørge et al. 2002), while in some rare cases, interactions may provide clear advantages to pinnipeds.

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Several authors have previously reported on the development of interactions between southern sea lion *Otaria flavescens*, and artisanal fisheries and fish farms (e.g. Aguayo & Maturana 1973, Torres 1979, Sielfeld et al. 1997, Aguayo-Lobo et al. 1998, Sepúlveda 1998). Southern sea lions have been reported to interact with the industrial purse-seiner's fleet of jack mackerel off Central Chile (Hückstädt & Antezana 2003). This interaction has been described as a modification of sea lions in order to benefit from being able to feed in close association with the fleet as a result of the herding effect of purse-seining. In addition, negative consequences of this interaction were considered lower than expected for both participants, with an operational consumption of 0.4% of the vessels' catches and an incidental mortality rate of 0.03 ind. haul⁻¹.

Although *otaria flavescens* has been historically considered as coastal for Chilean waters (Vaz-Ferreira 1979, Rivera 1990), recent studies have expanded its range to over 300 km from the coast for males and 250 km for females (Campagna et al. 2001).

Along the Chilean coast, jack mackerel is constituted as 1 stock unit, although it is distributed heterogeneously (Grechina 1998). The largest biomass is concentrated off Central Chile, between 32 and 40° S (SUBPESCA 2000), which supports elevated exploitation levels compared to other fishing grounds (north and south). On the other hand, 17% of the sea lion population is also concentrated in this area (Aguayo-Lobo et al. 1998).

Geostatistical analyses allow the description of the correlation, or spatial continuity, of 1 variable by modelling its variability (Isaaks & Srivistava 1989), and hence, making it possible to estimate values for that variable at any determined point (Petitgas 2001). Geostatistics rely on spatial models, which assume that the variables under study are random, as well as the actuality in the field being the outcome of one or more random processes, and that the models on which predictions are based are those of random processes (Webster & Oliver 2001). These features allow the data to be analysed without considering the restrictions of the sampling design.

Thus, a geostatistical approach constitutes a robust tool to estimate the spatial distribution of marine populations (Petitgas 1993, Rueda 2001). For Chilean waters, geostatistical tools have been used for spatial modelling and mapping of some important fishing resources like the anchoveta *Engraulis ringens* (Castro et al. 1996, Oliva et al. 2001, 2002, Cubillos et al. 2003), as well as for estimating the biomass of the squat lobster *Pleuroncodes monodon* (Roa & Tapia 2000). Nevertheless, there are no antecedents for the area on using geostatistical approaches with marine mammals.

Thus, this work is intended to spatially characterise the operational interaction between southern sea lions

and the jack mackerel fishing fleet by means of geostatistical analysis, using data collected directly from fishing operations of purse-seiners off Central-South Chile during 2002.

MATERIALS AND METHODS

The data were obtained directly from the operations of Central Chile's purse-seiner fleet. On board, observers collected data from April to September 2002, months with the greatest numbers of landings of jack mackerel between 1990 and 1997 (SUBPESCA 2000). Information from 82 fishing hauls, conducted by 4 vessels, was included and analysed in this study. These vessels are considered as average vessels for the jack mackerel purse-seiner's fleet in Central Chile, with lengths ranging between 46 and 66 m, widths between 10 and 12 m, and storage capacities between 1000 and 1440 m³.

The data consisted of the following variables: (1) number of sea lions per fishing haul, based on censuses of sea lions observed at the sea surface, around and inside the purse-seine net, using 10 to 30 × 30 binoculars during the last phases of the haul (net retrieval and transfer of the catch on board), when the maximum number of sea lions around purse-seiners is recorded (Hückstädt & Antezana 2003); (2) total catch per haul; and (3) number of purse-seiners within 12 n mile of the fishing vessel. This area was considered to be the distance that a sea lion could cover over the duration of a fishing haul (ca. 2 h) swimming at top speed, according to the velocities established for the species by Campagna et al. (2001).

Observations conducted by non-specialists, with more sea lions per haul than the maximum number reported by Hückstädt & Antezana (2003), were not considered in the analyses. Thus, 79 out of 82 fishing hauls were considered in this study (Fig. 1a).

