

Indian Ocean-scale predictions of seasonal whale shark distribution from opportunistic fisheries-based sightings

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SUMMARY

Despite being the largest marine fish, we still have few data describing the *Vulnerable* whale shark's (*Rhincodon typus*) pelagic distribution. We explore the extent to which ocean-wide and seasonal patterns in whale shark distribution correlate with remotely sensed environmental conditions.

We analysed a 17-year time series of whale shark sightings in the Indian Ocean collected by the tuna purse-seine fishery relative to concurrent data describing chlorophyll *a* concentration and sea surface temperature (SST) extracted from composite satellite images. Different sets of pseudo-absences were generated to account for spatio-temporal variations in sampling effort and probability of detection, and to test for model sensitivity to spatial variation. We applied spatial generalized linear mixed-effect models (GLMM) and Maximum Entropy (MaxEnt) to project whale sharks habitat suitability and its seasonal variation and to produce predicted maps of seasonal distribution probability.

The saturated GLMM including bathymetric slope, depth, distance to shore, mean SST, SST² (quadratic term), SST \square and chlorophyll *a* had the highest relative statistical support, with the highest percent deviance explained occurring when using random pseudo-absences: (57% in autumn, 35% in winter, 35% in spring and 20% in summer). The MaxEnt suggested that whale sharks respond mainly to variation in primary productivity and temperature in all seasons. Distance to shore and bathymetric slope had only minor influence on presence.

Prediction maps showed that within the sampled area, habitat use varies between seasons and follows a clockwise directional shift from autumn through to summer. In terms of habitat suitability, whale sharks move between different aggregation sites in the Indian Ocean.

This supports the hypothesis that whale sharks in this region comprise a single super-population at this scale of the Indian Ocean. By assessing the importance of temperature and productivity cues, we provide a basis for predicting pelagic distribution of the world's largest fish and provide a baseline for temperature-dependent predictions of future distributional changes.

RATIONALE

Most of the data available on whale shark sightings derives from tourism operations occurring near shore. Encounters in Open Ocean are rarely reported because “Investigating the ocean realm is generally difficult, resource-intensive and extensive” (Richardson & Poloczanska, 2008).

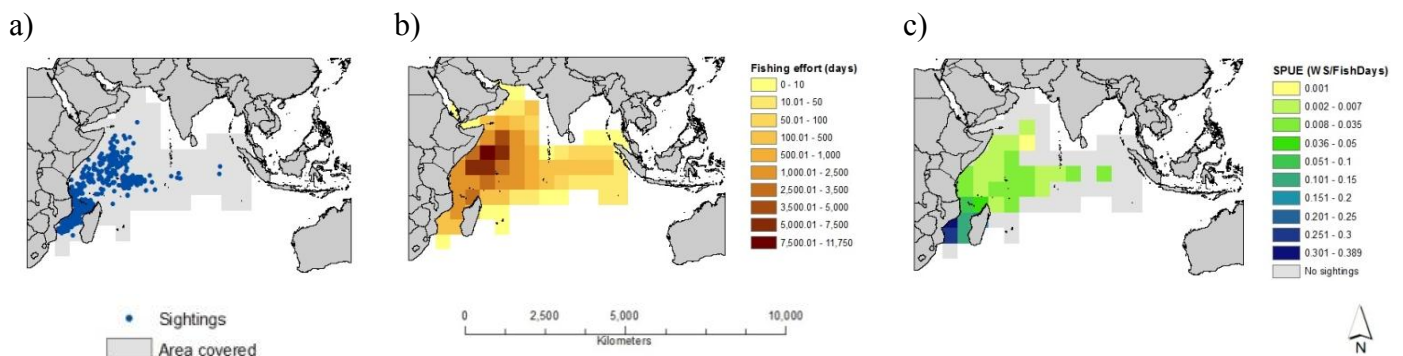
OBJECTIVES:

- Determine Spatio-temporal patterns in the whale sharks distribution over a broad spatial scale
- Identify the main drivers of seasonal changes in whale shark habitat use
- Derive prediction maps of whale shark habitat suitability accounting for seasonal changes in the environmental conditions

METHODS

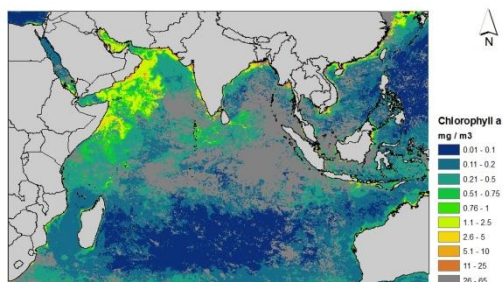
- 1) Use a UNIQUE DATABASE gathered by the Indian Ocean Tuna Purse-seiners (IRD-IOTC) comprising:
 - i. 17 years of data (1991-2007)
 - ii. Ocean wide sampled area
 - iii. 1185 whale shark sighted

Figure 1: a) Area sampled by the IOTC purse seiners and total whale sharks sighted; b) Associated effort in days spent fishing per 5°square; c) Whale sharks Sightings Per Unit Effort – SPUE

