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Distribution of megafaunal species in the Southwestern Atlantic: key ecological areas and opportunities for marine conservation

V. González Carman[1,2,3]*, A. Mandiola[1], D. Alemany[1], M. Dassis[1], J. P. Seco Pon[1], L. Prosdocimi[4], A. Ponce de León[5], H. Mianzan[1,2], E. M. Acha[1,2], D. Rodríguez[1], M. Favero[1], and S. Copello[1]

[1]*Instituto de Investigaciones Marinas y Costeras (IIMyC), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)—Universidad Nacional de Mar del Plata (UNMdP), Mar del Plata, Argentina*
[2]*Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP), Paseo Victoria Ocampo N° 1 (B7602HSA), Mar del Plata, Argentina*
[3]*Aquamarina—CECIM, Programa Regional de Investigación y Conservación de Tortugas Marinas (PRICTMA), Pinamar, Argentina*
[4]*Coordinación de Gestión de Pesquerías, Dirección Nacional de Planificación Pesquera, Subsecretaría de Pesca y Acuicultura, Buenos Aires, Argentina*
[5]*Departamento Mamíferos Marinos, Dirección Nacional de Recursos Acuáticos (DINARA), Ministerio de Ganadería, Agricultura y Pesca, Montevideo, Uruguay*

**Corresponding author. tel: +54 2234861292; e-mail: vgcarman@inidep.edu.ar; vgcarman@gmail.com.*

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During the last centuries, populations of marine megafauna—such as seabirds, turtles, and mammals—were intensively exploited. At present, other threats such as bycatch and pollution affect these species, which play key ecological roles in marine ecosystems as apex consumers and/or nutrient transporters. This study analyses the distribution of six megafaunal species (*Chelonia mydas*, *Caretta caretta*, *Dermochelys coriacea*, *Thalassarche melanophris*, *Otaria flavescens*, and *Arctocephalus australis*) coexisting in the Southwestern Atlantic to discuss their protection in terms of current management strategies in the region. Through the prediction of the species potential distributions and their relation to bathymetry, sea temperature and oceanographic fronts, key ecological areas are defined from a multi-taxa perspective. Information on the distribution of 70 individuals (18 sea turtles, 19 albatrosses, and 33 otariids) was obtained through satellite tracking conducted during 2007 – 2013 and analysed using a Geographic Information System and maximum entropy models. During the autumn – winter period, megafaunal species were distributed over the continental shelves of Argentina, Uruguay, and Brazil, mainly over the Argentine Exclusive Economic Zone and the Argentina-Uruguay Common Fishing Zone. Despite some differences, all megafaunal species seems to have similar environmental requirements during the autumn – winter period. Mostly waters shallower than 50 m were identified as key ecological areas, with the Río de la Plata as the habitat with the highest suitability for all the species. This area is highly productive and sustains the main coastal fisheries of Uruguay and Argentina, yet its role as a key ecological area for megafaunal species has been underestimated until now. This approach provides a basis to analyse the effect of anthropic activities on megafaunal species through risk maps and, ultimately, to generate knowledge to improve national and bi-national management plans between Argentina and Uruguay.

Keywords: biodiversity conservation, fronts, habitat use, otariids, seabirds, sea turtles, satellite tracking.

Introduction

Since the 16th century and well into the 20th century, populations of marine megafauna—such as sea turtles, birds, and mammals—were intensively exploited in their breeding sites for eggs, feathers, fur, oil, and meat (e.g. Crespo and Pedraza, 1991; Medway, 1998; Rodríguez and Bastida, 1998; Brooke, 2004; Broderick *et al.*, 2006; Croxall *et al.*, 2012). Past levels of exploitation have been reduced significantly, yet some wild populations remain at low levels if compared with historical baselines (Jackson *et al.*, 2001; McClenachan *et al.*, 2006; Grandi *et al.*, 2012). At present, these populations are far from being fully protected because of land-based (e.g. coastal development, introduced predators) and at-sea (e.g. pollution, bycatch and overfishing) threats (IUCN, 2014). Megafaunal species have been recognized as conservation priorities in marine ecosystems due to their key ecological role as apex consumers and/or nutrient transporters (Jackson, 2001; Heithaus *et al.*, 2008; Baum and Worm, 2009).

This study analyses the distribution of megafaunal species feeding in sympatry in the Southwest Atlantic. It focuses on the Warm Temperate Southwestern Atlantic (WTSA) province (*sensu* Spalding *et al.*, 2007) and on adjacent international waters, comprising part of the exclusive economic zones (EEZs) of Argentina, Brazil, and Uruguay (Figure. 1). In the region, megafaunal species are affected (or have the potential for being affected) by threats like interaction with fisheries and pollution (Fossette *et al.*, 2010; González Carman *et al.*, 2011, 2014a; Rodríguez *et al.*, 2013; Copello *et al.*, 2013, 2014). The region is ground for coastal and high seass fisheries targeting pelagic and bottom-demersal fish and crustaceans species (FAO, 2011) and incidental mortality of megafaunal species has been widely reported in a variety of fishing gear (e.g. Crespo *et al.*, 2007; Bugoni *et al.*, 2008; González Carman *et al.*, 2011; Favero *et al.*, 2013; Seco Pon *et al.*, 2013, 2015; Fossette *et al.*, 2014).

