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## Analysis of omissions of protected fish species during environmental impact assessments inferred with distribution models in southeastern coastal zone of Bahía de La Paz, Mexico

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### ABSTRACT

Protected species are relevant for decision-making regarding environmental authorization of development projects. In Mexico, prior to authorizing a development project, it is required to evaluate potential impacts through an environmental impact statement (EIS); this EIS must document the presence or absence of the protected species listed in the NOM-059-SEMARNAT-2010 standard within the project area and its surroundings (influence zone). However, *in situ* detection of some faunal groups similar to protected fish species (PFS) can be complex due to mobility and dynamics, difficulty of sampling, and lack of literature. Consequently, PFS could be inadvertently omitted during environmental impact assessments and this could strongly influence decision-makers related to approving the development site. To address this issue, we used our extensive history and experience of the region to document potential omissions of PFS in projects evaluated from 2005 to 2018 in the Bahía de La Paz. Omissions were inferred by cross-checking the declaration in the EIS and comparing impact areas of the projects with the PFS distribution areas predicted from ecological niche models. The results revealed, on average, that 74% of EIS examined did not declare PFS in the zone where the models indicated their potential presence. This unprecedented study has innovative implications for improving future decision-making and protection of regulated protected species and their habitats both in the bay and elsewhere in the marine and coastal environment.

### 1. Introduction

Protected species are significant elements for biodiversity conservation policies (Crosti et al., 2020), but they are also relevant in decision-making previous to the development of projects that could

affect a certain ecosystem (Heibult-Sawchuk et al., 2015; Aburto-Oropeza et al., 2018). For example, the presence of these species may influence the development of an investment project based on an environmental impact assessment. In Mexico, the legally protected flora and fauna species are listed in the official regulation NOM-059-

**Abbreviations:** CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora; IUCN, The International Union for Conservation of Nature.

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SEMARNAT-2010 (DOF, 2019), in which the risk categories indicate where such species are found. These species have a restricted geographic range, their habitat may be impacted by the development, they are vulnerable due to their biological/life history characteristics, and their populations have been impacted by human activities (DOF, 2019). For these reasons, they require special attention for conservation policies and decision-making. Many of these species are also included in the International Union for Conservation of Nature's Red List (IUCN, 2022) and eventually in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2022). According to the Federal Criminal Code of Mexico, harm, capture, or possession of these species is typified as a serious crime with penalties up to 12 years in prison and fines up to USD 2.5 million (DOF, 2021). Consequently, in an environmental impact assessment process, the presence of protected species within a site or region of interest could prohibit, limit, or modify the development of projects (works and activities) in Mexican territory according to the environmental legislation (DOF, 2014, 2022).

During the last few decades, implementing tourism projects in the Mexican coastal zone by the public or private sectors (OECD, 2017) have caused a positive socio-economic gain (Sánchez-López, 2020; Olmedo-Neri, 2021) but negative impacts on the natural environment and its ecosystem services (Valdéz et al., 2010; Campagna et al., 2011; Costanza, 2020; Mayani-Parás et al., 2022). Consequently, environmental impact authorizations from the federal government are required to perform developmental projects (DOF, 2014, 2022; Hundloe, 2021) as part of an administrative procedure that starts with an environmental impact statement (EIS) by the promoters (Palerm and Aceves, 2004; Perevochtchikova, 2013). The EIS declares the potential environmental impacts that the project may cause on the ecosystem, whose characteristics are assessed by appropriate federal authorities (DOF, 2014; Noble, 2017; Hundloe, 2021). One of the essential requirements during assessment is the identification of the protected species within the projected area and its influence zone (at the local scale) and within the adjacent region known as the environmental system (at the regional scale). The purpose of these requirements is to identify the presence of such species, their dynamics, and their potential interaction with the project which leads to better decision-making for its eventual authorization, conditioning, or rejection (Ortega-Rubio et al., 2001; DOF, 2014).

Nevertheless, verifying the presence or absence of protected species in geographic spaces could be limited for various reasons. These are: (1) technical and economic ability to perform an adequate flora and fauna sampling by the consultants and promoters of the project; (2) lack of scientific literature; (3) limited (technical and administrative) capacity of the authorities; and (4) species nature (rarity, size, mobility, temporality, and mimicry). The reasons are magnified when dealing with marine species because the accessibility to aquatic environments is commonly more complex and costlier than to terrestrial ones. Thus, it is likely that a number of EIS's do not declare some of the marine species, specifically the group of protected fish species (PFS), which likely cause highly relevant omissions. Similarly, some evaluating authorities omit them due to the lack of scientific information that supports their decision-making (Arthington et al., 2016; Alderete-Domínguez et al., 2019).

Currently, a methodology is available to predict marine suitable distribution areas for species, known as ecological niche modeling (Peterson et al., 2011). This type of modeling links a set of environmental variables with the sites where a species has been recorded by applying complex algorithms (Franklin, 2009) and then predicts their distribution in the geographic space. This technique has been used recently to predict the distribution of several faunistic groups in the marine and coastal environments (Robinson et al., 2017; Melo-Merino et al., 2020), including fish groups (Monk et al., 2010; Pittman and Brown, 2011; Urcádiz-Cázares et al., 2021a, 2021b).