Descriptive analysis. The descriptive spatial exploration was carried out based on the moving windows statistics approach (Isaaks & Srivistava 1989). By estimating the mean and standard deviation (SD) for the variables under study inside the moving windows, it is possible to assess the existence of anomalies both among the mean values, as well as anomalies of the variability of such values or heteroscedasticity (Isaaks & Srivistava 1989). The moving windows allow univariate analysis in small portions of a certain phenomenon, which is spatially modulated. In addition, this tool let us establish the occurrence of proportional effect among the data (understood as the linear relationship between mean and SD for each moving window), which would imply a violation of the second order stationarity assumption (Isaaks & Srivistava 1989).

The sampling area (36° 30' to 40° 30' S and 73° 30' to 76° 30' W) was partitioned into 11 square windows, each of an area of 2 × 2°, and overlapping by 1° with the neighbouring windows. The latter was done in order to consider a minimal number of observations for each window that would allow us to obtain reliable statistics and the necessary detail for the analyses (Fig. 1b).

In each established moving window, mean and SD were computed for the variables: number of sea lions per haul, catch per haul (ton) and number of purse-seiners. The existence of linear correlations among the variables was also approached (p = 0.05), as well as the presence of the proportional effect, which allows one to establish if changes in local variability are related or not, with local means (Isaaks & Srivistava 1989).

Geostatistical analysis. Firstly, the variables under study (number of sea lions, catch and number of purse-seiners) were normalised through logarithmic transformation of the observations, $\log_{10}(x + 1)$, and later structurally analysed using the variogram method which enables statistical modelling of the average degree of similarity between values of variable x , as a function of the distance (Rossi et al. 1992). Hence, the variables were analysed using the experimental variogram, $\gamma^*(h, \theta)$, defined as:

$$\gamma^*(h, \theta) = \frac{\sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2}{2N(h)}$$

where $z(x_i)$ is the value for the variable at point x_i , $z(x_i + h)$ is the value for the variable at a given location separated from x_i by a discrete distance h (km) and $N(h)$ is the number of pairs of observations separated by a distance h .

The presence of anisotropy among our observations, i.e. differences in the continuity range in different directions (Isaaks & Srivistava 1989), was approached as well and when confirmed, the axis of major continuity or azimuth, the anisotropy ratio (defined as the ratio between the range for the azimuth direction and the range for the direction perpendicular to the azimuth direction), and type of anisotropy (i.e. geometric and/or zonal) were determined. Therefore, anisotropy involves the orientation of the phenomenon under study due to spatial constraints of the area where it occurs. Particularly, at the Chilean coast, the distribution of marine populations and associated processes is commonly modulated by the coastal configuration. The second part of the geostatistical analysis consisted of modelling, or estimating, the theoretical variogram. Thus, the experimental variogram of any isotropic variable is adjusted to a determined model by minimising the weighted minimal square sum (WMSS) by the number of pairs for each distance category or lag

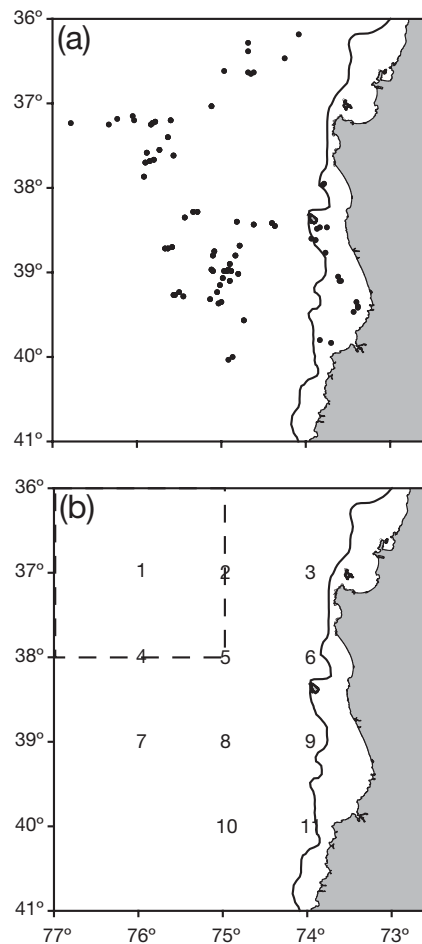


Fig. 1. Map of the study area showing (a) spatial distribution of sampled fishing hauls along Central Chile (n = 79) and (b) distribution and coverage surface of moving windows (2 × 2°) utilized in the descriptive analysis (Latitude °S, Longitude °W). The figure shows the 200 m depth iseline

(Cressie 1993). A large number of pairs per lag allows the estimation of a more robust variogram.

