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Spatial distribution of *Nematalosa nasus* (Bloch, 1795) of the Northern Indian Ocean in a changing climate

S. Swathy[1, 2], M. Anakha[1], K. R. Sreenath[2]*, K. K. Joshi[2], M. Koya[2] and P. O. Nameer[1]
[1]Academy of Climate Change Education and Research, Kerala Agricultural University, Kerala, India.
[2]ICAR- Central Marine Fisheries Research Institute, Kochi-682 018, Kerala, India.

*Correspondence e-mail: sreenath.ramanathan@icar.gov.in

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Original Article

Abstract

Globally, ocean climate is changing at unprecedented rates. Shifts of species distribution towards the northern latitudes are evident in many seas. The Northern Indian Ocean is warming at an alarming rate as compared to the other oceans. The increased rate of warming will cause substantial responses in the distribution of the pelagic fish species. Many fishes of the family Clupeidae form the mainstay of the marine fisheries of the countries bordering the Northern Indian Ocean. *Nematalosa nasus* is one of the important pelagic fish found in the region. This study tries to understand the distributional shifts of this species from the region in two future climate scenarios (RCP 6.0 & 8.5). The results indicate a higher influence of the current vector and mean temperature on the distribution of this species. A northward shift in the distribution range is observed in both the future scenarios as compared to the predicted current distribution.

***Keywords**: Species distribution model, maxent, climate change, RCP*

Introduction

Climate change is undoubtedly an alarming crisis that our planet is facing. The global ocean temperature will keep rising throughout the 21st century due to the climate change and the greatest warming is expected for the surface waters of the tropics and subtropical regions of the Northern hemisphere (IPCC, 2014). Ocean temperature trend is not uniform throughout the globe, but it shows a positive anomaly in almost all regions where the northern hemisphere holds the highest anomaly (Bahri *et al*., 2019). Climate change negatively influences the marine ecosystems by rising temperature, reducing productivity, distorting food webs, reducing oxygen, ocean acidification and shifts in species distribution (Hoegh-Guldberg and Bruno, 2010). Cheung *et al.* (2010) observe that the fish catch has increased tremendously in high latitudes by 30 to 70% whereas the tropics witnessed a decline in catch by 40%. Distributional shifts towards higher latitudes are commonly recorded in marine organisms, as the physiology, reproduction, and dispersal of marine species are strongly susceptible to temperature and ocean current patterns (Poloczanska *et al*., 2013).

Clupeidae is the most valuable family of food fishes in the world (Royce, 1996; Bani *et al*., 2019). Clupeids contribute significantly to the world's protein resources and benefit countries that import fish for animal feed and also to the economies of maritime nations (Blaxter and Hunter, 1982). Clupeidae contains 58 genera and 239 species of fish that are mainly marine and tropical (Frick *et al.*, 2020). In upwelling regions around the world, a few species of clupeids form a major single or dual-species fishery (Whitehead, 1985). *Nematalosa nasus*, commonly known as the Bloch's gizzard shad, is an anadromous clupeid fish that occupies marine, pelagic to neritic environments (Riede, 2004). This fish is mainly distributed in the Indo–Pacific, the western (Taher, 2010) and eastern (Mohsin and Ambak, 1996) Indian ocean and western central to north-west Pacific Ocean (Whitehead, 1985) and it formed one of the important commercially exploited fishes in India (Talwar and Kacker, 1984; Mukherjee *et al.*, 2016). *N. nasus* population across the southeast Arabian Sea is reported to have protracted spawning period with the post-monsoon season as the peak spawning month (Ramya *et al.*, 2016)

