

Running head: LEK to predict fish distribution

**Predicting species distribution from fishers' local ecological knowledge: a new
alternative for data-poor management**

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Abstract

Many developing countries lack information to manage their endangered species, urging the need for affordable and reliable information. We used Bayesian hierarchical spatial models, with oceanographic variables, to predict the distribution range of *Epinephelus marginatus*, the dusky grouper, for the entire Southwest Atlantic. We ran a model using scientific information gathered from the literature, and another using information gathered from fishers on species presence or absence. In both models, temperature was an important determinant of species occurrence. The predicted occurrence of the dusky grouper overlapped widely (Schoener's $D = 0.71$; Warren's $I = 0.91$) between the models, despite small differences on the southern and northern extremes of the distribution. These results suggest that basic information provided by fishers on species occurrence in their area can be reliable enough to predict species occurrence over large scales and can be potentially useful for marine spatial planning. Fishers' knowledge may be an even more viable alternative to data collection than what was previously thought, for countries that both struggle with financial limitations and have urgent conservation needs.

Keywords: Brazil; data-poor fisheries; dusky grouper; ethnobiology; species distribution model; *Epinephelus marginatus*

41 Introduction

42 One of the main obstacles that developing countries face to manage fisheries or
43 assign a conservation status to target species is a lack of basic and reliable information on
44 species, habitats and ecosystems (Kaufman et al. 2004; Mora et al. 2009; Houk et al. 2012;
45 Worm and Branch 2012; Pauly and Zeller 2016). Without this information, species
46 management is just a guessing game subject to failure (Hilborn 2007; Cinti et al. 2010;
47 Finkbeiner and Basurto 2015). Lack of reliable information also opens the possibility for
48 criticism, with resource users, for instance, opposing measures because they are not
49 convinced that they are necessary or legitimate (Jentoft 2000; Lopes et al. 2013b; Di Dario
50 et al. 2015). Precautionary approaches, which are usually advisable in such cases (Johannes
51 1998; Kaufman et al. 2004), are rarely implemented because of the high immediate
52 political, social and economic costs associated with management (Marshall and Marshall
53 2007; Gaines et al. 2010). While the “burden of proof” remains unjustly on science rather
54 than on users (Dayton 1998), managers and researchers need basic supporting data to
55 justify the need for immediate management (Houk et al. 2012; Roos et al. 2015, 2016).

56 However, acquiring species, ecosystem or fisheries data in developing countries is
57 proportionally costly, not only because funding for science and research is limited (science
58 usually ranks low in government priorities) (Chao et al. 2015; Pinheiro et al. 2015), but also
59 because such countries are burdened with bureaucracy, fear of biopiracy, lack of specific
60 tax incentives and access to technologies, and neglect for resource use statistics (Barber et
61 al. 2014; Pauly and Zeller 2016). In such a context, developing country researchers face the
62 constant need to seek innovative affordable solutions to data acquisition and effective
63 management implementation (Berkes 2003).

In fact, globally, two of the most successful management systems seem to be well-established practices in the developing tropics: co-management and customary management (Berkes 2003; Mora et al. 2009; Lopes et al. 2011; Cinner and Huchery 2014). These solutions include users in both the decision-making and surveillance processes (Castello et al. 2009) and rely on very little data (Castello, 2004).

Researchers have proposed that such knowledge and data gaps be filled with information provided by fishers, based on their knowledge and experience, which is known in the literature as fishers' local ecological knowledge - FEK or LEK (Johannes 1981; Moller et al. 2004; Silvano and Valbo-Jorgensen 2008; Silvano and Begossi 2010). Since the beginning, these studies have shown that fishers retain an amazing amount of accurate information on fish biology and ecology, such as diet, reproduction, habitat preference, and schooling habit of their target species (Neis et al. 1999; Silvano and Begossi 2010). More recently, studies using LEK have demonstrated the potential to tap into fishers' knowledge to reconstruct information on fish stocks and to detect stock declines unknown to science, given the lack of past scientific data. With regards to the latter, older fishers provide evidence for stock decline by reporting on their past catches (Tesfamichael et al. 2014; Bender et al. 2014; Damasio et al. 2015).

Clearly, fishers' LEK is not taken for granted, as it indeed should not be (Davis and Wagner 2003). Fishers' information, similar to any other information provided by humans, can be distorted by their cultural and socioeconomic background and by their perception and interpretation of reality (Jones et al. 2008; Ruddle and Davis 2011). For instance, fishers may attribute a strong predatory role to a given species if they think it competes with them for valuable prey (Davis et al. 2004). They can also overemphasize the role of certain food items on fish diets, if the food item is used as bait (Begossi et al. 2016).

Moreover, fishers may recollect their most positive memories (largest catch or largest fish) much better than their average day-to-day fishing success (Damasio et al. 2015). The role of research is to identify the information that is most applicable to management (Silvano and Valbo-Jorgensen 2008).

