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Evaluating and ranking the vulnerability of the marine ecosystem to multiple threats

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ABSTRACT

Marine ecosystem is threatened by a suite of climatic, anthropogenic, agricultural and aquacultural, and fishing stressors. Agriculture and anthropogenic activities are the major drivers of biodiversity loss by extensive use of pesticides and fertilizers, and encounter depleted soils and erosion due to unsustainable farming practices. This study provides an assessment of the various potential threats of that vulnerability of marine biodiversity in the Gulf of Mannar. The data was collected with a questionnaire that was distributed personally to more than 100 resource users from four districts of Gulf of Mannar Biosphere Reserve Trust (GOMBRT) in binary format. The data was then explored using the multivariate logit regression method, followed by Hosmer-Lemeshow test. The evaluation showed that all the determinants of various threats significantly affect the vulnerability of marine ecosystem. Among the studied factors, change in sea temperature, increase in fishing efforts, advanced farming practices, occurrence of endangered species, and tourism were the greatest threats (high log odds ratio), identified as the most important determinants affecting marine ecosystem.

Keywords: Agricultural, Anthropogenic, Climatic, Gulf of mannar, Marine ecosystem

Marine ecosystem of Gulf of Mannar (GOM) has wide biodiversity of various flora and fauna, covering 21 islands. It stretches from Rameswaram to Kanyakumari in Tamil Nadu. The stretch of the Gulf of Mannar has abundance of coral reefs and sea-grass beds which play an important role in global biochemical process and also have importance in breeding, spawning, and feeding areas for many important fishes. Now-a-days, marine biodiversity, ecosystem health and fisheries are threatened by several factors or threats. The anthropogenic activities, loss of vegetation and habitats, climate changes, destructive fishing, coral mining, pollution, industrial waste, etc. have resulted in the disappearance of several native and economically important fishes from the area, thus affecting the livelihood of the dependents population (Blasiak *et al.* 2017, Frolicher *et al.* 2018, Sumaila *et al.* 2019). One of the most pressing threats is climate change, such as temperature increment of aquatic and terrestrial systems, ocean acidification, and rising sea levels. It can alter biodiversity, sustainable management and conservation plan to maintain the ecosystem (Sumaila *et al*. 2011, Sunday *et al.* 2011, Urban 2015). It is responsible for fish migration, decrement of population dynamics of fish stocks, coral bleaching, soil erosion, loss of fish catch, and also the productivity and composition of the ecosystems on which fish depend for food and shelter (Arthur 2000, Munday *et al*. 2008, Barange *et al*. 2014). Thus, it affects the economy of fisheries and nations by affecting the fisheries sector, which is directly linked with food security, livelihoods, and employment (Sumaila *et al*. 2011, McClanahan *et al*. 2015).

Several studies indicate that marine species may be placed under threat of local or global extinction by the fishing effect (Wolff 2000, Dulvy *et al*. 2003). Fishing activities generate major disruptions in ecosystems such as the decline of fish population abundance (Worm *et al*. 2009), changes in the physical structure of the environment (Kaiser *et al*. 2002), reduction of mega-fauna and predators, and non-targeted species by bycatch (Komoroske and Lewison 2015) and damage to benthic habitats (Kaiser *et al*. 2002, 2003). Declines and extinctions can be associated with the loss of essential habitat and vegetation, overfishing and aquatic pollution (Watling and Norse 1998). Another important threat or factors affecting marine ecosystems' vulnerability is the anthropogenic activities in the oceans and along coasts (Halpern *et al*. 2015).

Vulnerability is often characterized as the degree to which a system can be susceptible or incapable of managing with antagonistic impacts of disturbances (Adger 2006). The earlier research on assessments of the ecosystem vulnerability majorly dealt with climate change (Mamauag *et al*. 2013), while assessments of fishing activity, anthropogenic factors, effect on biodiversity and advanced

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farming practices are scarce. Thus, the aim of the present study is to assemble and analyze the effects of several factors to show that various factors and/or threats affect the distribution and vulnerability of the marine ecosystem and develop our understanding of various factors.

