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Relative vulnerability assessment of Indian marine fishes to climate change using impact and adaptation attributes

National Innovations in Climate Resilient Agriculture

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Indian Council of Agricultural Research
Central Marine Fisheries Research Institute

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CMFRI

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NICRA
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Indian Council of Agricultural Research
Central Marine Fisheries Research Institute
Post Box No. 1603, Ernakulam North P.O.,
Kochi – 682 018, Kerala, India

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Dr. A. Gopalakrishnan
Director
ICAR-Central Marine Fisheries Research Institute
Post Box No. 1603, Ernakulam North P.O.,
Kochi – 682 018, Kerala, India
www.cmfri.org.in

Email: director@cmfri.org.in
Tel: +91-484 2394 867
Fax: +91-484 2394 909

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Foreword

India occupies sixth position globally in marine capture fish production. An estimated 1.0 million people are directly involved with fishing in India and 4.0 million people depend for their livelihood on the marine fisheries resources. The Indian marine fisheries sector is currently faced by several issues like over-capitalization, over-exploitation and climate change. The impacts of climate change on marine fisheries are amply visible in the Indian EEZ. The features associated with climate change like rise in sea surface temperature, change in season and intensity of monsoon, variation in current pattern, ocean acidification etc. are likely to make changes in the community structure and phenology of marine fishes. Such impacts have brought perceptible changes in the fishery of some species, forcing fisherfolk to make changes in fishing operations.

Fishes are poikilothermic–their body temperature varies with the surrounding environmental thermal conditions. While most poikilothermic organisms are capable of functioning over a wide range of temperatures, the metabolic costs of this are likely to be high. Some fishes are also affected by climate change during embryonic development and in fishes exhibiting temperature-dependent sex determination, differences in temperature as low as 1-2°C can significantly alter the sex ratio of populations. Phenological changes also abound. Spawning activity has shifted in some species to comparatively cooler months, and hatching success decreases at higher temperatures. It has been predicted that pelagic fishes, which generally spawn year round, and have higher generation turnover, will adapt faster than their benthic counterparts. Adaptation at different rates will cause shifts in the current ecological balance, resulting in loss of biodiversity. Some species may also suffer changes in their distributional range. Thus, it has become exceedingly clear that the varied risks posed by global warming and climate change present a significant danger to the health and survival of the denizens of the marine world, necessitating timely action and global cooperation to avert such a disaster.

It is in this background that CMFRI, under the leadership of Dr. Zacharia, has undertaken a study to assess the vulnerability of Indian marine fishes to climate change under the project "National Innovations in Climate Resilent Agriculture (NICRA)". I congratulate Dr. Zacharia, the theme leader Dr. Dineshbabu, and all those associated with this study for assessing the vulnerability of key species of fishes and invertebrates to climate change and the likely impact to the fishery. I am hopeful that this publication will be useful for improving adaptation planning (designing of policies and interventions), raising awareness of risks and opportunities, advancing scientific research and initiating mitigation options to successfully overcome the threats posed by climate change to Indian marine fisheries.

A. Gopalakrishnan | Director, CMFRI

Contents

Introduction

The threats of climate change to human society and natural ecosystems have been elevated to a top priority since the release of the fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2007 (FAO, 2009). The impacts of climate change will increasingly be experienced by many people, either directly, for example, by rising sea levels that inundate dwellings and other infrastructure, or indirectly by, for example, warming ocean temperatures that lead to shifts in the distribution, abundance, seasonal migrations, and reproductive patterns of commercially valuable marine species (Brander, 2010). Climate change is projected to impact broadly across ecosystems, societies and economies, increasing pressure on all livelihoods and food supplies, including those in the fisheries and aquaculture sector. Many coastal communities are already experiencing climate change impacts which are expected to continue (Cochrane et al., 2009; Pörtner et al., 2014; van Putten et al., 2014). However, climate change is not impacting all ocean regions equally. Sea surface temperature (SST) increase in some 20 regions is occurring at several times the average global rate of warming suggesting that coastal communities in these areas may be at higher risk compared to other regions (Hobday et al., 2015).

Northern Indian Ocean has been identified as one of the 17 climate change hotspots among the world oceans. These areas will warm faster than 90% of the world oceans. IPCC (2007) has projected a global annual sea level increase of 8 to 25 cm and SST increase of 0.8 to 2.5°C by 2050. India lies roughly between 6°N to 37°N latitudes. The Tropic of Cancer passes through the middle of the country. The southern parts, being closer to the equator, experience high temperatures throughout the year. The northern parts on the other hand, lie in the warm temperate zone. Hence they experience low temperatures particularly, in winter. Southern or peninsular India is surrounded by the Arabian Sea, the Indian Ocean and the Bay of Bengal, hence the climate in coastal India is equable or maritime.

India is one of the major fish producing countries in the world, contributing over 3% of both marine and freshwater fishes to the world production, and is ranked third in global capture fish production. India's Exclusive Economic Zone (EEZ) is spread over a total area of 2.02 million sq. km, i.e., 0.86 million sq. km on the west coast including the Lakshadweep Islands and 1.16 million sq. km on the east coast including the Andaman and Nicobar Islands with a continental shelf of half a million sq. km. The marine fisheries sector holds high potential for strengthening rural development, domestic nutritional security, employment generation, gender mainstreaming as well as export earnings. Indian marine fisheries, which existed as a sustenance fishery for years, underwent a series of changes with the advent of mechanisation in the 1950s, evolving itself into a multi-billion dollar industry. The production increased from 0.63 million metric tonnes (mmt) in the 1960s to an all-time high of 3.94 mmt in 2012 after which it gradually declined and stood at 3.4 mmt in 2015.

Even as global marine capture fisheries stand threatened by a multitude of factors, the situation in India is no different, or is perhaps more grave than in other fishing nations, with demand and production moving along divergent perpendiculars. The major issues shadowing Indian marine fish production include overfishing pressure and reducing yields, poor implementation of regulations, increasing pollution of coastal waters through anthropogenic activities, marine debris/litter accumulation in coastal waters, ghost fishing, inland water bodies being severely affected by way of pollution from effluent discharge and eutrophication, and increased threat of climate change on distribution and abundance of marine fishes.

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. 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 fishery-supporting species of finfishes and shellfishes. In this context, a detailed study was carried out to assess the vulnerability of key species of fishes and invertebrates likely to impact the fishery in the process of undergoing climate change induced alterations in phenology, reproductive performance, abundance and distribution.

While climate change is a global phenomenon, species respond physiologically and behaviorally to the characteristics of their local environment. There is a need for vulnerability assessment at species level as:

- Climate change impact will not be uniform as the habitats and biological traits of species are different (for example, the impact of vulnerability to temperature increase of pelagic fishes, will be different from that of demersal fishes or sedentary molluscs owing to their differential abilities for their movement and survival).

- Not many assessment methods are available for marine species unlike the terrestrial species. Hence, there is a need to develop a methodology for marine species.

- Managers will be able to identify the vulnerable species and areas, and take decisions.