Thus, based on our extensive faunal knowledge of the region and that ecological niche modeling is an efficient methodology to determine the

suitable distribution areas for PFS, we examined a large EIS database in order to estimate possible omissions when declaring and assessing a project's potential environmental impact. We investigated this possibility by addressing the following goals: (1) predict the distribution areas of the PFS listed in NOM-059-SEMARNAT-2010 (DOF, 2019) in Bahía de La Paz, Baja California Sur, Mexico; and (2) analyze the PFS omissions based on the EIS of the projects performed in the bay from 2005 to 2018. This research is the first to demonstrate and quantify PFS omissions during environmental impact assessments. This unprecedented study has the potential implications for decision-making and protection of regulated species, both in the bay as in any part of the surrounding marine and coastal environment.

## 2. Materials and methods

### 2.1. Study area

Bahía de La Paz (Fig. 1) is a water body located in the southern area of the Gulf of California where favorable habitats for ichthyofauna can be found. The southern coast is formed by a coastal lagoon with mangroves and muddy to sandy beach areas with extensive tidal flats. The northern coast is comprised of an irregular geomorphology with rocky beaches and cliffs between calcareous beaches and rocky reef and rhodolith bed areas (Urcádiz-Cázares et al., 2017). The southeastern part of the bay has important areas for endemic fish conservation (Urcádiz-Cázares et al., 2021a), which is also considered a fish hotspot area (Urcádiz-Cázares et al., 2021b).

The extent of this study or calibration area (~300 km<sup>2</sup>, Fig. 1) represents a geographical area at the local scale limited by the availability of information on the environmental layers of the southeastern coastal zone of Bahía de La Paz (Urcádiz-Cázares et al., 2017, 2021a). Due to this geographic extent and natural fish mobility, we consider the study area as an accessible site for the species. According to Peterson et al. (2011), our study area represents a likely subset of real geographic and environmental space for the species. Ideally, the accessible area should be limited up to where the species hypothetically arrive to predict their geographic ranges (Barve et al., 2011). Therefore, the focus of this study is to determine the abiotically suitable areas that are necessary at a local scale within the study area and to contrast these characteristics with the projected areas within the EIS. This calibration area corresponds to the background area during the modeling stage.

### 2.2. Protected fish species

A total of 533 fish species are reported in Bahía de La Paz, with eight of them being subjected to protection in the NOM-059-SEMARNAT-2010 (González-Acosta et al., 2018): *Chromis limbaughi*, *Hippocampus ingens*, *Holacanthus passer*, *Pomacanthus zonipectus*, *Rhincodon typus*, *Carcharodon carcharias*, *Opistognathus rosenblatti*, and *Poecilia butleri*. From these protected species, *H. ingens* and *C. carcharias* are also included in the International Union for Conservation of Nature's Red List (IUCN, 2022) as "vulnerable" whereas *R. typus* is mentioned as "threatened." With respect to *H. ingens*, *C. carcharias*, and *R. typus*, they are also listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2022).

### 2.3. Modeling distribution areas

To generate species distribution areas, we used the generalized automatic learning algorithm of maximum entropy, Maxent (Phillips et al., 2017). In Maxent, distribution models are developed with only presence data from species records. The maximum entropy probability distribution (the most dispersed) is found restricted to the environmental variable values (layers) where species occur and contrasted with background data from the calibration area (Elith et al., 2011). Maxent predicts the abiotically suitable areas for the species in the geographic

