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Ecological niche modelling of endemic fish within La Paz Bay: Implications for conservation

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A B S T R A C T

Endemic marine species are useful in determining and evaluating areas for conservation. Particularly Warm Temperate Province of the Northeast Pacific (WTPNP) includes priority conservation areas, but records of endemic marine species are limited, their distributions remains generally unknown, and often excluded in extant conservation plans. Within the WTPNP, the Balandra Protected Natural Area (BPNA) is located within La Paz Bay, and it is the only management area with a developed plan. However, marine endemic fish species have not been fully considering, and their protection status requires a re-evaluation, particularly the distribution of species with adequate spatial resolution. Despite the scarce information on marine endemic fishes, ecological niche modelling allows predicting distribution areas through occurrences of the species and their relationship with a set of scenopoetic environmental variables. The abiotically suitable areas based of the endemic marine fish species within the WTPNP documented within the Bay of La Paz were modeled and the high-value areas for conservation were established through a multi-species models; these spatial patterns of suitable areas were contrasted with the current state of fish protection. Modelling was performed with the Maxent software supplied with presence-only data of 18 species and four sets of environmental layers related to the geomorphology and bottom sedimentology, as well as the Euclidean distance measures from mangrove and rocky shore habitats. We generated sixteen distribution models that revealed that only 8.4 % of the predicted area, on average, was located within a maximum state of protection within the BPNA core zone. Moreover, the generated multi-species model reveals that only 17 % of the high-value areas ($\geq$ 9 species/hectare) were located in the core zone. These high-value areas indicate updating the current management program is required. Finally, the study illustrates how the predicted-areas can be linked to conservation strategies in the marine habitat space within and outside the BPNA.

1. Introduction

The Mexican Pacific marine territory is recognized for its biodiversity and endemism (Brusca, 2010). In this environment, two biogeographic realms converge, including two provinces and seven marine ecoregions (Spalding et al., 2007), where 1121 fish species have

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been reported (Espinosa-Pérez, 2014). This species richness represents 7% of the marine fish known worldwide (Nelson, Grande, & Wilson, 2016) and in the Warm Temperate Province of the Northeast Pacific (WTPNP), a number of endemic fishes have been reported (Castro-Aguirre, González-Acosta, & de la Cruz-Agüero, 2005; Del-Moral--Flores, González-Acosta, Espinosa-Pérez, Ruiz-Campos, & CastroAguirre, 2013; Palacios-Salgado, Burnes-Romo, Tavera, & Ramírez-Valdez, 2012). For example, between the Cortezian and the Magdalena Transition provinces, there are at least 79 endemic fish species grouped in 13 orders, 29 families, and 59 genera (Palacios-Salgado et al., 2012). In this region, most studies with endemic fish are limited to taxonomic listings, where the geographic distribution is generally unknown. Endemic species and multiple species restricted to geographical zones offer relevant information for the conservation of marine and coastal spaces (Arthington, Dulvy, Gladstone, & Winfield, 2016; Hobbs, Jones, & Munday, 2011; Kier et al., 2009; Tittensor et al., 2010). However, to contribute to the planning of conservation and management strategies, it is not only necessary to identify these important species, but also to recognize the areas in the marine space at an appropriate scale that allows the establishment of protection actions.

Determining the geographic distribution of marine fish is complex due to its volatile nature (Rijnsdorp et al., 2009; Ehrlén & Morris, 2015; Koenigstein, Mark, G€oßling-Reisemann, Reuter, & Poertner, 2016) and the lack of data, while highlighting the high costs of acquiring reliable field data. However, ecological niche modelling (ENM) is the most powerful current methodology for approximating the geographic distribution of species based on occurrences and a set of environmental layers (Franklin, 2009; Guisan et al., 2013; Peterson et al., 2011). This approach links the occurrences of species with a set of scenopoetic environmental variables based on the Hutchinsonian definition of the ecological niche to predict distribution areas (Colwell & Rangel, 2009; Hutchinson, 1957; 1978; Peterson & Soberón, 2012). Predicting suitable distribution areas of marine fishes using the ENM approach is a recent research line providing tools supporting the conservations and protection decision-making (Addison et al., 2013; Leathwick, Elith, Francis, Hastie, & Taylor, 2006; Monk et al., 2010; Moore, Drazen, Radford, Kelley, & Newman, 2016; Pittman & Brow, 2011; Schmiing, Diogo, Serrão Santos, & Afonso, 2014).

The southeast of La Paz Bay (Fig. 1) is characterized by a wide variety of coastal habitat types. It contains a lagoon protected by a sandy barrier, a coastline with dune environments, sandy and silty beaches, tidal flats, cliffs and diverse inlets (Velasco-García, 2009). There are mangroves, rocky shore with coral populations, areas with marine macro-algae, and rhodolith beds where important biological diversity is documented (González-Acosta et al., 2018; Reyes-Bonilla, 1992; Steller, Riosmena-Rodríguez, Foster, & Roberts, 2003). The seabed is dominated by unconsolidated sediments that vary from fine silts to very coarse sands (on average) with a percentage variation of carbonates (bioclasts of algae and marine invertebrates) ranging from 2 to 95 % (Urcádiz-Cázares, Cruz-Escalona, Nava-Sánchez, & Ortega-Rubio, 2017). In this environmental mosaic, nearly 300 fish species are reported from the total of 533 documented in La Paz Bay and six endemic species from Gulf of California are listed (González-Acosta et al., 2018).

The teleost fish and other groups such as marine animals are vulnerable to anthropogenic activities that have affected the marine environment in the last 20 years. Negative environment impact examples at La Paz Bay coastal zone are: urbanization (include industrial and residential discharge of sewage and wastewater), the modification of the coastline, dredging, ship waste, eutrophication by aquaculture and agriculture, urban solid waste, tourist activities, and multiple active fisheries (commercial and recreational); these impacts are inferred from those legally declared on environmental impact statements (SEMARNAT, 2020). The magnitude of these impacts is complex and generally unknown; however, when evaluating a development project, authorities need to decide which are viable and what adjustments should be made based on ecological and environment evidence (DOF, 1988, 2000a).

In Mexico, one of the main political-ecological instruments for conservation is protected natural areas. Within La Paz Bay, there are at least 11 policies and conservation instruments because of the wide array of environmental characteristics and the associated biological diversity (Urcádiz-Cázares, 2018). Among these, UNESCO has designated a World Heritage Site, included two Ramsar Sites (Fig. 1); however, they lack a plan that regulates management and conservation activities. The Balandra Protected Natural Area (BPNA) is a policy instrument highlighted due to the region having a high level of flora and fauna protection (DOF, 2012). This area is the only one with a management plan (DOF, 2015) where the activities that are allowed or prohibited are specified. The decrees of priority areas represent the first step for conservation; however, full protection for species and their habitats must be assessed.

Knowledge of the distribution areas of endemic fish species would contribute to re-evaluating the marine conservation areas and their current management plan. Given this framework, the purpose of this research is to predict abiotically suitable areas for the endemic fish of the WTPNP reported within La Paz Bay using ENM and assess normative endemic fish protection instruments applicable at locality. Additional critical areas with high value for conservation can be revealed base on multi-species predicted model. The above was undertaken with the purpose of contributing recommendations for the management and conservation of the species.

2. Methods

2.1. Endemic species and occurrence data

The endemic species chosen are those with records within the WTPNP (Fig. 1) under the assumption that they do not occur naturally in other ecoregions. The global fish records were downloaded from the database of the Global Biodiversity Information Facility (GBIF, 2020) and compared within the limit of the WTPNP (Spalding et al., 2007) using the geographic information system (ARCGIS 10.3). Of the total records, data with less than two occurrences per ecoregion prior to 1965, and specimens without vouchers in collections were excluded.

Thereafter, from the list of the endemic species of the WTPNP, a database was generated in the GIS with the presence-only and the geographic reference (UTM coordinates, geoid WGS84) of the species that have occurred within the study area. The occurrence data were obtained from the information available in the Colección Ictiológica del Centro Interdisciplinario de Ciencias Marinas del Instituto Politécnico Nacional from 1990 to 2020 (http://coleccion.cicimar.ipn.mx/), GBIF (www.gbif.org), and according to the records published within the Bay of La Paz (Abitia-Cárdenas, Rodríguez-Romero, Galván-Magaña, De-la-Cruz-Agüero, & Chávez-Ramos, 1994; Balart et al., 1995; González-Acosta, De-la-Cruz-Agüero, De-la-Cruz-Agüero, & Ruiz-Campos, 1999; Balart et al., 2006; González-Acosta et al., 2018). From the list, records with less than three occurrences were considered as insufficient or doubtful and were discarded. To generate the models were used 18 endemic species (Table 1) with more than 31 points of occurrence within the study area. Train, test and independent species occurrences were divided for calibration and evaluation sets as shown in Table 1.

