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Modelling sensitive habitats of the scalloped hammerhead shark (Sphyrna lewini) in the Isla del Coco National park (Costa Rica).

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INTRODUCTION

Climate change, pollution, and overfishing change the structure and functioning of pelagic ecosystems. We used Bayesian hierarchical spatial-temporal models to map the sensitive habitats of the hammerhead shark for observe changes in the distribution and abundance of this species are related with habitat characteristics, fishing intensity or more extreme climatic events and changes in the average sea surface temperature, including the El Niño Southern Oscillation.

MATERIALS AND METHODS

Hammerhead shark data

Visual censuses between 1993 and 2013 at 17 different sites around Isla del Coco, resulting in 28,647 immersions of ~60 min and ranged in depth between 10-40 m

Environmental data

Climatic variables:
Sea Surface Temperature (SST)
Sea surface salinity (SSS)
Chlorophyll-a concentration (Chl-a)

Bathymetric features:
Depth
Distance to coast
Slope

Hierarchical Bayesian spatial-temporal models

Y: number of hammerhead shark in each dive, is Poisson distributed with rate $t_i\,\lambda_{i,}$, t_i is a unit observation time at site *i*, λ_i is proportional to the relative individuals abundance at the site *i* and measures the expectation of sightings for a unit observation time, according to the general formulation:

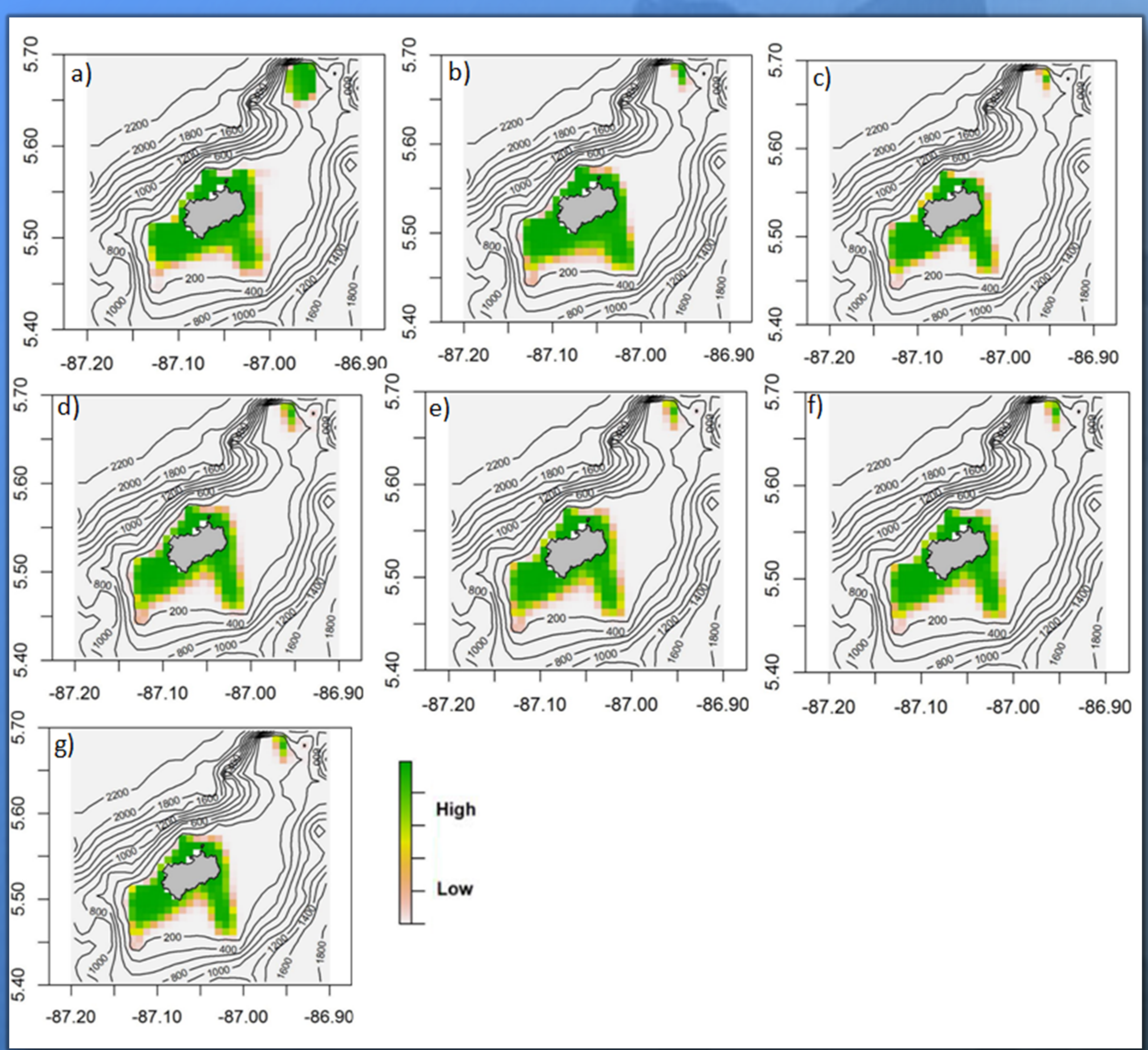
$$log(\lambda_{ijk}) = \alpha + X_{ij}\beta + Y_j + W_i + Z_k$$