Since in this study the 3 variables presented both types of anisotropy, the system of coordinates should be transformed according to the method proposed by Goovaerts (1997), resulting in an anisotropic model $g_2(h)$, expressed as a spherical isotropic model $g_2^t = (|h'|)$, with range a_ϕ :

$$g_2(h) = g_2^t(|h'|) = Sph\left(\frac{|h'|}{a_\phi}\right)$$

The spherical model is defined as:

$$\gamma^*(h, \theta) = \begin{cases} 0, & h = 0 \\ c_0 + c \left[\frac{3}{2} \left(\frac{\|h\|}{\beta} \right) \right] - \frac{1}{2} \left(\frac{\|h\|}{\beta} \right)^3, & 0 < \|h\| < \beta \\ c_0 + c, & \|h\| \geq \beta \end{cases}$$

Table 1. Descriptive spatial analysis based on the moving windows statistics approach. The table indicates the corresponding spatial range, number of fishing hauls sampled (n) and basic statistics for the variables under study

Moving window	Location		n	No. sea lions		Catch (ton)		No. purse-seiners	
	Latitude (° S)	Longitude (° W)		Mean	SD	Mean	SD	Mean	SD
1	36–38	75–77	18	2.11	3.32	72.22	31.35	10.5	4.15
2	36–38	74–76	21	8	9.26	125.24	131.59	9	4.98
3	36–38	73–75	10	15.1	9.39	254	212.61	4.6	3.24
4	37–39	75–77	28	8.29	10.38	137.86	124.99	3.89	2
5	37–39	74–76	34	13.83	15.86	190	145.26	8.47	5.34
6	37–39	73–75	19	16.05	17.74	285	154.43	9.96	5.08
7	38–40	73–75	30	15	8.88	215.26	121.26	8.74	4.92
8	38–40	74–76	34	16.49	14.5	235.57	140.65	7.56	4.80
9	38–40	75–77	19	14.74	15.07	221.13	143.36	5.57	4.16
10	39–41	74–76	15	10.53	5.26	201.67	118.59	7.67	4.92
11	39–41	73–75	15	12.27	7.60	193	138.69	8.87	3.6

The following parameters were estimated: *nugget* (C_0) or microscale error, *sill* ($C_0 + C$), which defines the asymptotic value for the variogram (C), and β or range, which defines the distance after which there is no correlation between observations (continuity).

The results obtained through the modelling were compared to the original values using the cross validation approach, which allowed one to test whether the variability of the observations is indeed reproduced by the theoretical variogram and the search parameters in the area (Englund & Sparks 1988). The search parameters were selected by estimating the mean square error (MSE) from the residuals obtained during the cross validation, choosing that parameter's combination with the minimum MSE, implying that both the bias and residuals' dispersion are close to zero.

Once the theoretical variogram and the search parameters were established, the data were spatially interpolated using ordinary point kriging, which enables the estimation of values for the variables, conferring more relative weight to estimations of closer points located inside the influence range (Petitgas 1996). Kriging results enabled bi-dimensional mapping of isolines, and hence allowed the definition of nuclei of high abundance for the number of sea lions, catch and number of purse-seiners in the sampling area.

RESULTS

Descriptive analysis

The mean number of sea lions per haul varied among windows, with a minimum of 2.11 sea lions (SD = 3.32, Window 1) and a maximum of 16.49 sea lions (SD = 14.5, Window 8). Higher mean values were observed in those windows located towards the south and closer to

the coastline. In general, standard deviation values showed great variability among the windows (Table 1).

Regarding the catch (Table 1), mean values per window varied between 72.22 (SD = 31.35, Moving Window 1) and 285 ton (SD = 154.43, Moving Window 6). A decreasing trend was observed in the NW direction (Windows 1, 2 and 4), whereas catches around 200 t were observed for the rest of the windows. It was also observed that Moving Window 3 presented the highest variation in catches (SD = 212.61).

The mean number of purse-seiners per window varied between 3.89 (SD = 2, Moving Window 4) and 9.96 (SD = 5.08, Moving Window 6). Unlike previous variables, the number of purse-seiners did not denote a notorious internal variation, which impeded determination of the presence of any differentiation among windows, or establishment of any spatial trend (Table 1).