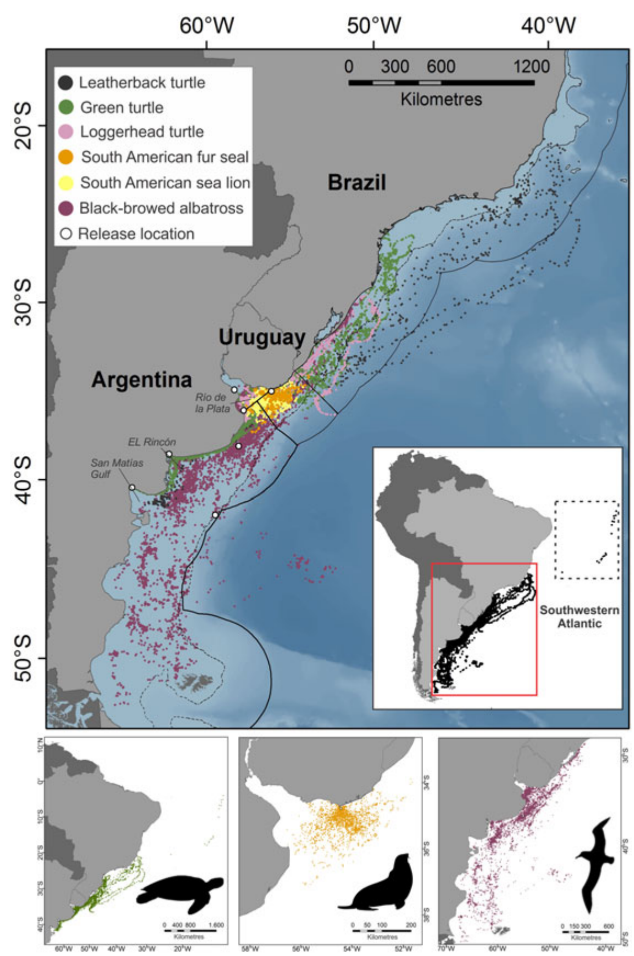

Figure 1. Distribution of tracked marine megafaunal species during autumn–winter (2007–2013) in the WTSA province and adjacent international waters. Upper panel shows locations by species in different colour codes (fixes inside dashed-line square of the inset belong to leatherback turtle). Lower panels show locations of megafaunal species grouped by taxa. EEZs of each country are delimited by solid line and 200 m isobaths by dotted line. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

Moreover, major metropolitan areas located along the coast (e.g. Buenos Aires, Montevideo, Rio de Janeiro) are responsible for the generation of large amounts of waste (Acha *et al.*, 2003; González Carman *et al.*, 2015) that affects megafaunal species due to the risk of ingestion or entanglement (e.g. Tourinho *et al.*, 2010; Denuncio *et al.*, 2011; González Carman *et al.*, 2014a; Jiménez *et al.*, 2015).

The oceanic region of the study area is also characterized by the opposing flows of the Brazil (subtropical) and Malvinas (subantartic) Currents that meet, in average, at 36°S (Olson *et al.*, 1988; Piola *et al.*, 2000; Lucas *et al.*, 2005). In this area, referred to as the Brazil/Malvinas Confluence, the two flows turn offshore in a series of large amplitude meanders (Figure. 2). The neritic region is characterized by a narrow shelf at the north which widens southward to form the broad Patagonian shelf. The northern shelf waters are of subtropical origin while those in the south are of subantartic origin, both are modified by continental drainage. Important oceanographic frontal systems (Acha *et al.*, 2004) are present in the area, such as those of the Río de la Plata (RDP), El Rincón (ERF), the mid-continental shelf (MSF), and the continental shelf break (SBF) (Figure. 2; Acha *et al.*, 2004; Piola *et al.*, 2005, 2008). The RDP is a two-layered estuarine system where freshwater flows seaward on the surface while denser and more saline shelf water intrudes along the bottom (Mianzan *et al.*, 2001; Acha *et al.*, 2008). This dynamic generates two salinity fronts separated by *c.* 150 km and connected by a salt-wedge: a bottom (RDP bottom) and a surface (RDP surface) front at the inner and outer part of the estuary, respectively. The discharge of estuarine water into the continental shelf forms as distinct surface layer of low salinity water that extends northeastward beyond 28–30°S (∼850 km from the estuarine area) during the austral autumn–winter period. This is known as the RDP plume, in which the boundary between the fresh and marine waters also forms a front (hereafter RDP plume, Muelbert *et al.*, 2008; Piola *et al.*, 2008). As well as the RDP fronts, the ERF separates relatively freshwaters (influenced by river discharges) from high salinity