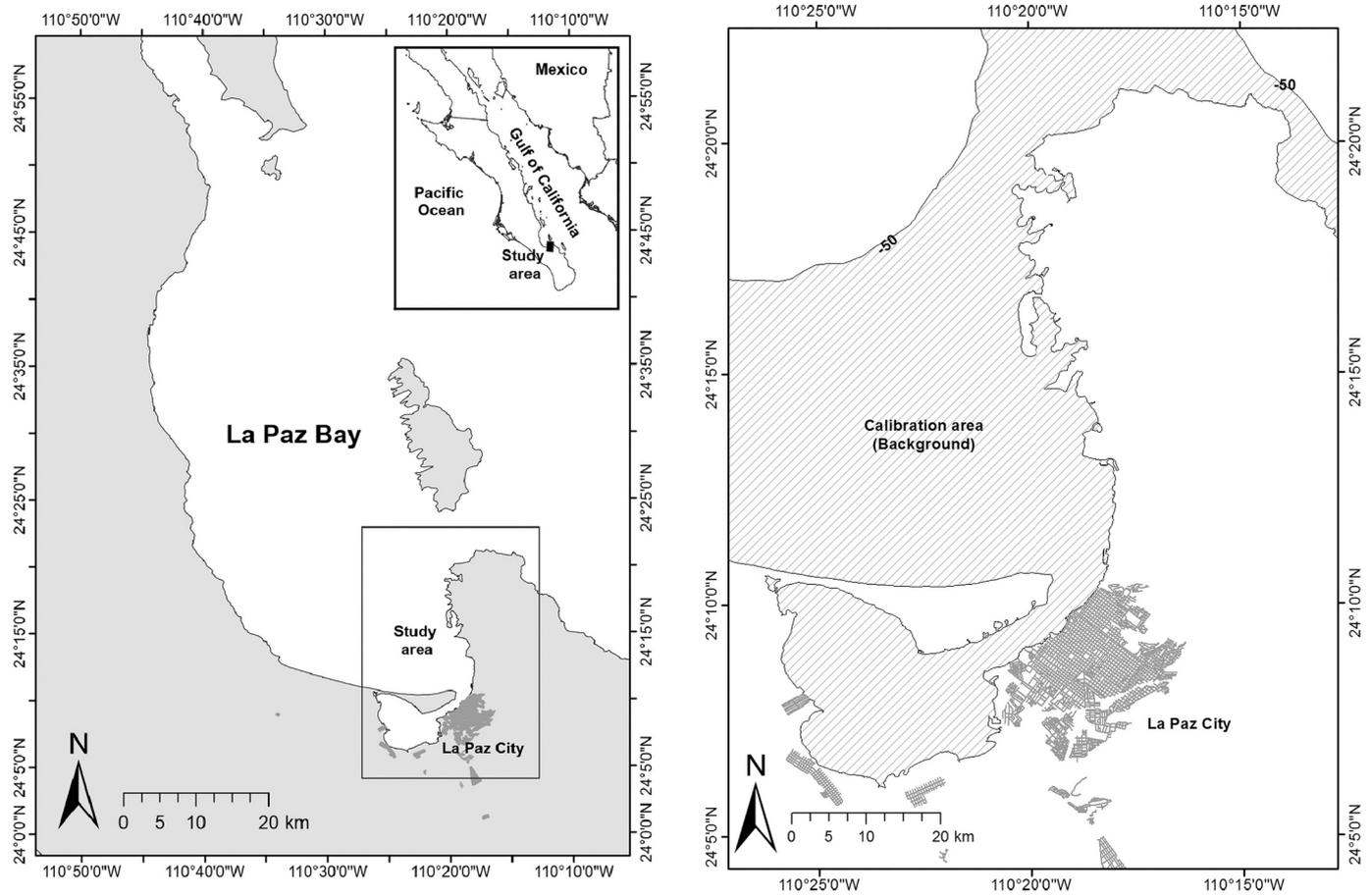


Fig. 1. Location of the area of study in Bahía de La Paz (southern Gulf of California), La Paz, Baja California Sur, Mexico. The calibration area (background) is considered from the coast (0 m) to a depth of 50 m within study area (hatched lines in the right figure).

space, starting from a set of environmental variables at the geographic scale called scenopoetic (Peterson et al., 2011). The modeling process consists of (1) database development with the records of species presence, (2) acquisition and treatment of the environmental layers, and (3) calibration and assessment of the models.

First, by means of geographic information systems (ArcGIS 10.4, ESRI, 2012) a database was developed with the location of the PFS presence records within the area of study. Such records were obtained from diverse bibliographical sources (González-Acosta et al., 1999; Malpica-Maury, 1999; Galván-Piña et al., 2003; González-Cabello, 2003; Viesca-Lobatón, 2005; Zayas-Álvarez, 2005; Balart et al., 2006; López-Rasgado, 2013; Payán-Alcacio, 2013; González-Acosta et al., 2018), as well as from the database Ichthyological Collection CICIMAR-IPN (<http://coleccion.cicimar.ipn.mx/>). In total, 143 presence points were recorded for the species *C. limbaughi*, *H. ingens*, *H. passer*, and *P. zonipectus*. These data were filtered to reduce the risk of spatial bias according to Boria et al. (2014) using as a criterion a minimum distance between points of 700 m. In this way, the data for the modeling was reduced to a total of 33 to 44 presence points for the species (Table 1). On the other hand, the species *R. typus* and *C. carcharias* were discarded

**Table 1**  
Presence records of protected fish species. Data were divided into training, test, and independent sets.

Species	Training	Test	Independent	Total
<i>Chromis limbaughi</i>	18	10	9	37
<i>Hippocampus ingens</i>	24	9	11	44
<i>Holacanthus passer</i>	19	9	5	33
<i>Pomacanthus zonipectus</i>	20	10	10	40

from the model due to their circumglobal distribution, and *O. rosenblatti* and *P. butleri* had insufficient records ( $n < 10$ ) for modeling accuracy.

Eight environmental layers (predictive variables) used in modeling were obtained from Urcádiz-Cázares et al. (2017, 2021a). These layers were depth (m), slope inclination (grade), and aspect (azimuth) which all describe the ocean bottom geomorphology; medium grain size of the sediment ( $\phi$ ,  $-\log_2$  of the distance in millimeters), sorting degree (standard deviation of the grain size), and calcium carbonate percentage (%) which describes the texture and composition of the superficial marine substrate, the Euclidean distance (m) from the rocky shore (with habitats of rocky reefs) and those with mangroves (fish breeding and nursing sites). The layers were examined to verify if a linear correlation existed between them through the ENMTools package (Warren et al., 2019) in R code v.4.0.3. Because the correlation was  $< 0.63$ , it avoided a multi-collinearity risk of obtaining biased results; thus, the layers were appropriate for the modeling (Merow et al., 2013). The environmental layers were grouped into 50 different sets, each set with a number of layers between 5 and 8 in combination.