Several reports show evidence of northward shifts among different species among clupeids (Vivekanandan *et al.*, 2009; Supraba *et al.*, 2016). Predictions on such changes in distributions can help us to take proper management actions (Molinos *et al.*, 2016). The Northern Indian Ocean (NIO) is considered to be one of the regions which is facing an accelerated rate of increase in sea surface temperature (Roxy and Gnanaseelan, 2020). Species distribution modelling is a potential tool for estimating the impact of climate change on geographical distribution (Beaumont *et al.*, 2008). Being pelagic, *N. nasus* is also expected to undergo distributional changes due to climate change though small pelagics especially clupeids are known to be more resilient than other marine fishes (Hutchings, 2000). Species distribution modelling of this group under different climate change scenarios can throw light to the future ranges of fish distribution and can help fishery managers immensely to make informed decisions to keep the fisheries sustainable. This study aims to assess the changes in the spatial distribution of this species in the NIO in future climate scenarios using a species distribution model.

Material and methods

Study Area

The geographical extent of the study area is limited to the NIO (0 to 32 N, 31 to 100 E). It is the warmest region among the tropical oceans (Roxy *et al.*, 2016) and its landlocked nature (Wafar *et al.*, 2011) makes it peculiar to study distribution of inhabitant fishes.

Data

The occurrence data of *N. nasus* were collected and compiled from the open-access database – Global Biodiversity Information Facility (GBIF). The current environmental variables and those for Representative Concentration Pathways (RCP) 6.0 and 8.5 selected were (Sea Surface Temperature (SST) mean, SST maximum, SSS mean and Ocean Current. The SST mean and maximum data of 4x4 km resolution were taken from the ocean color database of NASA (Feldman and McClain, 2010). Sea Surface Salinity (SSS) data with 1/4 x 1/4-degree resolution of Simple Ocean Data Assimilation ocean/sea reanalysis (SODA) (Carton *et al.,* 2018) and ocean current velocity from HYCOM Global with 1/12-degree spatial resolution (Bleck, 2002) were utilised. The projection of each layer is made up of GCS WGS 1984 coordinate system using ArcGIS software and clipped to the extent identical to the study area. This is then interpolated with Inverse Distance Weighting (IDW) using a mask polygon. The rasters were resampled to uniform resolution (9 x 9 km). All the files were converted to ASCII in ArcMap.

Species distribution modelling

The species distribution is done using the maximum entropy model (Maxent). Maxent is a machine learning approach that uses the present location of species as input, known as presence only data (Merow *et al.*, 2013). Maxent is one of the most widely used techniques for asserting environmental tolerance and species distribution from occurrence data (Warren and Seifert, 2011). Maxent also draws pseudo-absence points to the environmental variables to overcome the lack of absence points (Gomes *et al.*, 2018). In this study, we created the bias file using R software to limit the area for background selection and thereby reducing the sampling bias. The model evaluation is carried out using the ENMeval package in R and finalised the model settings with appropriate regularization multiplier and feature class combinations. The area under the receiver operating characteristic (ROC) curve or Area under the curve (AUC) provides a single measure of model performance. The maximum achievable AUC is 1 and the higher value of AUC indicates that the model can accurately differentiate between presence and potentially modeled location (Merow *et al.*, 2013). Species distribution is estimated with probability varying from 0 to 1 where zero represents the lowest and one is the highest probability of occurrence (Bagheri *et al.*, 2017).

Results

Model Evaluation

The area under the curve value for the model is 0.810 with standard deviation of 0.060 (Fig. 1). The model prediction for the current distribution shows current velocity as the greatest percentage contributor with value 73.5 and permutation importance 50.3. Mean temperature, maximum temperature and salinity contributes 13.3%, 8.2% and 3% respectively