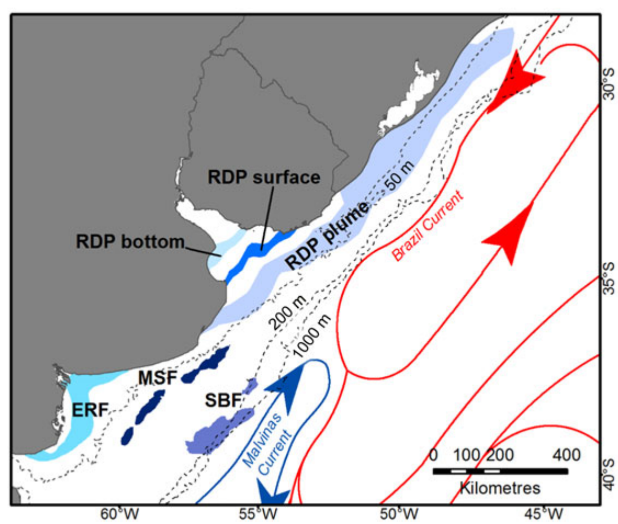

Figure 2. Oceanographic frontal areas in the WTSA province and adjacent international waters. Codes are: RDP bottom: Río de la Plata bottom front, RDP surface: Río de la Plata surface front, RDP plume: Río de la Plata plume front, ERF: El Rincón front, SBF: continental shelf break front, and MSF: mid-continental shelf front. Dotted lines indicate 50, 200, and 1000 m isobaths. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

waters generated at the San Matías Gulf (Figure. 1). The MSF holds a thermal front that separates coastal, mixed waters from stratified shelf waters (Lucas *et al*., 2005; Romero *et al*., 2006). Similarly, the SBF is characterized by a permanent thermohaline front that separates the shelf waters from the colder and saltier Malvinas waters (Acha *et al*., 2004; Piola *et al*., 2008).

These oceanographic frontal areas are known to be crucial habitats for megafaunal species in terms of increased feeding opportunities (Copello *et al*., 2011, 2013; Rodríguez *et al*., 2013; Acha *et al*., 2015). However, they may enhance threats to these species through the concentration of fishing activities (Alemany *et al*., 2014; Copello *et al*., 2014) and accumulation of drifting pollutants (e.g. plastics) (Acha *et al*., 2003; González Carman *et al*., 2014a). The analysis of the distribution of megafaunal species in relation to oceanographic frontal areas is therefore relevant to their conservation (Ramos *et al*., 2013; Scales *et al*., 2014), and the WTSA province and adjacent international waters remains an important region with significant data scarcity, in particular regarding multi-taxa studies.

This study identifies key ecological areas for megafaunal species in the WTSA province and adjacent international waters using a Geographic Information System (GIS) and a modelling tool rooted in maximum entropy. Specifically, it (i) describes the distribution of seabird, turtle, and otariid species; (ii) relates such spatial distribution to bathymetry, sea surface temperature (SST), and main oceanographic frontal areas of the region; and (iii) defines key ecological areas from a multi-taxa perspective. Results are discussed in relation to current management regimes and jurisdictions to identify conservation opportunities.

Methodology

Satellite tracking data

A total of 70 individuals from six megafaunal species were satellite tracked during austral autumn–winter (April to September) from 2007 to 2013: the Green turtle (*Chelonia mydas*), the Loggerhead turtle (*Caretta caretta*), the Leatherback turtle (*Dermochelys coriacea*), the Black-browed albatross (*Thalassarche melanophris*), the South American sea lion (*Otaria flavescens*), and the South American fur seal (*Arctocephalus australis*) (Figure. 1; Table 1). Electronic tags were deployed on the individuals to monitor their distribution after being released at the vicinity of their capture sites. Location information for all taxa were filtered according to different criteria depending on the species (see Supplementary material and Tables S1 and S2 therein).

Environmental data

The oceanographic frontal areas were defined according to those variables showing clear gradients related to the fronts. For the RDP and ERF, polygons between some selected isohalines were constructed in a GIS with the Feature to Polygon tool of ArcGIS 10.1® (Copyright© ESRI). The isohalines used were 12.5–22.5 for the RDP bottom, 20.0–25.0 for the RDP surface, 30.0–33.0 for the RDP plume, and 33.0–33.7 for ERF; according to Lucas *et al.* (2005), Piola *et al.* (2000, 2008), and Guerrero *et al.* (2010). The SBF and MSF were defined by satellite chlorophyll *a* (Chl *a*) patterns in a GIS. Following Alemany *et al.* (2014), Standard Mapped Images of satellite-derived chlorophyll *a* concentrations (NASA Ocean Colour; http://oceancolor.gsfc.nasa.gov, MODIS-Aqua sensor, processing level L3) were used to construct contour lines of 3 and 2 mg m^{-3} Chl *a* mean amplitude that defined the SBF and MSF polygons, respectively. Images corresponded to the 2007–2013 period and were limited to the area were the species co-occurred (197 by 166 pixels, 9 km spatial resolution). Following the same criterion, only the northern zone of the SBF was considered.

Bathymetric information for the study area was obtained from the GEBCO Digital Atlas and ETOPO2 Global 2′ Elevations datasets (British Oceanographic Data Centre and NOAA's National Geophysical Data Centre, http://gebco.net).

Climatological rasters from Aqua MODIS L3 SST were downloaded from NASA JPL PO.DACC website (ftp://podaac-ftp.jpl.nasa.gov/allData/modis/L3/docs/modis_sst.html, OBPG, 2002) to a GIS using the Marine Geospatial Ecology Tool (Roberts *et al*., 2010). Data were monthly climatologies of SST images of the study area for the period April 2007–September 2013, with a spatial resolution of 4 km.

