Species richness model for the Gulf of California, Mexico

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Version 2: September 15, 2015

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## Abstract

          There is a growing interest in identifying biodiversity hotposts for use in spatial planning and conservation planning exercises. As marine systems are threatened by accelerated human activities, biodiverse areas may serve as proxies to maintain ecosystem function and services, while efficiently using limited resources for conservation and resource management. We derived a species richness model by interpolating presence-only data from the Gulf of California, Mexico. We assembled a database with 160683 occurrence records corresponding to 10162 unique species assembled from on-line data repositories and published literature. We then show how assessment of biodiversity hotspots can be used in a marine spatial planning exercise in the Northern Gulf to identify areas where conflicts with other human uses can be ameliorated.

## ##Keywords: species richness; marine spatial planning; biodiversity; Gulf of California

## Introduction

Maintaining ocean health will require considering multiple human uses, their compatibilities and conflicts (Morawetz and Raedig 2007). Marine spatial planning (MSP) is an integrated framework that can be used to organize the spatial distribution of multiple human activities while maintaining delivery of ecosystem services (Douvere 2008). Maintaining biodiversity, species composition, and functional diversity are necessary to preserve ecosystem services (Morawetz and Raedig 2007). Biodiversity can determine multiple ecosystem functions, including productivity (Tilman, Lehman, and Thomson 1997), resilience (PALUMBI, McLEOD, and GRÜNBAUM 2008), and stable food web dynamics (Dulvy, Freckleton, and Polunin 2004). Analyzing the distribution of biodiversity can also aid in systematic conservation planning, where portions of the ocean requiring special management are identified (Ballard et al. 2012) and in the management of marine resources (N. Levin et al. 2014).  
Biodiversity can be measured in multiple ways, as species richness, composition, genetic or functional diversity; each metric provides information about a different attribute of ecosystem function and structure (Morawetz and Raedig 2007); overall, areas with higher diversity support greater ecosystem functions and services (Naeem 2006). In particular, species richness is a useful proxy for ecosystem structure and higher habitat diversity (Hewitt, Thrush, and Dayton 2008; Morawetz and Raedig 2007). Species richness can be used to estimate centers of biodiversity (Raedig et al. 2010).  
Effective management of marine resources requires detailed data on species distributions, however collecting detailed biodiversity data may require intensive and expensive sampling (N. Levin et al. 2014). Spatial biodiversity datasets that integrate and distribute data from multiple sources including natural history collections can now be searched and downloaded (i.e. Table 1), at the same time that computation and analytical tools are being developed that allow its analysis (GRAHAM et al. 2004). Presence-only data has been frequently used to map species biodiversity although it is frequently biased in favor of coastal areas, excludes offshore regions, and may be systematically inaccurate (Raedig et al. 2010).

Here, we apply an interpolation approach based on species occurrence data to identify biodiversity hotspots in the Gulf of California. We then illustrate how this model can be used to inform a marine spatial planning process in the Northern Gulf. The Gulf of California is one of the world's most biologically rich marine regions; it exhibits a high biological diversity, supports high productivity, and harbors large populations of marine taxa (S. E. Lluch-Cota et al. 2007). The Gulf of California contributes about half of Mexico's total fisheries production (Brusca 2010). The Gulf's biodiversity is at risk from anthropogenic impacts, including overfishing which alters trophic structure (Ainsworth et al. 2011), bottom trawling which disturbs benthic ecosystems (Meltzer, Blinick, and Fleishman 2012), and urban development which has altered the coastline (Morzaria-Luna et al. 2013); thus, spatial planning approaches are necessary to maintain ecosystem structure and function (Turk-Boyer et al. 2014). There have been several attempts to assess areas of high biodiversity in the Gulf of California, within the context of identifying important areas for conservation. For example, Ulloa et al. (2006) used 45, 895 taxa records from available databases and expert knowledge for a regional biodiversity assessment using spatial prioritization software. Meanwhile, Sala (2002) used species richness surveyed in rocky reefs across the Gulf to prioritize a network of marine reserves. The model presented here will also support a current effort to develop general MPA placement rules in the Gulf of California, implemented by The Nature Conservancy.