Taking this a step further, recent studies have started to test the usefulness of LEK data in ecosystems modeling (Anadón et al. 2010; Eddy et al. 2010). Although less detailed than traditional scientific modeling, LEK-based models can provide some of the required information for proper ecosystem management (Bevilacqua et al. 2016). It is known that fishers can identify areas in their own region where target species are, however, it remains to be tested whether fishers' LEK can be used to predict species occurrence (niche distribution). (Begossi et al. 2013). Although basic, the prediction of species occurrence may represent non-existent information for certain areas and for certain species (Roos et al. 2015). Knowing species–environment relationships and their suitable habitats could contribute to the implementation of marine spatial planning and, if necessary, the protection of relevant habitats for the conservation of some species (Agardy et al. 2011; Pennino et al. 2016). Habitat and species mapping are especially relevant for conservation programs for threatened or endangered species because they provide clear pictures of their distribution, and thus facilitate management of the marine environment (Roos et al. 2015).

Within this context, we modeled the distribution of *Epinephelus maginatus* (Lowe 1834), the dusky grouper, along the Southern Atlantic coast (South American coast). This species is economically relevant, has been widely exploited in Europe, Africa and South America, has been extensively studied in the Mediterranean (e.g., Bouchereau et al. 1999; Gilles et al. 2000; Andrello et al. 2013), and is considered endangered by the IUCN Red List. In the South Atlantic the species is much less known (Machado et al. 2003, 2008;

Andrade et al. 2003; Irigoyen et al. 2005). However, some studies have already suggested that in the Southern Atlantic *E. marginatus* has a smaller effective population size compared to its Mediterranean counterpart (Priolli et al. 2016), and that fishers have noticed significant declines in their catches over time (Lopes et al. 2013a). We also compared the distribution prediction generated from traditional scientific data to the one generated from information provided by fishers. Our intention was to provide alternative basic, reliable and cheap information for spatial planning and management of fish species that can be applied worldwide, particularly in areas where there is no other source of information available.

2. Material and methods

Scientific data

The scientific data used here to establish where *E. marginatus* was present or absent along the south Atlantic coast came from three different sources: 1) our own data collected through multiple projects, 2) bibliographic sources, and 3) online databases that provide data on species presence and absence (all sources are in Supplement S1). With respect to our own data, we used information present in our databases for the period 1988-2016, combined with geographical location of fishing grounds, which are published elsewhere (Begossi et al. 2013). With the exception of the period 2013-2016, when our research was specifically designed to sample and study *E. marginatus*, the remaining studies concerned small-scale fisheries in general, and we simply registered the presence of the dusky grouper whenever available in the landings (sometimes in numbers, sometimes in kilograms, sometimes just whether or not it was present). This means that the occurrence of *E. marginatus* may have been registered in a given site (fishing grounds) multiple times, as

our data is fishing data and not scientific sampling data. As most of our research to date has covered a specific part of the extensive Brazilian coast, we also carried out an exhaustive bibliographic review of previous research to account for existing information about geo-referenced occurrences or absences of *E. marginatus* in all South American waters (Supplement S1). The studies we identified were mostly scientific samplings that registered the presence of the species in a given site, using methods such as transects; where the researcher samples multiples areas near one another. For those cases, we randomly took one of the sampled locations and assigned the species presence (or absence) to it. To make sure we included all available information, we extracted presence data from online databases (Kaschner et al. 2013) and excluded duplicate observations. We then combined the three data sources pertaining to the presence or absence of *E. marginatus* into a single presence-absence dataset to perform a Bayesian spatial model with a binomial distribution.

Overall, we registered 826 suitable observations to run in the model (Figure 1a): 578 presences (356 from our own data, six presences from the AQUAMAPS database, and 216 presences from the bibliographic sources) and 26 absences (all from the bibliographic sources). Of the presence data, 43 were unique presences (registered just once).

Ethnobiological data

Following the same procedure used for the scientific datasets, an exhaustive literature review of previous studies was performed to collect occurrence information for all South American waters that were provided by fishers (Supplement S1). This information was usually obtained through interviews when fishers were asked if *E. marginatus* was present in their region. As these studies relied on interviews, no geo-referenced information was available. To account for an approximate location, we estimated the presence or

absence of the species in a coastal point close to the village where the interview took place (average of 120 meters away from the shore).

We recorded a total of 60 observations, of which 37 referred to presences and 23 to absences of *E. marginatus* (Figure 1b).

Environmental data

Overall, six environmental variables were considered to be potential predictors of *E. marginatus* distribution, both for the scientific and for the ethnobiological data: sea surface temperature (SST in °C), sea surface salinity (SSS in PSU), net primary productivity (NPP in mg C m⁻² d⁻¹), depth (in meters), slope (% grade) and concavity of the seabed. The latter variable is not a physical unit, but the second derivative of the bathymetry layer (or the slope of the slope) and represents whether a raster cell is on a hill (negative values) or in a valley (positive values). These variables were chosen as they had previously been associated with the presence of either the same species or a related species (Harmelin and Harmelin-Vivien 1999; Andrello et al. 2013).

SST and SSS were both extracted with a spatial resolution of 1° x 1° (~ 100 km) from NODS_WOA09 as long-term monthly climatological means provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at <http://www.esrl.noaa.gov/psd/>.

Net primary productivity (NPP) was retrieved from a 920 x 1680 global grid of NPP and calculated as a function of chlorophyll, available light, and photosynthetic efficiency using the entire SeaWIFS chlorophyll record (1998-2016) on the Ocean Productivity website with a spatial resolution of 1° x 1° (<http://www.science.oregonstate.edu/ocean.productivity/index.php>).