Species distribution modelling

A maximum entropy (MaxEnt) species distribution modelling (Phillips *et al*., 2006) was used to relate the distribution of megafaunal species to bathymetry, SST, and main oceanographic frontal areas of the region. MaxEnt predicts the potential distribution of a species from species occurrence data and environmental background data. It generates maps of habitat suitability (HS) scaled from lowest (blue) to highest (red) suitability (Phillips *et al*., 2006; Elith *et al*., 2011).

MaxEnt modelling was implemented in MaxEnt version 3.3.3 k for each megafaunal species. To limit autocorrelation, tracking location data were reduced to best daily locations using R (R 3.0.1, R Development Core Team, 2013). Best daily locations were positions with the highest quality location class recorded during a 24-h period (Supplementary Table S2). If more than one location was determined with equal quality within the 24-h period, the first received location was retained (Pikesley *et al*., 2013). Environmental layers for bathymetry, SST, and frontal systems were created in a GIS ensuring that they have the same geographic coordinate system (datum

Table 1. Metadata for marine megafaunal species satellite tracked in the WTSA province and adjacent international waters.

Common name	Scientific name	No. of individuals	Stage	Sex	Global conservation status (IUCN, 2014)
Green turtle	*Chelonia mydas*	9	J	U	Endangered
Loggerhead turtle	*Caretta caretta*	6	J	U	Vulnerable
Leatherback turtle	*Dermochelys coriacea*	3	A	F	Critically Endangered
Black-browed albatross	*Thalassarche melanophris*	19	A	16 F 3 M	Near Threatened
South American sea lion	*Otaria flavescens*	22	6 SA 16 A	F	Least Concern
South American fur seal	*Arctocephalus australis*	11	A	F	Least Concern

Codes are J, juvenile; SA, subadult; A, adult; U, unknown; F, female; M, male.

WGS 84), resolution (4 km), and spatial extent restricted to the area where all taxa co-occurred (i.e. 30–40°S, 45–65°W) (Supplementary Table S2). For SST data, monthly climatological images were combined into an image representing the mean SST using the Extract Multivalues to Points, Spatial Join and Polygon to Raster tools of ArcGIS 10.1® (Copyright© ESRI).

MaxEnt models were run 100 times, obtaining a mean response model from the 100 runs for each individual species. Each time, a random sample of 30% of the dataset was saved to test the model (Supplementary Table S2). To ensure convergence of the model, the number of iterations was set to 5000 (Young *et al*., 2011). The receiver-operating characteristic analysis and the area under the curve (AUC) were used to provide a single measure of model performance. An AUC value of 0.5 indicates that the performance of the model is no better than random, while values closer to 1.0 indicate better model performance (Phillips *et al*., 2006).

To compare the predicted HS maps generated for each megafaunal species, the Niche Overlap function of the Dismo package (Hijsmans *et al*., 2013) was used in R (R 3.0.1, R Development Core Team, 2013). This function computes niche overlap from pairwise predictions of species distributions with a measure derived from Hellinger distance called "I" (Warren *et al*., 2008, 2010). This similarity measure is obtained by comparing the estimates of HS calculated for each grid cell of a study area using a Maxent generated distribution model, after normalizing each model so that all suitability scores within the geographic space sum to 1. "I" ranges from 0 (when species predicted environmental tolerances do not overlap at all) to 1 (all grid cells are estimated to be equally suitable for both species) (Warren *et al*., 2008, 2010).

Multi-taxa key ecological areas were defined overlapping the species maps of HS in a GIS and calculating the weighted average of HS for each cell of the species maps as follows:

$$\text{multi - taxa HS} \;=\; \frac{\sum^{r_i} \times HS_{ij}}{N},$$

where r is a coefficient calculated as the ratio of the number of tracking locations used to run the model for species i ($i = 1, \ldots, N$), HS is the HS value in map cell j ($j = 1, \ldots, J$) for species i, N is the total number of species and J is the total number of map cells. The multi-taxa HS was then represented in a GIS using the Extract Multivalues to Points, Spatial Join, and Polygon to Raster tools of ArcGIS 10.1® (Copyright© ESRI).

Results

Distribution of megafaunal species in the Southwestern Atlantic

A total of 17 233 filtered locations was obtained from 2007 to 2013 for the six analysed species (Supplementary Table S2). Tracked taxa showed an ample distribution in the SW Atlantic, ranging from 2°S to 53°S, from coastal areas to the high seas, and dispersed over Argentinean, Uruguayan, and Brazilian EEZs and international waters (Figure. 1). Although the use of these areas was not homogeneous, tracked individuals spent a large proportion of their time (93%) in shelf waters. Individuals of all taxa spent most of the time in Argentinean waters (48%), followed by Uruguayan (29%), and Brazilian (14%) EEZs, while <9% of the time was spent in international waters.