Vulnerability assessments provide frameworks for evaluating climate impacts on different species with the aid of existing information and by combining the exposure and the sensitivity of a species to a stressor (Hare et al., 2016). 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 (Patt et al., 2009)

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 (Hare et al., 2016). 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 (Pecl et al., 2014). Following the studies conducted for the U.S. coasts (Gaichas et al., 2014; Morrison et al., 2015; Hare et al., 2016), Australia (Pecl et al., 2011; 2014), Africa (Hlohowskyj et al., 1996) and Philippines (Jacinto et al., 2015), this study on 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 was 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.

Background

Climate change is predicted to affect individual organisms during all life stages, thereby affecting populations of 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, ongoing ocean acidification trends or through shifts in hydrodynamics and in sea level (Pörtner and Peck, 2010). Climate change will impact fish and shellfish, their fisheries, and fishery dependent communities through a complex suite of linked processes (Hollowed et al., 2013). Oceans are the major sinks for atmospheric CO_2, and dissolution of more CO_2 makes the oceans acidic. These changes will have profound influence on the structure and function of marine ecosystems and marine life.

Ocean warming is currently one of the main driving forces causing changes in species abundance and distribution and, thus, in species composition in marine ecosystems (Perry et al., 2005). Alterations in the fishery and fishery resource profile in turn affect the coastal fishing communities that are 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 and proliferation 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.

- Coastal erosion, which may lead to loss of berthing facilities and fishing hamlets established close to the sea.

Climate-driven changes in the environment may affect the physiology, phenology, and behaviour of marine fish and shellfish at any life-history stage, and any of these effects may drive population level changes in distribution and abundance (Loeng and Drinkwater, 2007; Drinkwater et al., 2010; Jørgensen et al., 2012). Fish and shellfish will be exposed to a complex mix of changing abiotic (e.g. temperature, salinity, mixed layer depth, oxygen, acidification) and biotic (shifting distribution, species composition, and abundance of predators and prey) conditions making it difficult to predict the responses (Hollowed et al., 2013). 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 (Hare et al., 2016).

Climate change and fishes

Fish is a poikilothermic animal that cannot regulate body temperature through physiological process; this is regulated instead by environmental process. Fish physiology, like growth and reproduction is directly influenced by changes in temperature. With rising environmental temperature, the physiological activities of fishes also increase, which in turn increases the oxygen demand. But the solubility of oxygen in water is inversely related to temperature and salinity (Weiss, 1970). Thus, dissolved oxygen availability in water will decrease, resulting in the reduction of growth and reproduction success of fishes and prevent them from dealing as effectively with other environmental changes. This is particularly true in the case of fishes living in closed water bodies. In an open ocean system, several factors play a synergistic role in impacting the physiology of the organisms.

Pelagic fishes occupy the surface waters from the coast to the open ocean and are perhaps more prone to changes in environment than their demersal and benthic counterparts. While some of the most well-known are the large offshore apex predators such as tunas, billfish and sharks, the mid-trophic level small pelagic species, such as sardines, anchovies, and squids, are critical to ecosystem function. Pelagic fishes of all sizes have high ecological, economic and social value. The observed impacts of climate change are often restricted to changes in local abundance and distribution. Little is known regarding changes in phenology, physiology or community structure in relation to climate change. Ocean warming is likely to see changes in the distribution of a range of pelagic species in the Indian Ocean. Changes in productivity, for example, due to increased coastal upwelling, may lead to increases in abundance of some species, particularly of small coastal pelagic fishes, such as sardines and anchovies, in the large upwelling system between Cape Otway and the central Great Australian Bight (Hobday et al., 2009). Knowledge gaps include an absence of information on species habitat tolerances and empirical models for future prediction of species ranges and abundances. With regard to species, impacts on sharks are poorly known compared to the teleost fishes. The adaptation potential is high for many species because of significant opportunity for large scale movements of most pelagic species, and thus the main impacts are likely to be localised changes in composition of pelagic fish community (Hobday et al., 2009). While climate change is a global phenomenon, the physiological and behavioural responses of the species will be defined by the characteristics of the local environment they live in (Pecl et al., 2014).

Shifts in marine fish stocks in response to temperature changes

Shifts in geographical distribution occur in response to climate change and are generally most evident near the northern or southern boundaries of the geographic range of a species, where warming or cooling theoretically drives marine fishes to higher and lower latitudes, respectively (Pörtner and Peck, 2010). A number of studies have documented such changes within particularly well-studied ecosystems of the world's oceans including the North Sea and other parts of Europe (Beare et al., 2004; Perry et al., 2005; Rose, 2005). Furthermore, analyses have investigated whether there have been shifts in the seasonal timing (phenology) of crucial events such as spawning by fishes (Sims et al., 2005) and the spring blooms of phytoplankton and zooplankton (Wiltshire et al., 2008). Out-of-phase shifts between the former and latter can have large consequences for match and mismatch phenomena, for example, food availability for larval and juvenile fishes (Beaugrand et al., 2002), possibly leading to regime shifts (Beaugrand, 2004).

The range in tolerable temperatures is most narrow for fishes inhabiting high latitudes than for species at low latitudes. In contrast, the tolerance range tends to be widest for fishes inhabiting mid-latitudes where seasonal differences in temperatures are, on average, largest. Another important feature of thermal physiology within fish species is ontogenetic change in the width of thermal tolerance windows (Pörtner and Peck, 2010).

Inter-stock comparisons often indicate dome-shaped relationships between recruitment strength and water temperature experienced during the spawning season, with maximum recruitment at an intermediate temperature in both demersal and pelagic fishes (Brander, 2000; MacKenzie & Köster, 2004). For some broadcast spawning fish species, there is evidence that the size of populations is determined by the size and availability of spawning and nursery habitats (Rijnsdorp et al., 1992; Gibson, 1994;

Sparholt, 1996; MacKenzie et al., 2000). Limits on the availability of these habitats may act as a bottleneck for population size and productivity. In these cases, the focus should be on the effect of climate change on the critical life-history stages. As stated by Rijnsdorp et al., (2009), although the underlying mechanisms remain uncertain, available evidence suggests climate-related changes in recruitment success to be the key process, stemming from either higher production or survival in the pelagic egg or larval stage, or owing to changes in the quality/quantity of nursery habitats. Several studies have documented substantial temporal variation in the intensity of recruitment of juveniles at the end of the pelagic larval stage of many temperate (Cushing, 1975; Rothschild, 1986) and tropical (Russell et al., 1977; Sale et al., 1984; MacFarland et al., 1985; Victor, 1986; Doherty & Williams, 1988; Doherty, 1991) marine fishes, attributed primarily to pelagic processes that affect the survivorship of larvae (Robertson et al., 1993).

Correlation between climate variables and fish catch

Although fishing remains, by and large, the most dominant driver of population abundance, there is now substantial evidence of the impact of climate change and decadal variability on fish and invertebrate populations, with an increasing number of studies linking population models to climate models and projecting future climate change impacts on fish and invertebrate populations (Hare et al., 2016). The effects of environmental parameters on the distribution and abundance of oil sardine and mackerel populations along the southwest coast of India have been well documented (Krishnakumar et al., 2008). Studies correlating variations in sea surface temperature with marine fish catch from the Bay of Bengal along southeast coast of India indicated that the catches of oil sardine and mackerel showed an increasing trend over the last 25 years; seasonal analysis showed positive correlation of the catches with SST (Kizhakudan et al., 2014).