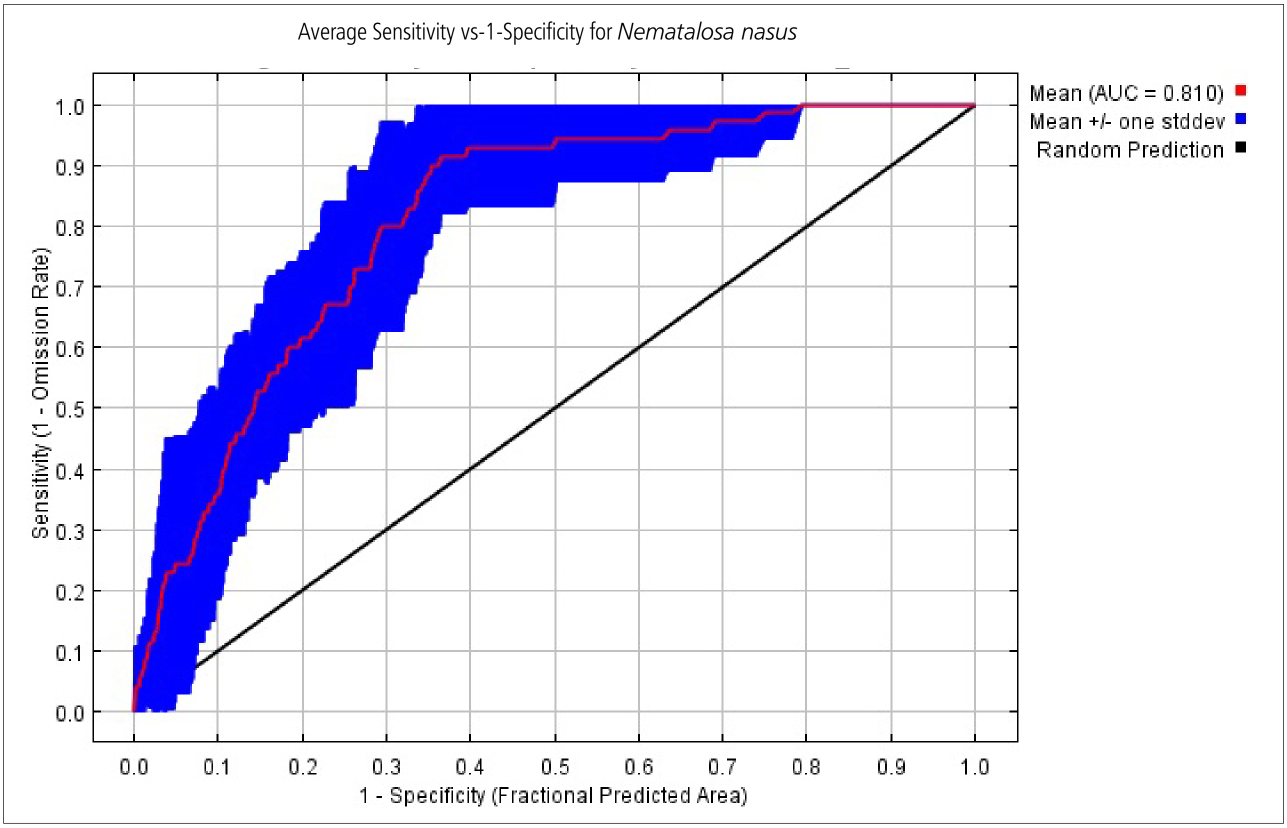


Fig. 1. The average sensitivity vs. 1- specificity graph for *N. nasus* showing the mean AUC and standard deviation for the predicted current distribution