There were differences in the spatial scale of at-sea distribution by the different taxa (Figure. 1). Sea turtles covered the largest marine area (c. 450 000 km^2), with the three species distributed from northern Brazilian waters to 42°S (exceptionally, one leatherback turtle undertook a long-distance journey north of 3°S into the high seas, see locations inside dashed-line square in Figure. 1). Black-browed albatrosses spread over an area about half the size of sea turtles, although tracked birds distributed further south reaching 53°S. Compared with the other taxa, marine mammals were confined to a smaller area (c. 80 000 km^2) between 33 − 37°S and 52 − 56°W within the RDP, near their breeding colony.

Distribution of megafaunal species in relation to bathymetry, SST, and frontal areas in the WTSA province and adjacent international waters

A total of 1643 locations were used to run the models. The potential distribution of each megafaunal species during the autumn–winter period in the study area are shown in Figure. 3. Distribution models generated for each species returned AUC values >0.8 indicating a good model performance (Table 2).

Green turtle highest suitable areas (red areas) were in shelf waters of the RDP (associated to the surface and plume fronts) and throughout ERF (Figure. 3), spanning shallow waters of <50 m. Medium suitable areas (orange to yellow areas) occurred in the interior of the RDP, the RDP bottom front and along the 200 m isobath between 30 and 33°S. For loggerheads, highest suitable areas were in shallow (<50 m) waters of the RDP (bottom, surface, and plume fronts) (Figure. 3). Leatherback highest suitable areas were in shelf waters of the RDP (mainly the surface front) and ERF. Medium suitable areas extended to the 50 m isobath and also to the east of the 200 m isobath between 30 and 33°S (Figure. 3).

Albatross highest suitable areas were in waters of the RDP (mainly associated to the RDP bottom front), ERF, MSF, and over the 200 m isobath between 35 and 37°S. Medium suitable areas extended through the continental shelf barely beyond the 50 m isobath and along the 200 m isobath between 37 and 40°S, up to the SBF (Figure. 3).

For otariids, highest suitable areas were in waters of the RDP, mainly associated with the RDP surface and plume fronts (Figure. 3). For the South American fur seal, high suitable areas reach the 200 m isobath at 34–35°S and medium suitable areas extended south along the coast limited by the 50 m isobath (Figure. 3).

Bathymetry had the greatest explanatory power for all species models (>61–85%), whereas frontal areas had the smallest explanatory power (<8%). The mean SST explained between 14 and 30% of the species distribution predicted by the models. For marine turtles and albatross, the mean SST explained 20–30% of the variation observed in the distribution of those species (Table 2). The models predicted that suitable areas for marine turtles occurred in waters >12°C, with maximum probability of occurrence between 18 and 22°C of mean SST. Suitable areas for albatross and otariids included colder waters with 12–16°C of mean SST.

Comparison of the distribution of megafaunal species and key multi-taxa areas in the WTSA province

Similarity measure "I" was close to 1 in all pairwise comparison between potential distributions indicating that megafaunal species have similar environmental requirements during the autumn–winter period (Table 3). More similar were the potential distributions among marine turtle species, among otariid species, and between Green turtles, Black-browed albatrosses, and South American fur seals. In particular, waters shallower than 50 m potentially hosted the most suitable environmental conditions for all megafaunal species (Figure. 4). Highest suitable areas were mostly in waters of the RDP (in the bottom, surface, and plume fronts),