Bathymetric features were derived from the MARSPEC database, (<http://www.marspec.org>), which is a world ocean dataset with a spatial resolution of 1 km x 1 km (30 arc-second) developed for marine spatial ecology (Sbrocco and Barber 2013).

To ensure the same spatial resolution, all environmental data were aggregated to the lowest spatial resolution common to them (1° x 1°), using the “raster” package in R (Hijmans et al. 2016) to avoid downscaling. This means that more detailed information, when available (e.g., slope), was retained. All environmental variables were standardized in order to enable relative weight comparisons between variables (Kinas and Andrade 2014). Multicollinearity was checked using Pearson’s correlation index. Other typical data exploration procedures were routinely done according to Zuur et al. (2010).

High correlations were found between SSS and SST ($r = 0.79$), NNP and SSS ($r = -0.91$) and NPP and SST ($r = 0.69$). Consequently, these variables were introduced separately in the different models.

Sampling uncertainties

As data were collected from different sources, a potential additional origin of variation on the species occurrence could be due to the observer effect, especially for the observations collected from the literature, from AQUAMAPS, and from fishers for whom we do not have any additional sampling information. The behavior of individual observers caused by random aspects, and/or unobserved sampling characteristics could have caused some of the variation in the data. Ignoring such non-independence of the data can lead to an invalid statistical inference (Roos et al. 2015; Costa et al. 2017). To remove any bias caused by observer-specific differences in the sampling process, an observer effect was added to the models (both for the scientific and ethnobiological datasets) as a random effect because there was no interest in knowing the specific nature of the observers.

206 *Statistical models*

207 The probability of *E. marginatus* occurrence (for both the scientific and
 208 ethnobiological data) was modeled using Bayesian Gaussian iCAR (intrinsic conditional
 209 autoregressive model) to take into account spatial autocorrelation (Latimer et al. 2006) and
 210 different sources of uncertainties. Bayesian species distribution models are especially
 211 suitable for data limited situations (Costa et al. 2017). We used a Gaussian iCAR (Besag
 212 1974) to account for any eventual spatial autocorrelation between observations, assuming
 213 that the probability of species presence at one site depends on the probability of species
 214 presence in neighboring sites. Assuming the random variable Y_i follows a Bernoulli
 215 distribution, it can take on a value of 1 or 0 depending on whether the habitat is suitable (Y_i
 216 = 1) or not ($Y_i = 0$), then:

$$217 \quad Y_i \sim \text{Bernoulli}(\pi_i)$$

$$218 \quad \text{logit}(\pi_i) = X_i\beta + Z_i + \rho_{j(i)}$$

219 where β represents the vector of the regression coefficients, X is the matrix of covariates, Z_i
 220 is the observer random effect, and ρ represents the spatial random effect for any given cell
 221 j . The relation between π_i , the covariates of interest and spatial effect is the usual logit link.

222 We used uninformative priors centered at zero with a fixed large variance of 100 for
 223 all parameters involved in the model and adopted a uniform distribution for the variance of
 224 the spatial effect.

225 We fit these models using the “hSDM” package (Vieilledent et al. 2014) of the R
 226 statistical environment (R Development Team 2017).

227 We fit the resulting models obtained by combining the mentioned variables and the
 228 respective interactions and compared them using both backwards and forwards approaches

using the standard Deviance Information Criterion (DIC) (Spiegelhalter et al. 2002). Lower values of DIC represent better compromises between fit and parsimony.

Finally, in order to plot the functional response between the selected environmental variables and the predicted values, we used the “ggplot” package of the R software to apply a smoothing function to attempt to capture the general patterns in the spatial trend of the species, while also reducing the noise. This technique uses locally weighted scatterplot smoothing (lowess), which is an outlier-resistant method that estimates a polynomial regression curve by using local and bootstrap techniques with the percentile method in order to account for the variability in the original lowess fit. With this methodology, each functional response shows a 95% confidence interval for the original lowess.

Model validation for occurrence

We validated the best selected model by using an internal 10-fold cross validation based on randomly selected training and test datasets (created by a random selection of 75% and 25% of the data respectively) (Fielding and Bell 1997), with the “*PresenceAbsence*” package in R (Freeman and Moisen 2008). We assessed the model’s performance by using the area under the receiver-operating characteristic curve (AUC) (Fielding and Bell 1997) and the “True Skill Statistic” (TSS) (Allouche et al. 2006).

Comparison of model predictions

We compared the predictions of *E. marginatus* distribution from the scientific and ethno datasets using the similarity statistics Shoener’s D and Warren’s I (Warren et al. 2008). These statistics range from 0 (no overlap between areas) to 1 (distributions are identical) (Pennino et al. 2016; 2017). We carried out these analyses using the *nicheOverlap* function of the *dismo* package (Hijmans et al. 2011) in R software.

Results

Scientific data

The occurrence of *E. marginatus* seems to be primarily determined by the depth, slope, and SST of the habitat, in addition to the spatial component that accounted for the residual spatial autocorrelation and the observer random effect (Table 1). The species is more likely to be present in shallow (≈ 300 -400 m, posterior mean = 3.71; 95% CI = [1.99, 5.64]) and cooler waters (11-25° C max, posterior mean = -4.63; 95% CI = [-8.10, -1.51]) (Figure 2a - c). Although the species seems to be present in areas ranging from sandy (low slope values) to rocky bottoms (high slope values), it showed a marked preference for a structured (rocky in most cases of the study area) seabed (slope value preference = 75-90; posterior mean = 0.18; 95% CI = [0.10, 0.99]), demonstrated by the highest occurrence probability at higher slope values (Figure 2b).