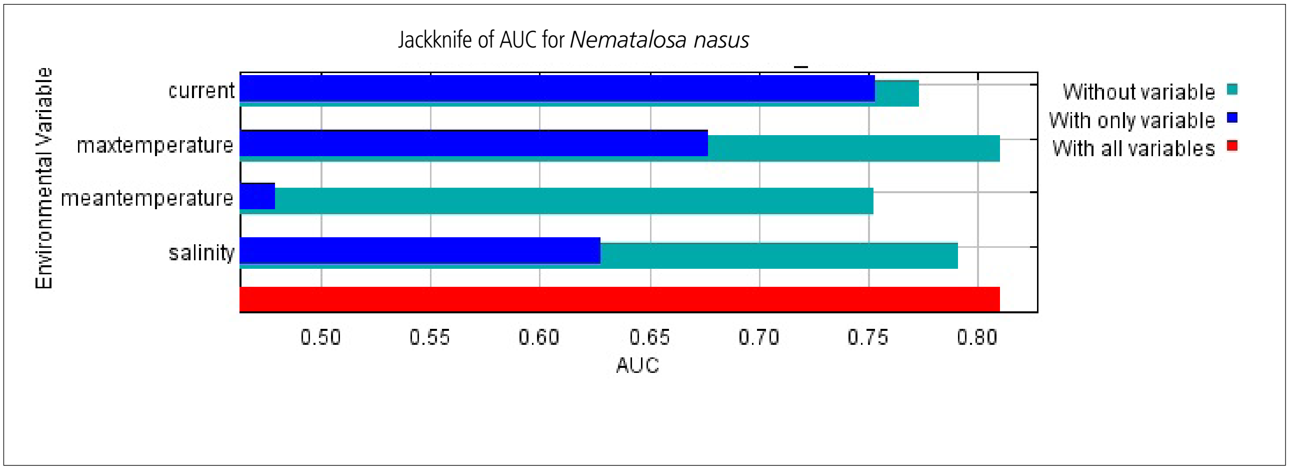


Fig. 2. Jackknife test showing the AUC values when a variable is used in isolation or the variable is excluded from the model

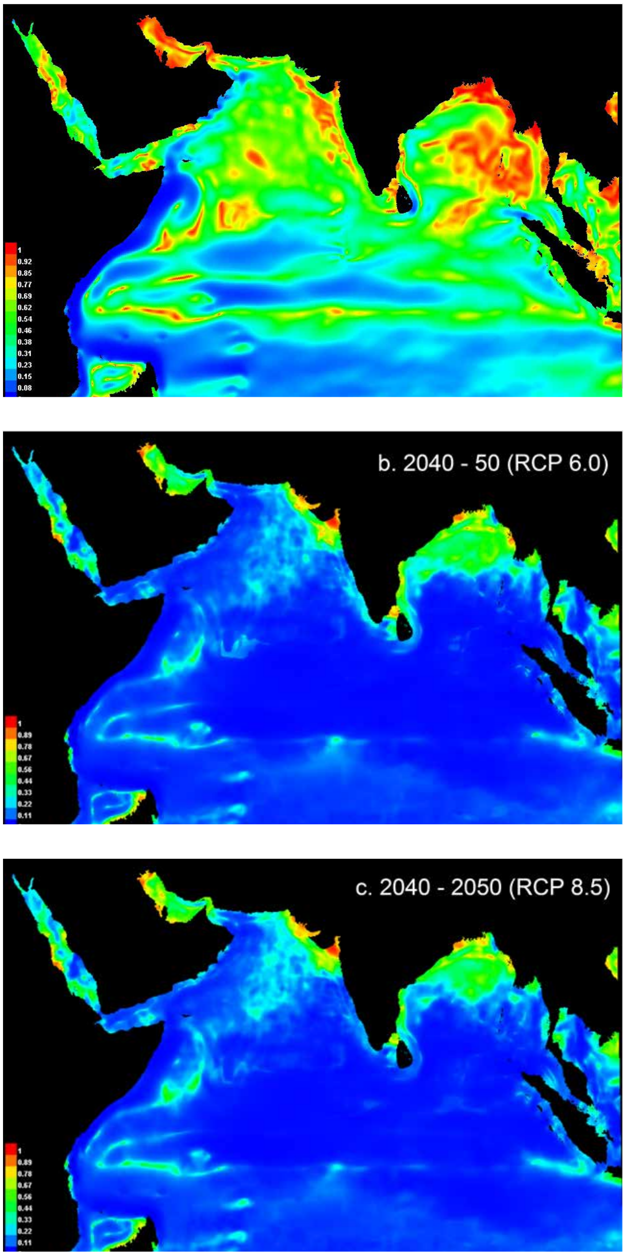
(Table 1). Jackknife test reveals that current velocity has the highest gain among all parameters when used in isolation (Fig. 2).