The number of sea lions and catch per haul were positively correlated only for those windows located to the northwest of the study area (Moving Windows 2, 3, 4, 5 and 7), with the only exception of Moving Window 1, where no relation was found.

There was no relation between the number of sea lions and the number of purse-seiners (Table 2), with the exception of Moving Window 1, where a positive significant relation was found between the variables ($r^2 = 0.49$).

Finally, no significant relation was found between number of purse-seiners and catch, for any window (Table 2).

Geostatistical analysis

Number of sea lions

The omni-directional variogram for this variable resulted in a minimal number of pairs per lag of 158

and a lag distance of 55.6 km. The azimuth direction (θ) was 30° W and the anisotropy ratio was 3.

The variable was adjusted to the anisotropic model $g_2(h)$, or spherical isotropic model $g_2^t = (lh'|)$ (WMSS = 3.49) (Fig. 2). The dependence spatial range for the number of sea lions (β) was slightly larger than 116 km, with a microscale error (C_0) corresponding to 46% of the sill (0.22). The kriging interpolation (Fig. 3) shows the presence of 2 nuclei of larger sea lion abundance (>1.25): a coastal nucleus, located at 72 km from the closest haul-out (38° 30' S, 74° 20' W), and an oceanic nucleus, located at 154 km from the closest haul-out (38° 20' S, 75° 20' W). Likewise, the map shows the existence of a low abundance nucleus at 109 km from the closest haul-out (38° 25' S, 74° 48' W). From the map, a spatial trend is evident with low abundances of sea lions in the NW direction, and larger abundances of sea lions towards the south and, obviously, towards the coast.

Catch

The experimental variogram for the variable catch (Fig. 5), presented a minimal number of pairs per lag of 98 and a lag distance of 40.7 km. The azimuth direction (θ) was 26° W and the anisotropy ratio was 4.27. The experimental variogram was adjusted to the anisotropic model $g_2(h)$ or spherical isotropic model $g_2^t = (lh'|)$ (WMSS = 5.63) (Fig. 4). The results showed a continuity range (β) of 33.3 km; the nugget (C_0) was 0, and the sill was 0.136. When C was interpolated through kriging (Fig. 5), the presence of several small nuclei with high catches was evident ($C > 2.3$), most of which were located far away from the coastline.

Table 2. Linear correlation coefficients (r^2) between the variables No. sea lions, catch and No. purse-seiners inside the moving windows. Significant correlations at the 95% confidence level (*)

Moving window	No. sea lions Catch	No. sea lions No. purse-seiners	Catch No. purse-seiners
1	0.39	0.49*	0.36
2	0.71*	-0.41	-0.30
3	0.52	-0.08	-0.28
4	0.76*	-0.15	-0.23
5	0.45*	-0.22	-0.28
6	0.04	0.30	0.34
7	0.57*	-0.09	-0.18
8	0.19	-0.03	0.04
9	0.03	-0.08	0.09
10	0.12	0.31	0.50
11	0.06	-0.37	0.01

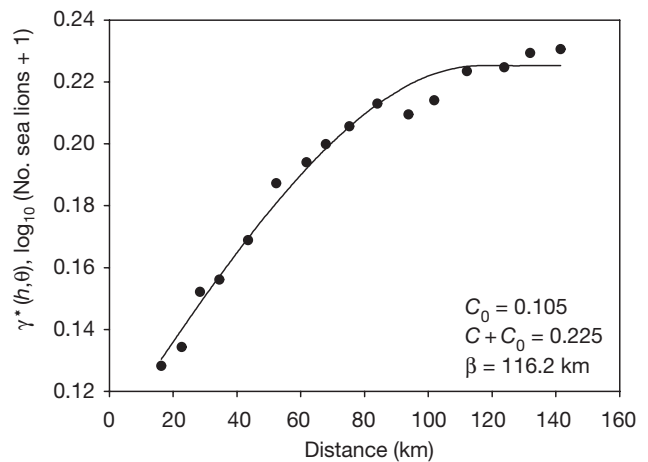


Fig. 2. Omni-directional variogram for variable log (No. sea lions + 1) (●), adjusted to the anisotropic model $g_2(h)$, or spherical isotropic model $g_2^t = (lh'|)$ (weighted minimal square sum [WMSS] = 3.49) (—)

Furthermore, the map denotes an increasing trend in catches towards the SE quadrant in the study area. On the other hand, towards the northwest, a decreasing trend in catches is evident ($C < 2.15$), as the nucleus with lower catches is consistently found in the NW area ($C < 1.0$).

