

## Predicting *Tachypleus gigas* Spawning Distribution with Climate Change in Northeast Coast of India

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### ABSTRACT

Species distribution models are used to predict ideal grounds, species range, and spatial shifts in an ecology over a span of time. With an aim to use Maximum entropy model (MaxEnt), presence records and pseudo-absence points are used to predict the *Tachypleus gigas* spawning activity for 2030 and 2050 in northeast India. The bearings of sixty *T. gigas* spawning grounds identified in 2018 were inserted into ArcGIS v.10.1. Meanwhile, 19 environment variables were inserted into MaxEnt v. 3.3.3, before the model performance was tested using receiver operational characteristics and area under curve (AUC). With an AUC of 0.978, 85% was achieved for isothermality (bio3) and 74% for temperature ( $\bar{x}$ = average) of the wettest quarter (bio8), all of which were inserted into ArcGIS to produce spatial maps. Although we learnt that *T. gigas* are still spawning in Odisha in 2030 and 2050, their distribution range is predicted to shrink due to the coastal morphology change. The climate conditions in Odisha revolve with the monsoon, summer and winter seasons from which, temperature variations do not only influence the annual absence/presence of spawning adults but also, the survival of juveniles in natal beaches. The use of MaxEnt offers novelty to predict population sustainability of arthropods characterized by oviparous spawning (horseshoe crabs, turtles, terrapins and crocodiles) through which, the government of India can take advantage of the present data to initiate the coastal rehabilitation measures to preserve their spawning grounds.

**Keywords:** ecology; sustainability; season; arthropod; environment; temperature

## INTRODUCTION

Land use, human presence as well as climate conditions, altogether influence the spatial distribution and population size of wildlife (Hoffmann et al., 2010). In particular, the land use from anthropic activities results in wildlife range reductions and when coupled with climate events, it can cause harmful delimiting of sensitive species (Haddad et al., 2015; Seganet al., 2016). At present, global climate emergency is responding to a permanent 2°C temperature increase that forced sensitive species into the sixth extinction (Keith et al., 2014). Yet, not all species have their wild statuses updated (IUCN Red list) nor are they safeguarded by the local legislations. Therefore, there is a need to map and predict the distribution patterns of these (conservation needed) wildlife to know about their population sustainability, whether they require legal protection as well as whether their inhabited areas are in need of intervention.

The present concern involves the horseshoe crabs of India which are ‘living fossils’ that last evolved 450 million years ago (John et al., 2018). In general, Asian horseshoe crabs emerge twice a month into shallow water areas having mixture of sand and mud as substrate for their spawning activity that coincides to lunar ebb tides (Alam et al., 2015; Pati et al., 2015; Nelson et al., 2016a; Nelson et al., 2016b; Biswal et al., 2016; Pati et al., 2018; John et al., 2018). Since the life cycle of horseshoe crabs completes in estuaries and intertidal zones, their home range is restricted to the natal beach vicinity where mature crabs will reproduce to sustain their population. Unfortunately, coastal infringement by anthropic activities in India is altering the nursery ground conditions where horseshoe crabs are changing their egg burying depths according to surface sediment compaction (Zauki et al., 2019; Nelson, et al., 2019). This practice indicates that sediments of horseshoe crab natal beaches are changing texture where some of the natural shore adjustments (erosion/accretion) make these areas no longer feasible for the horseshoe crab spawning activity (Nelson et al., 2015; John et al., 2017; Pati et al., 2020b). In the presence of climate emergency, incubated horseshoe crab eggs are exposed to extreme temperatures which firstly, increase the thermal shock thresholds, reduce the hatching success and then, make the nursery grounds unsuitable for hatchlings to develop (Nelson et al., 2015).