Predicted distribution

The predicted current distribution is mainly concentrated in the western coast of India, northern Bay of Bengal, Andaman

Table 1. Table showing the percentage contribution and permutation importance of each environmental variable for the predicted current distribution

Variable	Percent contribution	Permutation importance
Current	73.5	50.3
Mean Temperature	13.3	25.8
Max Temperature	8.2	14.8
Salinity	5	9.1



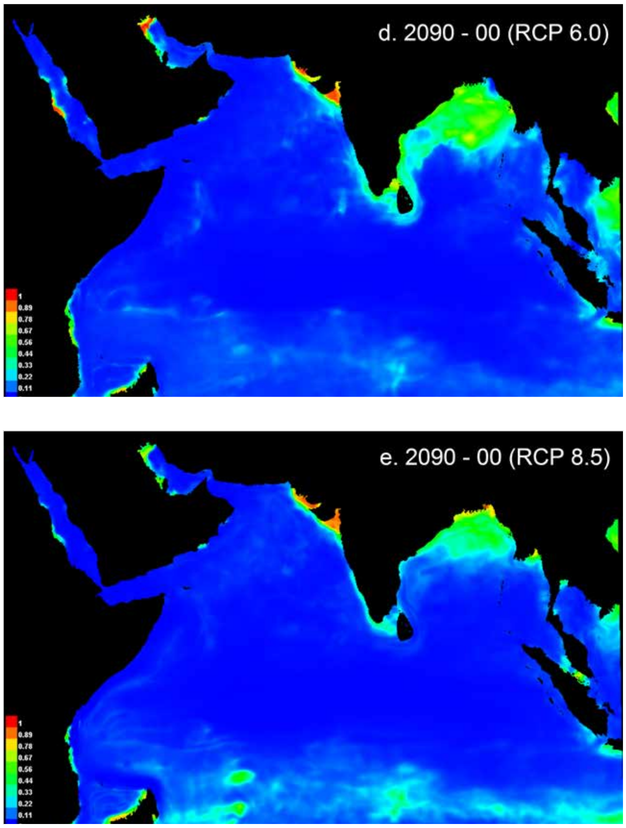


Fig. 3. Map showing the predicted current and future distributions of *N. nasus*

Sea, Persian Gulf, Red sea *etc.* with >85% probability (Fig. 3). The predicted distribution for 2040-2050 considerably decreases as that of the current distribution and the probability of distribution decreases from RCP 6.0 to RCP 8.5 with probability 50% to 75% (Fig. 3). The extent also shows a gradual decrease. The AUC values for RCP 6.0 and 8.5 are 0.759 (SD 0.044) and 0.770 (SD 0.063) respectively (Fig. 4). Current velocity shows the highest test gain when used in isolation among all the other environmental variables. It is also the one environmental variable that has the maximum percent contribution in both RCPs. The predicted distribution for 2090-2100 shows a further decline in the extent as well as in the probability of distribution (50-70%) (Fig. 3). The AUC values for RCP 6.0 and 8.5 are 0.810 (SD 0.087) and 0.772 (SD 0.066) respectively (Fig. 4).

Discussion

Global oceans are warming at 0.11°C per decade (Rhein *et al.*, 2013) and the Northern Indian Ocean has the maximum rate of increase in sea surface temperature (Beal *et al.*, 2020). Ocean warming has immense effects on the pelagic fishes than the demersal ones (Johnson *et al.*, 2018). Pelagic fishes may make poleward shifts in their distribution as a response to an increase in the ambient temperature (Poloczanska *et al.*, 2013; Rougier *et al.*, 2015). Currently, such distributional shifts of many of the pelagic species including the Clupeids that forms some of the major fisheries in the region are not known.