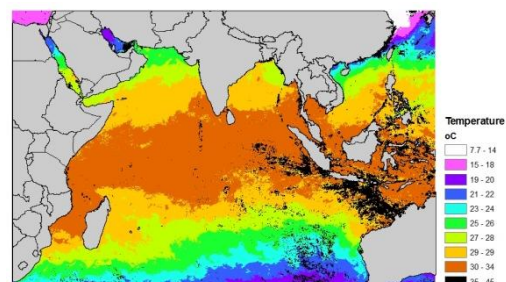


- 2) Use Satellite Imagery for environmental predictors

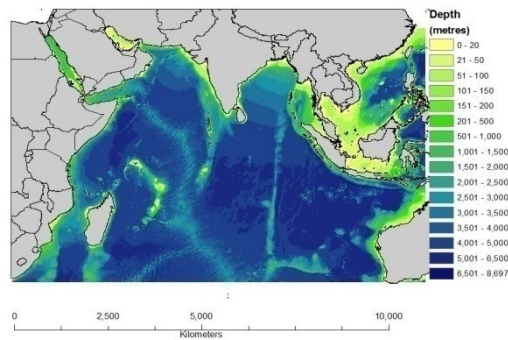
Chlorophyll a concentration derived from the SeaWiFS satellite



Sea Surface Temperature derived from the MODIS-Aqua satellite



Depth profile of the Indian Ocean derived from the GeBCO Bathymetry



- 3) Use Species Distribution Models to predict habitat suitability at the Indian Ocean scale:
 - i. MaxEnt – Presence-only model
 - ii. Generalized Linear Models
 - iii. Generalized Linear Mixed-effect Models – ensemble method

RESULTS

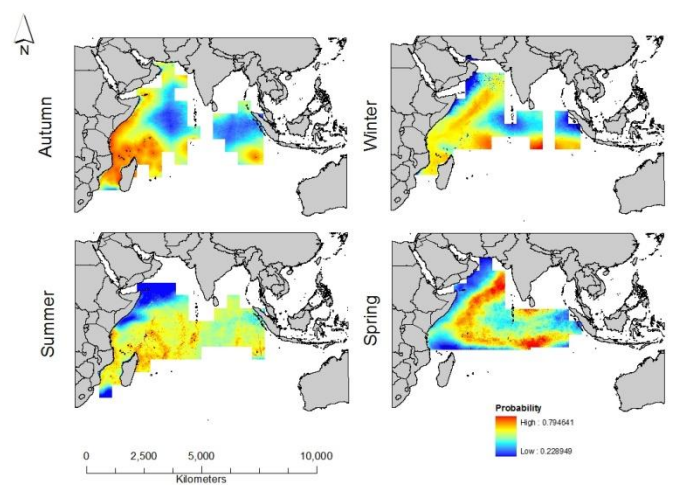
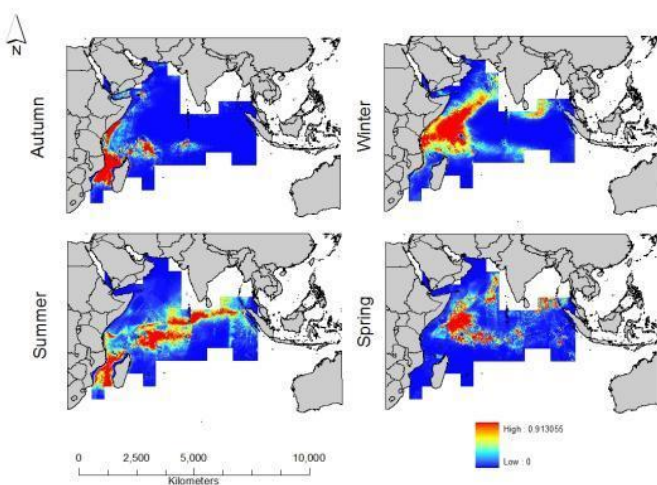
All three modelling approaches (GLM, GLMM and MaxEnt) resulted in similar predictive maps for each season, with major differences occurring for each season (see figure below with main outputs from models).

During autumn, areas predicted to be highly suitable were concentrated near the Mozambique Channel and close to shore in the south-eastern side of the African continent. A shift in habitat suitability was observed in winter towards the north and central Western Indian Ocean, spreading towards the east in a ‘C’ shape during spring and stretching from east to west south of equator in summer.

The environmental variables that seem to contribute the most to these model prediction were Chl *a* and SST (according to Maxent model) and a combination of all variables (according to the GLM/GLMM).

Maxent – Presence-only model

Generalized Linear Mixed Models (Ensemble)



Summer (Jan-Mar), Autumn (Apr- Jun), Winter (Jul- Sep) and Spring (Oct-Dec).

CONCLUSIONS

Results from our models are generally in accordance with published times for whale shark appearance in different aggregation sites within the Indian Ocean.

Despite no tagged or ‘fingerprinted’ (*sensu* (Speed, Meekan et al. 2007)) whale sharks observed traversing the Indian Ocean basin, our results are in accordance with previous suggestions that these animals are highly migratory - both genetic (Castro, Stewart et al. 2007; Schmidt, Schmidt et al. 2009) and satellite tracking data (Wilson, Stewart et al. 2007; Sleeman, Meekan et al. 2010) indicate a capacity for long-distance dispersal in this species.

Our seasonal distribution models were able to predict whale shark habitat suitability in a more extensive area than that covered by the sightings/tags data alone. The tools developed here can therefore be used to assess inter-annual variability in sightings at an ocean scale because global climatic conditions affecting productivity and temperature probably influence this species’ global distribution.

Acknowledgements

We thank the Indian Ocean Tuna Commission and Institut de Recherche pour le Développement (France), and in particular, M. Herrera and R. Pianet for providing data. Thanks to D. Fordham for discussion and advice. Funded by the Portuguese Foundation for Science and Technology (SFRH/BD/47465/2008) / FSE (European Social Funds), The University of Adelaide, Australian Institute of Marine Science, Flying Sharks and APECE (Portuguese Association for the Study and Conservation of Elasmobranchs).