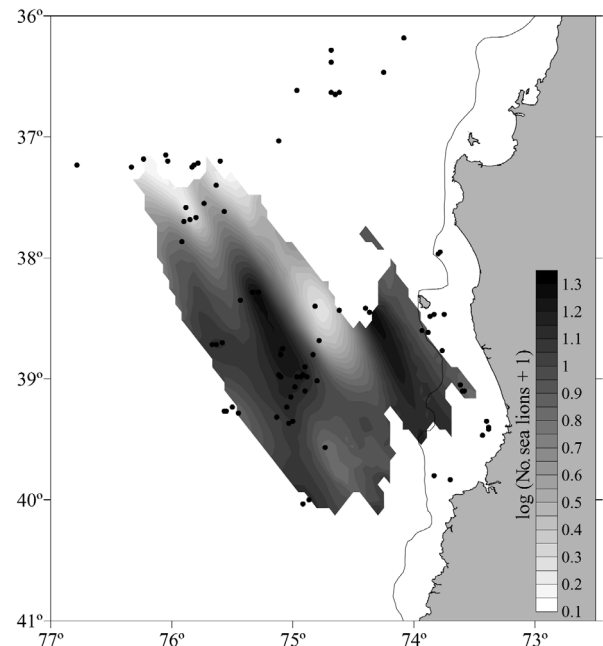


Fig. 3. Spatial interpolation obtained through ordinary point kriging for the number of sea lions, values expressed as log (No. sea lions + 1). Locations of sampled fishing hauls and the 200 m depth iseline are also shown

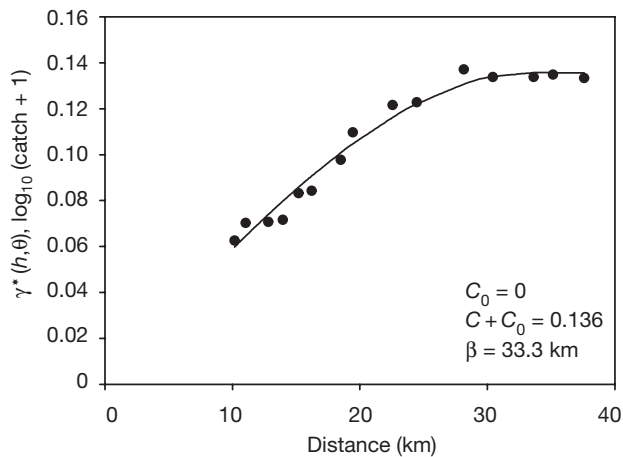


Fig. 4. Omni-directional variogram for variable $\log(\text{catch} + 1)$ (●), adjusted to the anisotropic model $g_2(h)$, or spherical isotropic model $g_2^I = (lh')$ (WMSS = 5.63) (—)

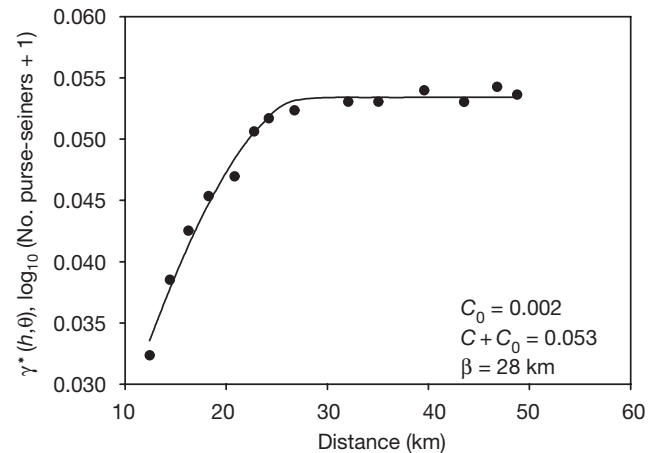


Fig. 6. Omni-directional variogram for variable $\log(\text{No. purse-seiners} + 1)$ (●), adjusted to the anisotropic model $g_2(h)$, or spherical isotropic model $g_2^I = (lh')$ (WMSS = 0.73) (—)