MATERIALS AND METHODS

This research addresses analysis of the vulnerable determinants affecting the marine ecosystem of Gulf of Mannar. These investigations were performed from the four districts, namely Ramanathapuram, Tuticorin, Tirunelveli and Kanyakumari, under Gulf of Mannar Biosphere Reserve Trust (GOMBRT). The data relating to different threats or factors that affect the vulnerability of the marine ecosystems of the Gulf of Mannar includes active participation of all societal groups, especially fishermen, fisherwomen, tourists, researchers, non-fishers, and was collected randomly from the four mentioned districts of Tamil Nadu. To collect these on-the-ground practices, a semi-structured questionnaire was distributed to more than 100 resource users. The questionnaire was designed to capture context-specific determinants in binary format. For their vulnerable aspects, this included asking dichotomous questions (yes or no) about their different sources of marine ecosystem vulnerability. The questions were open-ended and related to different climatic, biodiversity, fishing exercises, aquaculture and agriculture practices, and anthropogenic factors that directly influence the marine ecosystem.

The primary interrogative survey was carried out from October 2020 to February 2021. Information about determinants that affect the ecosystem was collected arbitrarily based on a pre-structured interview schedule and stratified random sampling. The quantitative and qualitative data gathered were encoded and summarized on Microsoft Excel (2019). The information was then analysed to produce summary statistics to compare the vulnerability determinant of several factors affecting the vulnerability of the marine ecosystem. The data was then explored using the multivariate logit regression method (Hosmer *et al.* 2013) followed by the Hosmer-Lemeshow test to assess the goodness of fit for binary response models.

The multivariate logistic regression model read as:

$$\text{logit}[\pi(X)]^n = \text{log}x\left(\frac{\pi_{ij}}{1-\pi_{ij}}\right) (1)$$

$$\log\left(\frac{\pi_{ij}}{1-\pi_{ij}}\right) = \beta 0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \alpha_i (2)$$

where $\pi(x)$, probability of an event; X_1, X_2, ……., X_n, predictors in the multivariate model; β_0, coefficient; β_1, β_2, ……. β_p, effect on the probability of an event as X changes; α_i, often assumed to follow a normal distribution with mean zero and constant variance {i.e., $\alpha_i \sim N(0, \sigma^0_\alpha)$} (Hosmer *et al.* 2013). The above equation shows the logistic regression, which transfers the dichotomous outcome by logit transformation.

RESULTS AND DISCUSSION

Based on the input of logit analysis, the vulnerability of the marine ecosystem was associated by various studied factors, viz. climatic, biodiversity, fishing, aquaculture and agriculture, and anthropogenic. Based on the standard inference of vulnerability determinants of climatic factors that evolved from a multivariate logit model, the log odds ratio of change in sea temperature (20.560) showed a highly significant role in affecting marine biodiversity or ecosystem as compared to other determinants, viz. changes in rainfall (7.922), wind pattern (5.922), shoreline (5.43) and season (3.249) (Table 1).

Many researchers found that changes in sea temperature affected the migration or movement and distribution of fish population, and the abundance of species (Portner and Peck 2010, Garcia *et al*. 2013, Masucci *et al*. 2019, Macusi *et al*. 2020). For fisherman, a generally unpredictable weather pattern potentially decreased their fishing time, leading to decreased production (Lehodey *et al*. 2006, Macusi *et al*. 2015). The wind pattern and rainfall also affected the sea-level rise and eroded their shorelines. The regression analysis showed a highly experienced hot temperature in the area and accompanied by a change in rainfall and wind. Leadley *et al*. (2010) reported that climate change would be the most substantial threat to marine biodiversity over the next few decades, even exceeding habitat destruction. Jackson *et al*. (2001) also stated that impacts of climate change were also expected to be amplified by several anthropogenic effects such as excessive fishing pressure and habitat loss.