The consequences of failing to curtail greenhouse-gas emissions in marine ecosystems are likely to be larger than previously expected (William et al., 2012). The tropical seas may suffer most from a high rate of local extinction and reduction in maximum catch potential, whereas higher latitude regions, such as the northern temperate regions, may gain. If small sized low value fishes with rapid turnover of generations can cope with climate change, they may eventually replace large sized high value fishes which are declining due to non-climatic factors (Vivekanandan, 2010). Fishes in both tropical and temperate regions are also likely to be impacted by reduction in body size. Other human impacts, such as overfishing and pollution, are likely to further exacerbate such impacts. Consequently, these changes are expected to have large implications for trophic interactions, ecosystem functions, fisheries and global protein supply.

Climate change may have good impacts too

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.

Coastal environment and marine fisheries scenario of India

The coastal zone of India is densely populated and stretches over 8,129 km. There are about 70 coastal districts, which occupy around 379,610 km^2, with an average population density of 455 persons per km^2, which is about 1.5 times the national average of 324 persons per km^2 (Vivekanandan, 2009). In the coastal districts, 25% of the population lives within 50 km from the coastline. About 30% of the population lives in the coastal areas, resulting in a very high density of >2000 persons per km^2.

The national marine fisheries census of 2010 carried out by CMFRI estimated the marine fishermen population in India as 4.0 million out of which 0.99 million are active fishermen. There are 72,559 mechanised vessels, 71,313 motorised vessels and 194,490 non-motorised vessels in operation. Small-scale fisheries contribute to almost the entire marine fish production of India as most of the fishing vessels are below 20 m OAL.

Out of the recent five-year average annual marine fish production of 3.6 mmt, 2.22 mmt was obtained from inshore waters of 0-12 nautical miles and 1.38 mmt from 12-200 nautical miles. The fishery resource base of India is constituted by a large variety of species (nearly 1,570 species of finfishes and about 1,000 species of shellfishes) co-existing in the same grounds. Among these, about 200 species of finfishes and shellfishes are of significant commercial importance. India's fishery resources can be broadly classified as:

- Pelagic resources, caught mainly by seines
- Demersal resources, caught mainly by trawls
- Crustacean resources
- Molluscan resources
- Seaweed resources

The major taxonomic groups representing the pelagic, demersal crustacean and molluscan resources are listed in Table 1.

Table 1. Major taxonomic groups supporting India's commercial marine fishery

Pelagic resources	Demersal resources	Crustacean resources	Molluscan resources
Clupeids	Elasmobranchs	Penaeid prawns	Bivalves
Bombay duck	Eels	Non-penaeid prawns	Gastropods
Half beaks & Full beaks	Catfishes	Lobsters	Cephalopods
Flying fishes	Lizardfishes	Crabs	
Ribbonfishes	Perches	Stomatopods	
Carangids	Goatfishes		
Mackerels	Threadfins		
Seerfishes	Croakers		
Tunnies	Silverbellies		
Billfishes	Big-jawed jumper		
Barracudas	Pomfrets		
	Mullets		
	Flatfishes		

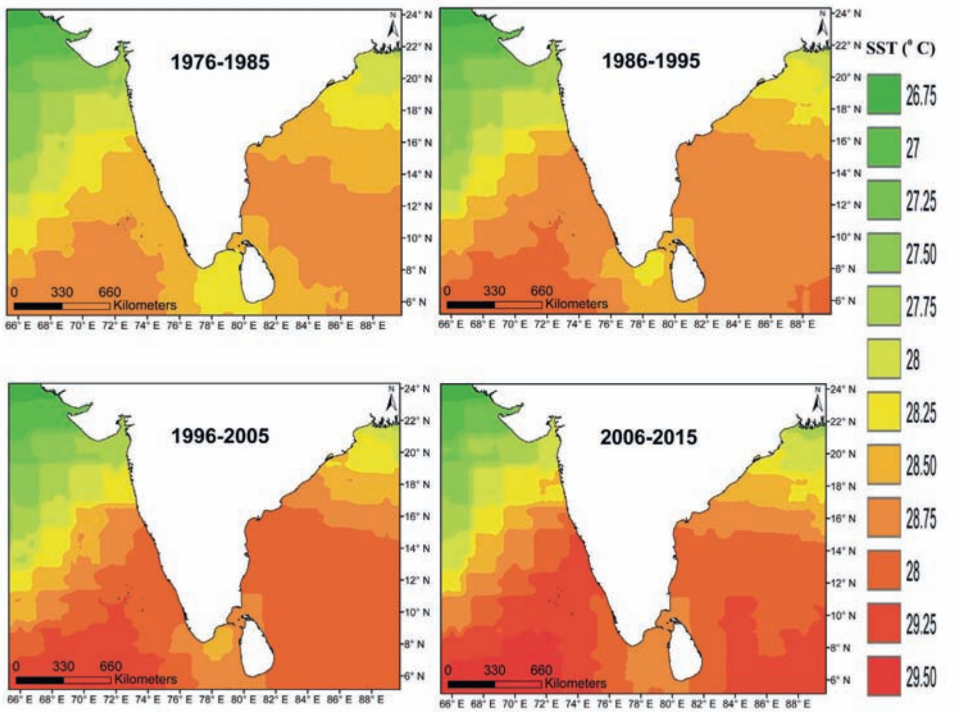
India's marine fish production is predominantly supported by pelagic resources. In 2015, pelagics formed 51.5% of the marine fish landings in the country, demersals 27.6% and crustaceans and molluscs formed 12.4 and 6.5% respectively. Annual average landings of many of the major resources have shown considerable increase over the period; however very high change has been noticed in landings of oil sardine, non-penaeid prawns, pomfrets and cephalopods during the last five years. No significant changes have been noticed for perches, mackerel, ribbonfish, croakers, carangids, Bombay duck, lesser sardines, silverbellies and penaeid prawns. Landings of apex predators like sharks, on the other hand, after registering an increase during 2000-04, have shown a decline in recent years.

The pattern of marine fish landings in India during the past fifty years clearly reveals that contribution by the artisanal sector to the total production was significant up to the sixties. As a result of the popularisation and consequent expansion of mechanised fishing during the subsequent periods along with motorisation of artisanal crafts, contribution by the artisanal sector declined considerably over the years. Trawling is now the most important among various fishing methods in India, and contributes about 55% to the total marine fish production in the country. The other major gears operated are seines (purse seines, ring seine), gillnets (small and large sized), hooks & line and long line.

The value of marine fish landings at the landing centres was estimated to be ₹19,753 crores during 2014; whereas at the retail point, the value was 52,363 crores. India earned an all-time high of US$ 5.5 billion (₹33,000 crores) from the export of marine products from the country in 2014-15 and 40% of the export earnings was obtained from marine capture fisheries.