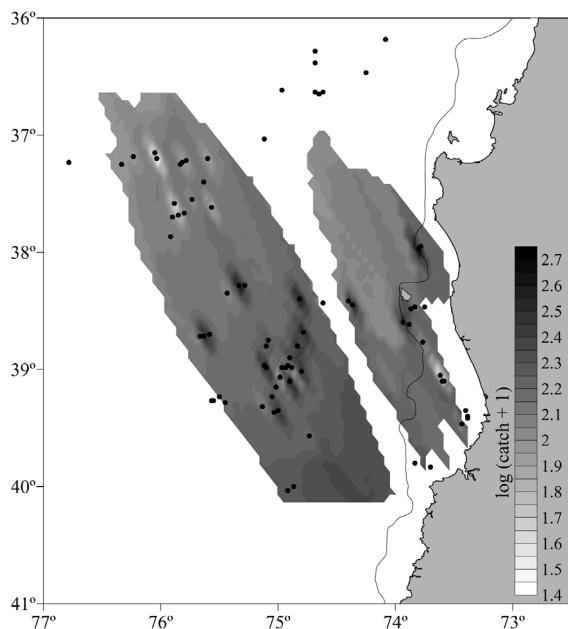


Fig. 5. Spatial interpolation obtained through ordinary point kriging for the catch, values expressed as $\log(\text{catch} + 1)$. Locations of sampled fishing hauls and the 200 m depth iseline are also shown

Number of purse-seiners

The structural analysis for this variable proved the occurrence of a slight anisotropy. The azimuth direction corresponded to $(\theta) 70^\circ \text{ E}$ and the anisotropy ratio was ca. 1.6. Therefore, the variogram of number of purse-seiners was also adjusted to the anisotropic model $g_2(h)$, or spherical isotropic model $g_2^I = (lh')$ (WMSS = 0.73; Fig. 6). The continuity range (β) was

28 km, the *nugget* (C_0) was 0.0019, which represents 3.7% of the *sill* (0.053).

From the map obtained through kriging (Fig. 7), there is an obvious absence of areas where the fleet concentrated its operations, with a low variability in the number of purse-seiners throughout the study area. Several minor nuclei with relatively low purse-seiner abundances were present (ca. 1.3), as well as some areas where the presence of purse-seiners was rare (ca. 0.35). Thus, the results showed a large homogeneity in the distribution of the fleet for the study area.

DISCUSSION

The study area is part of the Humboldt Current System (HCS), which flows northward along the coast of Chile and Peru in South America. Along the HCS, the biological productivity is very patchy in space, centered around isolated areas with special topography, like the shelf off Concepcion, Chile, at $36^\circ 30' \text{ S}$ (Sobarzo et al. 2001). During the austral summer (September–March), the mean surface wind in the study area is southerly, favouring the development of upwelling events with the consequent strengthening of biological productivity. This feature implies that this region alone supports between 50 and 90% of the annual Chilean fish catches (SERNAPESCA 2002).

The jack mackerel's commercial fishery presents a seasonal variability, highly influenced by the behaviour of the species, which migrates outside the Chilean Economical Zone for the reproduction period during mid-spring and summer months (SUBPESCA 2000). Thus, this study covered the period when the fleet is

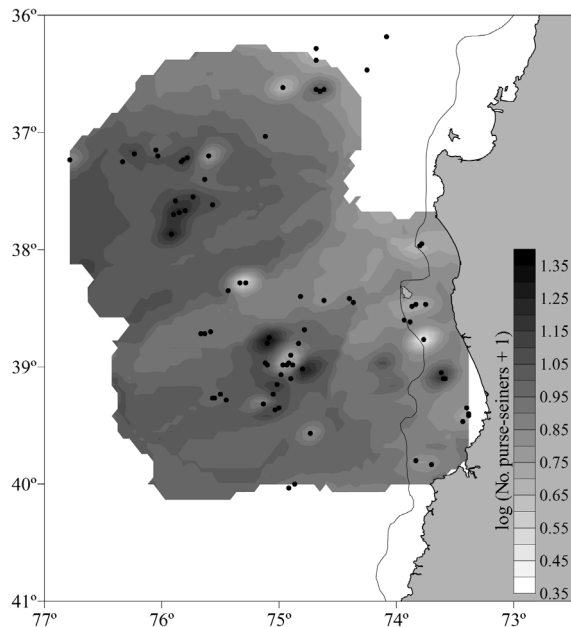


Fig. 7. Spatial interpolation obtained through ordinary point kriging for the number of purse-seiners, values expressed as $\log(\text{No. purse-seiners} + 1)$. Locations of sampled fishing hauls and the 200 m depth iseline are also shown