The assessment of the impact of the fisheries factor on the ecosystem is vital as a source of information for fisheries management. It indicates the need for management measures of the marine ecosystem (Goni 1998, Levin *et al*. 2009). In analyzing the effects of fishing on the vulnerability of marine ecosystem by logit model of regression analysis, the log odds ratio of increase in fishing efforts (25.249) and modernization of fishing crafts and gears (10.922) were higher among other vulnerability determinants. It had a significant impact on ecosystem vulnerability (Table 1) as compared to ghost fishing (1.560) and IUU (Illegal, unregulated, and unreported) fishing activities (2.43). The IUU fishing and ghost fishing activities had the lowest impact on the ecosystem. The scale of the impacts of ghost fishing is unknown, but their effects are not negligible (Goni 1998). Voluntary dumping or loss of fishing gear may lead to ghost fishing. Non-fishing activities may also have major impacts on the aquatic ecosystems through contamination, habitat modifications, and alteration of freshwater flows (FAO 1995a). They can also alter topography and the associated habitats and benthic communities. Fishing gear and craft also alter the marine habitats. All these fishing practices including overfishing, habitat destruction, and climatic change were associated with the removal of many important species on the marine ecosystem, that further affect ecosystem structure and functioning (Carpenter *et al*.

Table 1. Regression estimates of multivariate logit model of factors that affect the vulnerability of marine ecosystem dependent population of Gulf of Mannar, Tamil Nadu

Vulnerability determinant	Coefficient	SE	Wald coefficient	Significance	Exponential of (β)
Climatic factors					
Change in wind pattern	7.364	1.122	5.549	0.101	5.922
Change in season	5.356	0.234	12.423	0.001**	3.249
Change in sea temperature	2.066	0.315	15.470	0.001**	20.560
Change in shoreline	5.371	0.497	19.79	0.001**	5.43
Change in rainfall	-2.254	0.491	3.847	0.00*	7.922
Constant	-0.217	1.453	3.108	0.047	0.172
Fisheries factors					
Modernisation of fishing crafts and gears	1.746	0.324	7.619	0.001**	10.922
Increase in fishing efforts	0.976	0.493	3.047	0.001**	25.249
Ghost fishing	0.430	0.216	12.4830	0.005*	1.560
IUU fishing and non-fishing activities	0.235	0.702	10.635	0.001**	2.43
Constant	2.347	0.232	0.416	0.507	3.285
Aquaculture and Agriculture factors					
Farming of exotic, GMO species	5.132	0.248	15.679	0.001**	20.678
Use of antibiotics, pesticides and fertilizer	8.458	0.340	13.242	0.001**	5.390
Advanced farming practises	5.007	0.632	12.830	0.005*	23.432
Constant	1.347	0.254	0.388	0.507	3.975
Biodiversity factors					
Migration	4.421	0.112	11.679	0.001**	1.564
Endangered	0.986	0.432	18.242	0.001**	25.278
Extinction	4.547	0.231	1.830	0.001**	22.32
Introduction of exotic species	9.126	0.412	12.53	0.001**	8.678
Change and loss of vegetation	1.364	0.463	1.679	0.011*	12.098
Habitat degradation and destruction	8.180	0.442	11.242	0.001**	12.954
Constant	1.000	0.421	6.388	0.837	6.876
Anthropogenic factors					
Increase in population and crowding	1.787	0.562	4.898	0.001**	4.134
Untreated municipal waste	-9.334	0.346	2.432	0.001**	3.256
Tourism	-5.005	0.326	3.893	0.001**	10.578
Marine traffic and oil spill	-9.348	0.421	1.766	0.005*	2.432
Industrial waste	1.787	0.231	2.345	0.005*	3.876
Constant	2.673	0.405	0.875	0.507	2.543

Asterisk show the level of significance at $p<0.01$; ***, high significance; **, moderate significance; *, least significance.

1985, Hixon and Carr 1997). Impacts from fisheries on the ecosystem have been abundantly described and reviewed (Dayton *et al*. 1995, Goni 1998, Kaiser *et al*. 2003). Fishing also alters populations' age and size structure and thus ecological processes at a very large scale. The result conferred with the findings of Pauly (1979) that the overfishing and fishing craft or gear transforms were highly vulnerable threat resulting from the immature and stressed ecosystem. It may result in productivity changes and affect associated species. Some fishing gears also affect coral reefs, seagrass beds and sponge beds by increasing bottom abrasion and turbidity (Dayton *et al*. 1995, Goni 1998).