The best conditions for species occurrence in South America were met in shallow and structured grounds, with slightly cooler waters than those found in the north (observed by plotting the median posterior occurrence probability), specifically between the southeastern coast of Brazil (state of Espírito Santo) and Rio de Plata in Uruguay (Figure 3). The expected occurrence of *E. marginatus* in the north of Argentinian Patagonia was driven by three reports of its presence in the literature, but there are few observations here and the presences could be rare events.

Ethnobiological data

Based on the ethnobiological dataset, the main predictors of *E. marginatus* habitats were depth and SST, along with the spatial component that accounted for the residual spatial autocorrelation and the observer random effect (Table 2). In this specific case, slope

was not relevant. This was expected given that the occurrence locations were assigned to the ocean grid point closest to the reporting village, therefore disregarding the local type of seabed.

According to the presence data credited to the fishers, *E. marginatus* was also expected to occur in shallow (posterior mean = 3.49; 95% CI = [2.35, 7.10]) and cooler waters (posterior mean = -5.24; 95% CI = [-7.48, -0.22]). However, given that species presence or absence was assigned to the ocean grid point closest to the reporting village in our study, i.e., areas which are usually shallow, the actual most relevant information is the effect of water temperature (Figure 4). Higher occurrence probabilities were found at a depth range of ≈ 250 -450 m (Figure 4a). Interestingly, the species occurrence probability was shown to be most likely at a temperature range of between 11° C and 25° C, which is the exact range predicted from the scientific dataset (Figure 4 b).

The expected geographical distribution of *E. marginatus* in South America suggests a wider distribution pattern along the Brazilian coast than the one we observed in the scientific database (based on its median posterior probability). For instance, based on the ethnobiological data, the species is expected to occur further up north, especially between the northeastern Brazilian state of Sergipe and the southern state of Santa Catarina (Figure 5).

Model performance and comparisons

For both datasets, all the best models achieved AUC values of >0.65 , which indicates a good degree of discrimination between the locations where a species is present and where it is absent. For the scientific dataset the AUC value was 0.83, whereas this value was slightly lower for the ethnobiological dataset (0.73). Similarly, a higher TSS

value was achieved using the scientific dataset (0.74 versus 0.67). However, again both datasets achieved values higher than 0.60, indicating a good ability for the models to predict real absence and presence records for *E. marginatus*.

Interestingly, the predictions generated from both models showed an excellent degree of overlap, suggesting high similarity between them (Schoener's $D = 0.71$; Warren's $I = 0.91$).

Discussion

This study highlights two major points of relevance: (i) it is the first reliable occurrence prediction of the dusky grouper *E. marginatus* carried out using a state-of-the-art species distribution model (Costa et al. 2017), (ii) and it provides evidence that such models can be built from data-poor situations, such as when the only information available is that provided by fishers.

Similar to what has been shown in the Mediterranean, where *E. marginatus* has been widely studied, in our study we also expected that the species would have a strong preference for sub-tropical shallower waters, and for habitats with complex topography (Mesa et al. 2002). Whereas in well studied parts of the Mediterranean the species has been shown to prefer areas with a depth of up to 50 m (Heemstra and Randall 1993), our model of the Southwest Atlantic waters suggested a higher likelihood of its occurrence in areas with a depth of between 300 - 400 m. Although different *E. marginatus* populations (Mediterranean x Southwest Atlantic) might be suited to different habitats, we cannot rule out the possibility that overfishing or coastal degradation in the Southwest Atlantic plays a role (Bruslé 1985; Morris et al. 2000; Begossi et al. 2012), thus making it harder to find adults in shallower waters. Even in the Mediterranean the species can be found in deeper

waters (up to 250 m), especially adults (Harmelin and Harmelin-Vivien 1999). We did not have information on individual size, which may have supported the depth pattern observed in the Mediterranean. Still, the habitat suitability comparison between regions is a rough attempt, since this is the first prediction ever made for this species using similar models.

What is mainly innovative here is the suggestion that mere information provided by geographically dispersed fishers on whether they catch this species in their customary fishing grounds or not is enough to predict species distribution and achieve results similar to those made with scientific data. This achievement is especially relevant given our sampling limitations. For instance, our technique of allocating a random spot right across from each fishing village where species occurrence was mentioned, to represent where the species is caught, is an important caveat, because we did not consider ground specificities. Clearly fishers go to specific grounds, such as rocky outcrops, to catch the dusky grouper (Begossi and Silvano 2008; Begossi et al. 2012), but this information was not available in most of the papers we reviewed. Nevertheless, even considering this limitation, the predictive model was accurate enough to show between 71% and 91% of overlap with its counterpart scientific model, in addition to performing well as a reliable predictive model (see values of AUC and TSS). Similar to the scientific model, the ethnobiological model also predicted *E. marginatus* occurrences in cooler and shallower waters. However, depth in this case was just an artifact of our method of assigning a random point in the water to represent its occurrence. On the other hand, for a species that seems to have a well-established temperature range (Hereu et al. 2006), the simple information of village location works as an accurate predictor of expected species occurrence, especially because small-scale fishers do not venture to distant grounds with their small vessels.