Since the horseshoe crab spawning grounds are presently becoming unfavorable, we anticipate a reduction in their population size, which also coincides with reducing spatial range over a period of time. While species distribution relates with bioclimatic tolerance, we are able to delineate future explanatory using statistical models (Zhang et al., 2019; Vargas-Piedra et al., 2020 according to the Global Biodiversity Information Facility (GBIF)). Thus, with an objective to predict the horseshoe crab spawning activity in the future, we employed a species distribution model called maximum entropy that uses nineteen bioclimatic inputs of 2018 to produce the arthropod distribution maps of 2030 and 2050. Although several attempts like phylogenetic, spatial mapping and *in situ* investigations were attempted to ascertain the horseshoe crab population size and their distribution (John et al., 2017), the data coverage is less convincing to update the *T. gigas* and *C. rotundicauda* wild statuses in IUCN Red List (Basudev et al., 2013; Pati & Dash, 2016; John et al., 2018). With novelty on species distribution, we are certain the bioclimatic output of 2030 and 2050 is convincing for targeted-strategies on horseshoe crab conservation in India and also solid evidence to support the updating of *T. gigas* and *C. rotundicauda* population statuses (IUCN Red List) in the wild.

## MATERIALS AND METHODS

### Data collection from the study sites

A total of sixty *T. gigas* spawning sites were identified (from field sampling and secondary data) between Balasore and Ganjam (Srikulam Border) along the Odisha coast in 2018 by considering the crab’s primary presence for its availability in these areas. A quadrat (10×10 m) was used to attain bearings (Garmin Fenix 5, USA) of all horseshoe crab spawning grounds which was then prepared in the CSV format using Microsoft Excel 2010. Meanwhile, a total of nineteen climatic inputs (listed in Table 1) are sourced from <http://www.worldclim.org> and integrated in Maximum Entropy v.3.3.3 (100 km<sup>2</sup> sensitivity) by adopting standard protocols (Phillips et al., 2006). A 2018 base map (25 m<sup>2</sup> map resolution) for Odisha was constructed in ArcGIS v. 10.1 (USA).

**Table 1.** Relative contributions and permutation from the maximum entropy model to predict the most influencing environmental variables to the horseshoe crab spawning grounds

Code	Environmental variables	Unit	Contribution	Permutation ( $nPr = \frac{n!}{n-r!}$ )
Bio-1	Annual mean temperature	°C	0.22	0.78
Bio-2	Mean diurnal temperature range	°C	0.23	0.77
Bio-3	Isothermality	-	0.84	0.16
Bio-4	Temperature seasonality	C of V	0.16	0.84
Bio-5	Max temperature of warmest month	°C	0.46	0.54
Bio-6	Min temperature of coldest month	°C	0.43	0.57
Bio-7	Temperature annual range	°C	0.65	0.35
Bio-8	Mean temperature of wettest quarter	°C	0.74	0.26
Bio-9	Mean temperature of driest quarter	°C	0.22	0.78
Bio-10	Mean temperature of warmest quarter	°C	0.48	0.52
Bio-11	Mean temperature of coldest quarter	°C	0.34	0.66
Bio-12	Annual precipitation	mm	0.29	0.71
Bio-13	Precipitation of wettest month	mm	0.42	0.58
Bio-14	Precipitation of driest month	mm	0.21	0.79
Bio-15	Precipitation seasonality (coefficient of variation)	-	0.35	0.65
Bio-16	Precipitation of wettest quarter	mm	0.19	0.81
Bio-17	Temperature annual range	mm	0.52	0.48
Bio-18	Precipitation of warmest quarter	mm	0.43	0.57
Bio-19	Precipitation of coldest quarter	mm	0.30	0.7

## Model performance

Following the framework, the default value in maximum entropy was set to iteration of 500 and convergence range = 0.00001 (Fig. 1). The model was calibrated (location and environmental data) using jackknife resampling that uses an increasing series of sites from 15 (25%), 30 (50%), 45 (75%) to 60 (100%) as standard protocol (Phillips et al., 2009). The performance of the model uses receiver operational characteristics (ratio between random and categorized variables) and area under curve in the range of 0 to 1, where 0 implies poor performance and 1 indicates perfect performance (Fielding & Bell, 1997). The sensitivity of the model was adjusted to low false-positive (c.a. receiver operational characteristics) so that area under the curve has narrow range (0.9–1.0). Only then, the output files (probability) were exported into ArcGIS v10.1 for the horseshoe crab distribution in 2018, 2030 and 2050.