2.2. Environmental variables and calibration areas

The environmental variables used for the modelling were obtained from Urcádiz-Cázares et al. (2017) and included the depth of the water column, the percentage content of calcium carbonates in the marine substrate, and the mean grain size and the sorting (dispersion) of the sediment. Additionally, four raster layers that were generated were the mean slope of the ocean floor, the azimuthal orientation of the slope (aspect) to relate geomorphological features of the bottom with the sites of occurrence of the species, Euclidean distance layers from mangrove

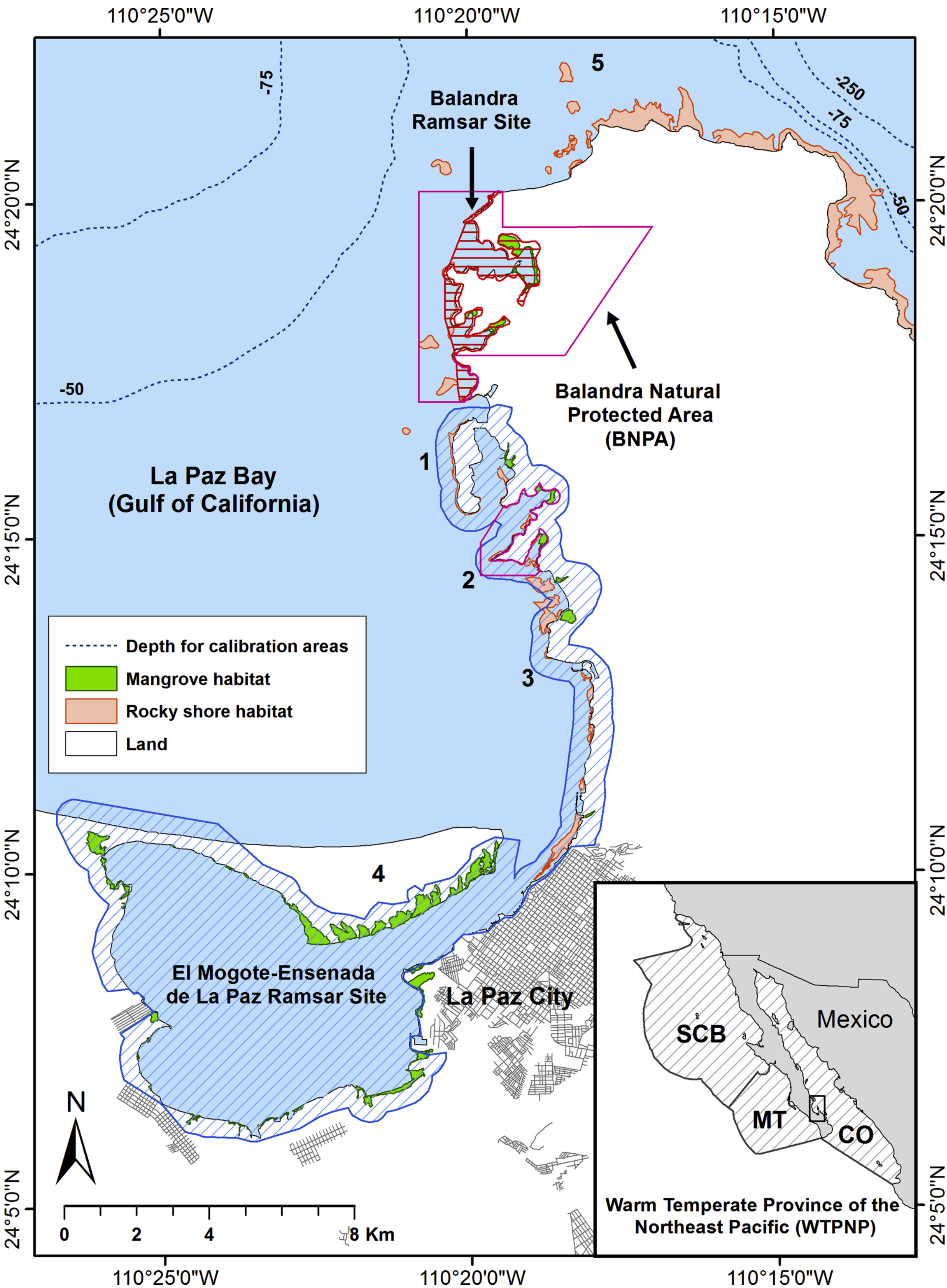

Fig. 1. Study area location, Balandra Natural Protected Area, Ramsar sites, and Warm Temperate Pacific Northeast Province and marine ecoregions. The extent used for modelling is defined as blue marine portion from the coastline up to −50, −75 and −250 m of depth. Localities: 1 Pichilingue Harbord, 2 Punta Colorada, 3 Punta Prieta, 4 El Mogote sandbar, and 5 San Lorenzo Channel. Marine ecoregions: SCB = Southern California Bight, MT = Magdalena Transition, and CO = Cortezian. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Table 1
Endemic fish records from Warm Temperate Province of the Northeast Pacific (WTPNP) marine ecoregions and species occurrences within study area. SCB = Southern California Bight, MT = Transition of Magdalena, CO = Cortezian, (Spalding et al., 2007). Total occurrences (n_{total}) were divided into training (n_{train}), test (n_{test}), and independent (n_{ind}) categories.

Species	WTPNP records Ecoregions	Study area occurrences n_{total}	n_{train}	n_{test}	n_{ind}
Acanthemblemaria crockeri	CO	32	21	7	4
Barbulifer pantherinus	CO	32	19	8	5
Chaenopsis alepidota	SCB, CO, MT	42	27	9	6
Chriolepis zebra	CO	30	19	6	5
Chromis limbaughi	CO	31	19	7	5
Coralliozetus micropes	CO	34	21	7	6
Crocodilichthys gracilis	CO	33	20	7	6
Cynoscion parvipinnis	SCB, CO, MT	38	24	8	6
Emblemaria hypacanthus	CO	36	23	8	5
Exerpes asper	SCB, CO, MT	35	24	6	5
Gobiosoma chiquita	CO	50	35	10	5
Hypsoblennius gentilis	SCB, CO, MT	40	26	10	4
Ophidion iris	CO	33	20	7	6
Paraclinus sini	SCB, CO, MT	26	14	7	5
Paralabrax auroguttatus	SCB, CO, MT	44	28	10	6
Porichthys analis	SCB, CO, MT	31	18	7	6
Quietula y-cauda	SCB, CO, MT	77	52	16	9
Urobatis maculatus	SCB, CO, MT	48	30	11	7

and rocky shore zones (coastline and bottoms dominated by rocks or rocky reef, i.e., > 50 %) were generated. These layers allowed us to measure the relationship between fish occurrences and the relative proximity to these habitats (Hogarth, 2015; Little, Williams, & Trowbridge, 2009). The mangrove and the rocky shore zones were digitized (visual analysis) using satellite imagery and field supervision. We validated these polygons with the information from Velasco-García (2009) and González-Zamorano, Nava-Sánchez, León de La Cruz, and Díaz-Castro (2011). The layers were processed with the spatial analysis tools Euclidean distance, aspect, and slope contained in the GIS. All environmental layers have a high spatial resolution of 0.01 km^2 (1 hectare) and, and we refers to indirect and distal layer types according to Austin (2002).

We used three calibration areas delimited by maximum depth for the species set at -50, -75, and −250 m. However, they are also geographically limited by the availability of environmental layers (see the extent in Fig. 1). Ideally, the calibration area should approximate the accessible area of the species (Barve et al., 2011) to predict the geographic range, but, in this case, the study is limited to a reduced geographic space (accessible to all species) where its goal is to predict suitable areas for conservation purposes in the locality.

To evaluate possible collinearity between the environmental layers combinations, we calculated the Pearson correlation coefficient using ENMTools (Warren et al., 2019) of the three calibration areas. In all cases, the software showed correlation values < 0.65 between layers, which supports the viability of layers for modelling.

2.3. Models calibration and evaluation

The modelling was performed with the maximum entropy algorithm (Phillips, Anderson, & Schapire, 2006) using Maxent v.3.4.1 (Phillips, Anderson, & Schapire, 2020), which was chosen because: 1) the data was presence-only; and 2) reasonable performance has been demonstrated with small sample sizes (Monk et al., 2010; Pearson, Raxworthy, Nakamura, & Peterson, 2007; Wisz, Hijmans, Peterson, Graham, & Guisan, 2008). For model calibrations, we used the kuenm package in R code (Cobos, Peterson, Barve, & Osorio-Olvera, 2019), which allows the development of multiple candidate models assigning different combinations of the parameters in Maxent. For each species, all possible types of feature combinations (linear, quadratic, product, threshold, hinge) were used for different values of the regularization multipliers (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 8 and 10) and for the four sets of environmental layers (Table A, supplementary material). For each species, 2108 candidate models were generated using the training occurrences.

