A brief story of spatial modeling at southwestern Atlantic Ocean

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Short Report

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Abstract

Spatial modeling of marine species is widely developed for biogeography, ecology and management purposes. However, hundreds of articles have been concentrated in the northern hemisphere marine environments and only a few dozens for the southern hemisphere. Through a bibliometric analysis I identified strong and weak aspects of studies approaching spatial modeling for species inhabiting the southwestern South Atlantic Ocean – SWAO. Studies on marine mammals and seabirds, based on presence-only and scenopoetic input data and through maximum entropy (MaxEnt) and generalized linear/additive models (GLM/GAM) are the highlights. A tiny quantity of articles have investigated the regional impacts of climate changes over species distribution (e.g., species displacement) or added alternatives for the management of fishing activities and its impacts on non-target species (e.g. incidental catch). I listed the articles used as baseline, discuss the aspects of my findings and claim to scientific community the need to strengthen the spatial modeling routine over SWAO.

Keywords: ecological niche; Latin America; scientific production

Introduction

Know the spatial distribution of marine species is one of the main objectives of scientists, fishers, industry and, managers worldwide in order to learn more about biogeography/ecology of species (e.g. Lezama-Ochoa et al. 2020), fishery avoidance (e.g. Paradinas et al. 2016; Mannocci et al. 2020) or consequences of human-caused impacts (e.g. Jones and Cheung 2015). Spatial modeling techniques have been developed to fulfill many of these objectives and, in general, have performed well its forecasting role (i. e. Pennino et al. 2016). For example, 'presence-only' based methods (e.g. MaxEnt) allow the identification of favorable areas for rare or sparsely sampled species, meanwhile more complex 'data hungry' methods also allow to incorporate information about spatial effect (Pennino et al. 2014) and/or bidirectional effect in presence of modeled species (Wilkinson et al. 2019; Paradinas et al. 2020).

However, hundreds of articles have been concentrated in northern hemisphere marine environments, mainly in temperate northern Atlantic and Pacific marine biogeographic realms, remaining only a few dozens for southern hemisphere (Robinson et al. 2017; Melo-Merino et al. 2020; Rodrigues et al. 2022); including the southwestern south Atlantic Ocean - SWAO (between 22ºS – 55ºS and 40ºW – 70ºW; Franco et al. 2017). The SWAO covers the adjacent coastal and oceanic zones of Brazil, Uruguay and Argentina, is important in many aspects such as for international and local fisheries (Haimovici 1997) and is a claimed zone for management (Cardoso et al. 2021). The main oceanographic feature that makes SWAO a productive zone is the confluence of the warm Brazil Current and the cold Falklands Current that seasonally moves northward during the winter (south Brazil) and southward during the summer (Uruguay, north Argentina) (Mendonça et al. 2017).

Identify strong and weak aspects of studies approaching spatial modeling over SWAO is a necessary aid for future needs for researches addressing this issue. Through a short communication (following suggestion by Joaquin & Tan 2021) and bibliometric analysis this paper aims to bring the state of the art of spatial modeling applied for species inhabiting the SWAO, exploring aspects such as most studied taxonomic groups, type of biological and environmental data, sub-regions most studied, methods applied and, focus of research.

Methods

I used the Science Citation Index Expanded (SCI-EXPANDED) database of Clarivate Analytics Web of Science (WoS) and Scopus database to search the scientific literature on the use of spatial modeling on southwestern Atlantic Ocean (updated on August 30, 2022). I combined two groups of terms ("ecologic* niche model*" or "specie* distribution model*" or "habitat suitability model*" or "bioclimatic* envelope model*" or "habitat model*" or "spatial model*") and ("southwest* atlantic" or "southwest* south atlantic" or "west* atlantic" or "west* south atlantic" or "south-west* atlantic" or "south-west* south atlantic" or "SW atlantic" or "SW south atlantic" or "south atlantic"). The terms were searched in title, abstract and author keywords at both platforms. In my search only scientific articles published in English until December 2021 were considered. The initial search resulted in 136 articles, of which 72 were from the WoS and 64 were from Scopus databases. However, 53 were duplicated among the two databases, resulting in 83 articles after removal. Next, I manually revised each of the 83 articles to exclude the studies that were developed in areas other than SWAO (between 22ºS – 55ºS and 40ºW – 70ºW; Franco et al. 2017, that did not modeled marine species, or that did not was in scope of spatial modeling. This step reduced the number of articles to 43 published between 2011 and 2021.