actively fishing on this resource in Chilean waters. During the jack mackerel's migration period, the purse-seiner's fleet focuses on non-migratory jack mackerel, as well as alternative resources (e.g. whiptail hake), but monthly catches drop to less than 50 000 t (SUBPESCA 2000). Since sea lions interacting with purse-seiner fleets are mainly adults (L. A. Hückstädt & T. Antezana unpubl. data), it is expected that the interaction will decrease during this period, as coincidentally sea lions enter into their reproductive period and feeding is dramatically reduced.

Several authors have approached the topic of interactions between pinnipeds and fisheries, as well as their causes and consequences, in distinct ecosystems worldwide (Northridge 1984, Wickens 1995). Nonetheless, limited attention has been paid to spatial aspects of such interactions, even though a better understanding of the spatial scales of these relationships would facilitate the implementation of management plans and mitigation of the derived conflicts (Bjørge et al. 2002). In this study, the interaction that occurs between the jack mackerel commercial fishery and southern sea lions (Hückstädt & Antezana 2003) was approached from a spatial perspective for the first time.

Southern sea lions have been proposed as a coastal species off the Chilean coast (Rivera 1990). However, in Argentinean waters (Argentinean Patagonia and Falkland Islands), diverse research programs have

implemented satellite tracking of lactating females and sub-adult males (Werner & Campagna 1995, Thompson et al. 1998, Campagna et al. 2001), recording the presence of sea lions offshore up to 258 and 307 km from the closest haul-out for females and males, respectively (Campagna et al. 2001). On the other hand, these authors describe southern sea lions as a species associated with the continental shelf, which can reach 400 km from the coast in that area. In the present study, sea lions were observed occurring in association with the jack mackerel fishing fleet at distances of up to 300 km from the closest haul-out point, coinciding with the spatial range described for the species in Argentinean waters. Nevertheless, the Chilean continental shelf is considerably narrower than the Argentinean, with a maximum width of 66 km in the study area (Sobarzo et al. 2001). It would, therefore, appear that the southern sea lion is not associated with the continental shelf since it can reach waters far away from the continental shelf edge, with depths of about 5000 m. The Northern fur seal *Callorhinus ursinus* has also been known to reach waters off the continental shelf during post-breeding trips (Loughlin et al. 1999).

The methodological approach used in this work to estimate the abundances of sea lions around purse-seiners, based on the number of sea lions observed from the bridge on the surface, does not reflect the level at which the actual population of sea lions is involved in this interaction, but only the presence of a certain number of sea lions interacting with commercial fishery. It is likely that only certain individuals have learnt to scavenge from the fishing vessels, and the effect of this interaction on the entire population remains unknown until an independent measure permits us to establish what fraction of the population is involved with this the jack mackerel commercial fishery.

However, the results obtained using this approach allowed us to analyse the interaction, from a spatial perspective. In addition, it was possible to identify areas where this interaction intensified, or where more sea lions have learnt to scavenge from purse-seiners, probably associated to the fishing effort in the surrounding areas.

During the descriptive analysis, differences were observed among windows regarding the number of sea lions and catches, both increasing towards the south of the study area. The number of purse-seiners, however, did not manifest any clear spatial pattern. The results enable us to propose the occurrence of 3 different types of moving windows for the study variables: (1) windows in a coastal range (Moving Windows 3, 6, 8, 9, 10 and 11), where the highest mean number of sea lions was recorded with no relation to either catches or the number of purse-seiners; (2) win-

dows in an intermediate range (Moving Windows 2, 4, 5 and 7), with a midway mean number of sea lions, significantly related with catches; and (3) Moving Window 1, located at the farthest distance from the haul-outs, with the lowest mean number of sea lions and significantly related to the number of purse-seiners. For Type (1) windows, sea lions are not related with stimuli such as catches or number of purse-seiners, both of which could be thought of as food availability stimuli for the sea lions. On the other hand, sea lions reach Type (2) windows in relation with the catches for this area, and only a scarce number of sea lions reach Type (3) windows, associated with the stimuli represented by the number of purse-seiners operating at such long distances from the coast, which sea lions presumably follow.