Although overall the expected distribution was the same for both methods, there are

some differences worth investigating. The first is the extended expected distribution down south, towards Argentinian Patagonia, which is observed only in the scientific modeling approach. We considered species occurrence along the southern coast of Brazil, close to the mouth of Rio de la Plata in Uruguay, and in Argentinian Patagonian due to three reports that expanded the geographical limit of the species occurrence in the last decades (Irigoyen et al. 2005; Condini et al. 2016). The species is by no means common in those waters, although the existence of suitable habitats in the region might represent a future geographical range in a warming world (Perry et al. 2005). However, the ethnobiological model could not predict *E. marginatus* occurrence south of Brazil because no study has ever approached Uruguayan and Argentinian fishers about species occurrence in that region.

Another striking difference between the two models was that the ethnobiological model predicted the expected occurrence of the dusky grouper to be at the southern tip of the northeastern Brazilian coast, which is north of what the scientific model predicted. With the exception of three identical reports from the online databases that attributed the presence of *E. marginatus* to the southern part of the Brazilian northeast, the scientific model did not predict the northeast region to house the species (although there were some reports of its presence in an offshore location in the north). In specific ethnobiological studies designed to confirm its existence in the north with fishers, no such confirmation was obtained above -12° degrees of latitude (Ribeiro 2016). However, the region between -15° and -12° degrees seems to be a grayish zone, with some fishers reporting its occurrence (Silvano et al. 2006). The northern limit of the *E. marginatus* distribution established from information given by fishers seems to be close to a geographical barrier for some species, such as some of the Dasyatidae rays (Costa et al. 2017). One possible explanation has to do

371 with the San Francisco river; a large warm river that could be working as a barrier for
372 multiple species for various reasons, such as changes in temperature (Costa et al. 2017).
373 For *E. marginatus*, for instance, the warm river waters may make the northern coast unfit
374 for it. This break also broadly coincides with the breaks between the ecoregions of
375 Spalding et al. (2007).

376 However, it is not possible to rule out the possibility that fishers may have been
377 mistaken, confounding *E. marginatus* with another similar grouper that does occur in the
378 region, *E. morio* (Valenciennes, 1828) (Costa et al. 2003; Begossi et al. 2012). Another
379 possibility is that the fishers that mentioned the occurrence of *E. marginatus* north of its
380 known distribution are those relatively close to the expected distribution limit of this
381 species. They could be fishers that encounter the grouper when fishing slightly down south.
382 Although small-scale fishers in Brazil are not really mobile, performing mostly daily
383 fishing trips close to their villages (Lopes et al. 2009), some cross state borders to fish in
384 other regions (Silva, pers. comm.). This could represent an opportunity to come across
385 species not usually found close to their home villages. Finally, we should not disregard the
386 species' past presence in the area either, perhaps in lower abundances that were either
387 overfished or dislodged with warmer waters over the last decades.

388 It is also important to take into account larval dispersal distances where predictions
389 differed slightly between models. For the Mediterranean it is estimated that the median
390 distance for larval dispersal is 120km, but a maximum distance of 906 km is also possible
391 (Andrello et al. 2013). If larvae reach such distances, we could expect some sporadic
392 occurrences of the species outside its standard geographical limits when the larvae
393 eventually find some intermittent favorable conditions to settle. That would possibly allow
394 the maturation of a few extralimital adults beyond the species range, although not enough

395 to form a viable fishing population.

396 Overall, this study points towards a promising low-cost approach (LEK) to provide
397 baseline data and to fill knowledge gaps to support not only fisheries management but also
398 marine conservation initiatives, such as marine spatial planning. Regardless if it is to be
399 used alone or as part of an integrative approach, we advise future studies on fishers' local
400 ecological knowledge to compile data on species occurrence per fishing ground with their
401 respective locations (e.g., Begossi et al. 2013). We also recommend future studies to be
402 specifically designed to collect LEK fish abundance data to support its reliability as a
403 conservation tool (Anadón et al. 2010). Finally, it is worth mentioning that this study also
404 shows that the integration of multiple sources of information into science and management
405 is a potentially invaluable tool. Such tool should not be overlooked, despite the limitations
406 of integrating information obtained through different sampling designs, which limit the
407 statistical methods that can be used. Indeed, further statistical advancements should work
408 towards developing single models that can account for all the variability that emerges
409 from combining data collected with different sampling techniques over distinct temporal
410 and spatial coverage. The Bayesian approach may provide the answer to combine datasets
411 from different sampling schemes while maintaining a sound statistical framework.

412 In conclusion, this is the first study to predict *E. marginatus* occurrence along the South
413 American coast, which is highly relevant given the threatened state of the species and its
414 importance as a fishing target (Sadovy de Mitcheson et al. 2013). Our study could also possibly be
415 hinting at an expected future distribution towards the southern cooler waters in the future (Perry
416 et al. 2005), by confirming the existence of suitable habitats close to Patagonia. Moreover, our
417 study demonstrated that with little data, provided by fishers, it is possible to get accurate species

distributions at least for species limited by more general aspects such as temperature and salinity, which are not expected to vary greatly between fishing grounds. For species whose occurrence are affected by different requirements, more specific ethnobiological knowledge might be necessary, whereas fishers may not be able to provide accurate information for species they do not target regularly. Nevertheless, sampling ethnobiological data to predict the distribution of target species (or species with which people interact regularly) is affordable and allows the coverage of large geographical areas, which may be a considerable advancement for data-poor countries with urgent needs for proper fisheries management. Ethnobiological data can also be incorporated into integrative and potentially more informative approaches to advance marine spatial planning and conservation in general.