To evaluate the performance of the candidate models and selection of the best, three criteria were considered as established by the program default. First, models are statistically significant ($p < 0.05$) using the test occurrence data (Table 1) through the partial receiver operating characteristic (partial ROC, Peterson, Papes, & Soberón, 2008) where statistical significance was determined by a bootstraping of 30 % of testing occurrences, 500 interactions, and probabilities are assessed by direct count of the proportion of bootstrap replicates for which the mean AUC ratio is ≤1.0. Second, models have a low omission rate considering a threshold of error up to 0.05 indicating how well models created with training occurrences predict test occurrences (Anderson, Lew, & Peterson, 2003). Finally, the complexity of the models contain minimum values of the Akaike Information Criterion corrected for small samples (AICc, Warren & Seifert, 2011) which indicates how well models fit to the data while penalizing complexity to favor simple models. From the previous criteria, 184 models were selected from 18 species, which were constructed with the “logistic” output, bootstrap (30 % data for testing), jackknife analysis enabled, and 20 replications to obtain an average model.

Finally, these selected models were contrasted with the independent occurrences of the modelling using the mean AUC ratio of partial ROC and considering omission error rates of 0.05. These two criteria allowed evaluation of the significance with independent information of the modelling (Cobos et al., 2019). The final models were those that met the two criteria previously described and, these models were evaluated with the Continuous Boyce Index (CBI), which offers complementary information about model robustness, and it is insensitive to the prevalence of species (CBI, Hirzel, Le Lay, Helfer, Randin, & Guisan, 2006). This index was implemented in R code from Di Cola et al. (2016) using the output of final average models and independent occurrences.

2.4. Binary and multi-specie maps

The Maxent output illustrated models with continuous values from 0 to 1 for each pixel distributed in the geographic space. Final average models were transformed to binary maps assuming a threshold value above which is suitable for the presence of the species (pixel = 1) and below it as unsuitable (pixel = 0). The criterion to determine the threshold was the maximum true skill statistics value (Franklin, 2009; Peterson et al., 2011) which provides predictions that are more accurate because it is based on sensibility and specificity (Leroy et al., 2014). The transformation to binary maps using GIS allowed adding the suitable areas of the species to obtain a multi-species map model that indicates the number of endemic fish per pixel (species/hectare) that can potentially occupy the same abiotically space. The univariate distribution of the multi-species map pixels was classified into three classes with the standardized method of "natural breaks" (Jenks & Caspall, 1971) included in the GIS. The method determines a homogeneous data grouping in relatively different classes and has widely used in ecological niche modelling (e.g., Costa, Taylor, Kracker, Battista, & Pittman, 2014; Silva-Angelieri, Adams-Hosking, Ferraz, de Souza, & McAlpine, 2016). The natural breaks upper-class interval was categorized as “high value” and it represent the areas for conservation.

2.5. Conservation status of fish

To evaluate the normative conservation status of endemic fish, we reviewed the management plan of the BPNA and with the help of the GIS, the abiotically suitable areas predicted by the models were compared with the protected areas (core and buffer zones). Finally, we estimated the protection area proportion by linking the actions allowed and prohibited in the management plan.

3. Results

A total of 37,944 candidate models was generated from 18 endemic fishes (Table 1) of the WTPNP within study area. Only 0.5 % of candidate models (best models) met three performance criteria during calibration: statistically significant $p < 0.05$, low omission rate with 0.05 error threshold, and minimum values of AIC. For each species, final models chosen and evaluated by independent occurrences are showing in Table 2. The partial ROC values and omission rate with including zero values, indicates good model performance. The CBI indicates a positive-moderate correlation >0.6 of final mean model outputs with the true probability of presences. However, *Acanthemblemaria crockery* and *Cynoscion parvipinnis* models showed a low CBI value (0.54 and -0.37) and no significant omission rates; these were discarded for subsequent analysis.

The environmental variables with the greatest contribution to the prediction of abiotically suitable area (Table B, supplementary material) were the distance from mangrove areas (mean of 49 % for 7 species), and the distance from rocky shore (mean of 44 % for 7 species). Depth and calcium carbonate content in the marine substrate had secondary contributions. Only *Paraclinus sini* reported depth as the lead variable, with a contribution of 45.5 %.

The binary maps (abiotically suitable areas for species above a threshold of mean final models) of endemic fishes are showing in Fig. 2 and their predicted area in Table 3. Maps indicated a restricted distribution for the species *Chriolepis zebra*, *Chromis limbaughi*, and *Barbulifer pantherinus* (<6.5 km^2) between two polygons of BPNA. By contrast, *Urobatuis maculatus* and *Porichthys analis* show extensively occupied the coastal zone (36 and 64 km^2) of La Paz Bay region. The rest of distributions areas (6.5 to 36 km^2) of binary maps showed a continuous or patchy distribution over the coastline at northern portion of the study area, from the Punta Prieta area to Punta Colorada, even to the San Lorenzo Channel. Only species *Quietula y-cauda* and *Hypsoblennius gentilis* had distribution in both La Paz Lagoon and rocky shore of the northern portion of study area.

According to the predicted area, a mean of 8.4 % are captured in the BPNA core zone, while the mean of 27.8 % area is found in the buffer zone. Outside of BPNA, predicted areas of endemic fishes have a mean of 63.8 %. The multi-species model show pixel values from 0 to 16 species/hectare (Fig. 3). According to the natural breaks classifications of predicted pixels, areas with high value (≥ 9 species/hectare, Fig. 4) are reduced to 11.1 km^2 distributed on the coastline from the Punta Prieta to San Lorenzo Channel. In the same way, only 17 % of this significant area are protected by core zone of BPNA.

4. Discussion

4.1. Areas and conservation

The BPNA and its management plan are a relevant policy instrument for protecting both terrestrial and marine flora and fauna in the study area. The core zone consists of a maximum protection polygon where activities that generated an adverse environmental impact are prohibited. Likewise, fishing or specimens collecting for research is prohibited. Despite these important conservation rules, our results indicate that only 8.4 % on average of the predicted areas of the 16 endemic fishes fell within the protected core zone (Table 3). In the buffer zone of BPNA, sustainable use is allowed, that is, artisanal fishing and the collection of fish with regulatory controls are allowed. It is also possible to develop some infrastructure projects and activities with prior authorization from federal agencies (through an environmental impact assessment). The main restrictions in the buffer zone are meant to avoid activities resulting in pollution and adverse environmental impacts according to the criteria of the authorities (DOF, 1988, 2000a). Despite this zone occupying part of the BPNA, moderate protection of marine organisms is only denoted in the management plan. The mean predicted area of endemic fishes binary maps within the buffer zone is about 27.8 %. In contrast, multi-species maps indicate the critical spatial distribution of high-value areas (≥9 species/hectare) is partially concentrated within the BPNA (Table 2, Fig. 4). Only 17 % of these high-value areas are protected within the core zone.

In order to improve the protection and conservation of the areas in question, we recommend the incorporation of at least these 16 endemic species and their binary and multi-species maps predicted in this work to be considered in future management plans or to establish or extend protected areas. Because these results are based on new analyses and independent of the initial declaration of the BPNA (DOF, 2012), new efforts from society and authorities can be redirected using these novel results. Specifically, in areas of high value, we recommend that prohibitions on dredging and any benthic or coastline modification projects. Likewise, we recommend allowing only low-impact economic development, such as underwater ecotourism (scuba diving) and guided visits for the recognition and appreciation of fishes and other marine organisms in areas of high-value. For this, two strategies can be considered: 1)

Table 2
Final model evaluations performed with test occurrences and independent occurrences. RM = regularization multiplier; FC = feature classes used during calibration, Set = set of environmental variables layers, BM = Best models selected from candidates models, M AUC r = Mean AUC ratio, p ROC = Partial ROC, OR = omission rate, AICc = Akaike Information Criterior corrected, P = number of parameters, CBI = continuous Boyce Index. Discarded models*. Full species names found in Table 1.