To calibrate the models, the kuenm package (Cobos et al., 2019) in R code was implemented, which allowed different combinations of the parameters to be assigned in Maxent. All the possible combinations of the types of responses or features (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 50 different environmental layer sets. In total, 25,600 models were generated for each species. To assess these models and select the best one, three criteria were used. First, the model had to be the most statistically significant ( $p < 0.05$ ) in testing for occurrence data (Table 1) by means of the partial area under the curve of the receiver operating

characteristic curve (pAUC/ROC) with 500 interactions and bootstrapping with 35% of testing of occurrence data (Peterson et al., 2008). Second, the model has a low omission rate considering an error threshold up to 0.05 (Anderson et al., 2003). Finally, the model must have minimum values of the Akaike Information Criteria (Warren et al., 2019). Considering these three criteria, 205 final models were identified

for the four species. These models were constructed using logistic output, bootstrapping with 30% data for testing, jackknife analysis, and 30 repetitions to obtain an average model. Final models were contrasted with the occurrences independently of the model (Table 1), using again the previous three criteria until the best model was selected for each species. Finally, the output of the models resulted in probability maps

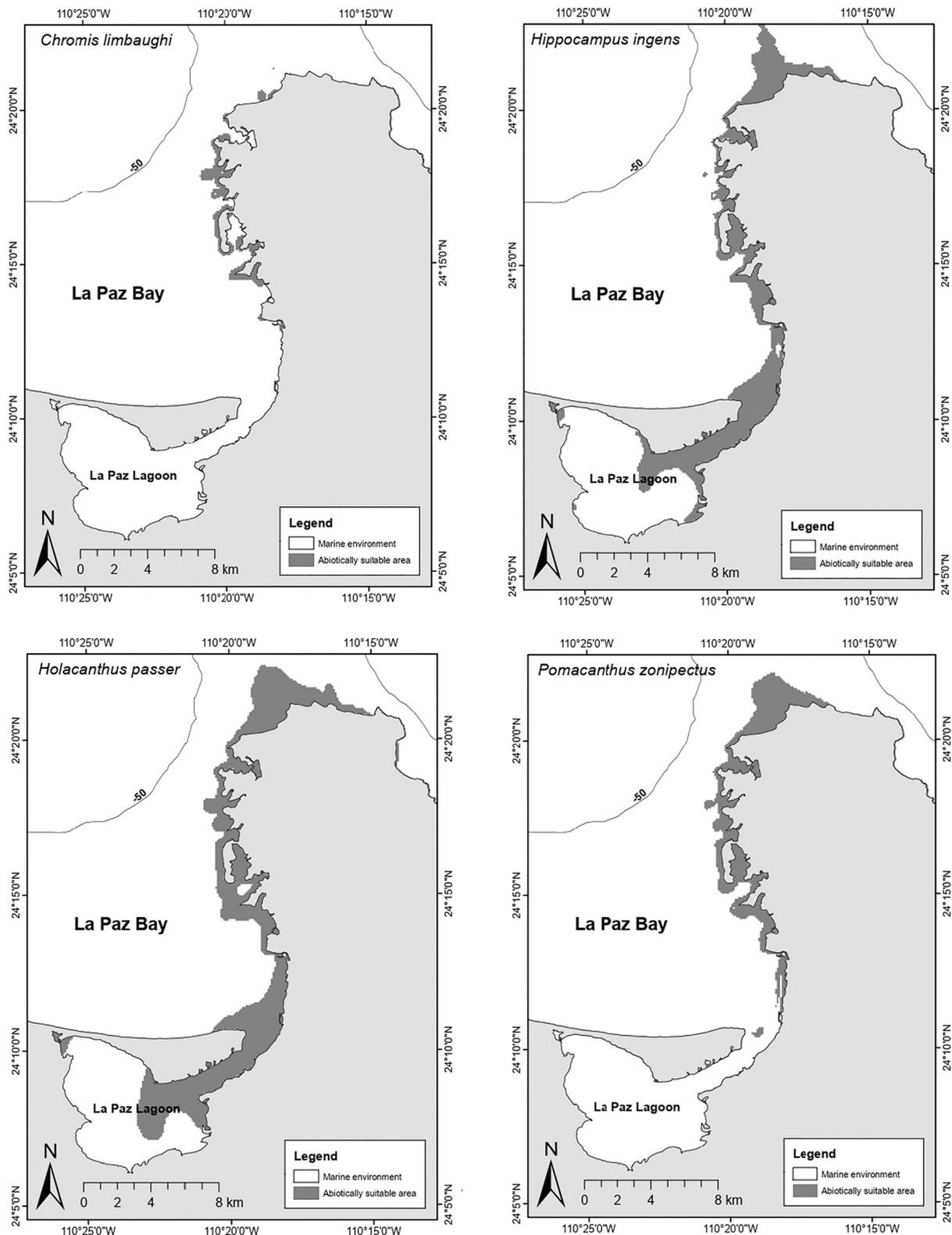


Fig. 2. Models of distribution areas (abiotically suitable area) for the four protected fish species listed in the official Mexican regulation NOM-059-SEMARNAT-2010.

with continuous values for the presence of species expressed between 0 and 1. Nevertheless, the presence/absence threshold needs to be established to delimit binary maps, i.e., species presence/absence areas maps (distribution models). Thus, the criteria of the 10% percentile of the predicted values at sites of species presence was used as a threshold (Peterson et al., 2011). Therefore, the distribution models allowed comparing geographically the presence areas against the environmental impact polygons and influence zones of the declared development projects in the bay.