428

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Table 1: Comparison of the most relevant *E. marginatus* scientific dataset models. Deviance Information Criterion (DIC) scores measure the goodness-of-fit of each model. Predictor acronyms are: sea surface temperature (SST), sea surface salinity (SSS), net primary productivity (NPP), depth (D), slope (S) concavity of the seabed (C), spatial effect (ρ), observer effect (Z). Relevant environmental predictors are indicated by *, i.e., those predictors with 95% credibility intervals not covering zero. The best model is highlighted in bold.

Models	DIC
$1 + \text{SST}^* + \text{D}^* + \text{S} + \text{C} + \text{Z}^* + \rho^*$	47.43
$1 + \text{SST}^* + \text{D}^* + \text{S}^* + \text{Z}^* + \rho^*$	45.62
$1 + \text{D}^* + \text{S} + \text{Z}^* + \rho^*$	50.58
$1 + \text{D}^* + \text{C} + \text{Z}^* + \rho^*$	52.36
$1 + \text{SST}^* + \text{D}^* + \text{Z}^* + \rho^*$	47.74
$1 + \text{SSS} + \text{D}^* + \text{S} + \text{Z}^* + \rho^*$	50.38
$1 + \text{SSS} + \text{D}^* + \text{Z}^* + \rho^*$	50.17
$1 + \text{NPP} + \text{D}^* + \text{S} + \text{Z}^* + \rho^*$	51.77
$1 + \text{NPP} + \text{D}^* + \text{Z}^* + \rho^*$	57.97
$1 + \text{NPP}^* + \text{Z}^* + \rho^*$	57.36
$1 + \text{S} + \text{Z}^* + \rho^*$	61.08
$1 + \text{D}^* + \text{Z}^* + \rho^*$	51.44
$1 + \text{SST}^* + \text{Z}^* + \rho^*$	57.19
$1 + \text{SSS}^* + \text{Z}^* + \rho^*$	57.66

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666 Table 2: Comparison of the most relevant *E. marginatus* ethnobiological dataset models.

667 Deviance Information Criterion (DIC) scores measure goodness-of-fit. Predictor acronyms

668 are: sea surface temperature (SST), sea surface salinity (SSS), net primary productivity

669 (NPP), depth (D), slope (S) concavity of the seabed (C), spatial effect (ρ), observer effect

670 (Z). Relevant environmental predictors are indicated by *, i.e., those predictors with 95%

671 credibility intervals not covering zero. The best model is highlighted in bold.

Models	DIC
$1 + \text{SST}^* + \text{D}^* + \text{S} + \text{C}^* + \text{Z}^* + \rho^*$	21.54
$1 + \text{SST} + \text{D} + \text{S} + \text{Z}^* + \rho^*$	19.61
$1 + \text{D} + \text{S} + \text{Z}^* + \rho^*$	18.57
$1 + \text{D}^* + \text{C}^* + \text{Z}^* + \rho^*$	17.12
$1 + \text{SST}^* + \text{D}^* + \text{Z}^* + \rho^*$	14.89
$1 + \text{SSS} + \text{D} + \text{C} + \text{Z} + \rho^*$	15.13
$1 + \text{SSS} + \text{C}^* + \text{Z}^* + \rho^*$	16.39
$1 + \text{SSS} + \text{D}^* + \text{Z}^* + \rho^*$	18.70
$1 + \text{NPP} + \text{D}^* + \text{Z}^* + \rho^*$	19.23
$1 + \text{NPP} + \text{Z}^* + \rho^*$	21.31
$1 + \text{C}^* + \text{Z}^* + \rho^*$	16.53
$1 + \text{D}^* + \text{Z}^* + \rho^*$	18.26
$1 + \text{SST}^* + \text{Z}^* + \rho^*$	19.24
$1 + \text{SSS} + \text{Z}^* + \rho^*$	21.48