	Final models evaluation with test occurrences on calibration									Final models evaluation with independent occurrences			
Species	RM	FC	Set	BM	M AUC r	p ROC	OR	AICc	P	M AUC r	p ROC	OR	CBI
*A. crockery**	4	lt	4	3	1.95	0	0	424	5	1.93	0	0.3	0.54*
B. pantherinus	0.8	lq	2	4	1.98	0	0	345	6	1.98	0	0	0.63
C. alepidota	2	qt	4	3	1.88	0	0	589	8	1.91	0	0	0.77
C. zebra	1	lt	2	5	1.99	0	0	318	7	1.97	0	0	0.73
C. limbaughi	2	lp	1	1	1.98	0	0	337	6	1.96	0	0	0.83
C. micropes	2	lqp	2	5	1.97	0	0	416	5	1.96	0	0	0.93
C. gracilis	0.4	l	2	7	1.94	0	0	402	5	1.96	0	0	0.66
*C. parvipinnis**	0.5	q	4	18	1.84	0	0	553	3	1.78	0	0.4	−0.37*
E. hypacanthus	10	lh	1	9	1.92	0	0	451	4	1.93	0	0	0.78
E. asper	6	qh	1	8	1.94	0	0	433	5	1.96	0	0	0.61
G. chiquita	2	qp	2	5	1.92	0	0	721	7	1.93	0	0	0.88
H. gentilis	3	lq	1	9	1.81	0	0	580	5	1.78	0	0	0.80
O. iris	0.1	l	2	42	1.96	0	0	433	6	1.95	0	0	0.73
P. sini	1	lq	4	3	1.92	0	0	571	6	1.93	0	0	0.77
P. auroguttatus	0.6	l	1	23	1.94	0	0	301	5	1.94	0	0	0.69
P. analis	3	qp	2	16	1.85	0	0	447	4	1.85	0	0	0.61
Q. y-cauda	2	l	1	6	1.78	0	0	1107	7	1.79	0	0	0.60
U. maculatus	0.8	lqp	4	17	1.89	0	0	645	8	1.83	0	0	0.88

(a)

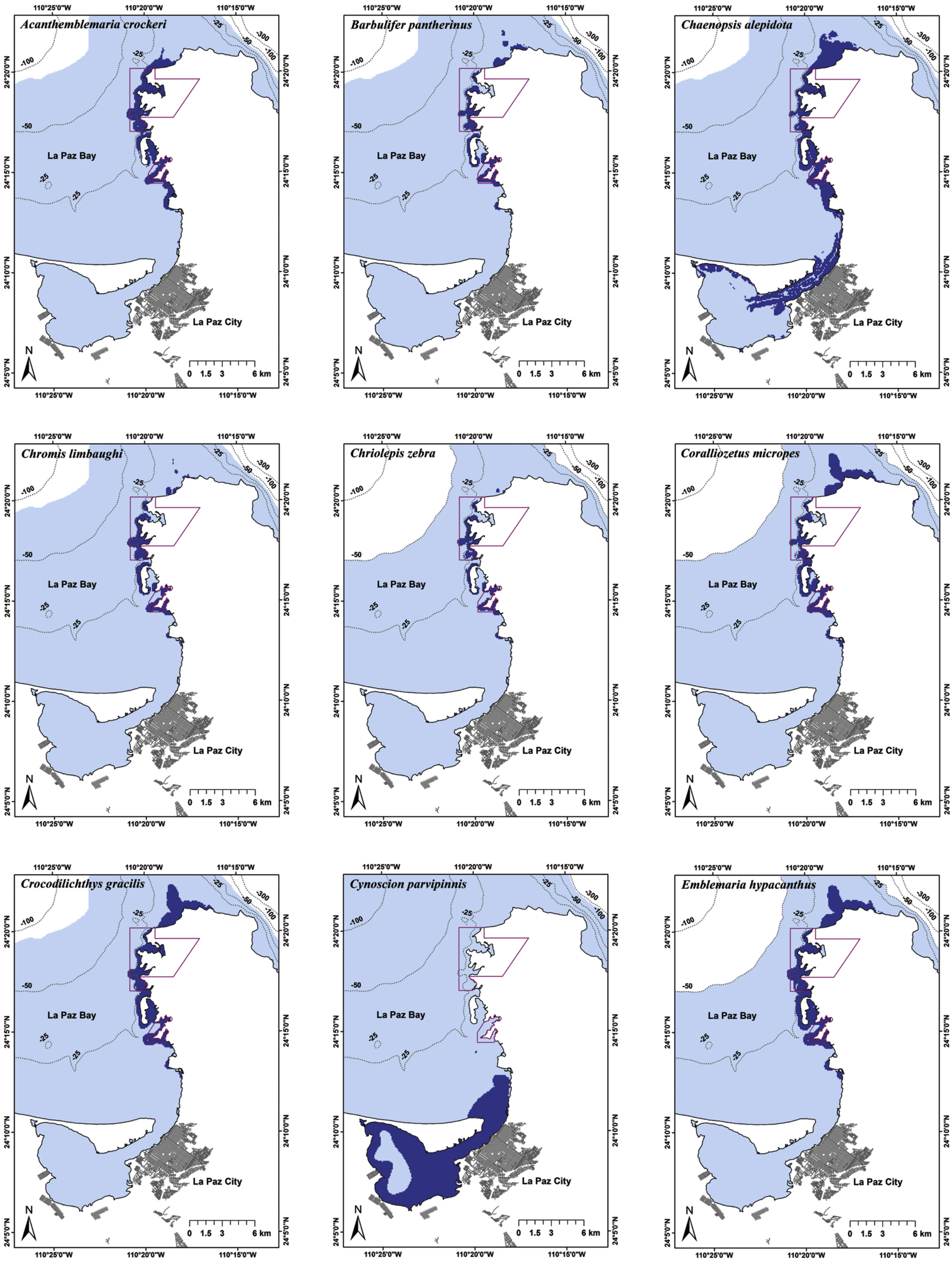

Fig. 2. Abiotically suitable areas (binary maps) of endemic fish models (dark blue area) and extent using for calibration (blue light area) for the 18 endemic species. The pink polygon is the location of the Balandra Protected Natural Area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

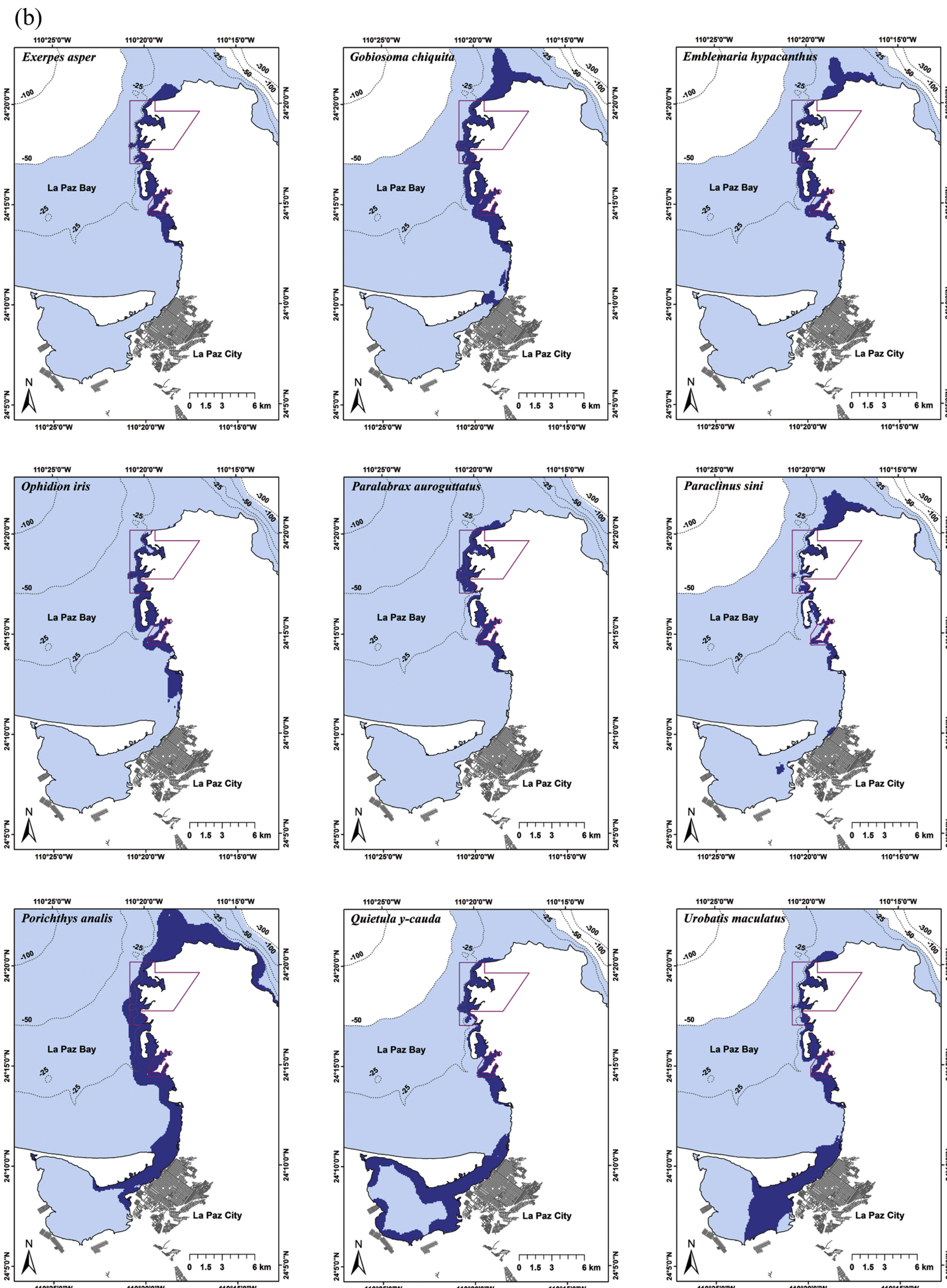

Fig. 2. (*continued*).