### 2.4. Omissions records

In a subsequent stage, projects and their EIS were identified within the area of study from 2005 to 2018 using the *Gaceta Ecológica* (2022) from Official Journal of the Federal Government of Mexico was reviewed (DOF, 2022). All the coastal projects of the Municipality of La Paz in Baja California Sur were identified, and their EIS were downloaded from the official page and others were requested from the secretariat given their public access. In total, 48 projects were identified within the area of study and polygons of each project (works and activities) were located using ArcGIS 10.4 (ESRI, GIS). To establish the influence zone of each project, a buffer was applied in a radius of 1 km to simulate the environmental impacts on the marine and coastal environments at a reasonable minimum distance.

Omissions analysis of PFS was performed at both regional and local scales. The first one questioned if EIS's declared the presence of any PFS within their environmental system (regional scale), in such a way that omissions were quantified and collated with the records of González-Acosta et al. (2018). For the analysis at this scale, six species (*C. limbaughi*, *H. ingens*, *H. passer*, *P. zonipectus*, *R. typus*, *C. carcharias*) were considered. At the local scale, EIS's were reviewed to verify if they had declared the presence of the four PFS modeled (Table 1) within a project polygon and its influence zone. This geographic information was overlaid with the distribution areas modeled using ArcGIS 10.4 (ESRI, 2012), in such a way that PFS potential omissions were quantified. Because the predicted area in the models depends on the value of the presence/absence threshold, the PFS omission percentages are sensitive to this value. For this reason, a sensitivity analysis was implemented to observe how the PFS omissions vary in relation to different threshold values. We use 10th, 20th, 30th and 40th percentile training presence threshold, minimum and mean training presence threshold.

## 3. Results

### 3.1. Distribution areas

The PFS distribution area models (Fig. 2) had values of pAUC/ROC >0.92 when sets of five environmental layers were used and met favorable evaluation criteria – they were statistically significant ( $p < 0.05$ ) with a rate of omission equal to zero (using 0.05 as the threshold error), and a minimum AIC value. The main variables that contributed to the distribution area (Table 2) for all four species, on average, were the Euclidian distance from the rocky shore habitats (33.3%) and mangrove zones (25.3%), as well as depth of marine water (22.4%).

**Table 2**

Contribution percentage (%) of each environmental layer (variable) in models for protected fish species. ED = Euclidian distance from habitat. Note that the final models were performed using the five environmental layers.

Species	Depth	Slope	Grain size	Sorting	ED rock shore	ED mangrove
<i>C. limbaughi</i>	5.0	–	3.8	0.01	65.7	25.3
<i>H. ingens</i>	36.6	–	12.1	7.2	9.3	34.9
<i>H. passer</i>	13.3	–	27.2	4.3	27.8	27.3
<i>P. zonipectus</i>	34.5	5.7	15.9	–	30.3	13.6
Mean	22.4	5.7	14.8	2.8	33.3	25.3

The distribution of blue-and-yellow damselfish, *C. limbaughi*, is restricted to irregular coastlines and the rocky shore of the northern portion of Bahía de La Paz, whereas the Pacific seahorse, *H. ingens*, and king angelfish, *H. passer*, show a continuous distribution from the northern point of the bay toward the coastal lagoon entrance. In contrast, the Cortes angelfish, *P. zonipectus*, shows a similar distribution to *H. ingens* and *H. passer*, except for the lagoon (Fig. 2).