India's coastal zone is endowed with abundant coastal and marine ecosystems that include a wide range of mangroves, coral reefs, sea grasses, salt marshes, mud flats, estuaries, lagoons, and unique marine and coastal flora and fauna. India also has major stocks of corals, fish, marine mammals, reptiles, turtles, sea grasses and sea weeds. The ecological wealth of the oceans provides livelihood to millions of people. Over 4 million people in about 3,182 fishing villages along the Indian coastline live directly off the seas. India's marine environment faces a number of pressures, arising out of the needs of people, and the multiple uses that coastal and marine areas are being put to. These pressures contribute to the depletion of marine resources and degradation of the marine environment. More than any other environment, the marine and coastal environments are perhaps more vulnerable to the uncertainties of climate change. These changes may cause significant damage to the coast and to the inhabitants of nearby areas.

Sea Surface Temperature Map (1976-2015)



Increase in world temperature is projected to range from 0.3 to 6.4°C by 2090-2099 relative to 1980-1999 (IPCC, 2007). The temperate and polar latitudes are predicted to experience a higher temperature change than tropical and subtropical latitudes (ACIA, 2004). The variation of SST in Indian seas during the 40 years from 1976 to 2015 revealed that it has increased by 0.602°C along northeast India, by 0.597°C along northwest India, by 0.690°C along southeast India and by 0.819°C along southwest India. However, the rate of change in SST was highest in northwest India (0.0156°C/annum) followed by southwest India (0.0132°C/annum), southeast India (0.005°C/annum) and northeast India (0.001°C/annum), indicating greater climate change impact along the west coast than the east coast.

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 (Clark, 2006). The prioritisation 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 (Hobbs and Kristjanson, 2003). The overall impact of climate change on fishery and ecological interactions is depicted in Fig. 1.

Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. IPCC (2007) defines vulnerability as the "degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climatic variability and extremes". Vulnerability assessments (VA) can play a vital role in the design of appropriate adaptation and mitigation policies targeted towards climate change and its impacts on marine and aquatic ecosystems, and those who depend upon these resources for their livelihood and well-being (Barsely et al., 2013). Assessing which particular individual, group, community, region, species or nation is vulnerable, and in what ways, enables clear and effective responses to be formulated.

In this book, we present an approach and identify a set of methodologies for evaluating the vulnerability of marine fishes to climate change from the Indian coast. Realizing that the impact of climate change on fishes is a reality, the document aims at understanding

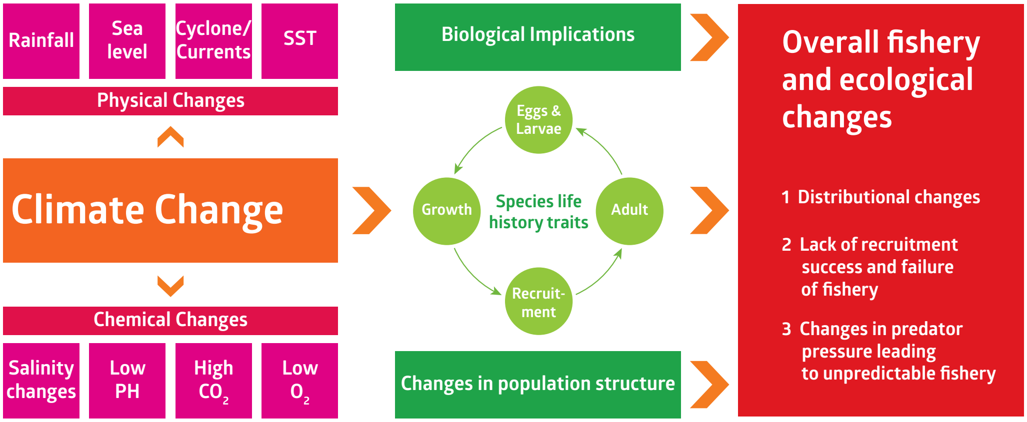


Fig. 1. Flowchart of the impact of climate change on fisheries

and assessing the vulnerability of selected commercially important marine finfish and shellfish species to the synergic effect of climate change and existing fishing pressure. For this, we reviewed existing methods used in other parts of the world and identified key species and factors which make fish species vulnerable.

Approach & 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 (Morrison et al., 2015).

Review of existing methods to assess species vulnerability

Investigations on the impact of climate change on many economically important marine species have been carried out in different parts of the world (Hollowed et al., 2009; Hare et al., 2010; Hazen et al., 2012; Plaganyi et al., 2013; Wayte, 2013). Such studies usually require considerable time and resources. 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). Several studies have been carried out using similar methodologies (Pecl et al., 2014; Morrison et al., 2015). Some studies incorporate a third component, adaptive capacity (Chin et al., 2010; Johnson and Welch, 2010; Glick et al., 2011), 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 (Williams et al., 2008; Morrison et al., 2015). A comparison of parameters and attributes used in some of the earlier studies and the present study is given in Table 2.

Need for a method suitable for Indian conditions

The criteria developed in earlier studies were most 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

Table 2. Comparison of parameters & attributes used in some of the earlier studies and the present study

Source	Method	Parameters & Attributes		Study area
Morrison et al., 2015	Vulnerability assessment framework to develop vulnerability matrix and assign vulnerability rank	**1.**	**Exposure factors**	
		i.	Ocean temperature	
		ii.	Variance in ocean temperature	
		iii.	Estuarine temperature	
		iv.	Salinity	
		v.	Ocean acidification (pH)	
		vi.	Precipitation	
		vii.	Dissolved oxygen	
		viii.	Circulation	
		ix.	Sea level rise	
		2.	**Sensitivity attributes** (includes adaptive capacity)	
		i.	Habitat specificity	
		ii.	Prey specificity	
		iii.	Sensitivity to ocean acidification	
		iv.	Sensitivity to temperature	
		v.	Stock size/status	
		vi.	Other stressors	
		vii.	Adult mobility	
		viii.	Spawning cycle	
		ix.	Complexity in reproductive strategy	
		x.	Early life history survival and settlement	
		xi.	Population growth rate	
		xii.	Dispersal of early life stages	
Gaichas et al., 2015	Risk assessment framework by initially scoping and identifying the relevant units for assessment, then conducting qualitative Level 1 risk analysis, followed by semi-quantitative (employing ranked scores) Level 2 analysis	**1.**	**Climate-related risks**	**Northeast US continental shelf**
		i.	Temperature	
		→	Warmer surface temperature	
		→	Warmer bottom temperature	
		→	Increased warm water	
		→	Thermal habitat volume	
		ii.	Hydrography	

	→	Change in prevailing winds
	→	Rise in sea level
	→	Shifts in major boundary currents
	iii.	Salinity
	→	Fresher surface salinity
	→	Fresher bottom salinity
	iv.	Mixing
	→	Impeded vertical mixing
	→	Increased riverine water inputs
	v.	Oxygen
	→	Lower dissolved oxygen
	vi.	Acidity
	→	Increased acidity
	vii.	Weather
	→	Increased storm frequency
	→	Increased storm intensity
	viii.	Cumulative
	→	Change in seasonal timing
	→	Earlier spring
	2.	**Community sensitivity**
	i.	Habitat specificity
	ii.	Prey specificity
	iii.	Sensitivity to ocean acidification
	iv.	Complexity in reproductive strategy
	v.	Sensitivity to temperature
	vi.	Early life history survival and settlement requirements
	vii.	Stock size/status: B/BMSY
	viii.	Other stressors (pollution, disease, food web impacts etc.)
	ix.	Dispersal of early life stages (eggs and larvae)
	x.	Adult mobility
	xi.	Annual spawning events

