Chapter 09

Techniques for Vulnerability Assessment of Indian Marine Fishes

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Introduction

Climate change, as we know today, refers to collective changes in the characteristic regional climate conditions arising as an aftermath of increased carbon dioxide (CO_2) emission into the atmosphere by a conglomerate of anthropogenic activities. Climate change is predicted to affect individual organisms during all life stages, thereby affecting populations of a species, communities and the functioning of ecosystems. The effects of climate change in aquatic ecosystems can be direct, through changing water temperatures and associated phenology, the lengths and frequency of hypoxia events, through ongoing ocean acidification trends or through shifts in hydrodynamics and in sea level. The vulnerability of a species to climate change is generally considered as the extent to which abundance or productivity of species in a region could be impacted by climate change and decadal variability.

Alterations in the fishery and fishery resource profile in turn affect the coastal fishing communities dependent on fishing for their livelihood. In addition to this, extreme climatic events often take a heavy toll on fishing and allied activities. Some of the common and direct impacts of climate change on marine fisheries and marine fishing communities include:

- Changes in ocean currents and water column mixing, which alter larval dispersal and food availability. Typically, warm water increases stratification, decreasing productivity.
- Changes in primary productivity, which influence distributional shifts and abundance of several fish species leading to redistribution of stocks and species, and consequent changes in species composition in the fishery as well as altered trophic level interactions.
- Introduction or survival of invasive species.

- Emergence of harmful algal blooms and spread of bacterial/viral diseases.
- Changes in timing of ecological events, which could alter the biological performance of key species leading to alterations in fishery recruitment patterns.
- Elevated sea levels which may kill coral reefs and other living communities that constitute habitat for fish and shellfish, particularly in estuaries, and coastal erosion, which may lead to loss of berthing facilities and fishing hamlets established close to the sea.

Positive impacts of Climate change

Climate change can, and in some cases already does, affect fisheries in many ways; some effects have been clearly documented, and others are only a matter of speculation. Many effects are uncertain and most have not yet been quantified. While people tend to view any change from the current status as negative, some changes may have positive effects, such as faster growth of fish and shellfish, and extension of range into newly productive regions. Predicted fisheries effects of climate change fall into two classes: those associated with the biological health and viability of fish stocks, and those that impinge on the safety or the social, cultural, and financial sustainability of fishermen and fishing communities.

Assessing the vulnerability of fish species to climate change

There is ample evidence of the impacts of global climate change on marine environments. Organisms, however, do not respond to approximated global averages. Regional changes are more relevant in the context of ecological response to climate change. Hence, global-scale climate models may be unable to simulate observed changes in temperature and rainfall or the intensification of coastal upwelling in many areas, but regional-scale models may be able to do this. The prioritization of resources to inform adaptation of commercial fisheries could consider the economic value of fisheries, importance of species to ecosystem function, potential of species to respond favourably to adaptation interventions and/or the probability of persisting through significant environmental change. Against the background of changing climate, which we know is a definite happening event, and the paucity of accurate information on the actual changes that this event induces or can induce in different fish species, there is a large uncertainty hovering over Indian marine fisheries, which already faces the threat of overfishing and pollution impacts. Vital information for fishery managers and policy-makers therefore, would ideally be an exhaustive information base on the likely effects of changing climate on major fisherysupporting species of finfishes and shellfishes. Overall impact of climate change on fishery and ecological interactions is given in flow chart (Fig 1)

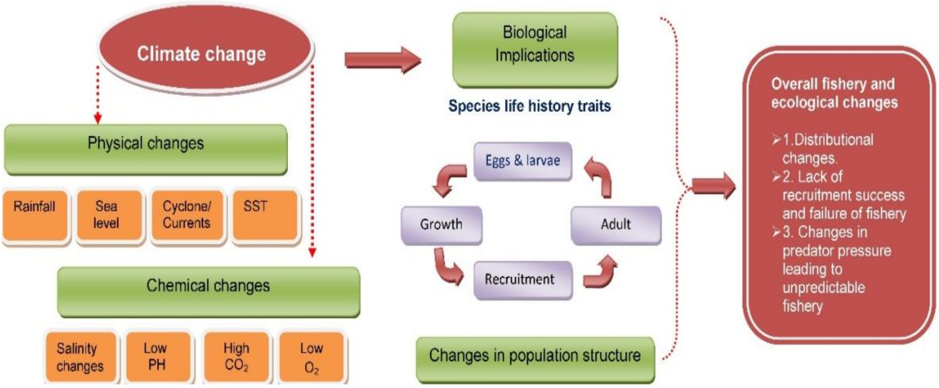

Figure 1. Flowchart of the impact of climate change on fisheries

Vulnerability assessments provide framework for evaluating climate impacts on different species with the aid of existing information and combining the exposure and the sensitivity of a species to a stressor. Vulnerability assessments (VAs) can be used for many different purposes, including improving adaptation planning (designing of policies and interventions), raising awareness of risks and opportunities, and advancing scientific research.