The species distribution modelling has an important role in tackling the problem during scenarios where shifts in marine fishes had led to ambiguous knowledge on the existing distribution of marine fishes (Marshall *et al.*, 2014). It is a potential tool for estimating the impact of climate change on range shifts (Beaumont *et al.*, 2008). In the past three decades, there have been many developments in the field of species distribution modelling, and multiple methods are now available. Most of them require systematic abundance data produced by

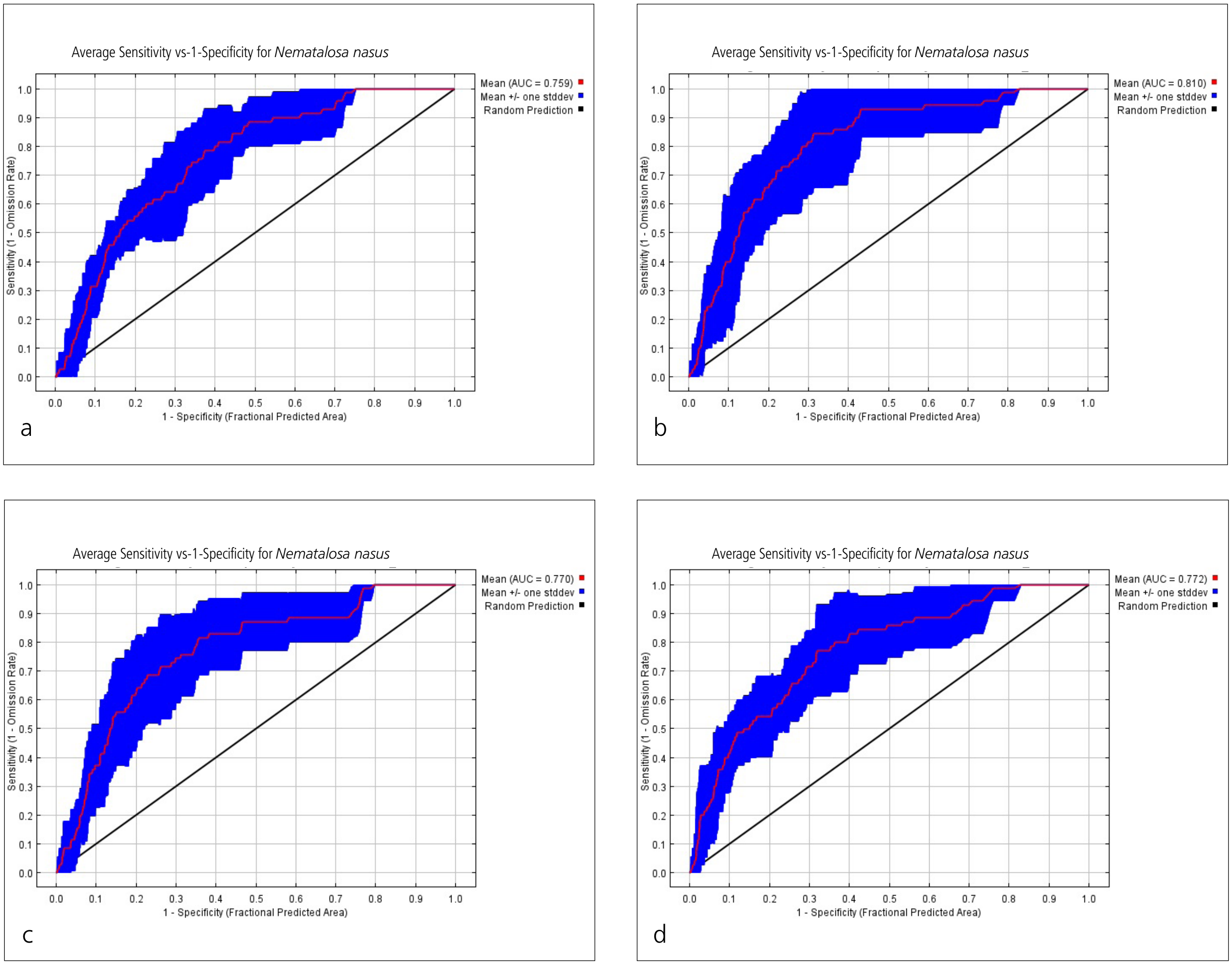


Fig. 4. The average sensitivity vs. 1- specificity graph for *N. nasus* showing the mean AUC and standard deviation for the predicted future distributions. a) 2040-50, RCP 6.0; b) 2040-50, RCP 8.5; c) 2090-00, RCP 6.0; d) 2090-00, RCP 8.5

formal surveys. However, when such data is sparse, such as in the case of *N. nasus* from our study region, Maxent will be an excellent option that can model presence-only data (Phillips *et al.*, 2006; Phillips *et al.*, 2009; Wang *et al.*, 2018).

Bloch Gizzard shad is one of the commercially important fish belonging to the clupeid family (Laj, 1987; Froese and Pauly, 2020). Climate change causes variations in ocean conditions such as ocean currents, water temperature, and coastal upwelling that adversely affect marine productivity (IPCC, 2007). Species richness inside the assemblage is also altered, due to the changes in habitat quality caused by climate change (Wilson *et al.*, 2008). In our study, we tried to predict the current and future distribution of *N. nasus* in the Indian waters. Using the maxent model, the major regions of the current distribution is predicted as the Bay of Bengal, Andaman Sea, western coast of India, the Persian Gulf, Red sea. However, the future distribution of the same species in Indian waters shows gradual decline throughout all the RCPs. This points out the substantial influence of the future state of climate change on this pelagic species.