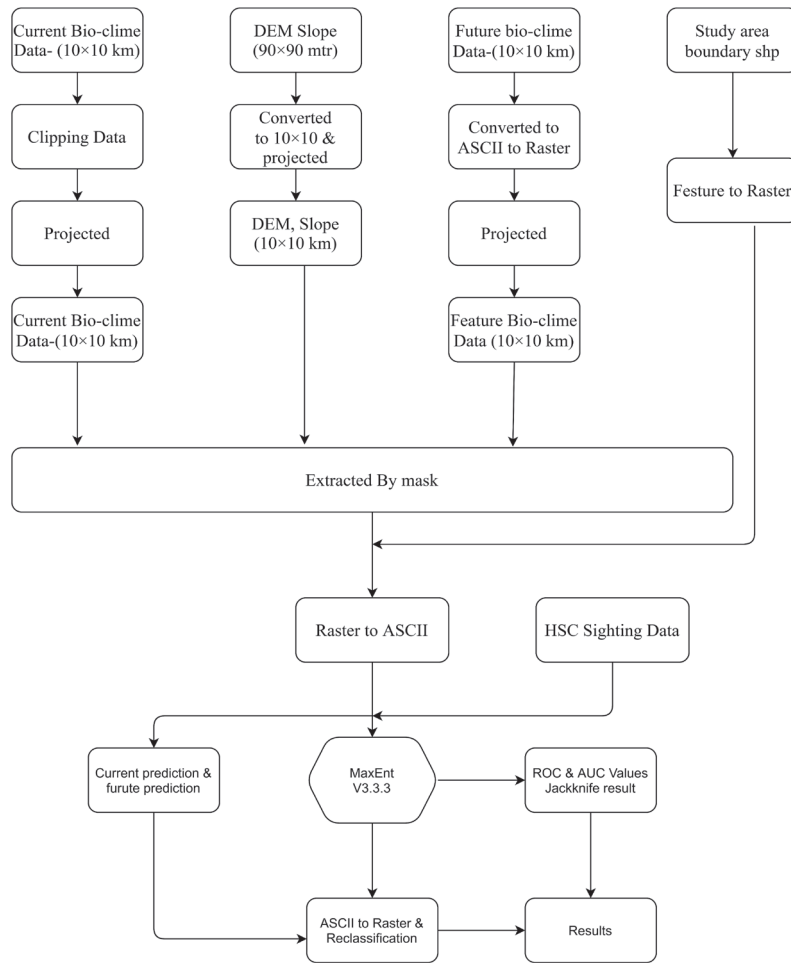
## RESULTS

With low false-positive for receiver operational characteristics, the area under the curve was 0.978. This indicates that spatial mapping and environmental data are not biased and takes