Then I classified each of 43 articles among: 1) year of publication, 2) large taxonomic groups, 3) type of biological data (presence-only, presence-absence, count, catch rate), 4) type of environmental data (abiotic, $\text{biotic}_{\text{non-interactive}}$, $\text{biotic}_{\text{interactive}}$; based on Soberón & Nakamura 2009), 5) number of environmental data, 6) modeled sub-region (adjacent to Argentina, Brazil, Uruguay or combined), 7) methods applied (e.g. MaxEnt, GLM), 8) number of methods applied, 9) focus of research (e.g. biogeography/current, climate changes). The results were showed in terms of number of articles or frequency and all analyses and plots were developed in R (R Core Team 2022) through the *ggplot2 v.3.3.5* (Wickham 2016), and *bibliometrix* v.3.2.1 (Aria & Cuccurullo 2017) packages.

Results

Forty-three articles among eleven years (2011-2021) were retained and used in further analysis. Eight large taxonomic groups were identified highlighting marine mammals and seabirds, followed by cartilaginous fishes, mollusk, bony fishes, corals, crustaceans, red algae, ascidians and kelps (Fig. 1a). Presence-only and abiotic + $\text{biotic}_{\text{non-interactive}}$ were the most popular types of biological and environmental data, respectively (Fig. 1b). Specifically for environmental data, between 3 and 34 environmental layers were used. Most studies included the adjacent zones of the three countries, but highlighting the sub-region off Brazil (Fig. 1c). MaxEnt and GLM/GAM were the most applied methods (Fig. 1d). Between one and ten different methods were applied together, commonly combining the output through ensemble approach. The majority of studies focused in discuss biogeography and current distribution of species (77%) followed by projection of invasive species (19%) (Table I). Articles discussing climate changes and conservation aspects were also detected (Table I). The reference list of retained articles is available in Table I.

Discussion

Spatial modeling is a few explored research area in SWAO considering just few dozen of articles published since 2011 and, demonstrating a large knowledge gap and delay compared to other research areas at SWAO (results not showed) and other regions world around (Robinson et al. 2017; Melo-Merino et al. 2020). For me it is clearly necessary that researchers studying the SWAO explore more this type of modeling techniques. The potential to create a georeferenced probability maps of distribution (even, in fact, being a spatial abstraction of ecological niche; Peterson & Soberón 2012) may contribute a lot for ecology, behavior, invasion, biogeography, fishery, among others disciplines. I know the hardy reality of scarce sampling for adjacent marine environments of South America, but I really believe that presence-only and fishery-dependent data are still feel explored – a lot of outputs could be generated! On the other hand, I may have failed to retain all articles applying spatial modeling due to the search terms used. However, I argue that the adequate terminology was contemplated in search terms and, simpler terms (such as “distribution”, “spatial”) would result in a bunch of articles, most beyond the scope of this study.

Articles on marine mammals and seabirds were the most frequents. These two taxonomic groups cover species that are at the same time key ecological links between environments they participate in (Bugoni et al. 2010; Troina et al. 2021) and threatened by human activities, such as fisheries (Bugoni et al. 2008; Cardoso et al. 2011; Gianuca et al. 2020; Secchi et al. 2021). Habitat preferences, overlap, segregation and migration are examples of topics addressed by such articles (Ramos et al. 2015; Seyboth et al. 2015; Quillfeldt et al. 2015; Pollet et al. 2019; Bamford et al. 2021). Although the relevance of both groups, the advance in spatial modeling studies for bony fishes, cartilaginous fishes and invertebrates is necessary to create a more realistic picture of the spatio-temporal trends of these organisms in SWAO, mainly in face of fishing, ecology and behavior dynamics. Additionally, there is no a specific sub-region being studied; this positive fact reinforces the need to strengthen a collaborative network between researchers of the three countries.