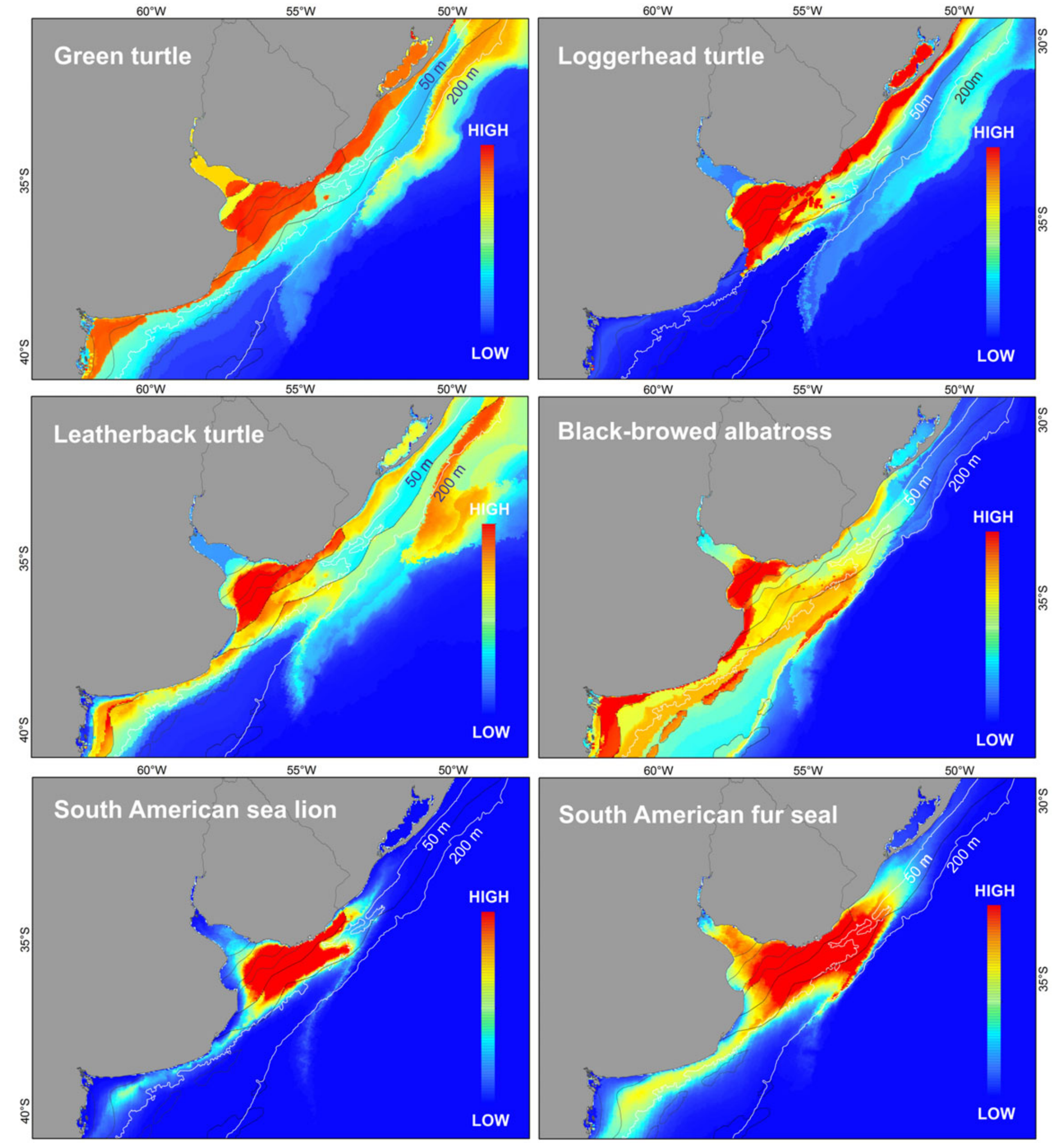

Figure 3. Potential distribution of megafaunal species during the autumn – winter period in the WTSA province and adjacent international waters modelled through maximum entropy. Black lines delimit oceanographic frontal areas and white lines indicate 50 and 200 m isobaths. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

encompassing an area of ca. 85 000 km^2. Medium suitable areas extended south along the coast to the ERF and were limited by the 50 m isobath. At the latitude of 34–35°S, high to medium suitable areas extended to the 200 m isobath (Figure. 4).

Discussion

The Green turtle, the Loggerhead turtle, the Leatherback turtle, the Black-browed albatross, the South American sea lion, and the South American fur seal were widely distributed in waters of the Southwestern Atlantic, mostly over Argentinean, Uruguayan, and Brazilian shelves. For the three taxa—sea turtles, seabirds, and otariids—mostly shallow waters no deeper than 50 m were identified as key areas (i.e. highly suitable). Particularly, the RDP frontal areas were identified as the habitat with the highest suitability for all the species, presumably due to good feeding opportunities. The novel multispecies approach taken in this study expands the bounds of individual species data sources, aiming to provide a basis for the development of multi-taxa management tools to protect vulnerable marine species and their habitats in the region.

Distribution modelling of megafaunal species

Modelling performance was good judging by the AUC values obtained for all species (Table 2). The potential distributions of the six megafaunal species seem to be defined mostly by the 50 m isobath (Table 2). Only the model generated for the Leatherback turtle exhibited medium suitable areas in the oceanic realm (Figure. 3), a species considered to be oceanic during most part of their lifetime (Bolten, 2003). Marine turtle potential distribution was also influenced by higher mean SST than albatross and otariids, as expected for ectothermic animals that perform seasonal movements from warmer coastal waters of Argentina and Uruguay in summer to coastal and oceanic areas off southern Brazil in winter (López-Mendilaharsu *et al*., 2009; González Carman *et al*., 2012, 2016).

Frontal areas had low explanatory power than expected, especially when compared with bathymetry. This can be due to the nature of the environmental layer used to predict the potential distribution of the species, which integrates information from salinity and Chl *a* concentration through the spatial definition of frontal and non-frontal areas. It was not possible to use GIS layers of Chl *a* or salinity values (as for SST) because of restrictions imposed by the modelling procedure. MaxEnt requires all the environmental layers have the exact same extent of data to execute the model (Young *et al*., 2011). But Chl *a* values in coastal waters, and especially within the RDP, are highly overestimated compared with values in the open sea due to coloured dissolved organic matter altering their optical properties (Piola *et al*., 2008). In addition to this, *in situ* bottom and surface salinity values were not available for the entire study area, and satellite-derived salinity are only available for surface layers and in a coarse spatial resolution ($1^\circ \times 1^\circ$).