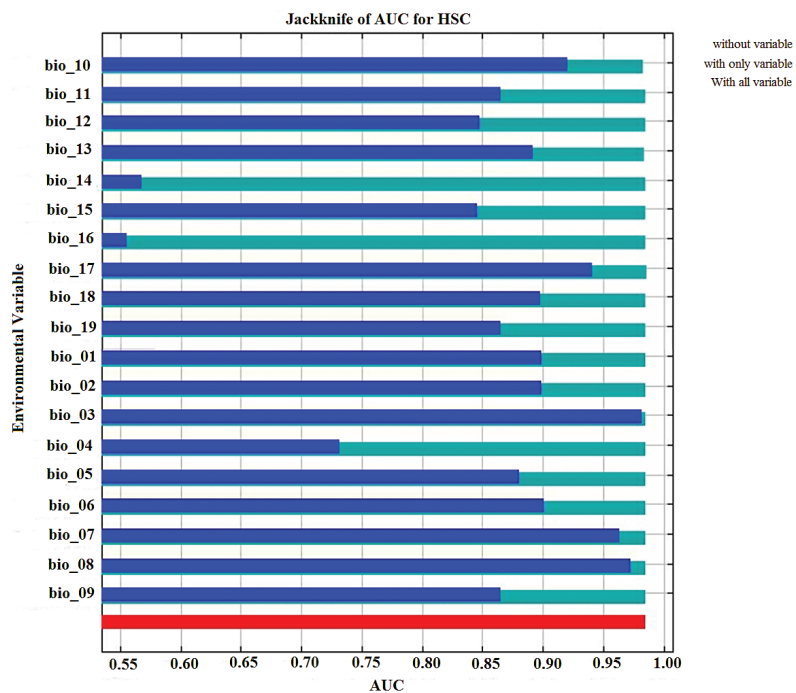
into account random chances as probability *vis-à-vis* prediction by the model. In fact, the calibration that used jackknife resampling indicated that temperature (bio7) and precipitation of driest quarter (bio17) are producing the highest (0.983) area under the curve value (Figs. 2–3). Moreover, isothermality (bio3; 84%) and temperature ( $\bar{x}$  = average) of the wettest quarter (bio8; 74%) are key variables that influence the model's sensitivity (Table 1; Fig. 3). The spatial-temporal maps produced by ArcGis are labeled with the values of 0-1 to indicate 'high' (0.85–0.92), 'medium' (0.77–0.85), and 'low' (0.45–0.62) occurrences for *T. gigas* spawning in northeast India in 2018, 2030, and 2050 (Fig. 4).