Table 3
Endemic fish predicted areas and percentage of protection relative to the Balandra Protected Natural Area (BPNA) zoning.

Species	Predicted area (km^2)	BPNA core zone Maximum protection (%)	BPNA buffer zone Medium protection (%)	Outside BPNA Without protection (%)
Barbulifer pantherinus	8.98	9.7	43.4	46.9
Chaenopsis alepidota	35.31	5.5	13.5	81
Chriolepis zebra	6.74	11.5	57	31.5
Chromis limbaughi	9.39	9.3	51.7	39
Coralliozetus micropes	15.28	7.1	27	65.9
Crocodilichthys gracilis	18.57	10.4	26	63.6
Emblemaria hypacanthus	20.46	7.9	27.5	64.6
Exerpes asper	15.04	12.9	30.6	56.5
Gobiosoma chiquita	30.47	6.4	21.6	72
Hypsoblennius gentilis	42.95	4	16.2	79.8
Ophidion iris	16.88	10.1	30	59.9
Paraclinus sini	17.03	11.4	17.7	70.9
Paralabrax auroguttatus	14.87	12.4	46.5	41.1
Porichthys analis	64.06	3	12.7	84.3
Quietula y-cauda	43.66	7.9	12.6	79.5
Urobatis maculatus	38.41	5.1	10.9	84
Mean	24.88	8.4	27.8	63.8

through the modification, expansion, or update of the current BPNA decree (DOF, 2000b); and 2) through the legal decree of new protected natural areas that can be declared by the municipal, state, or federal government.

Outside the BPNA, predicted abiotically suitable areas corresponds on average to 63.8 % and remains vulnerable for endemic fishes and other marine organisms. Marine-coastal space is susceptible to the development of projects, where the environmental authority is obliged to evaluate the impacts to decide if each project is viable. The binary maps offer sufficient detail and can be used as a guide in decision-making during environmental impact assessments.

4.2. Models performances and limitations

The performance of 18 endemic fish models, based on a rigorous evaluation process with testing and independent occurrences, documented 16 significant models with low omission rate, low AICc, and moderate CBI (Table 2). Our approach showed the capacity to model endemic fishes in the coastal-marine zone of the region. Although the 16 models achieved acceptable performance in the prediction of areas using a subset with small independent occurrences, these could also be evaluated in an ideal scenario through a large independent subset of real presence and absence occurrences (Peterson et al., 2011). All models can be improved with larger sample sizes, and we suggest exploring future larger data sets with similar modelling algorithms for comparison among the resulting distributions.

The main limitation of this study has been the geographic availability of information on environmental layers and scarce information on endemic fish occurrences. Although these layers have high spatial resolution, they frame a relatively localized extension and do not take into account a wide biogeographic extension related to the possible accessible area (Barve et al., 2011) of the species. In this sense, we approached models considering samples ($n > 31$, Table 1) focused on the environmental space and not properly sampling over a wide geographical area. However, the goal of this study has not been to determine the geographic ranges of the fish, but to find abiotically suitable areas, limited to the proposed spatial extent to map and improve policy instruments for conservation and protection of economically-valuable marine habitat.

Moreover, it should also be noted that marine fish exhibit ontogenetic changes in predator-prey tradeoffs and in specific environmental requirements throughout the life cycle (Kimirei et al., 2013; Rijnsdorp, Peck, Engelhard, Möllmann, & Pinnegar, 2009) that can modify their distribution and abundance spatially and temporally (Ehrlén & Morris, 2015; Heath et al., 2012; Koenigstein et al., 2016). In the early embryonic and spawning adult stages, fish are less sensitive to temperature variation (Dahlke, Wohlrab, Butzin, & Pörtner, 2020; McKenzie et al., 2020), whereas in the adult stage they are more tolerable to changes in dissolved oxygen (Elshout, Dionisio Pires, Leuven, Wendelaar Bonga, & Hendriks, 2013). Embryos and larvae, in general, are influenced by variation in pH and carbon dioxide concentration as well (Chambers et al., 2014). These differences in environmental requirements associated with ontogeny can lead to some species remaining transitory in the distinct environments they visit where it is possible to associate them with an ecological role when they are adult; as in the selection of spawning, rearing, shelter, and food areas (González-Acosta et al., 2018). In contrast, these environmental requirements also contribute to other species remaining resident (with limited movement) in specific habitat types, such as the endemic fish modeled, as early stages were not considered because of scarce occurrence data. Thus, distinct ecological roles are not associated with our modeling and delineated areas of distribution should be interpreted as a general approximation of the abiotically suitable area by adult fishes and without any specific role. If any life cycle or a specific ecological role are considered in the future, distribution areas may likely change. A more detailed study would be relevant to improve management and conservation strategies in the marine environment relative to distinct life history stages.

In addition, fish populations may show seasonal, annual, and/or decadal scales (Lehodey et al., 2006) in habitat use. Therefore, it is relevant to note that the construction of the models comes only from historic data (1990–2020) collected in different seasons and by different authors. This implies that the models do not quantify seasonal or decadal changes in the distribution, richness or abundance of the species across the period studied, but rather incorporates all the available information into a single distribution map and calculations of areas inside and outside the currently protected area. In this way, the historical occurrences of the fish will show those abiotically suitable areas that are with greater probability occupied compared to other areas, leaving aside these important dynamics. Therefore, it is advisable to consider both the temporal nature of suitable habitat and its role in species conservation in future work that will require more detail habitat-specific information for the species of interest. Even with the limited information available on the endemic fishes studied, these models represent a first approximation of the geographical distribution by fishes, which is highly relevant by the political instruments of conservation.

4.3. Environmental variables

Models performance indicates that the environmental layers (variables) related to the morphology of the seabed (depth, slope, and aspect), the marine substrate (calcium carbonate content, mean grain size, and sediment sorting), and those related to distance from specific habitats types (mangrove and rocky shore) are useful for predicting distribution areas in the marine environment. Geomorphological variables and Euclidean distance from particular habitats types have been used as efficient predictors in distribution studies (Leathwick et al., 2006; Monk et al., 2010; Pittman & Brow, 2011; Schmiing et al., 2014). Our models indicate that mangrove and rocky shore Euclidean distance layers are most important variable to prediction of endemic fish distributional areas (Table B, supplementary material), highlighting the