Methods for assessing species vulnerability have been described through quantitative approaches developed to examine climate impacts on productivity, abundance and distribution of different species of marine fishes and invertebrates Fisheries offers several socio-economic benefits to coastal fishing communities, and early warning of potential changes to fish stocks will provide managers and other stakeholders the opportunity to adapt to these impacts. Vulnerability of Indian fish stocks was conducted on identified priority species that contribute significantly to the fishery along the Indian coast, and on which substantial biological information were already available. The outcome of the study is envisaged to provide a strong base for evolving strategic fishery management plans for highly vulnerable stocks to counter the likely impacts of a changing climate in the long run.

Methodology

Assessment of the vulnerability of individual fish and invertebrate species to climate change is a prerequisite to understand or predict changes in the species composition and abundance in a particular region. While it is an established fact that climate change influences the marine environment, distribution and abundance of marine species and their phenology in spatial and temporal scales, the impact of climate change on marine organisms may not be uniform for all species and regions as it depends on the biological and behavioural characteristics of the organisms.

Investigations on the impact of climate change on many economically important marine species have been carried out in different parts of the world. A transparent assessment methodology was developed by Morrison et al. (2015) to determine the relative vulnerability of fish stocks to changing climate. The assessment takes into account the impacts of climate change induced by anthropogenic influences and natural factors. Most vulnerability assessment methods are based on two components – exposure and sensitivity of the species to different criteria, which include environmental parameters (exposure attributes), species biological characteristics and anthropogenic influence on the species (sensitivity attributes) and some studies incorporate a third component, adaptive capacity defined by biological characteristics that aid the species to overcome the negative impacts of high sensitivity or exposure. Some studies combine adaptive capacity with sensitivity.

The criteria developed in these studies were suitable for temperate and semi-tropical countries where species diversity is less, and there are relatively few methods of fishing operations. For a tropical country like India with wide variations in environmental parameters and a marine fishery which is characteristically multi-species, multi-gear and multi-ground, these criteria are insufficient to present a true picture of species vulnerability. Therefore in line with the methodologies described in earlier studies, sets of environmental, biological and fishery-based criteria were developed to suitably define the characteristics of tropical Indian species of fishes and invertebrates and their fishery in the region (Table 1).

Table 1. Criteria developed for vulnerability assessment

Environmental criteria	**Biological criteria**	**Fishery related criteria**
Sea surface Temperature	Fecundity	Anomaly in CPUE
Rainfall	Complexity in early development	Exploitation rate
Ocean current Speed	Growth coefficient	Price
Ocean current direction (S to N)	Trophic level	Gear
Coastal upwelling index	Longevity/Life span	

Chlorophyll concentration	Lc/Lm
	Horizontal distribution
	Duration of spawning
	Prey specificity

A top-down approach was adopted for developing the criteria for vulnerability assessment (FAO, 2015) with base-line information classified through a series of expert opinion workshops on the subject.

A working group of fifteen scientists working on different groups of finfishes and shellfishes, representing different geographical zones of the Indian coast, with sound knowledge on stock characteristics, fishery biology and ecology, interacted at three national workshops and evolved a suitably modified methodology to be adopted for different species in various zones.

Vulnerability Assessment Design

The primary assumption behind the vulnerability assessment methodology used is that current biological performance indices and expected exposure to climate change can be used to evaluate the relative vulnerability of a species. While exposure (E) is the projected magnitude of change in the physical environment due to climate variations, and defines the nature and degree to which a species is exposed to climatic variations, sensitivity (S) indicates the extent to which a species is affected due to its life history traits influenced, either adversely or beneficially, by anthropogenic activities, and, adaptive capacity (A) defines the ability (or potential) of a species to adjust successfully to climate or environmental change. In this study, we chose to represent the three components as separate sets of attributes. Based on the attributes, each component was assigned a score. The Vulnerability (V) was then estimated from the relation:

$$V = (E+S) - A$$

Exposure (E) attributes and their scoring

Exposure attributes used are those climatic variables which could impact the biological or behavioural characteristics of the selected species. Out of several environmental parameters initially considered for inclusion under exposure attributes, 6 environmental parameters *viz.*, sea surface temperature (SST), rainfall, current speed, current direction, upwelling index and chlorophyll concentration, were selected for as exposure attributes. Table 2 gives the parameters, period and source of data of exposure attributes.