- α is the intercept,
- β represents the vector of the regression coefficients
- X_{ij} is the vector of explanatory covariates at year *j* and location *i*
- Y_j is the component of the temporal unstructured random effect at the year t_j
- W_i represents the spatially structured random effect at location *i*
- Z_k is the random effect of the observers.

Model validation

- Variable selection was performed beginning with all possible interaction terms, but only the best combination of variables was chosen.
- Such choice was based on two criteria:
- Deviance Information Criterion (DIC) [1]: measure for goodness-of-fit
- Cross validated logarithmic score (LCPO) measure [2]: measure of the predictive quality of the models

RESULTS AND DISCUSION



Predictive maps of the abundance of the hammerhead shark (*Sphyrna lewini*) aggregated in intervals of 3 years: (a) 1993-1995; (b) 1996-1998; (c) 1999-2001; (d) 2002-2004; (e) 2005-2007; (f) 2008-2010; (g) 2011-2013.

Abundance was mainly explained by bathymetry, Chl-*a*, SST, slope, the interaction between SST and Chl-*a*, and the random spatial and temporal effects, according to the model with the best fit (based on the lower DIC and LCPO).

Predictive maps suggest a decreasing trend in the abundance of hammerhead shark between 1993 and 2013, but such trend showed no correlation with the ENSO events.

Depth: The spatial patterns are consistent with the model predictions, as higher abundances were predicted in shallower waters, closer to the coast where the productivity is higher and where the seabed shows some structuring. Previous studies have observed the hammerhead shark is commonly between 45 and 90m, and close to the island [3], which was confirmed here, as all predictive maps estimated higher abundances in depths between 30-90 m, and lower abundances between 100-200 m.

Chlorophyll and water: temperature is strongly related with ecosystems primary production, by influencing the availability of food [4].

Seabed topography and structure: Isla del Coco sits atop the Coco Volcanic Cordillera, a submarine mountain offshore the southern part of Costa Rica [5], which apparent attracts aggregation of hammerhead sharks [6]. Indeed, seamounts may act as midocean reference points that occasionally harbor increased prey densities that attract this species [7].

The predictive maps also showed that the southeast part of the island holds higher abundance of hammerhead shark. Since slope and bathymetry vary little around Isla del Coco [8] the preference for these areas could be due to a higher average concentration of nutrients. The south side of the island is influenced by the North Equatorial Counter Current and high values have been reported from that area [9], which could generate a higher productivity in the southeast.

CONCLUSION: the decreasing pattern in the abundance of the Hammerhead Shark in Isla del Coco and shifts in its geographical distribution could be due to a combination of SST, nutrients changes and fisheries-induced effects. Further studies are needed to clarify the effects of temperature on changes in the species distribution. However, for the first time and due to the novel methodology used here, there is some insight on the vulnerability of Hammerhead Shark to climatic events and intense fishing pressure that led to changes in its distribution even within a protected area. Such findings only reinforce the knowledge of how much we lag behind regarding the protection of large pelagic species. However, using approaches as the one developed here to predict the spatial distribution of vulnerable species may help design integrated programs for more efficient management of marine resources.

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