The feeding patterns of sea lions and seals reflect the availability and distribution of their prey (Boyd & Croxall 1992). The jack mackerel fishing operations represent an accessible and abundant source of prey for southern sea lions (Hückstädt & Antezana 2003). Hence, it can be proposed that if the sea lion has indeed acquired the modality of feeding from the fishing vessels instead of the typical searching and pursuing behaviour (Shaughnessy et al. 1981), then there should be a spatial co-occurrence between the sea lions and the catches and position of the jack mackerel fishing fleet, considering that the distribution of some marine mammals is tightly related to biological (such as food sources) and physical factors (Karschner et al. 2001).

In general, sea lion abundance patterns and catches are similar spatially, with a correspondence between both variables: decreasing toward the NW, while increasing toward the SE quadrant of the study area. For both nuclei with high abundances of sea lions (coastal and oceanic), the closest haul-out corresponded to Isla Mocha, a reproductive colony with an estimated population of 1100 individuals (Aguayo-Lobo et al. 1998). Furthermore, these centres are spatially overlapped with nuclei where high catches were recorded, and thus, these can be proposed as hot-spots of the interaction between sea lions and purse-seiners, since the number of sea lions can be considered as indicative of the intensity of the interaction.

The bathymetry of the area under study is characterised by the presence of a very shallow and narrow continental shelf (less than 200 m in depth and about 36 n miles in width), followed by very a steep continental slope (less than 50 n miles) and then reaching the sea bed with depths over 4500 m. The coastal hot-spot was located above the continental slope, where the depths are about 2500 m, whereas the oceanic hot-spot is located over a rising of the ocean bottom, at a depth of 4000 m.

No clear relationship was found between the number of sea lions and the number of purse-seiners, with the exception of the oceanic hot-spot, where a low abundance of purse-seiners was recorded, and another centre, where the inverse relationship was found (low abundance of sea lions, high abundance of purse-seiners). This centre was also recorded as a low catch centre, and the same pattern between catches and number of purse-seiners was also recorded at the coast (ca. 39° S) and north of Isla Mocha.

Thus, it is possible to propose a defined sector where the interaction between southern sea lions and the jack mackerel purse-seiner fleet gains a greater importance, located between 38 and 40° S and between 75° 30' W and the coastline. Karschner et al. (2001) propose that the hot-spots overlapping between marine mammal feeding grounds and fisheries in the North Atlantic correspond to the most productive fishing zones, but also areas from which most reports of fishing-mammals interactions originate. In this study, the location of hot-spots co-occur with those areas of greatest fishing yield for the jack mackerel commercial fishery, here represented as catches, and therefore, the areas where the interaction with the sea lions is more intense.

As mentioned above, it remains unknown what fraction of the population is engaged in this interaction with the jack mackerel fishing fleet off central Chile. However, the results obtained from the present study indicated that the largest catches and number of sea lions are concentrated in the area surrounding Isla Mocha's colony.

Although the historical development of commercial fishery in the area is not well known, during 2002, purse-seiner fleets were focused preferentially in this zone (L. A. Hückstädt unpubl. data), and presumably the animals that interacted with the vessels came from the colony of Isla Mocha.

It has been proposed that the animals engaged in this interaction actually approach the fishing vessels, acquiring then their food directly from the fish caught in the net (L. A. Hückstädt & T. Antezana 2003, unpubl. data). In general, the fishing fleet probably concentrates its effort around this area because of the high biomass of jack mackerel found, and the presence of sea lions around the purse-seiners is explained not by the availability of free prey, but by the stimuli implied by the presence of the fishing vessels and, possibly, the noise of their engines (Hückstädt & Antezana 2003).

The above statement could be reinforced if it is considered that, on those occasions when observations were conducted in the surroundings of Cobquecura colony (the largest colony of sea lions in the area), only a scarce number of sea lions were observed in associa-

tion with the low number of purse-seiners operating (and hence a less intense stimuli for the sea lions to approach). In addition, the fishing fleet does not operate in this area very often, which could imply that only a few sea lions from this colony are accustomed to obtaining their food directly from the jack mackerel fishing fleet. Hückstädt & Antezana (2003) propose that sea lion density at fishing grounds may be associated with a learned knowledge of the productivity of the fishing grounds instead of the distance to the haul-outs, which is reinforced by the results of this work.

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