Pecl et al., 2014	Rapid assessment of species sensitivity to climate change using a three-step process to evaluate the relative sensitivity of key commercial fisheries species	**1. Abundance** i. Fecundity ii. Recruitment period iii. Average age at maturity iv. Generalist vs. specialist - food & habitat **2. Distribution** i. Capacity for larval dispersal or larval duration ii. Capacity for adult/ juvenile movement iii. Physiological tolerance-latitudinal coverage of adult species as a proxy of environmental tolerance. iv. Spatial availability of unoccupied habitat for most critical life stage-ability to shift distributional range **3. Phenology** i. Environmental variable as a phenological cue for spawning or breeding - cues include salinity, temperature, currents, & freshwater flows ii. Environmental variable as a phenological cue for settlement or metamorphosis iii. Temporal mismatches of life-cycle events-duration of spawning, breeding or moulting season iv. Migration (seasonal and spawning)	**Southeastern Australia**

Chin et al., 2010	Integrated Risk Assessment to Climate Change (IRACC) by assessing vulnerability components and integrating them to derive the predicted vulnerability of each species of sharks and rays	**1. Climate change factors** I. Direct (affecting the species directly) i. Water temperature ii. Ocean acidification iii. Freshwater input II. Indirect (affecting the habitat) i. Ocean circulation ii. Water and air temperature iii. Sea level rise iv. Severe weather v. Freshwater input vi. Light and ultra-violet radiation vii. Ocean acidification **2. Ecological groups defined by habitat types and associated biological and physical processes** **3. Vulnerability components: exposure, sensitivity and rigidity** I. Exposure → Extent of overlap between species' geographical and bathymetric range and habitat use with predicted footprint of climate change factor II. Sensitivity i. Rarity ii. Habitat specificity III. Rigidity (=Adaptive capacity) i. Trophic specificity ii. Immobility iii. Physical or chemical intolerance iv. Latitudinal range	**Australia's Great Barrier Reef**

Present study	Vulnerability assessment framework to develop vulnerability matrix and assign vulnerability rank	**1. Exposure factors** i. Sea surface temperature ii. Rainfall iii. Ocean current (speed & direction) iv. Coastal upwelling v. Chlorophyll concentration **2. Sensitivity attributes** i. Fecundity ii. Complexity in early development iii. Growth coefficient iv. Trophic level v. Longevity or life span vi. Lc/Lm vii. Anomaly in CPUE viii. Exploitation rate ix. Price **3. Adaptive capacity** i. Distribution - horizontal & vertical ii. Duration of spawning iii. Prey specificity	**India**

and multi-ground, these criteria are insufficient to present a true picture of species vulnerability. Moreover, in India which is spread over large geographical area with different climatic conditions, the exposure factors differ between regions. Therefore, following the methodology 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 3).

Table 3. 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 baseline information classified through a series of expert opinion workshops on the subject. A working group of eighteen scientists (appendix 2A), working on different groups of finfishes and shellfishes, from different geographical zones of the Indian coast, Consultant with sound knowledge on stock characteristics, biology and ecology, interacted at three national workshops and evolved a suitably modified methodology to be adopted for different species in various zones.

Selection of geographical zones for the study

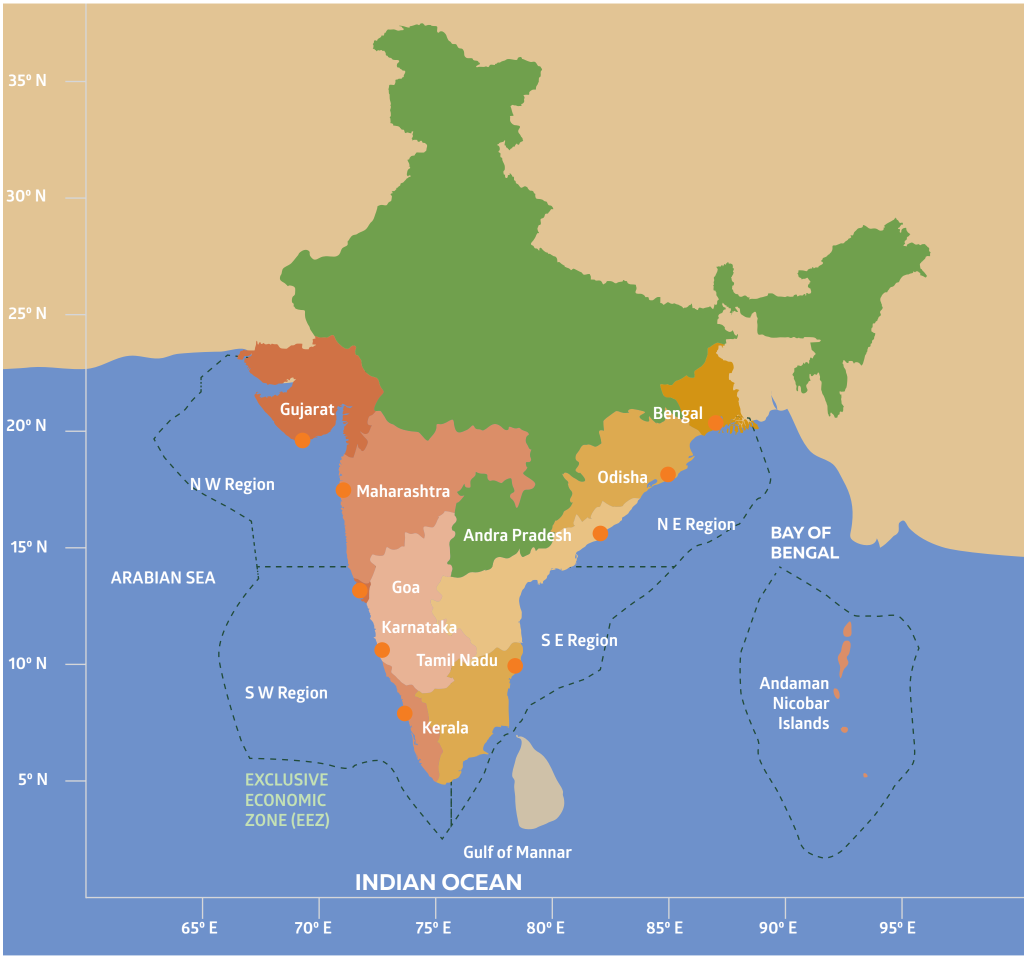


Fig.2. Different geographical zones selected for the study

Peninsular India extends down from the Arabian Sea bordering the Gulf of Kutch on the northwest coast up to Cape Comorin overlooking the Indian Ocean at the southern tip of the country and further north along the Coromandel coast bordering the Bay of Bengal, up to the Sunderbans on the northeast coast of India. The Indian coast exhibits wide diversity in climatic and oceanic conditions, in terms of temperature ranges, precipitation levels, length of seasons, rainfall, riverine flow, wind patterns, current patterns and coastal upwelling. The wide variation in climatic conditions demands evaluation of zone-wise species vulnerability along the coast. Based on this, the coast was divided into four different geographical zones *viz*. northeast (NE), northwest (NW), southwest (SW) and southeast (SE) (Fig. 2.)