### 3.2. Omissions analysis

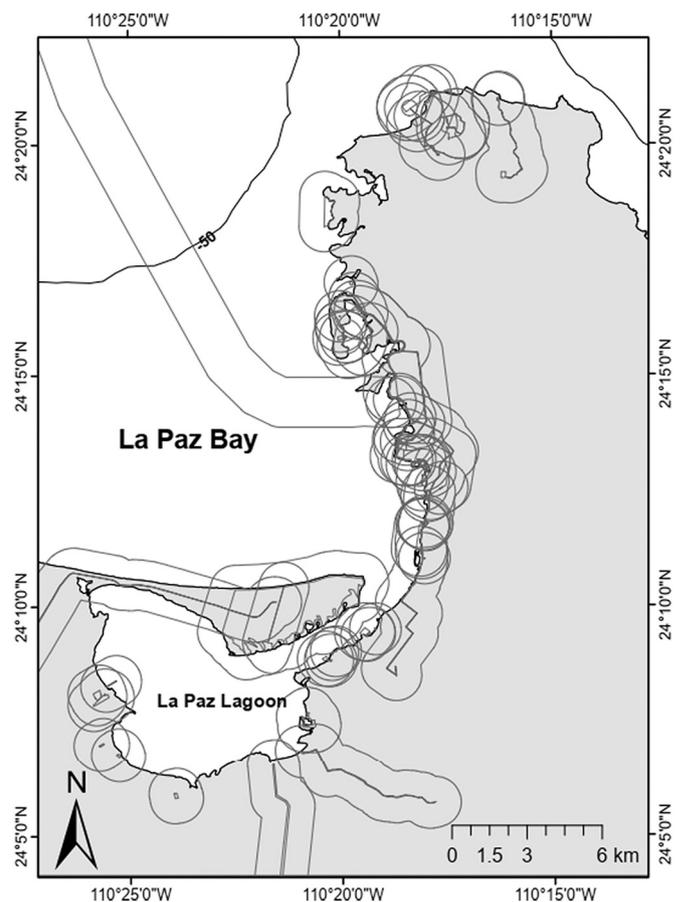
Forty-eight projects and their EIS documents were identified in the bay (see Fig. 3). Analyses at the regional scale revealed that, 73% to 98% (84% on average) of EIS omitted PFS within their environmental system. Table 3 shows the percentage of omission per species in each EIS.

Analyses at the local scale indicated that only one study declared the presence of PFS within the polygons of project area and its influence zone in the coastal area of Bahía de La Paz (Table 3). PFS model distribution areas (Fig. 2) were overlaid on the polygons of each one of project area (works and activities) and its influence zone (Fig. 3) and revealed that, between 50 and 94% (74% on average) of the EIS omitted the presence of PFS along study area coastal zone.

## 4. Discussion

### 4.1. Protected fish species omissions and their implications

EIS analysis at regional scale in Bahía de La Paz revealed an omission



**Fig. 3.** Locations of the 48 projects areas (works and activities) and their influence zone (buffer of 1 km) declared in the environmental impact statements (EIS) from 2005 to 2018. Using a geographic information system, each project area and its influence zone were overlaid with the protected fish species (PFS) distribution areas to detect potential omission at the local scale.

**Table 3**

Relationship of protected fish species (PFS) presence declared in environmental impact statements (EIS) studies within the environmental system (regional scale) and within the working and activity project areas (local scale). Likewise, the predicted presence is listed by the models of the distribution areas within the working and activity areas of each project. *Chromis limbaughi* (*C. lim*), *Hippocampus ingens* (*H. ing*), *Holacanthus passer* (*H. pas*), *Pomacanthus zonipectus* (*P. zon*), *Rhincodon typus* (*R. typ*) and *Carcharodon carcharias* (*C. car*). Note that at the regional scale six PFS were used and for the local scale only four PFS.

Project	Declared within the environmental system?						Declared within the project area and influence zone?						Predicted within the project area and influence zone?			
	<i>C. lim</i>	<i>H. ing</i>	<i>H. pas</i>	<i>P. zon</i>	<i>R. typ</i>	<i>C. car</i>	<i>C. lim</i>	<i>H. ing</i>	<i>H. pas</i>	<i>P. zon</i>	<i>R. typ</i>	<i>C. car</i>	<i>C. lim</i>	<i>H. ing</i>	<i>H. pas</i>	<i>P. zon</i>
05FD083	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
05T0002	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	No
05VD001	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
06HD007	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
06HD119	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
06TD043	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
06TD072	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
06TD111	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
07HD012	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
07HD069	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
07P0012	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
07T0019	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
07TD131	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
08H0010	No	No	No	Sí	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
08HD089	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
08HD107	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
08HD113	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
08T0018	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No
09FD010	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
09TD023	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
10FD079	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
10HD002	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
10T0009	Yes	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes
10TD040	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
11TD030	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
12TD039	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
12TD080	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
13T0001	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
17V0042	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
14HD055	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
14HD056	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
15HD002	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
15T0001	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
15T0010	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
15TD071	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
16TD047	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
18E0033	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
18ID025	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
18PD140	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
18TD121	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
18TD042	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
18TD047	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No
18TD083	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
18TD089	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
18V0018	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
18V0019	No	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
12TD055	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
03T0004	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
% Not declared	85	90	77	73	83	98	98	100	98	98	100	100	-	-	-	-
% Omission	85	90	77	73	83	98	-	-	-	-	-	-	50	94	88	65

rate from 73 to 98% for the PFS (*C. limbaughi*, *H. ingens*, *H. passer*, *P. zonipectus*, *R. typus*, *C. carcharias*) explicitly subjected to legal protection by the NOM-059-SEMARNAT-2010 (DOF, 2019) and despite such species inhabiting Bahía de La Paz (González-Acosta et al., 2018). As part of the regulation in the matter of environmental impact assessment, the promoters were obligated to explore the adjacent areas to the project and within the environmental system to evidence the presence or absence of the protected species in NOM-059-SEMARNAT-2010 (DOF, 2019, 2022) with the objective of analyzing the possible environmental impacts toward their habitats or populations. According to the model predictions obtained for *C. limbaughi*, *H. ingens*, *H. passer*, and *P. zonipectus*, 50 to 94% of the EIS studies omitted their presence within the areas of each project and its influence zone. Although the projects performed in the bay have evidently impacted PFS by a certain magnitude, quantifying and documenting their negative effects within the