## DISCUSSIONS

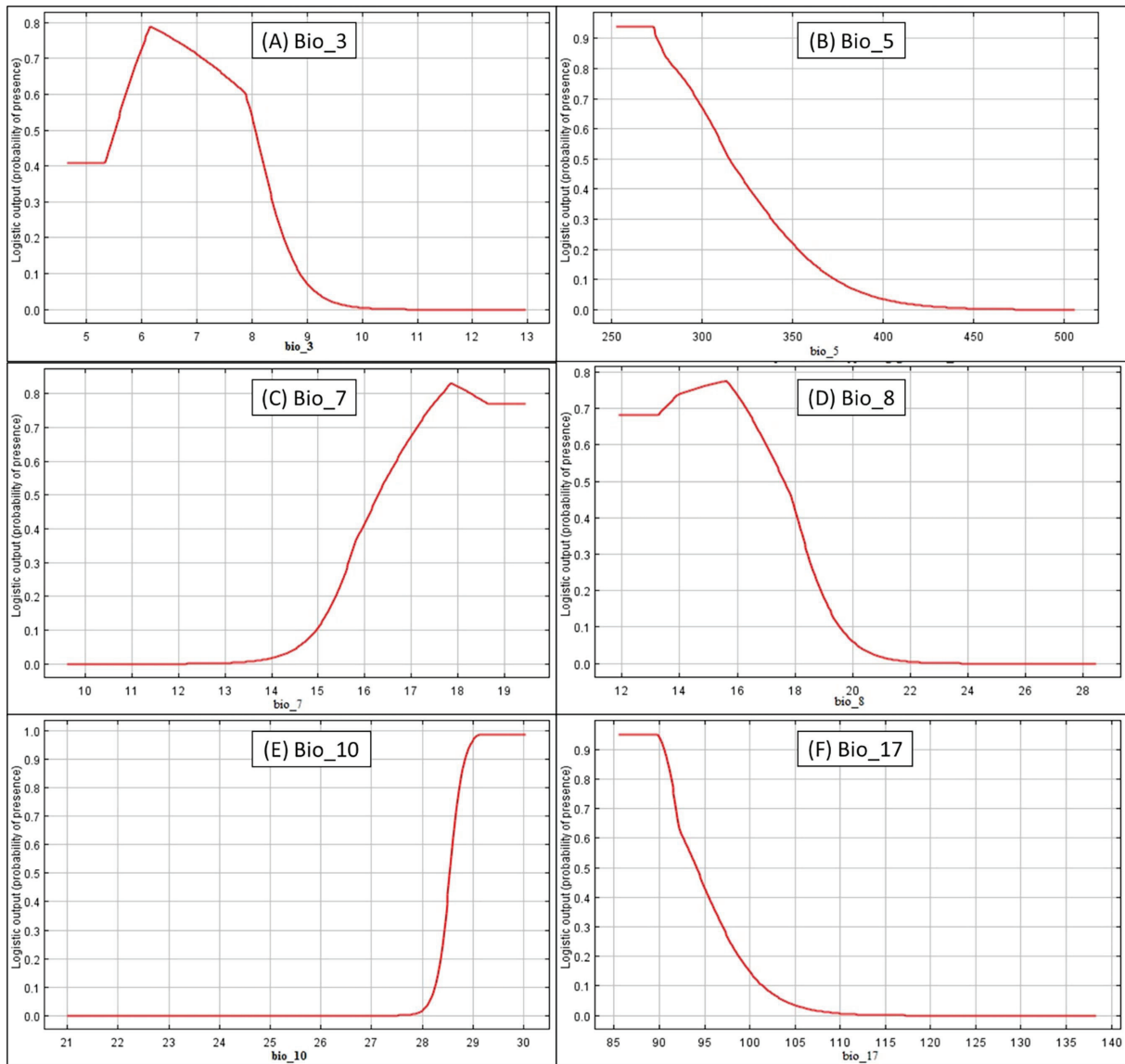
The distribution *vis-à-vis* spawning ground of *T. gigas* occurs within a 0.2–1.2 km<sup>2</sup> area in the sites situated between Balasore and Ganjam (northeast India; Fig. 4). The model indicates a reducing spatial scale trend (probability) when moving from 2018 to 2030 and then 2050 for *T. gigas* spawning grounds. It shows 0.85–0.92 for the northern districts (Balasore and Bhadrak), which reduces to 0.77–0.85 (Kendrapara and Jagatsinghpur) and reaches 0.45–0.62 (Puri and Ganjam) for the south districts. Similarly to the



**Figure 1.** The framework for maximum entropy model calibration, performance and validation in the presence of environment and the horseshoe crab spawning site data



**Figure 2.** Values for area under the curve (AUC) in the presence of jackknife resampling to calibrate the maximum entropy model. The abbreviations denote: HSC = *T. gigas* spawning grounds; bio = environment data from Table 1