Selection of species

Preliminary analysis of historical data on fishery showed that there is a wide variation in the species composition and biological responses of the species in different geographical zones. Accordingly, about 30-36 major commercially important finfishes and shellfishes were selected for the study from each zone, with catch-dependent weighted representation of pelagic, demersal, crustacean and molluscan resources (Fig. 3.) In all, 68 species (Table 4) were selected, of which many were common to two or more zones and some were characteristic to a particular zone.

Table 4. Species selected for vulnerability study

Sl No	Group	Scientific Name
1	Pelagic	*Chirocentrus dorab*
2	Pelagic	*Chirocentrus nudus*
3	Pelagic	*Coilia dussumieri*
4	Pelagic	*Coryphaena hippurus*
5	Pelagic	*Decapterus russelli*
6	Pelagic	*Encrasicholina devisi*
7	Pelagic	*Euthynnus affinis*
8	Pelagic	*Harpadon nehereus*
9	Pelagic	*Katsuwonus pelamis*
10	Pelagic	*Megalaspis cordyla*
11	Pelagic	*Mugil cephalus*
12	Pelagic	*Rastrelliger kanagurta*
13	Pelagic	*Sardinella fimbriata*
14	Pelagic	*Sardinella gibbosa*
15	Pelagic	*Sardinella longiceps*
16	Pelagic	*Scomberomorus commerson*
17	Pelagic	*Scomberomorus guttatus*

Sl No	Group	Scientific Name
18	Pelagic	*Sphyraena jello*
19	Pelagic	*Sphyraena obtusata*
20	Pelagic	*Stolephorus indicus*
21	Pelagic	*Tenualosa ilisha*
22	Pelagic	*Thunnus tonggol*
23	Pelagic	*Thunnus albacares*
24	Pelagic	*Trichiurus lepturus*
25	Demersal	*Carcharhinus limbatus*
26	Demersal	*Cynoglossus macrostomus*
27	Demersal	*Epinephelus diacanthus*
28	Demersal	*Himantura imbricata*
29	Demersal	*Johnius carutta*
30	Demersal	*Lactarius lactarius*
31	Demersal	*Nemipterus japonicus*
32	Demersal	*Nemipterus randalli*
33	Demersal	*Otolithes cuvieri*
34	Demersal	*Otolithes ruber*

Sl No	Group	Scientific Name
35	Demersal	*Otolithoides biauritus*
36	Demersal	*Pampus argenteus*
37	Demersal	*Parastromateus niger*
38	Demersal	*Pennahia anea*
39	Demersal	*Plicofollis dussumieri*
40	Demersal	*Plicofollis tenuispinis*
41	Demersal	*Priacanthus hamrur*
42	Demersal	*Protonibea diacanthus*
43	Demersal	*Saurida undosquamis*
44	Demersal	*Saurida tumbil*
45	Demersal	*Scoliodon laticaudus*
46	Demersal	*Sphyrna lewini*
47	Demersal	*Upeneus sulphureus*
48	Demersal	*Upeneus vittatus*
49	Crustacean	*Acetes indicus*
50	Crustacean	*Charybdis feriata*
51	Crustacean	*Fenneropenaeus indicus*
52	Crustacean	*Fenneropenaeus merguiensis*
53	Crustacean	*Metapenaeopsis stridulans*
54	Crustacean	*Metapenaeus dobsoni*
55	Crustacean	*Metapenaeus monoceros*
56	Crustacean	*Metapenenaeus affinis*
57	Crustacean	*Panulirus polyphagus*
58	Crustacean	*Penaeus monodon*
59	Crustacean	*Penaeus semisulcatus*
60	Crustacean	*Parapenaeopsis stylifera*
61	Crustacean	*Portunus pelagicus*
62	Crustacean	*Portunus sanguinolentus*
63	Crustacean	*Solenocera crassicornis*
64	Molluscs	*Perna viridis*
65	Molluscs	*Sepia aculeata*
66	Molluscs	*Sepia pharaonis*
67	Molluscs	*Sepiella inermis*
68	Molluscs	*Uroteuthis (Photololigo) duvaucelii*

Thirty two species were selected from the NE coast, 36 from the NW coast and 30 each from the SE and SW coasts. Species selection was done based on abundance of a species in a particular zone, its contribution to the fishery, economic importance, growth and reproductive performance and prey-predator interactions.

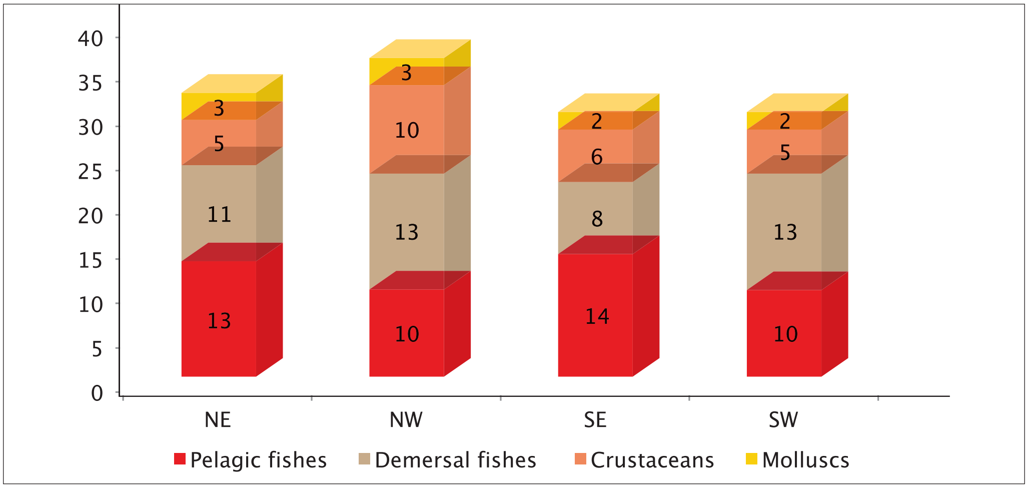


Fig. 3. Group-wise and zone-wise dispersion (by numbers) of selected species

Vulnerability Assessment Design and Selection of Attributes

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 (Chin et al., 2010; Johnson and Welch, 2010; Foden et al., 2013; Pearson, 2014; Pecl et al., 2014). 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. Vulnerability (V) was then estimated from the relation:

$V = (E+S)-A$

Exposure Attributes

Concept: To assess the extent to which different species are liable to be affected by future climate change events from the degree of their exposure to variations in different environmental conditions that influence the biological processes of the species.

Table 5. 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 Meterological 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 Oceancolor Aquamodis

Climate change induced impacts are hard to single out to a particular factor since most environmental traits work together as a conglomerate in eliciting responses from the targets. Incidentally, these factors are themselves inter-related to one another.

Out of several environmental parameters initially considered for inclusion under exposure attributes, six parameters *viz*., sea surface temperature (SST), rainfall, current speed, current direction, upwelling index and chlorophyll concentration, were selected (Table 5).