The observations of agriculture and aquaculture-based threats in the present study revealed that the log odds ratio of advanced farming practices and farming of exotic and GMO species were significant over antibiotics, pesticides and fertilizer. The result showed that advanced farming practices (23.432) and farming of exotic and GMO species (20.678) had significantly altered the marine ecosystem. Despite the potential benefits of applying genetic engineering in agriculture to improve the quality and reliability of the food supply, public and scientific concerns have been raised about environmental and food safety of GM crops. There are two major point of views in farming practices: on one hand, advanced farming and GMO or exotic species farming must be considered essential for promoting sustainable agriculture by reducing the use of pesticides, decreasing CO_2 emissions, conserving soil and moisture (Conner *et al*. 2003, James 2011), whereas, on the other hand, it has side effects in term of potentially adverse impacts on marine ecosystem and human health also. In this field, there is a wide exposure for a wide range of pharmaceuticals, including hormones, steroids, antibiotics, and pesticides in soils, surface water,

and groundwater, which have caused imbalances in the ecosystems (Boxall 2004). The present study's findings indicated that use of antibiotics, pesticides, and fertilizers (5.390) used in advanced farming also had an impact on the marine ecosystem (Table 1). Several studies resulted in instability of new genes, significant loss of biodiversity, and an increase in the use of chemicals in agriculture (Nap *et al*. 2003, Buiatti *et al*. 2013) resulting in a negative effect on the marine ecosystem.

The alteration of the habitat by various human or anthropogenic activities may be physical (e.g. by adding artificial structures like artificial reefs, oil rigs, aquaculture installations), mechanical (e.g. through the "ploughing" effect), or chemical. The anthropogenic activities were directly linked with the aquaculture and agriculture factors, fisheries factors and biodiversity factors. Among these, habitat destruction and pollution along with climatic change are important stressors that can contribute to species extinction. Thus, the biodiversity determinants also contribute a pessimistic role towards the vulnerability of the marine ecosystem-dependent population of Gulf of Mannar, Tamil Nadu. Among these, results showed that the log odds ratio of endangered (25.278) and extinct species (22.32) had a significant impact on the marine ecosystem, as both of them were the most important ecosystem species. The change and loss of vegetation (12.098), and habitat degradation and destruction (12.954) were other important factors which affect the ecosystem (Table 1). Loss of habitats, tourism, increase in population, pollution, industrial waste, untreated municipal waste, and marine traffic were directly related to human actions, and recovery from these problems are rarely straightforward. Habitat destruction poses the greatest threat to species. The world's forests, swamps, plains, lakes, and other habitats continue to disappear due to anthropogenic activities, habitat fragmentation, geological processes, climate change, and the introduction of invasive species. These determinants were further responsible for endangered and extinction, migration of several species and reducing biodiversity.

The analysis showed that among the determinants of anthropogenic factors, tourism had a great impact on marine ecosystem vulnerability (10.578) as compared to other threats, viz. population increment (4.134), industrial waste (3.876), untreated municipal waste (3.256) and marine traffic (2.432) (Table 1). Anthropogenic or human activities affect nearly every marine ecosystem by creating a difficult challenge for conservationists (Glover and Smith 2003).

The findings of the present study of Hosmer-Lemeshow test were significantly following the goodness of fit model test in all studied factors, viz. climatic, fisheries, aquaculture and agriculture, biodiversity and anthropogenic with all vulnerable determinants (p=0.310; 0.985; 0.563; 0.429; 0.416) (Table 2) which proved the significant relationship between the determinants and vulnerability of marine ecosystem.

Table 2. Hosmer-Lemeshow test

Threat	Chi square	df	p-value
Climatic factor	5	3	0.310
Fisheries factor	4	2	0.985
Aquaculture and Agriculture factor	3	1	0.563
Biodiversity factor	6	3	0.429
Anthropogenic factor	5	3	0.416

From the findings of the present study, it can be concluded that there are several important threats that have large functional impacts on the marine ecosystem. The study suggests that climate change such as strong weather disturbances, fishing activity, anthropogenic and aquaculture factors affect the fishing grounds. All these threats interact together, affecting livelihood, tourism, endangered species, habitat loss, advanced farming practices, increase in fishing efforts, etc. Our findings suggest that the coastal communities are experiencing the impacts of climate change, modification of fishing efforts, new GMO practices, vegetation and habitat loss, and wide tourism.

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