The common use of presence-only biological data and Maximum Entropy method was expected (Melo-Merino et al. 2020). Presence-only has exponentially growing in the last decades due to its easy-to-collect nature available by large repositories (e.g., Global Biodiversity Information Facility - GBIF, Distributed Information System for Biological Collections, and Ocean Biodiversity Information System - OBIS). Coupled to this nature, MaxEnt only needs the presence-only input data to develop its outputs – it basically finds a maximum-likelihood distribution for the species considering the given environmental information at the presence-only points, imported as geographic coordinates (Phillips et al. 2004). Data from fisheries (count and/or catch rate), if used adequately (Pennino et al. 2016), can be an important alternative to develop 'data-hungry' models (e.g., GLM, GAM, hurdle models) and to improve the quality of outputs (and forecast). Furthermore, all studies have used abiotic or abiotic plus biotic non-interactive environmental data and none considered biotic interactive data. Temperature, depth and sediment grain size are common examples of abiotic data and, chlorophyll-a concentration (or similar, such as phytoplankton concentration), is the most common biotic non-interactive data. Such type of data can be combined under 'scenopoetic' terminology which makes reference to "conditions, including aspects of climate, physical environment, edaphic conditions, etc., that impose physiological limits on species' ability to persist" (Soberón & Peterson 2005; Soberón & Nakamura 2009). By the other side, 'bionomic' variables refers to biotic interactive data (Soberón & Nakamura 2009), a worrying gap in my survey, once the distribution estimate can be more accurate using this type of data (Barber et al. 2021).

Most studies focused in biogeography/current distribution issues meanwhile invasive species were addressed in minor scale. The first kind of issue was expected in face of previous bibliometric analysis (Melo-Merino et al. 2020), however is noteworthy the concern about invasion of corals (Riul et al. 2013; Carlos-Júnior et al. 2015), red lionfish (Evangelista et al. 2016), brittle star (Derviche et al. 2021) and shrimp (Alves et al. 2021). Spatial modeling for management purposes (e.g., bycatch hotspots) were not detected and should be addressed in future.

In summary, the number of spatial modeling studies on SWAO is scarce and, although some advances can be observed (e.g. Prado et al. 2020; Saüt et al. 2022), more effort is still needed to reach the desired magnitude. Beyond the exposed here, spatial modeling techniques has also the potential to discover populations and unknown species, estimate extinction risk for species, conservation planning and link niches to evolutionary processes (Peterson et al, 2011); approaches I did not detected in the survey. I would like the bibliometric analysis presented here encourage researchers to use more frequently this tool in order to advance the spatial issues of the species inhabiting the SWAO, including all faces the spatial modelling approach can provide.

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Figure 1. Number or frequency of articles among (a) major taxonomic groups (mammals, seabirds [orange], cartilaginous fishes, mollusk, bony fishes, corals [blue], crustaceans, red algae, ascidians and kelps [grey]), (b) type of biological (BIO) and environmental (ENV) data, (c) sub-regions (Uruguay – UR, Brazil – BR, Argentine – AR) and, (d) methods applied (Maximum Entropy – MaxEnt, Generalized Linear/Additive Models – GLM/GAM, Boosted Regression Trees – BRT, Bioclim, Mahalanobis distance, Random Forest – RF, Artificial Neural Network – ANN, Surface Range Envelope – SRE, Multiple Adaptive Regression Splines – MARS, Support Vector Machines – SVM, Classification and Regression Trees – CTA, Domain, Ecological Niche Factor Analysis – ENFA, Flexible Discriminant Analysis – FDA, Gower, Minimum-Volume Ellipsoids – MVE, Maximum Likelihood – MaxLike, Habitat Suitability Index – HSI, Non-parametric probabilistic environmental niche – NPPEN).