populations is complicated and outside the scope of this study. Even more uncertain are the impacts on fish populations caused by the projects illegally performed or those previously implemented before the publication of the environmental impact legislation (< 1988). The results revealed high omissions occurred in Bahía de La Paz, and possibly currently occurring in the bay and in other marine regions in Mexico. Evidently, omissions that occurred during the assessment could cause negative impacts to the marine and coastal ecosystems and, consequently, contravene the international objectives of biodiversity conservation (Villarroya et al., 2014; Aburto-Oropeza et al., 2018) and sustainability goals (Kolhoff et al., 2018; Costanza, 2020; Koff, 2021).

The PFS omission implicitly indicates a breach of highly relevant regulatory policies. Although damage to protected species is clearly considered a serious crime in Mexico – more than just a criminal offense – the record of these species’ presence in EIS obligates the promoters to

be subjected to environmental bonds (in the case where the project is authorized) to guarantee the compliance of conditions that the same evaluating authorities consider pertinent for the protection of the species' populations (DOF, 2014). Consequently, identifying and declaring the presence of protected species must be the main elements for investing in measures to mitigate, monitor, and compensate negative impacts (Perevochtchikova, 2013; Villarroya et al., 2014). On the other hand, omitting the presence of protected species and, consequently, not linking environmental impacts to them are sufficient criteria for authorities to reject a development project (DOF, 2014).

#### 4.2. Possible omission factors

Several factors could have been attributed to the omission of the protected species in the EIS by the consultants and promoters, as well as by the evaluation's authorities. One of these factors is the fish nature, such as size and mobility. For example, the blue-and-yellow damselfish is a relatively small species (typically <12 cm), and this condition makes it difficult to observe in the marine environment and could contribute to its omission. On the other hand, the Pacific seahorse is a naturally cryptic specie and often hides among rocky substrates and patches of algae, which is why it might not be observed, and is unintentionally omitted. In contrast, detecting large species such as the whale shark or the great white shark could be easy as long as the observer coincides with the presence of the individuals during a given sampling. Due to the widespread mobility of this type of species, its detection during sampling is unlikely. Accordingly, environmental consultants and project promoters could record them as absent and omit them within the environmental system and project area. Sometimes the consultants do not sample on a regional scale, and then the presence or absence of a species is inferred from the literature. In this sense, it is possibly that the whale shark and great white shark were ignored under the argument that their interaction within the project area is unlikely. However, it is a legal obligation to declare all protected species and link them to the projects (DOF, 2014), in this case, demonstrating the low probability of PFS interactions with the project. In general, the fish species have different mobility patterns influenced by their needs for feeding, reproduction, refuge, spawning, and nursery throughout their life cycle (González-Acosta et al., 1999). Mobility and seasonality for some species may be the reason for an absence in the marine environment during an inadequate sampling period. In the marine environment, detecting a "true absence" has a higher margin of error than a "true presence" for a given species (Peterson et al., 2011). Consequently, studies based on species presence-only data are generally more robust than those using presence and absence data and thus our use of Maxent on presence-only data is justified.

Additionally, the ability of a consultant to detect species presence in the marine environment can be an issue. The promoters hire environmental consultants to perform the EIS, which ideally should sample the environmental system and study area of each project with the purpose of describing the marine and coastal biotic elements. Therefore, availability of human resources and technical capacity (knowledge and experience) to perform the EIS plays a fundamental role in detecting and classifying PFS. Moreover, the spatio-temporal sampling effort for the different fish groups (and other flora and fauna groups) is dependent upon the available budget. A monthly sampling plan during one or more years is ideal to identify fish seasonality, diversity, and abundance patterns. However, their sampling design and duration requires elevated costs and greater time and effort, which are not convenient for promoters.

When planning the development of investment projects (e.g., hotels, desalination plants, marine infrastructure, roads), promoters generally require a short period of time to obtain environmental permits (reduces costs over time) and that the EIS costs be as cheap as possible. Despite species protection being of public interest and coming from international treaties, the provision of services to perform an EIS (where the

protected species are declared and bound to the impacts of the projects) is a private process subjected to the market (Micheli, 2002). In fact, the EIS evaluation has been a closed process with rare cases of democratic social participation (Palerm and Aceves, 2004). The promoters generally select those who perform the cheapest, fastest, and most effective EIS over those that work with quality, planning, ethics, and professionalism. Mexican legislation allows any moral person (enterprise) or independent consultant (including those with any degree in bachelor studies) to develop and manage an EIS. All previously mentioned could influence omission of protected species strongly.