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Figure legends

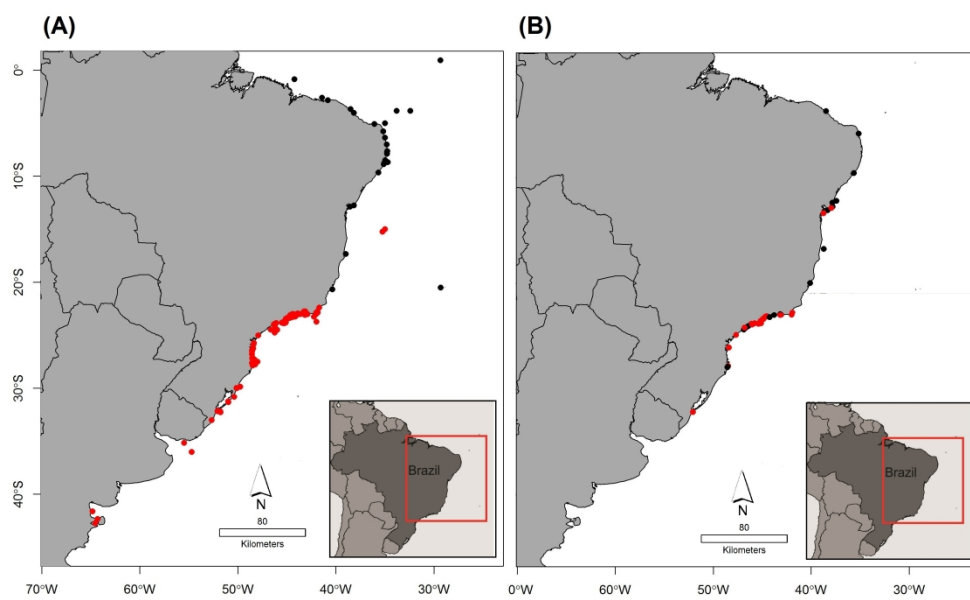
Figure 1: Sampling locations for the scientific (a) and ethnobiological (b) datasets. Red dots indicate presences, while black dots reflect absences.

Figure 2. Smooth function of the predicted occurrence probability for depth (a), slope (b) and SST (c), using the scientific dataset. The solid line is the smooth function estimate and shaded regions represent the approximate 95% credibility interval (CI).

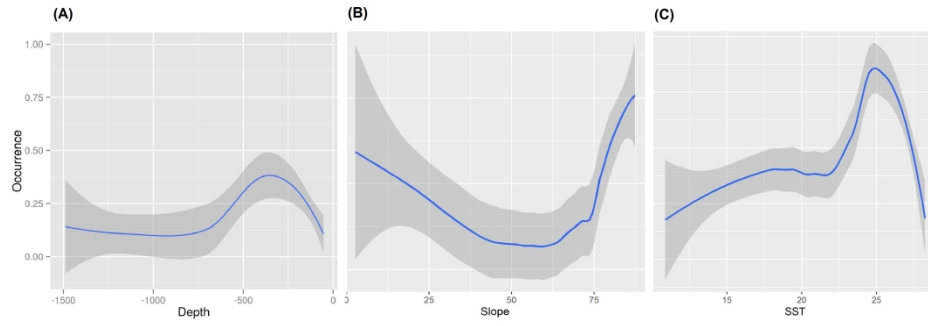
Figure 3. Mean occurrence probability of the *E. marginatus* species along South American waters, obtained using the scientific dataset on its presence/absence.

Figure 4. Smooth function of the predicted occurrence probability of depth (a) and SST (b), using the ethnobiological dataset. The solid line is the smooth function estimate. Shaded regions represent the approximate 95% credibility interval (CI).

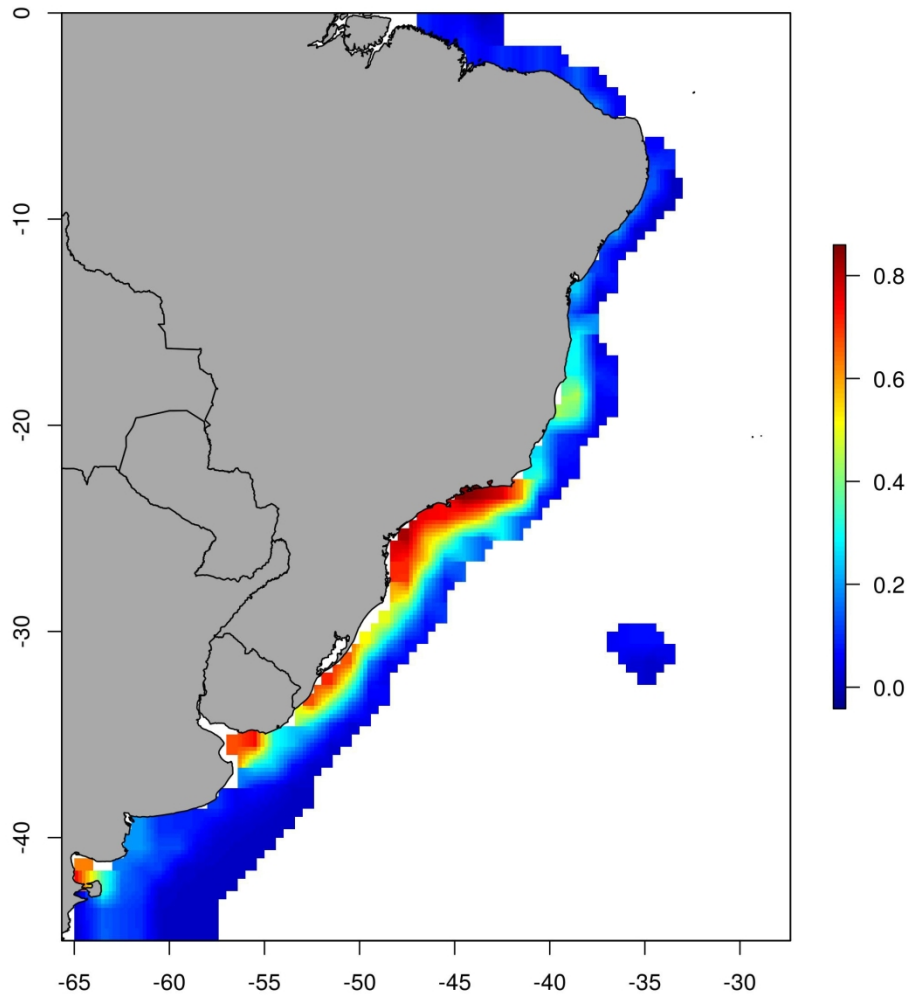
Figure 5. Mean occurrence probability of the *E. marginatus* species along South American waters obtained using the ethnobiological dataset.