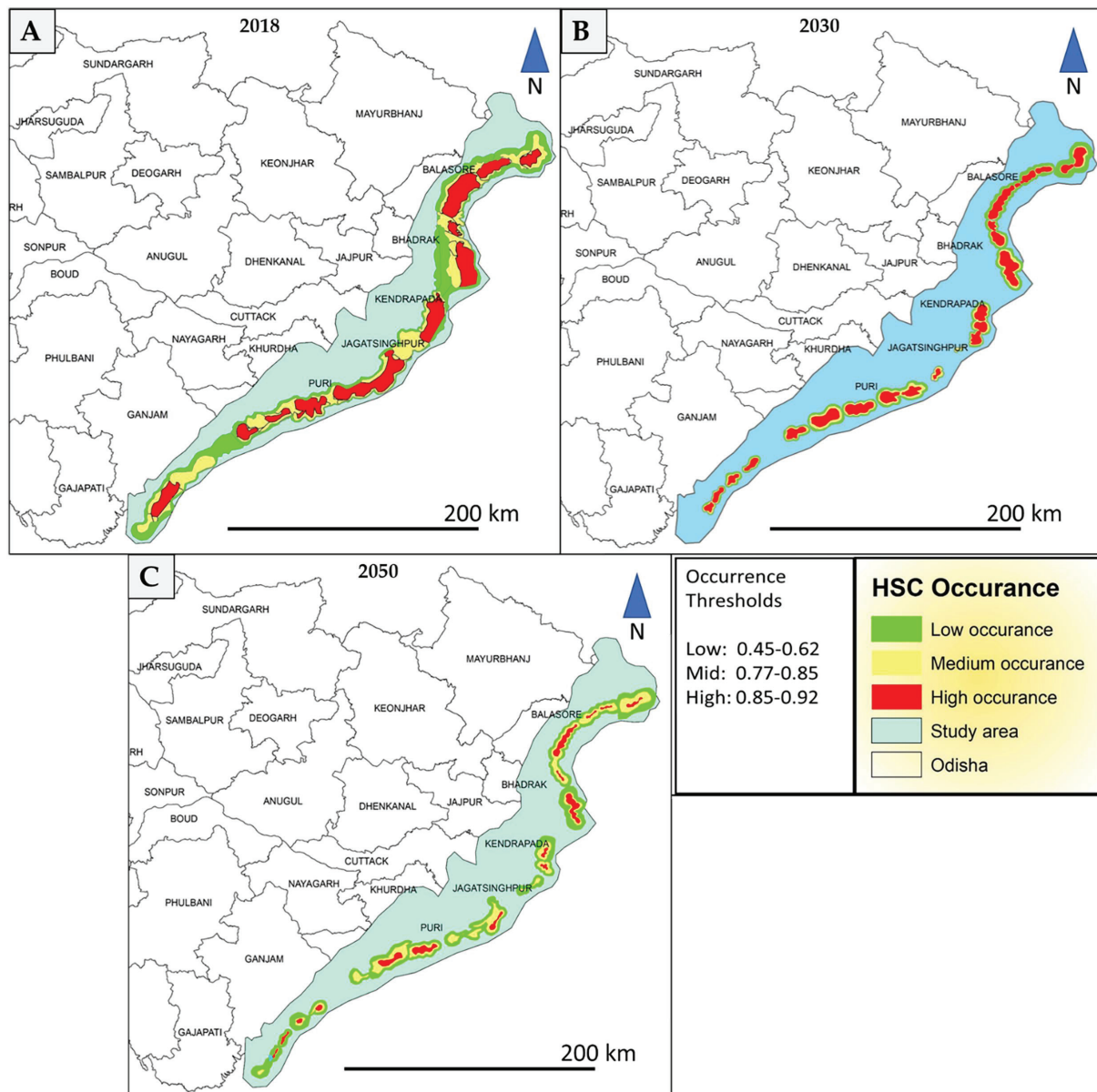


**Figure 3.** Probability from the maximum entropy model for the most influential factors towards the horseshoe crab spawning grounds in Odisha, northeast India

present findings, maximum entropy is sensitive to predict a species range in their habitat or the habitat that could be available (distribution in fragmented forests) for the species in the future (Hamilton et al., 2015). Moreover, values (probability) from maximum entropy model were predicting impacts by ticks from land use (development) using present tick distribution and environment data (Braunisch et al., 2008). Therefore, we consider the maximum entropy predictions to have close (or actual) similarities with the situations in 2030 and 2050 in northeast India because firstly, coastal exploitation (land use and fisheries) is a current (and unresolved) issue and secondly, the inclusion of horseshoe crabs into Wildlife (Protection) Act 1972 (Schedule IV) excluded them from capture fisheries (bycatch) in India. Thus,

fishermen (numbers expected to increase with the expansion of the human population by 2030 and 2050) do not sell the horseshoe crabs for consumption and would instead, discard the crabs or nets containing entangled crabs (entirely) on the beach where the crabs suffocate and die from becoming stranded.