Table 2. Exposure attributes used in the study

Attribute	Period of data	Data source
Sea surface Temperature	1975-2014 (40 years)	ICOADS
Rainfall	1975-2014 (40 years)	Indian Metrological Department
Ocean current Speed	1979-2014 (36 years)	oceanmotion.org (NASA)
Ocean current direction (S to N)*	1979-2014 (36 years)	oceanmotion.org (NASA)
Coastal upwelling index	1975-2014 (40 years)	NOAA PFEL
Chlorophyll concentration	1997-2014 (14 years)	NASA OceancolorAquamodis

Anomalies of sea surface temperature were calculated for a period of 40 years from 1975 to 2014. The sum of the absolute values of extreme negative and positive values of the anomalies were taken. From this value 30, 20 and 10 % were taken to rank the data set of SST as High, Medium and Low, respectively. After scoring, the total number of years with low, medium and high ranks was pooled. The pooled data was then multiplied with 1, 2, and 3 for low, medium and high ranks respectively. The value obtained was summed up and divided by the number of years to obtain the final scores for the respective zones. The value between 0.1-1 was classified as low, 1.1-2 as medium and 2.1-3 as high vulnerability. Similar procedure was followed for rainfall, ocean current speed and direction and chlorophyll concentration. Weightage factors were also accorded to each attribute depending on the exposure of the species to the attribute, limited by its horizontal or vertical spatial distribution (Table 3).

Table 3. Zone-wise and realm-wise weightage given to exposure attributes

Zone	Realm	Attribute & weightage			
		SST	Current speed	Current direction	Upwelling
NW	Pelagic	1.5	2	2	0.75
	Column	1.25	2	2	0.75
	Demersal	1.0	2	2	0.75
SW	Pelagic	1.5	2	2	0.5
	Column	1.25	2	2	0.5
	Demersal	1.0	2	2	0.5
SE	Pelagic	1.5	2	2	1
	Column	1.25	2	2	1
	Demersal	1.0	2	2	1
NE	Pelagic	1.5	2	2	1

Column	1.25	2	2	1
Demersal	1.0	2	2	1

The level of exposure of species to SST varies from surface to the bottom; the species occupying the pelagic realm are more exposed to SST variations than those in the column and demersal realms. For species in the pelagic realm, a weightage of 1.5 was applied for SST while a weightage of 1.25 was given to species distributed in column waters and 1.0 for demersal fishes. In the case of current speed and direction, the weightage was given based on dependency on this parameter for the dispersal of eggs and larvae, with greater weightage of 2.0 given to species with eggs and larvae that are liable to be carried away by current. For upwelling, differential weightage was given for different zones since there is considerable difference in the extent of upwelling along the west and east coasts of India. Upwelling is a seasonal phenomenon along NW and SW coasts of India. However the intensity is more along the SW coast. Accordingly weightage of 0.5 was given to SW coast and 0.75 to north-west coast. Rainfall and chlorophyll was given the same weightage for four zones.

Sensitivity (S) attributes and their scoring

For sensitivity attributes, the biological characteristics of species that are indicative of their ability or inability to respond to environmental changes and exploitation/fishery related pressures are used. For this study 9 attributes were selected based on time series data for a period 40 years (1975- 2015) on fishery and biology of each species extracted from published information available in CMFRI repository (eprints@cmfri). Data collected through detailed biological study done during 2011-2015 in different zones under the NICRA project was also used.

The sensitivity attributes were scored by the 15 experts working from the Institute on pelagic, demersal, crustacean and molluscan resources. For each attribute, scoring was limited to a scale of 1-3, representing low, medium and high ranking. Table 4 presents the sensitivity attributes and the scale limits for each attribute used in the study.