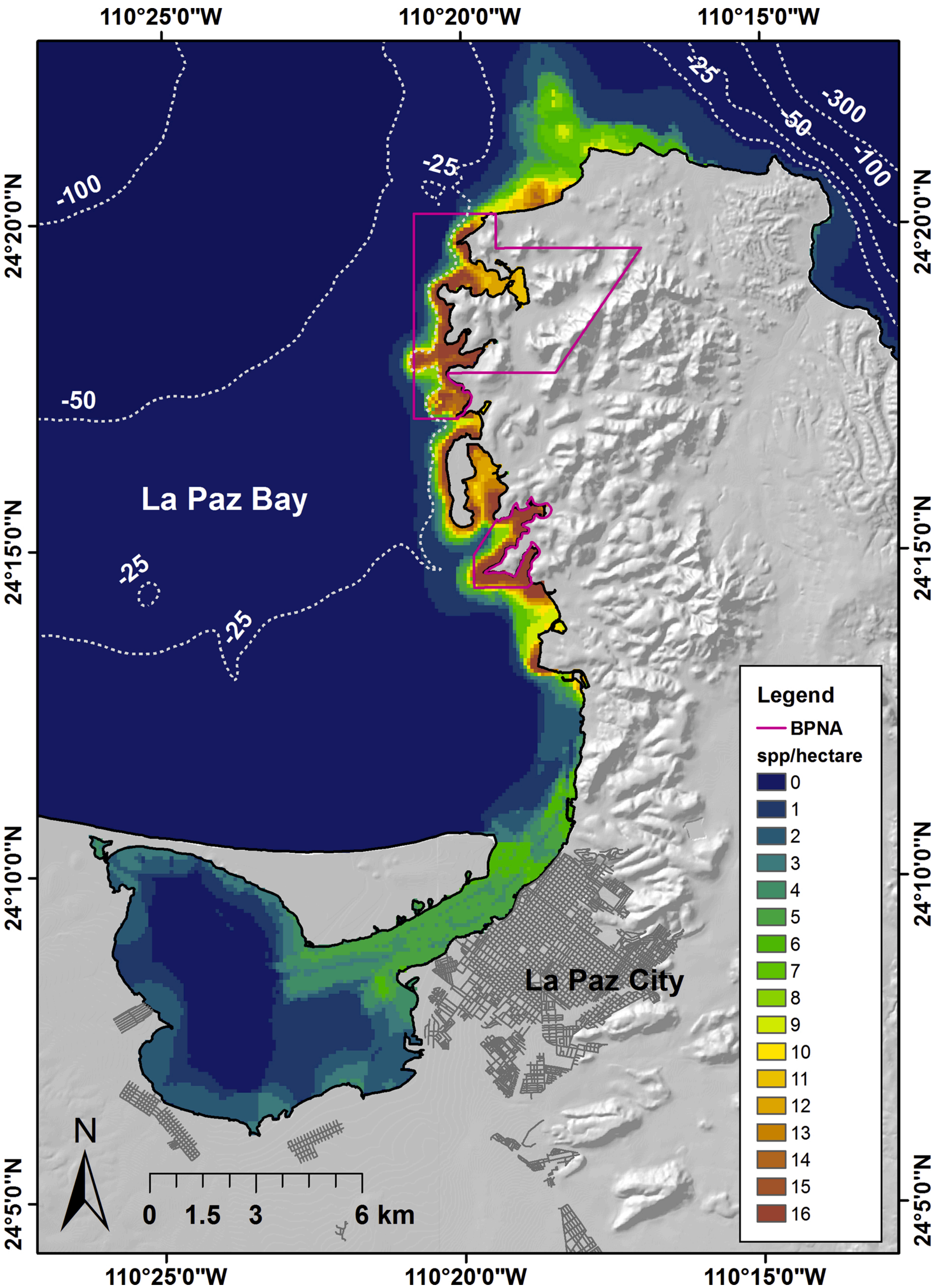

Fig. 3. Multi-species map model. Scale show predicted number of endemic fish species per hectare. The pink polygon is Balandra Protected Natural Area.

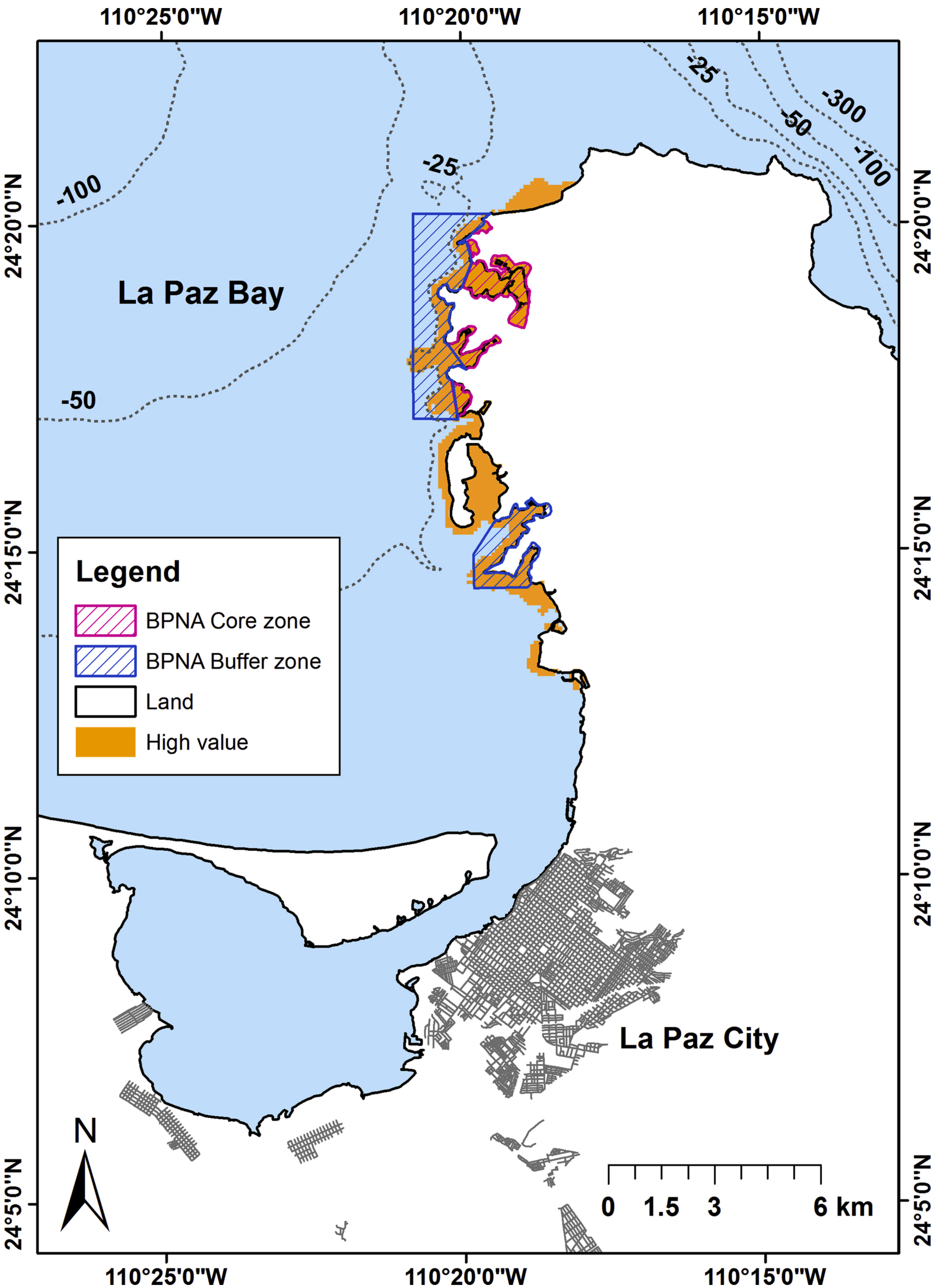

Fig. 4. High value areas from multi-specie map with ≥ 9 species/hectare (orange color) relative to the Balandra Protected Natural Area core and buffer zones.

importance of these layers that indirectly relate the functions of the species in these specific habitats types.

This is consistent for example, for some cryptic fishes, such as *Coralliozetus micropes*, reported to live in rocky shore of limited shallow water depth, and using carbonate organism tubes for protection and feeding (Allen & Robertson, 1994; Balart et al., 2006). For this particular species, the variable of Euclidean distance from rocky shore contributed 46.2 %, depth 25.2 %, and calcium carbonate sediment content 16.8 % of model predictions, showing congruence with the set of environmental layers. Additionally, *H. gentilis* is reported as a fish associated with estuarine areas with mangroves (González-Acosta et al., 2018) and our modelling of this species indicates that the Euclidean distance to mangrove zones is the most important variable with 72.4 % predictive capacity.

5. Conclusions

This study presents the first endemic fishes distribution models from WTPNP using ecological niche modelling within the Bay of La Paz. The results indicate only 8.4 %, of average, of the predicted area for endemic fishes have maximum status of protection within the BPNA core zone. Multi-species maps revealed the high value areas for endemic fish species, but only 17 % of that area are rigorously protected within the core zone. We recommend that the areas categorized as high value are protected and that all activities that generate adverse impacts (specifically dredging) should be restricted and that they be classifies as spaces exclusively for conservation (inside and outside the BPNA). Additionally, we suggest that the distribution of endemic species be explicitly considered in the management plan of the BPNA in order to assess the expansion of the core zone towards areas with high-value of endemic fishes. Moreover, we demonstrated the capacity to predict distributional areas for fish with acceptable model performance using their relationships to geomorphological, sedimentological (marine substrate), and proximity to rocky shore habitats and mangrove habitats as predictors. Our approach clearly contributes to the evaluation of important marine fish habitat types and leads to a reevaluation of currently established marine protected natural areas within La Paz Bay, Mexico such as the BPNA.

The results of this study act as a pragmatic tool reflecting the knowledge of endemic fish distributions and can contribute to long-term decision making during the environmental impact assessments of infrastructure projects that are slated for development in this area. Thus, these models are highly relevant for linking the coastal-based urbanization projects and vital habitat and fish conservation practices in La Paz Bay.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jnc.2021.125981.

References

Abitia-Cárdenas, L. A., Rodríguez-Romero, J., Galván-Magaña, F., De-la-Cruz-Agüero, J., & Chávez-Ramos, H. (1994). Lista sistemática de la ictiofauna de Bahía de La Paz, Baja California Sur, México. *Ciencias Marinas, 20*, 159–181. https://doi.org/10.7773/cm.v20i2.963.

Addison, P. F. E., Rumpff, L., Bau, S. S., Carey, J. M., En Chee, Y., Jarrad, F. C., et al. (2013). Practical solutions for making models indispensable in conservation decision-making. *Diversity & Distributions, 19*, 490–502. https://doi.org/10.1111/ddi.12054.

Allen, G. R., & Robertson, D. R. (1994). *Fishes of the tropical eastern pacific* (p. 352). Honolulu: University of Hawaii Press.

Anderson, R. P., Lew, D., & Peterson, A. T. (2003). Evaluating predictive models of species' distributions: Criteria for selecting optimal models. *Ecological Modelling, 162*, 211–232. https://doi.org/10.1016/S0304-3800(02)00349-6.

Angelieri, C. C. S., Adams-Hosking, C., K.M.P.M.d.B. Ferraz, de Souza, M. P., & McAlpine, C. A. (2016). Using species distribution models to predict potential landscape restoration effects on Puma conservation. *PloS One, 11*(1), Article e0145232. https://doi.org/10.1371/journal.pone.0145232.