Biological importance of the RDP for megafaunal species

The RDP and neighbouring waters have been recognized as a highly productive area sustaining a range of commercial fisheries (Mianzan *et al*., 2001; Chaluleu, 2002; Carozza, 2010; Sánchez *et al*., 2011). However, its role and relevance from the ecological perspective for megafaunal species has been underestimated. Although there were differences in the time of sampling (i.e. not all individuals were tracked at the same time, see Supplementary Table S1) −and thus our conclusions on multi-taxa key ecological areas should be taken with caution−, information on the feeding ecology of the individual species support the RDP as the main area for all species. They would benefit from high biomasses of their natural prey, but also from anthropogenic or facilitated resources (fishery discards and other by-products of fishery operations, as well as surface or shallow-diving predators during the recovery of the fishing gear). Green and leatherback turtles forage on gelatinous plankton such as medusae (*Liriope tetraphylla* and *Lychnorhiza lucerna)* (Estrades *et al*., 2007; González Carman *et al*., 2014b), which are highly abundant in estuarine waters (Mianzan and Guerrero, 2000; Alvarez Colombo *et al*., 2003). Loggerhead's diet is known to include salps (Martinez Souza, 2009) that reach high biomasses in adjacent shelf waters (Mianzan and Guerrero, 2000; Alvarez Colombo *et al*., 2003). The Black-browed albatross is known not only to feed on fish, cephalopods, and in some areas crustaceans but also to approach fishing vessels looking for discards, offal, and prey facilitated by fishery operations, in particular trawlers that heavily exploited the area (ACAP, 2010; Copello *et al*., 2014; Mariano-Jelicich *et al*., 2014; Seco Pon *et al*., 2015). Summer diet of otariids from Isla de Lobos (35.1°S, 54.9°W) is dominated by Whitemouth croaker (*Micropogonias furnieri*), Weakfish (*Cynoscion guatucupa*), and Argentine anchovy (*Engraulis anchoita*) (Naya *et al*., 2000, 2002; Ponce de León and Pin, 2006; Franco-Trecu *et al*., 2013), two target species for the commercial fisheries operating in the area (Sánchez and de Ciechomski, 1995; Chaluleu, 2002; Jaureguizar *et al*., 2003).

The relatively minor use of other oceanographic frontal areas—namely ERF, MSF, and SBF—by megafaunal species could be, at least partially, attributed to season, sex, and life stage of the studied individuals. For example, juvenile Black-browed albatross (not analysed in this study) intensively use the SBF at the latitude of the RDP during autumn and winter (Falabella *et al*., 2009). Post-breeding males of South American sea lions (in contrast to females studied here) disperse from haul out sites on the coast of Argentina to Uruguay and northern Patagonia (Giardino *et al*., 2014), at the latitudes of the MSF and ERF. Hence, the association of megafaunal species to such frontal areas could be important under other circumstances or periods in the annual cycle. In fact, the SBF is important for other megafaunal species not included in this study, like the Southern Giant petrel, the Wandering albatross (*Diomedea exulans*), and the Southern Elephant seal (*Mirounga leonina*) (Croxall and Wood, 2002; Campagna *et al*., 2006; Falabella *et al*., 2009; Quintana *et al*., 2010).

Table 2. AUC values and relative contributions of the environmental variables to the Maxent models.

		Variable contribution (%)		
Species	AUC	Frontal areas	Bathymetry	Mean SST
Green turtle	0.878	0.5	85.3	14.2
Loggerhead turtle	0.936	3.4	76.7	19.9
Leatherback turtle	0.867	7.9	67.2	24.9
Black-browed albatross	0.890	5.9	66.5	27.6
South American sea lion	0.984	7.0	66.0	27.0
South American fur seal	0.957	7.4	61.6	31.0

Table 3. Similarity measure "I" showing the overlap between pairwise predictions of megafaunal species potential distributions.

	Green turtle	Loggerhead turtle	Leatherback turtle	Black-browed albatross	South American sea lion	South American fur seal
Green turtle		0.89	0.94	0.84	0.65	0.89
Loggerhead turtle			0.89	0.66	0.71	0.75
Leatherback turtle				0.76	0.62	0.75
Black-browed albatross					0.66	0.87
South American sea lion						0.88
South American fur seal						