Sea surface temperature

An environmental parameter on which global warming and climate change have far reaching effects, sea surface temperature (SST) is perhaps the single most influential factor governing the physiological processes of marine organisms. Most tropical species are widely distributed across latitudinal zones and experience large scale SST variations. Over a period of time, such species would have developed innate abilities to adapt to these variations. This may mask the actual effect of rising SST due to climate change. In the absence of information on the specific temperature requirement of each species considered in this study, the criterion taken for the current analysis is SST anomaly. Anomaly estimates effectively normalize the data so that they can be easily compared to derive more accurately the temperature patterns with respect to what is normal for different places within a region. Anomalies better describe climate variability over larger areas than absolute temperatures do, and allow more meaningful comparisons between locations and more accurate calculations of temperature trends.

Implications: Water temperature is a major limiting factor affecting the growth and physiology of most aquatic species. Species that are subject to wider SST anomalies are likely to adapt better to a changing climate rather than species that have remained within the confines of a small range of SST without much variation.

Rainfall

Rainfall is an important climate factor that plays a major role in the spawning and larval cycles of many fish and shellfish species along the Indian coast. Peak spawning season in many fishes have been found to coincide with monsoon rains, particularly along the west coast of India (Qazim, 1973). Rainfall also causes increased river run-off into the sea, creating favourable estuarine conditions for juveniles of several species of fish and shrimp. Variations in rainfall patterns are likely to imbalance the spawning cycles of at least some of the pelagic fishes that move to inshore waters for spawning.

Implications: Together with other climate variations, changes in rainfall pattern and intensity can affect fish abundance primarily by affecting phytoplankton abundance, and thereby, primary production. Species that thrive under varying rainfall trends may adapt better to climate change impacts. Species that rely to a great extent on the timing and pattern of annual rain cycles for different biological processes are likely to be more vulnerable to climate induced changes.

Ocean current speed & direction

Ocean currents have a strong say in the distribution, abundance and migration of fishes. Largely responsible for ocean water mixing and replenishing the productivity of the seas, ocean currents can be a proxy to assess climate change impacts due to warming seas and changing wind patterns. Fish migration, larval movement, plankton distribution and coastal upwelling are all impacted directly by changes in ocean current speed and direction.

Implications: Changes in ocean current patterns will reflect directly on fish abundance and distribution. Species that are dependent on regular ocean currents are likely to be more vulnerable to any climate change induced variations. Pelagic species are likely to be more affected by alterations in ocean current patterns.

Coastal upwelling index

The phenomenon of coastal upwelling is a boon for marine fisheries particularly supported by pelagic fishes and shrimp. Upwelling results in the pumping of nutrient-rich deeper waters into the illuminated surface layers in the coastal zone, resulting in phytoplankton blooms that nourish a vigorously productive zooplankton community as well as massive resident populations of small pelagic fish (sardines, anchovies, etc.) that are extremely important to the world's fisheries (Bakun et al., 2015). However, increased upwelling intensity could eventually create a hypoxic environment which would not favour plankton blooms. In this study, exposure to coastal upwelling was taken as a criterion for arriving at the net score of exposure attributes. Fish species affected by coastal upwelling were given unit score against this attribute while others were given no score.

Implications: Coastal upwelling bears much significance in India's marine fisheries, particularly the mud bank fisheries along the southwest coast during the SW monsoon.

Chlorophyll concentration

Phytoplankton are the primary food producers that form the foundation of marine food webs. Ocean warming may have direct negative impacts on the production of phytoplankton (Bakun et al., 2015), which in turn will have cascading effect on the entire food web, and on the success rate of larval recruitment of several marine species since phytoplankton are food to most marine larvae. Chlorophyll concentrations in the water are a direct indicator of the richness of the phytoplankton population, and thereby, of primary production. The abundance of many pelagic fish species and shellfish larvae is directly correlated with the abundance of phytoplankton and chlorophyll concentrations. Climate change impacts such as variations in SST, rainfall and ocean currents directly impact chlorophyll concentrations.

Implications: The greater the dependency of a species on primary producers, the greater the probability that it will be among the first to be affected by climate change events. Pelagic planktivorous species are most likely to be vulnerable to changes in chlorophyll concentrations.

Scoring

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 was 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 0.1-1.0 was classified as low, 1.1-2.0 as medium and 2.1-3.0 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 6).

The level of exposure of species to SST varies from surface to 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 NW coast. Rainfall and chlorophyll were given weightage for the four zones.

Table 6. 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

Sensitivity Attributes

Concept: To assess the extent to which the biological characteristics of a species could either play a limiting role in the capacity of a species to naturally replenish its stock/population before environmental changes or fishing pressure can induce a drastic reduction therein, or help the species to adapt and withstand the impact of such external forces.

For this study, nine attributes were selected based on time series data for a period of 40 years (1975-2015) on fishery and biology of each species extracted from published information available in CMFRI repository (eprints@cmfri.org.in). Data collected through detailed biological study done during 2011-2015 in different zones under the NICRA project was also used.

Fecundity

The reproductive output of a species is by and large determined by the fecundity of the species. Primarily estimated from the average number of eggs in gravid females at the time of sampling, these estimates are raised to the number of maturation cycles in a year and further to the number of reproductively active years the fish may be presumed to have, based on its longevity and age at maturity. Fecundity is an important index used to derive the annual recruitment and spawning stock ratio in stock assessment, and is therefore a characteristic with marked influence on the abundance and stability of a population.

Implications: High fecund fishes are generally more resilient to negative impacts likely to cause population decline while low fecund fishes are considered to be more susceptible to population decline due to various factors.

Complexity in early development

Stock recruitment of a species is greatly determined by the success with which it progresses through different stages in its life history beginning with egg production to successful spawning, fertilization, hatching, larval dispersion and completion of larval development. Larval dispersion is an important aspect that ensures abundance of the species in nearby areas where favourable conditions for hatching of the eggs and larval development exist. In species with floating eggs, adaptation to the salinity/oxygen conditions is achieved through regulation of the specific gravity/egg diameter (Ojaveer and Kalejs, 2005).

Implications: Fishes with less complex development cycles and fast larval progression are more likely to overcome limitations defined by unexpected changes in the environment. Floating eggs and widespread dispersion are advantageous. In species with long larval cycles, differential dietary patterns and habitat selectivity in the course of larval and juvenile development limit the success of population recruitment in the face of drastic environmental changes and extreme climate events. Demersal eggs which are denser are relatively less advantageous since the options of a wider distribution are closed.

Growth coefficient

The von Bertalanffy growth coefficient 'K' is an ideal proxy for assessing the population growth rate or productivity, which is the capacity of a stock to reproduce and recover (Morrison et al., 2015) when it is subject to reduction due to high mortality rates. The higher the growth coefficient, the better will be the population growth rate, indicating a relatively healthy stock biomass at any given point of time. In general, smaller species with short life spans are likely to grow at faster rates and will exhibit quick population generation time compared to larger, slow growing species with long life spans.

Implications: Species with faster population growth rate, i.e., high growth coefficient, are likely to be more resilient to climate change. Most small pelagics fall within this category and their population productivity, characterised by high growth coefficient, high fecundity, short life span, smaller length at maturity and high number of recruits, tends to put them at a definite advantage over larger species with very small growth coefficients.