Independent of where EIS originates in the private sector, the environmental authorities should adhere to the legal framework in ecological and environmental matters (DOF, 2014, 2022) to perform and properly recognize the protected species. In this sense, other factors that may contribute to omissions are the possible limitation of the environmental authorities (evaluators) in terms of experience and knowledge on certain faunal groups, especially marine fish. Data availability of the protected species of the scientific and technical works is equally important (Sampedro-Ávila et al., 2015). If an EIS declares "no protected species were detected in the project area", then the management authorities should question the findings and evaluate the scientific literature or PFS data bases of the Federal Secretariats. Studies on marine protected species distribution and ecology is biased and scarce in Mexico, which is why it is a factor that likely influences omissions. Relevantly, article 3 of the regulation in environmental impact (DOF, 2014) indicates the consultants must sign a declaration where "the best techniques and methodologies used by the scientific community of the country and the greatest information available" were applied. Therefore, if no information about protected species distribution is available, then the authorities cannot legally refute the "absence" hypothesis of a declared species in a projected area and influence zone. This regulation obliges consultants to use updated scientific references that include protected species, especially those with distribution areas. Therefore, the relevant utility of ecological studies focused on modeling the ecological niche of protected species is encouraged as such science-based methods could have a beneficial impact on decision-making by environmental authorities and better protect Mexican natural resources for future generations.

#### 4.3. Sensitivity analysis

The PFS presence predicted area in the model's changes according to the selected threshold value. Below a threshold, species are considered absent, and above this, they are considered present. The higher the threshold value, the predicted area decreases as well as the percentage of omissions. This threshold increase also leads to the loss of information on the distribution areas but said area reduction involves an increase in suitability. For models with presence-only data, establishing an appropriate threshold is complex (Liu et al., 2013); however, the minimum training presence threshold (the lowest predicted value associated with a calibration presence record) has been widely used (Pearson et al., 2007), as well as the 10th percentile presence threshold of such data (Peterson et al., 2011). The maximum value of the True Skill Statistics (TSS) or Sum of Sensitivity and Specificity (SSS) (Liu et al., 2013) is also infrequently used, but sometimes, they result in low values, even below the minimum training presence threshold. Based on our sensitivity analysis (Table A and Fig. A supplementary material), the use of the 10th percentile presence threshold value in this study comprises a reduction of the predicted area by 67%, on average, using of the maximum TSS/SSS. This implies a decrease in omissions of 8% on average, thus, the reduction of the predicted area is moderately sensitive to the threshold change, and it is not so for the percentage of omissions.

#### 4.4. Distribution areas

The distribution models represent the functional abiotically suitable

areas based on environmental variables and sites where the species have been reported within the area of study. A limitation of this research is that models do not represent a complete Grinnellian niche because the geographical distribution ranges of the species are not considered (Barve et al., 2011) and, thus, their environmental ranges. The models used in this study are also limited to the spatial availability of the environmental layers in an appropriate local scale. Nonetheless, significant predictions of abiotically ideal areas for fish with these characteristics have been made in the literature (Monk et al., 2010; Pittman and Brown, 2011; Urcádiz-Cázares et al., 2021a, 2021b).

The geographical ranges modeled of the Cortes angelfish and Pacific seahorse have limits recorded from the coasts of California, U.S.A. to the coasts of Perú (Allen and Robertson, 1994; Arellano-Martínez et al., 2007; Lourie et al., 2016). Whereas, the range of the king angelfish comprises the limits of the Mexican Pacific down to Perú (Sánchez-Alcántara et al., 2006), and the endemic Mexican blue-and-yellow damselfish is distributed mainly in the Gulf of California (Martínez-Torres et al., 2014; Urcádiz-Cázares et al., 2021a). Such species are associated with rocky reefs that have coralline patches and are considered non-migratory species found in depths from 0 to 50 m. In the distribution models in this study, the variables that greatly contributed to the prediction were proximity to rocky shore, depth, and distance to mangrove zones, which are consistent with the species habitat.

## 5. Conclusions

This unprecedented study reveals the large percentage of PFS omissions during the development of a number of EIS's and environmental impact assessments in Bahía de La Paz, Mexico. Both consultants, promoters, and environmental authorities could use these methodologies to reduce omissions and improve regulation bonding of the PFS (and other species groups) within and among development projects in marine and coastal zones. The novel proposal of omission analysis can be used to focus studies with diverse protected species both in the aquatic and terrestrial environments with the objective of identifying weaknesses during the EIS and improving decision-making in environmental impact and protection of regulated species.

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## CRedit authorship contribution statement

**Francisco Javier Urcádiz-Cázares:** Conceptualization, Writing – original draft, Methodology, Funding acquisition, Formal analysis. **Víctor Hugo Cruz-Escalona:** Supervision, Project administration, Writing – review & editing, Resources. **Mark S. Peterson:** Writing – review & editing, Validation. **Adrián Felipe González-Acosta:** Writing – review & editing, Validation. **Emigdio Marín-Enríquez:** Software, Formal analysis, Writing – review & editing. **José Manuel Borges-Souza:** Investigation, Validation. **Arturo Del-Pino-Machado:** Software, Resources. **Alfredo Ortega-Rubio:** Supervision, Resources, Writing – review & editing.

## 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.

## Data availability

No data was used for the research described in the article.

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## Appendix A. Supplementary data

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