Although the horseshoe crab research in India has received funding for product development and conservation (Alam et al., 2015; Chinnary et al., 2015; Pati et al., 2020a; Pati et al., 2020b; Pati et al., 2020c; Pati et al., 2015), it is difficult to follow-up with the communities because of inaccessibility, poor network connectivity and travel (districts are large in India) to secluded areas. The use of maximum entropy offers spatial coverage and is easily applied to predict the



**Figure 4.** Predicted horseshoe crab spawning ground coverage in the coastal areas of Odisha, northeast India. The markings are as follows: A = presently at 2018; B = predicted situation in 2030 and C = predicted fragments of the remaining *T. gigas* spawning grounds in 2050

future conditions at the area of study (Remya, et al., 2015; Raghavan et al., 2020). In fact, the novelty of this study involves using maximum entropy to predict the horseshoe crab spawning grounds over a large area (c.a. Odisha coastline of >450 km). At present, we have horseshoe crab awareness projects on sea ranching practices for larvae recruitment but, our challenge is sand mining and coastal reclamation (groyne, rip-rap and wave breaker) which not only alter the coastal morphology (indicated in 2030 and 2050 spatial maps) but also the sediment compaction. Sedimentation has changed the shore texture of the horseshoe crab spawning grounds

in Malaysia where conditions (2009–2017) have become less favorable for the spawning activity of *T. gigas* and *C. rotundicauda* (Nelson et al., 2015; Nelson et al., 2016a; Fairuz-Fozi et al., 2018; John et al., 2018; Nelson et al., 2019; Zaku et al., 2019). We expect a similar observation in Odisha where such structures (groyne, rip-rap and wave breaker) are implemented to reduce the shore erosion. In fact, these structures will sink (water depth increases) the horseshoe crab spawning grounds and become perturbed by stronger currents that can convert natal beaches to become unfavorable for the horseshoe crab spawning activity.

The combination of findings in the present study and afore mentioned literature on the *T. gigas* spawning grounds are current situations (2018) while the maximum entropy predicts that spawning grounds will become fragments or spatially scarce in 2030 and 2050. Degradation through sedimentation (Nelson et al., 2015; Nelson et al., 2016b) is unavoidable because communities reside and use coastal areas for their routine activities and livelihood. The government of India regulates a ‘no fishing season’ of 61 days (April-June) during the summer months under Fisheries Act 1897 to allow natural restocking, but this implementation challenges the livelihood of some local communities (Mishra, 2013; Ngasotter et al., 2020). Therefore, the only effective measure to conserve the horseshoe crab populations is bycatch assessments, sea ranching and diverting development projects away from the coastal areas that have mangrove vegetation. These suggestions will not only monitor trends in the horseshoe crab population sizes but also preserve existing (known) horseshoe crab spawning grounds so that repetitive work (through continuous monitoring) can be avoided and instead, the resources are used to identify other spawning grounds in the area.

## CONCLUSIONS

Species mapping over a spatial range overcomes the need for continuous monitoring using biostatistics. With maximum entropy, calibration using jackknife, sensitivity using receiver operation characteristics and validation using area under the curve, the probability produced from climatic variables of 2018 predicts the spawning activity of *T. gigas* across space and time (2030 and 2050). With findings indicating maximum *T. gigas* spawning activity in northern districts and the reducing the number of events when moving south, we have pieced together the changing shore morphology, impacts by climate and the persistence of horseshoe crabs in their natal areas in Odisha (northeast India). The Indian government has implemented safeguarding measures like seasonal fishing ban and the inclusion of horseshoe crabs into the Wildlife (Protection) Act 1972 which have now made them a bycatch. Overall, to reduce the climate impacts on the horseshoe crab spawning activity, it would be best to shift coastal development away from mangrove forests and known horseshoe crab spawning grounds. This should follow

with bycatch assessments to monitor the removal of crabs from the wild and also spread awareness using sea ranching where larvae recruitment would increase the chances of horseshoe crab development into sexually mature adults for their population to sustain throughout the Odisha coastline.

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