Our results also indicate that the most important factor triggering the current and future distribution for this species is the current velocity. Guided by in situ observations, reanalysis products, and model experiments, Hu *et al.* (2020), Voosen (2020) showed that, driven by an increased surface wind velocity, there occurred substantial total kinetic energy of global ocean currents over the past two decades and is expected to continue in the future. Many studies have been conducted to evaluate the effects of current velocity on microfauna and fishes on riverine ecosystems (Neilson *et al.*, 2010; Rosenfeld *et al.*, 2011; Clark *et al.*, 2013; Mu *et al.*, 2019). However, studies on the variations of environmental parameters like ocean current on the distribution of marine fish species due to climate change are scarce. Our results offer scope for further studies on the effect of current velocity on marine fish distribution.

The mean temperature is the other factor generating the species shift. Many researchers (Brander *et al*., 2003; Muhling *et al*., 2017) have already described the changes in the spatial distribution of pelagic fishes due to an increase in sea surface temperature. Vivekanandan *et al.* (2009) observed the poleward shifts of yet another major clupeid in the region, the Indian Oil Sardine (*Sardinella longiceps*), due to the warming of the tropics. As compared to the current vector, temperature and salinity was observed to have a lesser influence on the distribution. The fact that *N. nasus* is a euryhaline species and is observed even in the estuarine waters indicates that this species has a higher capacity to withstand changes in the salinity in the future.

N. nasus, being an economically valued species among the clupeids, assessing its shift in distribution due to climate change also has a huge significance in clupeid fisheries. This study shows the potential distribution in current and future scenarios of *N. nasus* and thereby delineating boundaries and planning management strategies accordingly. Our study concludes that *N. nasus* is a pelagic species that is highly vulnerable to the effects of climate change. It is a common fact that the exploited fishes unveil subsequent responses in accord with both catch induced and climate-induced impacts (Nye *et al*., 2009). The consequent response of marine fish to climate change is its shift in distribution (Frank *et al.,* 1990). However, the landlocked nature of the NIO, will limit such possibilities and hence, the lack of chances of redistributions may erase the local population in the region.

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