Table 4. Sensitivity attributes with scale limits for impact scoring

Attributes	**Low impact**	**Medium impact**	**High impact**
	1	**2**	**3**
Fecundity	More than 0.5 million eggs	1000 to 0.5 million eggs	Less than 1000 eggs
Complexity in early	Parental care	Demersal eggs	Complex lifecycle

development	Pelagic eggs with simple larval development		with different larval stages
Growth coefficient	More than 1	0.51 to 1	Less than 0.5
Trophic level	Less than 3	3-3.9	More than 4
Longevity/Life span	Less than 2.5 years	2.5 to 5 yrs,	More than 5
Length of capture (Lc)/ Length at maturity(Lm)	>0.8	0.6-0.79	<0.6
Anomaly in CPUE*	≥1	≥ 2	> 3
Exploitation rate	<0.5	0.51-0.7	>0.7
Price	Below Rs 100	100-350	More than 350

Adaptive Capacity (A) attributes and their scoring

Adaptive capacity attributes used are primarily biological and ecological traits that could help the species to adapt to a fluctuating or changing environment. Four attributes were selected for this study. Based on expert opinion for each attribute the scoring was limited to a scale of 1-3, representing low, medium and high. Table 5 gives the various adaptive capacity attributes used and their scoring.

Table 5. Adaptive capacity attributes with scale limits for adaptability scoring

Attributes	**Low**	**Medium**	**High**
	1	**2**	**3**
Horizontal distribution	Less than 5 states	5 to 7 states	Distribution in 8to 9 states (at least 0.5%)
Vertical Distribution	80% catch in depth specific gears	26-79% catch in 2 depth specific gears	Upto 25% catch from 3 or 4 depth specific gears
Duration of spawning	Less than 4 months	Extends from 4 to 7 months	Spawning extends for 8 months
Prey specificity/No. of prey groups/Niche breadth	Narrow (<0.3)	Medium (0.31-0.69)	Broad (>0.7)

Horizontal distribution was defined from the abundance of the species in commercial fish landings in different zones/states along the Indian coast. Vertical distribution was defined by the maximum occurrence of the species in different gears operated at different depths. Duration of spawning was defined by the number of months with high incidence (50%) of ripe and spawning individuals of the species in the fishery. Prey specificity/Number of prey/niche breadth was defined from research data and from those available in *Fishbase* website.

Vulnerability (V) assessment

The sum of exposure and sensitivity is the impact. For preparation of vulnerability matrix, climatic variables (exposure attributes) were given more weightage as the sensitivity traits are dependent on changes in the climatic variables. Accordingly the following combinations of exposure and sensitivity scores were fixed as binding -

S. No.	Exposure	Sensitivity	Impact
1	L	M	L
2	M	H	M
3	H	M	H
4	L	H	M

Vulnerability score of <1 was considered as low vulnerability, 1.0-1.5 as medium and >1.5 as highly vulnerable. Vulnerability matrix for different geographical zones was generated by plotting impact versus vulnerability score (Figure. 2).

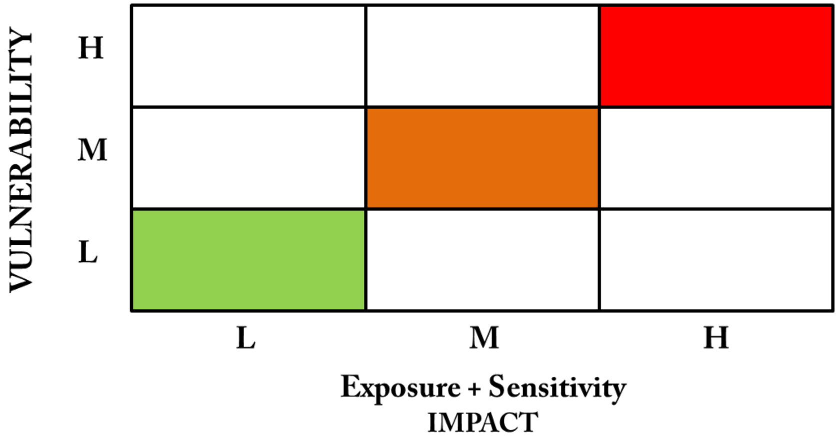

Figure 2. Vulnerability Matrix based on component scores for exposure and sensitivity (impact) and adaptive capacity.

Using the vulnerability assessment report

Effective management of India's marine fishery is a challenging task, considering its multidimensional diversity facets. Single species assessment and management models are unlikely to create the necessary impacts, and ideally, a concerted approach using a combination of single-species, multispecies and ecosystem based assessments is advocated. Identifying species that are liable to be highly or least impacted by climate change, immediately or in future, will play a key role in deriving management measures most suited to ensure a sustainable fishery, without impinging on the economic benefits of the fishing communities, particularly the artisanal sector. The ultimate goal of fishery management is to ensure the sustenance of the resource, the fishery and the livelihood of the stakeholders. To this means, such vulnerability assessment reports would serve as the keystone for constructive fishery management options through gear modification and target species diversification so as to decrease targeting of and dependency on highly impacted species and promote fishery of less impacted and resilient species which will help to sustain the fishery in the long run.