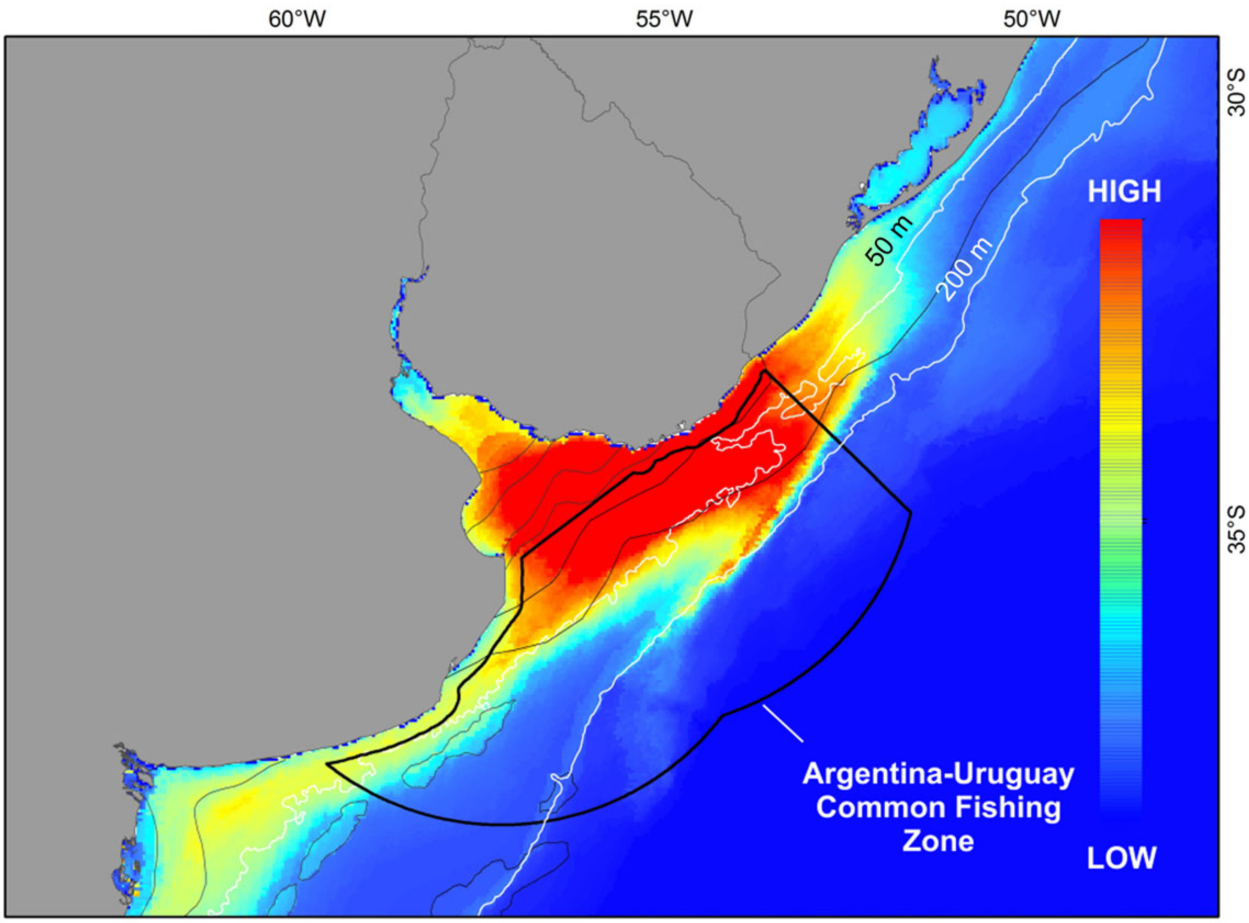

Figure 4. Overlap map of potential distribution of megafaunal species during the autumn–winter period in the WTSA province and adjacent international waters. Black lines delimit oceanographic frontal areas and white lines indicate 50 and 200 m isobaths. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

Opportunities for conservation of megafaunal species

The RDP is an area under international administration through the RDP Bilateral Treaty (*Tratado del Río de la Plata y su Frente Marítimo*) established between Argentina and Uruguay in 1973. This treaty administrates human activities, such as fishing and coastal development, to ensure sustainability, prevent pollution and promote research, and management to evaluate and preserve resources. Since several megafaunal species intensively use the area and interact with (and may be affected by) human activities, this treaty and its enforcement authority—the Technical Commission of the Maritime Front—are key instruments for their conservation and management. So far, bilateral coordinated actions involving the conservation of marine megafaunal species have been neglected in this forum. But our new understanding of the potential distribution of six megafaunal species of conservation concern improves the probability of success of protection measures in the RDP. The relatively restricted geographic area identified as a multi-taxa key area should be taken into account when zoning of human activities, especially those activities conducted in the Argentina-Uruguay Common Fishing Zone (Figure. 4). Future actions to be applied in this area and under this treaty could, for instance, focus on addressing the interactions between megafaunal species and commercial fisheries—such as bycatch and competition for resources—and on preventing and reducing marine pollution in terms of plastic debris disposed from coastal areas as well as from fishing activities. These actions should also be included into Argentina National Action Plans for seabirds, marine mammals, and sea turtles, in some cases already adopted on either side of the RDP but lacking of any coordination in terms of implementation.

Other threatened megafaunal species inhabiting the RDP area could be beneficiaries of protection actions promoted from these instruments, namely the Franciscana dolphin (*Pontoporia blainvillei*), the Magellanic penguin (*Spheniscus magellanicus*), the Manx (*Puffinus puffinus*), Great (*Ardenna gravis*) and Sooty (*A. grisea*) shearwaters, the Northern Royal albatross (*Diomedea sanfordi*), and the White-chinned (*Procellaria aequinoctialis*), the Spectacled (*P. conspicillata*), and the Southern Giant (*Macronectes giganteus*) petrels (Nicholls *et al.*, 2002; Falabella *et al.*, 2009; Guilford *et al.*, 2009; Ronconi *et al.*, 2010; Secchi, 2010; Hedd *et al.*, 2012; Reid *et al.*, 2014; Blanco and Quintana, 2014). Next steps should focus on more comprehensive analyses with the addition of more species, improvement of models through the inclusion of other variables (e.g. wind, surface currents, and fishing activity) as well as the assessment of the impact of fisheries and pollution on megafaunal species through risk or sensibility maps within the Rio de la Plata.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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