## Methods

Our analysis was based on species occurrence data for marine taxa obtained from on-line repositories (Table 1), which include records from observations and samples. These databases allow queries through an application programming interface (API), permitting the retrieval of large numbers of records over specific geographical areas. We also included sea grass and shark records collected by Ulloa et al. (2006) for a regional assessment; records for target species fishing zones (Cudney-Bueno et al. 2009) and fishing sites (Turk-Boyer et al. 2014); fish and invertebrates monitored in subtidal transects (Mungia et al. In Press); and blue crab (Loaiza-Villanueva et al. 2009), rock scallop, and black murex population assessments (Cudney-Bueno et al. 2009). We eliminated duplicate geographical records for each species, records that were incorrectly georreferenced, and records identified to a taxonomic resolution different from species. Finally, we checked for name validity and updated synonyms.

**Table 1. Data sources**

## <!-- html table generated in R 3.2.1 by xtable 1.7-4 package -->  
## <!-- Thu Jan 21 16:41:31 2016 -->  
## <table border=1>  
## <tr> <th> Name </th> <th> Taxa </th> <th> Link </th> </tr>  
## <tr> <td> Ocean Biogeographic information System (OBIS) </td> <td> Marine species </td> <td> www.iobis.org </td> </tr>  
## <tr> <td> Global Biodiversity Information Facility (GBIF) </td> <td> General </td> <td> www.gbif.org </td> </tr>  
## <tr> <td> HOLOS Ecoinformatics Engine (EcoEngine) </td> <td> General </td> <td> holos.berkeley.edu </td> </tr>  
## <tr> <td> VertNet </td> <td> Vertebrates </td> <td> www.vertnet.org </td> </tr>  
## <tr> <td> Biodiversity Information Serving Our Nation (Bison) </td> <td> General </td> <td> bison.usgs.ornl.gov </td> </tr>  
## <tr> <td> ebird </td> <td> Birds </td> <td> ebird.org </td> </tr>  
## <tr> <td> iDigBio </td> <td> General </td> <td> www.idigbio.org </td> </tr>  
## <tr> <td> FishBase </td> <td> Fish </td> <td> www.fishbase.org </td> </tr>  
## </table>

We used the approach developed by Raedig et al. (2010) to estimate species richness patterns through interpolation. This approach is useful for presence-only data that represents areas that have been visited, species that have been found, and includes species with few occurrences (<5). We briefly describe the algorithm, more details are found in Raedig et al. (2010). The first step was to overlay species richness point data to a 9 km2 grid. We used this scale to match the resolution of previous studies analyzing species distribution areas (Reyes-Bonilla et al. unpublished data) and fishing zones (Moreno-B’aez et al. 2012) in the region.  
The algorithm then performs an interpolation based on a conditional triangulation using the centroids of the grids. Interpolated species ranges were then summed across species to create an estimate of species richness. To reduce the impact of uneven sampling effort, a weighing factor was then incorporated based on the ratio of the number of species recorded in a quadrat and the maximum number of species reported for each center of species richness in the grid map. For each specific quadrat, higher weights indicate that a larger fraction of interpolated species richness is used in the final estimation. The species richness estimate is expressed as normalized index between 0 and 1. The robustness of the interpolation is then estimated by repeating the interpolation in subsamples of species points to cross-validate the interpolated species ranges. The cross-validated richness estimate is divided by the weighted species richness to obtain the mean robustness per quadrat.