Arthington, A. H., Dulvy, N. K., Gladstone, W., & Winfield, I. (2016). Fish conservation in freshwater and marine realms: Status, threats and management. *Aquatic Conservation Marine and Freshwater Ecosystems, 26*, 838–857. https://doi.org/10.1002/aqc.2712.

Austin, M. P. L. (2002). Spatial prediction of species distribution: An interface between ecological theory and statistical modelling. *Ecological Modelling, 157*, 101–118. https://doi.org/10.1016/S0304-3800(02)00205-3.

Balart, E. F., Castro-Aguirre, J. L., Aurioles-Gamboa, D., García-Rodríguez, F., Villavicencio, & Garayzar, C. (1995). Adiciones a la Ictiofauna de Bahía de La Paz, Baja California sur, México. *Hidrobiológica, 5*, 79–85.

Balart, E. F., González-Cabello, A., Romero-Ponce, C., Zayas-Alvarez, A., Calderón-Parra, M., Campos-Dávila, L., et al. (2006). Length-weight relationships of cryptic reef fishes from the southwestern Gulf of California, méxico. *Journal of Applied Ichthyology, 22*, 316–318. https://doi.org/10.1111/j.1439-0426.2006.00670.x.

Barve, N., Barve, V., Jiménez-Valverde, A., Lira-Noriega, A., Maher, S. A., Peterson, A. T., et al. (2011). The crucial role of the accessible area in ecological niche modeling and species distribution modeling. *Ecological Modelling, 222*, 1810–1819. https://doi.org/10.1016/j.ecolmodel.2011.02.011.

Brusca, R. C. (2010). *The Gulf of California biodiversity and conservation.* Tucson: Arizona University Press.

Castro-Aguirre, J. L., González-Acosta, A. F., & de la Cruz-Agüero, J. (2005). Lista anotada de las especies ícticas anfipacíficas, de afinidad boreal, endémicas y anfipeninsulares del Golfo de California, México. *Universidad Y Ciencia, 21*, 87–108.

Chambers, R. C., Candelmo, A. C., Habeck, E. A., Poach, M. E., Wieczorek, D., Cooper, K. R., et al. (2014). Effects of elevated CO2 in the early life stages of summer flounder, *Paralichthys dentatus*, and potential consequences of ocean acidification. *Biogeosciences, 11*, 1613–1626. https://doi.org/10.5194/bg-11-1613-2014.

Cobos, M. E., Peterson, A. T., Barve, N., & Osorio-Olvera, L. (2019). Kuenm: An R package for detailed development of ecological niche models using Maxent. *PeerJ, 7*, Article e6281. https://doi.org/10.7717/peerj.6281.

Colwell, R. K., & Rangel, T. F. (2009). Hutchinson's duality: The once and future niche. *Proceedings of the National Academy of Sciences of the United States of America, 106*, 19651–19658. https://doi.org/10.1073/pnas.0901650106.

Costa, B., Taylor, C. J., Kracker, L., Battista, T., & Pittman, S. (2014). Mapping reef fish and the seascape: Using acoustics and spatial modeling to guide coastal management. *PloS One, 9*(1), Article e85555. https://doi.org/10.1371/journal.pone.0085555.

Dahlke, F. T., Wohlrab, S., Butzin, M., & Pörtner, H. O. (2020). Thermal bottlenecks in the life cycle define climate vulnerability of fish. *Science, 369*, 65–70. https://doi.org/10.1126/science.aaz3658.

Del-Moral-Flores, L. F., González-Acosta, A. F., Espinosa-Pérez, H., Ruiz-Campos, G., & CastroAguirre, J. L. (2013). Lista anotada de la ictiofauna de las islas del golfo de California, con comentarios sobre sus afinidades zoogeográficas. *Revista Mexicana de Biodiversidad, 84*, 184–214. https://doi.org/10.7550/rmb.27335.

Di Cola, V., Broennimann, O., Petitpierre, B., Breiner, F. T., D'Amen, M., Randin, C., et al. (2016). Ecospat: An R package to support spatial analyses and modeling of species niches and distributions. *Ecography*. https://doi.org/10.1111/ecog.02671.

DOF (Diario Oficial de la Federación). (1988). Ley General del Equilibrio Ecológico y la Protección al Ambiente. *Diario Oficial de la Federación 28 de enero de 1988*.

DOF (Diario Oficial de la Federación). (2012). Decreto por el que se declara área natural protegida, con el carácter de área de protección de flora y fauna, la región conocida como Balandra, localizada en el municipio de La Paz, en el Estado de Baja California Sur. *Diario Oficial de la Federación, Secretaría de medio Ambiente y Recursos Naturales 30 de noviembre del 2012*.

DOF (Diario Oficial de la Federación). (2015). Acuerdo por el que se da a conocer el resumen del Programa de Manejo del Área Natural Protegida con el carácter de Área de Protección de Flora y Fauna Balandra. *Diario Oficial de la Federación 29 de octubre de 2015*.

DOF (Diario Oficial de la Federación). (2000a). Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente, en materia de Evaluación de Impacto Ambiental. *Diario Oficial de la Federación 31 de octubre del 2000*.