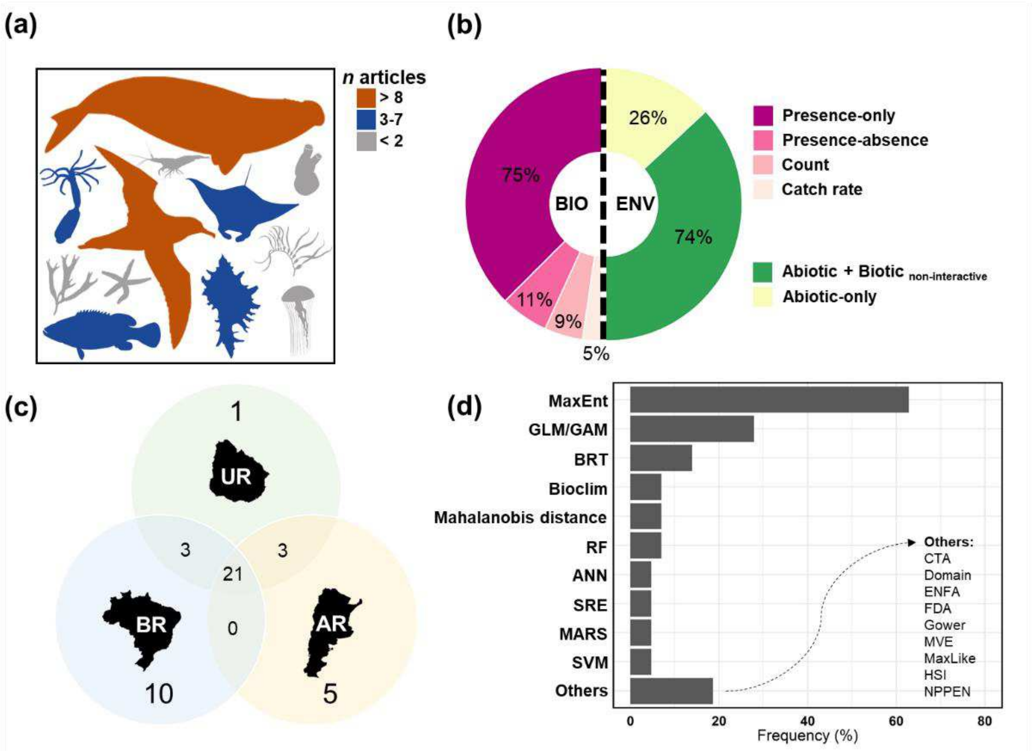

Table I. List of retained articles of spatial modeling over SWAO and its focus of research.

References	**Focus of research**
Carranza et al. (2011)	Biogeography/Current distribution
Chang et al. (2012)	Biogeography/Current distribution
Yesson et al. (2012)	Biogeography/Current distribution
Riul et al. (2013)	Invasion
Mendoza-Becerril & Marques (2013)	Biogeography/Current distribution
Quillfeldt et al. (2013)	Biogeography/Current distribution
Tardin et al. (2013)	Biogeography/Current distribution
Fromentin et al. (2014)	Biogeography/Current distribution
Puetz et al. (2014)	Biogeography/Current distribution
do Amaral et al. (2015)	Biogeography/Current distribution
Ramos et al. (2015)	Biogeography/Current distribution
Seyboth et al. (2015)	Biogeography/Current distribution
Quillfeldt et al. (2015)	Biogeography/Current distribution
Carlos-Júnior et al. (2015)	Invasion
Klippel et al. (2015)	Biogeography/Current distribution
Lucifora et al. (2015)	Biogeography/Current distribution
Evangelista et al. (2016)	Invasion
Dellabianca et al. (2016)	Biogeography/Current distribution
Carranza et al. (2017)	Biogeography/Current distribution
Krüger et al. (2017)	Conservation
Blanco et al. (2017)	Biogeography/Current distribution
do Amaral et al. (2018)	Biogeography/Current distribution
Lopes et al. (2019)	Biogeography/Current distribution
Battini et al. (2019)	Invasion
Pastor-Prieto et al. (2019)	Biogeography/Current distribution
Pollet et al. (2019)	Biogeography/Current distribution
Barbosa et al. (2020)	Biogeography/Current distribution
De Wysiecki et al. (2020)	Biogeography/Current distribution

Petean et al. (2020)	Biogeography/Current distribution
Coelho et al. (2020)	Biogeography/Current distribution
Feitosa et al. (2020)	Biogeography/Current distribution
França et al. (2020)	Biogeography/Current distribution
Koerich et al. (2020)	Invasion
Derviche et al. (2021)	Invasion
Castro et al. (2021)	Invasion
Alves et al. (2021)	Invasion
Anderson et al. (2021)	Climate Changes
Koerich et al. (2021)	Biogeography/Current distribution; Climate Changes
Baines et al. (2021)	Biogeography/Current distribution
Bamford et al. (2021)	Biogeography/Current distribution
Lobo et al. (2021)	Biogeography/Current distribution
Jimenez et al. (2021)	Biogeography/Current distribution; Conservation
Passos et al. (2021)	Biogeography/Current distribution