Finally, we derived a species richness model for the Punta Borrascoso - Puerto Lobos, Sonora coastal corridor. This area is a well-studied, distinct management unit for fisheries (Turk-Boyer et al. 2014). The corridor serves as a case study on how species richness models may be integrated into marine spatial planning. As an example, we estimated the overlap between the richness index and an index describing the economic value of fisheries in the corridor. Previously, fishing areas in the Northern Gulf were previously assessed through participatory mapping (Moreno-B’aez et al. 2012). Economic fishing importance was then calculated by normalizing the weights assigned during interviews to fishing grounds based on their relative importance of target species by total fishing area. The value was multiplied by 2006-2007 average beach price, and summing across species; the final index is expressed on a 0-1 scale(Moreno-BÃ¡ez 2010). The overlap layer was calculated by subtracting the economic value index from the richness index in each spatial grid cell and normalizing the resulting value. High overlap index values represent high richness/low fisheries value areas and low values are high fishing value/low richness.

The analysis was carried out in the R statistical framework (R Core Team 2015). We used packages rvertnet (Chamberlain, Ray, and Barve 2015), rbison (Chamberlain 2015), rebird (Maia et al. 2015), ridigbio (Michonneau and Collins 2016), and ecoengine (Ram 2015) for data retrieval; dplyr (Wickham and Francois 2015) and sperich (Lange, Lautenbach, and Raedig 2015) for data analysis; taxize (Scott Chamberlain and Eduard Szocs 2013; Chamberlain et al. 2014)to validate species taxonomy; ggmap (Kahle and Wickham 2013), cowplot (Wilke 2015), and ggplot2 (Wickham 2009) for data presentation; and rmarkdown (Allaire et al. 2015) and knitr (Xie 2015; Xie 2013; Xie 2014) for reproducible research. The database of species occurrence and accompanying metadata is deposited at the Knowledge Network for Biocomplexity (KNB) repository (<https://knb.ecoinformatics.org>). The R code used for the analysis is available in GitHub, <https://github.com/hmorzaria/Biodiversity>

## Results and Discussion

The preliminary database had 10162 records corresponding to taxa observed or collected between 1860 and 2014. After eliminating duplicate records and correcting for synonyms and valid scientific names, the final database had 160683 records belonging to 10162 unique species distributed across the Gulf (Figure 1). As a comparison, previously, Brusca (2010) indicated 6000 animal species had been recorded in the Gulf. The database produced here is a comprehensive account of recorded species in the Gulf of California. When species records are converted to a point to grid map (Figure 1), we can observe species richness centers in the Upper Gulf and along the coast. These are areas that are easily accessible and have been the focus of multiple research studies.

**Figure 1**. Species records and point to grid species richness map in the Northern Gulf of California

Figure 2

The final richness map adjusts for sampling effort according to the center of species richness (Figure 2). Our model of species richness showed that the Midriff Islands and the southern Gulf are important biodiversity centers. Although we used a larger number of species records than previous studies, we identified similar biodiversity centers.

**Figure 2**. Indices for interpolated species richness and robustness in the Gulf of California.

Figure 3

We then extracted the species occurrence records found in the Punta Borrascoso - Puerto Lobos coastal corridor (Figure 4).

**Figure 4**. Species records in the Punta Borrascoso - Puerto Lobos coastal corridor

Figure 4

These 17623 records were used to generate a richness model specific to the coastal corridor. We then estimated the overlap between richness and fisheries value in the coastal corridor (Figure 5). Within the context of marine spatial planning, this index highlights areas areas where maintaining biodiversity could result in lower economic impacts.

**Figure 5**. Indices of interpolated species richness, robustness, economic value, and overlap between richness and economic value in the Punta Borrascoso - Puerto Lobos coastal corridor.  
Figure 5

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devtools::session\_info()

## Conclusions

We developed a species ocurrence database drawing on the wealth of data that has been aggregated by researchers in the Gulf of California. The database we developed may also be used to analyze species ocurrence patterns through modeling techniques that describe spatial species-habitat relationships (Ballard et al. 2012).

## Acknowledgements

          This project was part of the marine spatial planning process for the Punta Borrascoso - Puerto Lobos coastal corridor; we thank the technical advisory committee for feedback on an early version of the biodiversity model. The project was funded through a Blue Solutions (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of the Federal Republic of Germany) grant to CEDO Intercultural. Author roles: data analysis, HML MMB, data acquisition HML GCP MMB PTB, writing HML GCP MMB PBT.

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