DOF (Diario Oficial de la Federación). (2000b). Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente, en materia de Áreas Naturales Protegidas. *Diario Oficial de la Federación 28 de diciembre del 2004*.
Ehrlén, J., & Morris, W. F. (2015). Predicting changes in the distribution and abundance of species under environmental change. *Ecology Letters, 18*, 303–314. https://doi.org/10.1111/ele.12410.
Elshout, P. M., Dionisio Pires, L. M., Leuven, R. S., Wendelaar Bonga, S. E., & Hendriks, A. J. (2013). Low oxygen tolerance of different life stages of temperate freshwater fish species. *Journal of Fish Biology, 83*(1), 190–206. https://doi.org/10.1111/jfb.12167.
Espinosa-Pérez, H. (2014). Biodiversidad de peces en México. *Revista Mexicana de Biodiversidad, 85*, s450–s459. https://doi.org/10.7550/rmb.32264.
Franklin, J. (2009). *Mapping species distributions: Spatial inference and prediction (Ecology, biodiversity and conservation)*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511810602.
GBIF. (2020). *Global biodiversity information facility* [October 2020] https://www.gbif.org.
González-Acosta, A. F., De-la-Cruz-Agüero, G., De-la-Cruz-Agüero, J., & Ruiz-Campos, G. (1999). Ictiofauna asociada al manglar del estero El Conchalito, Ensenada de La Paz, B.C.S, México. *Oceánides, 14*(2), 121–131. http://www.repositoriodigital.ipn.mx/handle/123456789/14823.
González-Acosta, A. F., Balart, E. F., Ruiz-Campos, G., Espinosa-Pérez, H., Cruz-Escalona, V. H., & Hernández-López, A. (2018). Diversidad y conservación de los peces de la bahía de La Paz, Baja California Sur, México. *Revista Mexicana de Biodiversidad, 89*, 705–740. https://doi.org/10.22201/ib.20078706e.2018.3.2145.
González-Zamorano, P., Nava-Sánchez, E. H., León de La Cruz, J. S., & Díaz-Castro, A. C. (2011). Patrones de distribución y determinantes ambientales de los manglares peninsulares. In E. F. Félix-Pico, E. Serviere-Zaragoza, R. Riosmena-Rodríguez, & J. L. León-De-La-Luz (Eds.), *Los manglares de la península de Baja California Sur* (pp. 67–104). Baja California Sur, Mexico: Centro Interdisciplinario de Ciencias Marinas, Centro de Investigaciones Biológicas del Noroeste, S. C., & Universidad Autónoma de Baja California Sur.
Guisan, A., Tingley, R., Baumgartner, J. B., Naujokaitis-Lewis, I., Sutcliffe, P. R., Tulloch, A. I. T., et al. (2013). Predicting species distributions for conservation decisions. *Ecology Letters, 16*, 1424–1435. https://doi.org/10.1111/ele.12189.
Heath, M. R., Neat, F. C., Pinnegar, J. K., Reid, D. G., Sims, D. W., & Wright, P. J. (2012). Review of climate change impacts on marine fish and shellfish around the UK and Ireland. *Aquatic Conservation: Marne and Freshwater Ecosystems, 22*(3), 337–367. https://doi.org/10.1002/aqc.2244.
Hirzel, A. H., Le Lay, G., Helfer, V., Randin, C., & Guisan, A. (2006). Evaluating the ability of habitat suitability models to predict species presence. *Ecological Modelling, 199*, 142–152. https://doi.org/10.1016/j.ecolmodel.2006.05.017.
Hobbs, J. P. A., Jones, G. P., & Munday, P. L. (2011). Extinction risk in endemic marine fishes. *Conservation Biology, 25*(5), 1052–1055. https://doi.org/10.1111/j.1523-1739.2011.01698.x.
Hogarth, P. J. (2015). *The biology of mangroves and seagrasses* (third edition, p. 304). Oxford: Oxford University Press.
Hutchinson, G. E. (1957). Concluding remarks. *Cold Spring Harbor Symposia on Quantitative Biology, 22*, 415–427. https://doi.org/10.1101/SQB.1957.022.01.039.
Hutchinson, G. E. (1978). *An introduction to population ecology*. New Haven: Yale University Press.
Jenks, G. F., & Caspall, D. C. (1971). Error on choroplethic maps: Definition, measurement, reduction. *Annals of the Association of American Geographers, 61*(2), 217–244. http://www.jstor.org/stable/2562442.
Kier, G., Kreft, H., Lee, T. M., Jetz, W., Ibisch, P. L., Nowicki, C., et al. (2009). A global assessment of endemic and species richness across island and mainland regions. *Proceedings of the National Academy of Sciences of the United States of America, 106* (23), 9322–9327. https://doi.org/10.1073/pnas.0810306106.
Kimirei, I. A., Nagelkerken, I., Trommelen, M., Blankers, P., van Hoytema, N., Hoeijmakers, D., et al. (2013). What drives ontogenetic niche shifts of fishes in coral reef ecosystems? *Ecosystems, 16*, 783–796. https://doi.org/10.1007/s10021-013-9645-4.
Koenigstein, S., Mark, F. C., G€oßling-Reisemann, S., Reuter, H., & Poertner, H.-O. (2016). Modelling climate change impacts on marine fish populations: Process-based integration of ocean warming, acidification and other environmental drivers. *Fish and Fisheries, 17*(4), 972–1004. https://doi.org/10.1111/faf.12155.
Leathwick, J. R., Elith, J., Francis, M. P., Hastie, T., & Taylor, P. (2006). Variation in demersal fish species richness in the oceans surrounding New Zealand: An analysis using boosted regression trees. *Marine Ecology Progress Series, 321*, 267–281. https://doi.org/10.3354/meps321267.
Lehodey, P., Alheit, J., Barange, M., Baumgartner, T., Beaugrand, G., Drinkwater, K., et al. (2006). Climate variability, fish, and fisheries. *Journal of Climate, 19*, 5009–5030. https://doi.org/10.1175/JCLI3898.1.
Leroy, B., Bellard, C., Dubos, N., Colliot, A., Vasseur, M., Courtial, C., et al. (2014). Forecasted climate and land use changes, and protected areas: The contrasting case of spiders. *Diversity & Distributions, 20*, 686–697. https://doi.org/10.1111/ddi.12191.
Little, C., Williams, G. A., & Trowbridge, C. D. (2009). *The biology of Rocky Shores* (second edition, p. 352). Oxford: Oxford University Press.
McKenzie, D. J., Zhang, Y., Eliason, E. J., Schulte, P. M., Claireaux, G., Blasco, F. R., et al. (2020). Intraspecific variation in tolerance of warming in fishes. *Journal of Fish Biology*, 1–20. https://doi.org/10.1111/jfb.14620.
Monk, J., Ierodiaconou, D., Versace, V. L., Bellgrove, A., Harvey, E., Rattray, A., et al. (2010). Habitat suitability for marine fishes using presence-only modelling and multibeam sonar. *Marine Ecology Progress Series, 420*, 157–174. https://doi.org/10.3354/meps08858.
Moore, C., Drazen, J. C., Radford, B. T., Kelley, C., & Newman, S. J. (2016). Improving essential fish habitat designation to support sustainable ecosystem-based fisheries management. *Marine Policy, 69*, 32–41. https://doi.org/10.1016/j.marpol.2016.03.021.
Nelson, J. S., Grande, T. C., & Wilson, M. V. H. (2016). *Fishes of the world* (fifth edition, p. 752). New Jersey: Hoboken: John Wiley and Sons.
Palacios-Salgado, D. S., Burnes-Romo, L. A., Tavera, J. J., & Ramírez-Valdez, A. (2012). Endemic fishes of the cortez biogeografic province (Eastern Pacific Ocean). *Acta Ichthyologica et Piscatoria, 42*(3), 153–164. https://doi.org/10.3750/AIP2011.42.3.01.
Pearson, G. R., Raxworthy, C. J., Nakamura, M., & Peterson, T. A. (2007). Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography, 34*, 102–117. https://doi.org/10.1111/j.1365-2699.2006.01594.x.
Peterson, A. T., & Soberón, J. (2012). Species distribution modeling and ecological niche modeling: Getting the concepts right. *Natureza and Conservacion Brazilian Journal of Nature Conservation, 10*(2), 102–107. https://doi.org/10.4322/natcon.2012.019.
Peterson, A. T., Papes, M., & Soberón, J. (2008). Rethinking receiver operating characteristic analysis applications in ecological niche modeling. *Ecological Modelling, 213*, 63–72. https://doi.org/10.1016/j.ecolmodel.2007.11.008.
Peterson, A. T., Soberón, J., Pearson, R. G., Anderson, R. P., Martínez-Meyer, E., Nakamura, M., et al. (2011). *Ecological niche and geographic distribution*. pp. 314. New Jersey: Princeton University Press.
Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling, 190*, 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026.
Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2020). *Maxent software for modeling species niches and distributions (Version 3.4.1)*. Available from http://biodiversityinformatics.amnh.org/open_source/maxent/. Accessed on 2020-10-01.
Pittman, S., & Brow, K. A. (2011). Multi-scale approach for predicting fish species distributions across coral reef seascapes. *PloS One, 6*(5), e20583. https://doi.org/10.1371/journal.pone.0020583.
Reyes-Bonilla, H. (1992). New records for hermatypic corals (Anthozoa: Scleractinia) in the Gulf of California, Mexico, with an historical and biogeographical discussion. *Journal of Natural History, 26*, 1163–1175. https://doi.org/10.1080/00222939200770671.
Rijnsdorp, A. D., Peck, M. A., Engelhard, G. H., Möllmann, C., & Pinnegar, J. K. (2009). Resolving the effect of climate change on fish populations. *ICES Journal of Marine Science, 66*(7), 1570–1583. https://doi.org/10.1093/icesjms/fsp056.
Schmiing, M., Diogo, H., Serrão Santos, R., & Afonso, P. (2014). Assessing hotspots within hotspots to conserve biodiversity and support fisheries management. *Marine Ecology Progress Series, 513*, 187–199. https://doi.org/10.3354/meps10924.
SEMARNAT. (2020). *Secretaría de Medio Ambiente y Recursos Naturales, Sistema Nacional de Trámites*. Last accessed: October, 2020 http://sinat.semarnat.gob.mx/Gaceta/aniosgaceta.
Spalding, M. K., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., et al. (2007). Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. *BioScience, 57*(7), 573–583. https://doi.org/10.1641/B570707.
Steller, D. L., Riosmena-Rodríguez, R., Foster, M. S., & Roberts, C. A. (2003). Rhodolith bed diversity in the Gulf of California: The importance of rhodoliths structure and consequences of disturbance. *Aquatic Conservation Marine and Freshwater Ecosystems, 13*, 5–20. https://doi.org/10.1002/aqc.564.
Tittensor, D. P., Mora, C., Jetz, W., Lotze, H. K., Ricard, D., Berghe, E. V., et al. (2010). Global patterns and predictor of marine biodiversity across taxa. *Nature, 466*(26), 1098–1103. https://doi.org/10.1038/nature09329.
Urcádiz-Cázares, F. J. (2018). *Valoración del espacio marino en la Bahía de La Paz mediante el modelado de nicho ecológico de peces: una estrategia de conservación*. PhD Thesis. La Paz, Baja California Sur, Mexico: Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas.
Urcádiz-Cázares, F. J., Cruz-Escalona, V. H., Nava-Sánchez, E., & Ortega-Rubio, A. (2017). Clasificación de unidades del fondo marino a partir de la distribución espacial de los sedimentos superficiales de la Bahía de La Paz, Golfo de California. *Hidrobiológica, 27*(3), 399–409.
Velasco-García, J. A. (2009). *Ambientes geológicos costeros del litoral de la Bahía de La Paz, Baja California Sur, México*. MSc Thesis. La Paz, Baja California Sur. Mexico: Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas.
Warren, D. L., & Seifert, S. N. (2011). Ecological niche modeling in Maxent: The importance of model complexity and the performance of model selection criteria. *Ecological Applications, 21*(2), 335–342. https://doi.org/10.1890/10-1171.1.
Warren, D. L., Matzke, N., Cardillo, M., Baumgartner, J., Beaumont, L., Huron, N., et al. (2019). *ENMTools (Software Package)*. https://doi.org/10.5281/zenodo.3268814. https://github.com/danlwarren/ENMTools.
Wisz, M. S., Hijmans, R. J., Peterson, A. T., Graham, C. H., & Guisan, A. (2008). Effect of sample size on the performance of species distribution models. *Diversity & Distributions, 14*, 763–773.