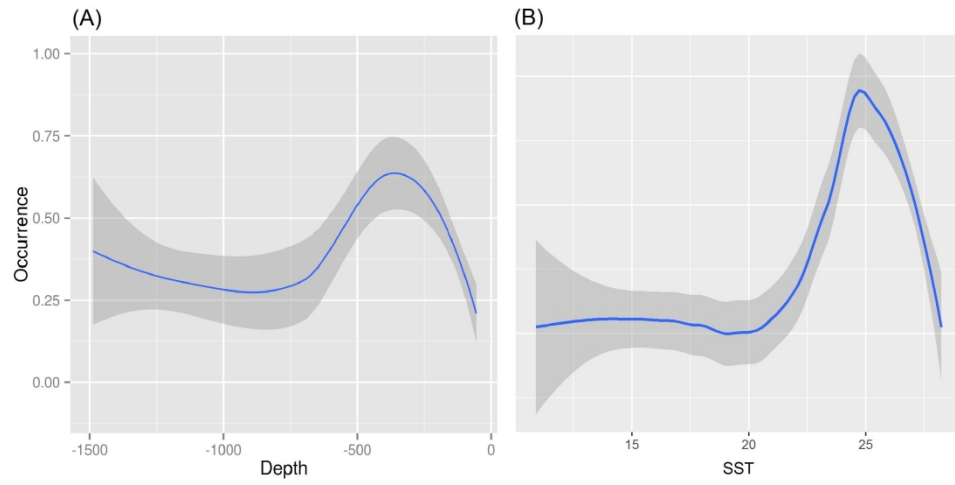
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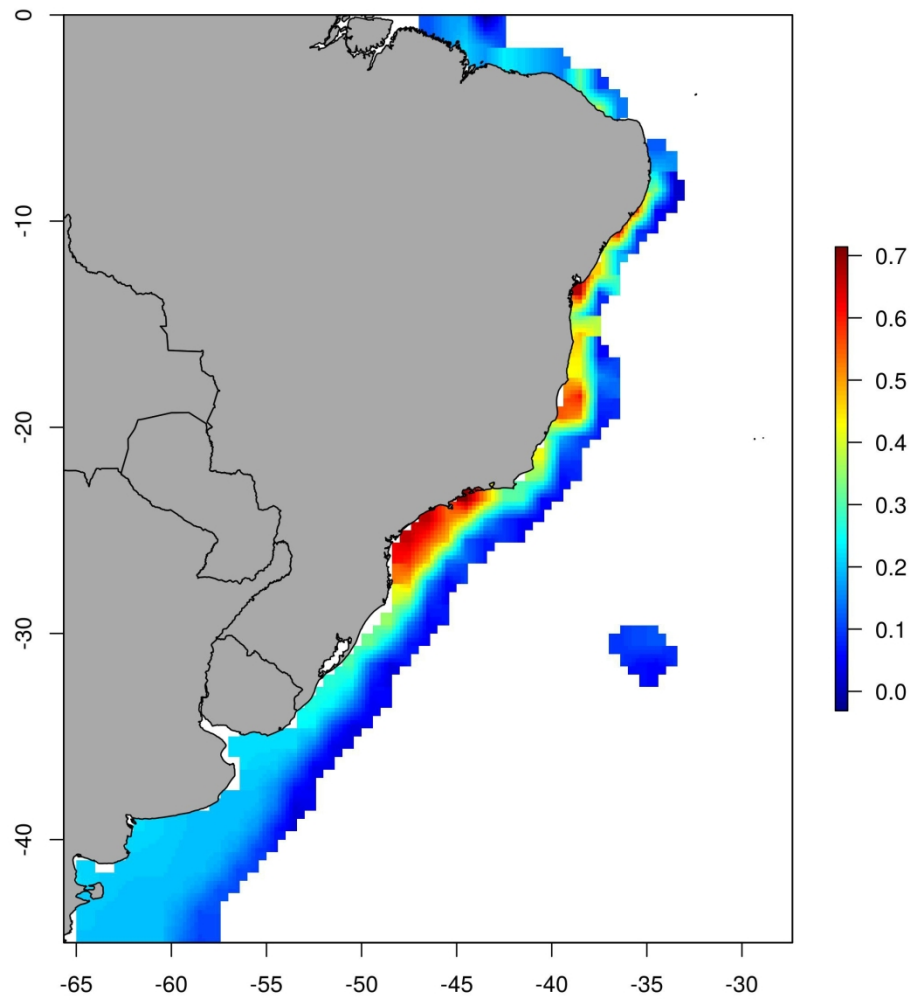
369x127mm (300 x 300 DPI)



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243x117mm (300 x 300 DPI)



186x219mm (300 x 300 DPI)