Trophic level

Climate change is likely to impact all trophic levels in an ecosystem, albeit to different scales. The ecosystem response to climate change will depend on the response of individual species and the resulting effect on trophodynamic interactions among species (Rijnsdorp et al., 2009). In the marine ecosystem, the first impact of climate change induced variations in the environment is likely to be felt at the lower trophic levels of the plankton community. This will in turn trigger a network of action-reaction responses that will alter the food web and ultimately change the survival and recruitment success of key species, particularly at the higher trophic level of tertiary consumers. Ecosystems with simple trophic food webs are likely to respond faster to climate change, rather than ecosystems thriving on complex networks with a high diversity of biota. In either case, high trophic level species are likely to be the worst-hit.

Implications: High trophic level species are likely to be more vulnerable to climate change than low trophic level species. Although vulnerability of the species is dependent on a multitude of factors eliciting numerous underlying responses, trophic state is a major determinant of the ability of a species to adapt to a change that may upset the ecological network of which it is a part.

Longevity/Life span

Longevity of a species decides some of its vital stock characteristics like growth rate, age at maturity, reproductive output and number of annual recruits. Longevity can at times be a major limiting factor in the successful replenishment of stock subjected to high fishing pressure particularly within an ecosystem with clear differentiation of stock structure, i.e., where juveniles and adults of a species inhabit different sub-habitats. The prolonged exposure of adult populations of a long-living species to exploitation results in large-scale removal of the larger sizes, leading to a reduction in the mean size and age of the population over time. Fishes with high longevity are often slow-growing, with slow reproduction rates; the number of annual recruits is also limited.

Implications: Short-lived species characterised by high reproductive rates are likely to respond to changes in their environment relatively rapidly, whereas the responses of long-lived species will be slower (Perry et al., 2005; Rijnsdorp et al., 2009). In addition to being more vulnerable to stock depletion from overexploitation, species with a long life span are therefore likely to be more vulnerable to climate change.

Lc/Lm

The size of fishes at major life history events is a useful criteria in assessing the growth, reproductive performance and survival success of species within a habitat range. In fishery based assessments using length frequency data, the size at first maturity (Lm), usually calculated as the length at which 50% of the individuals are mature, is an important index which helps in estimating the spawning stock biomass. The length at first capture (Lc) is taken to be the smallest length at which the cumulative catch is 25% of the total catch. The Lc/Lm estimate is a very simple index which indicates the size at which the species is prone to be exploited and the probability of the individuals having bred at least once before capture. This index is dependent to a very great extent on the longevity of the species, its growth and maturation rate, the number of recruits and the fishing pressure it is exposed to. However, this is not a very rigid index as fish species are generally flexible in their age and size at sexual maturity (Rijnsdorp et al., 2009) and often adapt their maturation process to changes in environment (such as increased temperature) or undue fishing pressure.

Implications: Species with a high Lc/Lm index are likely to be less vulnerable to climate change rather than those with a lower index. When entry into the fishery is close to the size at first maturity, the chances of the individuals having spawned at least once are higher, thus allowing an opportunity for natural stock replenishment. This is particularly desirable in the case of long-living fishes with slow maturation rates, poor reproductive output and limited stock size.

Anomaly in CPUE

Fishing is undoubtedly the most important external factor of human origin that jeopardizes status of many marine fish stocks of commercial significance. From subsistence fisheries to demand-based, market-based and need-based targeted fisheries, this industry has evolved through several decades of modernisation, innovations and industrialisation. While the magnitude of fish catch or landing gives a holistic picture of trends in resource distribution, the actual abundance of species or fish stocks is seldom clear. With selective deployment of fishing gear and regulatory measures in fishing effort, the catch per unit effort (CPUE) is a more accurate reader of spatio-temporal changes in species abundance. Changes in CPUE are more often the result of changes in fish abundance caused due to external disturbances.

Implications: Fishing in a climate change impacted ecosystem can show much fluctuation in the catchability of different species. Rijnsdorp et al., (2009) observed that climate change could affect the distribution of particular species and hence their susceptibility to particular fishing fleet, becoming more or less "catchable" as a result. Climate change induced alterations in the reproductive output of a species, and hence its recruitment, will also be reflected in a corresponding decrease or increase in CPUE of any particular gear targeting that species. Fluctuations in CPUE can thus be an indicator of the vulnerability of a species to climate change.

Exploitation rate

Fishing pressure and climate change are bound to interact and create multiple simultaneous alterations within the marine ecosystem, particularly in coastal waters. Exploitation rates for different commercially important species are a major indicator of the future vulnerability of the species to climate change impacts. Fishing will greatly influence the size structure and species composition of fish assemblages and thus will eventually affect predator-prey relationships (Rice and Gislason, 1996; Daan et al., 2005; Rijnsdorp et al., 2009). Climate induced alterations in species composition and abundance are likely to be further enhanced by increased fishing pressure. The impact of interaction between exploitation and climate change will depend on the response of individual species and the disturbances caused in the prevailing patterns of ecosystem structure and function (Heath, 2005; Rijnsdorp et al., 2009)

Implications: Species that are subject to high exploitation are likely to be more vulnerable to climate change. Productivity of fish populations, in terms of biomass, is determined by recruitment, growth, and mortality (Rijnsdorp et al., 2009). Fast rates of removal by fishing may not offer the species sufficient time to replenish its stock through natural recruitment, particularly so in the case of large, slow growing predators like sharks and rock cods. Fishery-induced impoverishment of stock structure can increase the sensitivity of a previously "robust" stock to climate change (Ottersen et al., 2006).

Price

Demand (local and global) and market trends control the price of fish, which in turn augments the process of targeted fishing operations and selective removal of high value species. There will also be an added pressure on particular size groups of the targeted resources. Price thus has an additive role in increasing the impacts of high exploitation rate and overfishing.

Implications: High value fishes are likely to be subject to higher fishing pressure, and are thus prone to be more vulnerable to climate change impacts. Demand, market, price and fishing pressure form a close network that equally influences and is influenced by climate change induced alterations in fish abundance and distribution.

Scoring

For each attribute, scoring was limited to a scale of 1-3, representing low, medium and high ranking. Table 7 presents the sensitivity attributes and the scale limits for each attribute used in the study.

Table 7. Sensitivity attributes with scale limits for impact scoring

Attributes	Low impact	Medium impact	High impact
	1	2	3
Fecundity	< 0.5 million eggs	1000 to 0.5 million eggs	> 1000 eggs
Complexity in early development	Parental care; Pelagic eggs with simple larval development	Demersal eggs	Complex lifecycle with different larval stages
Growth coefficient	< 1	0.51 to 1	> 0.5
Trophic level	> 3	3-3.9	< 4
Longevity/Life span	> 2.5 years	2.5 to 5 yrs,	< 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 ₹	> 100	100-350	< 350

Adaptive Capacity Attributes

Concept: To assess the success of a species in overcoming the negative impacts of environmental aberrations through natural or adaptive elasticity in biological traits and ecological interactions which help regulate or maintain its distribution and abundance even under unfavourable circumstances.

Adaptive capacity attributes are primarily indicative of the ability of a species to adapt to a fluctuating or changing environment. Four attributes were selected for this study - horizontal distribution, vertical distribution, duration of spawning and prey specificity (or number of prey or niche breadth).

Horizontal distribution

High abundance is an important precondition for successful establishment of a species in a new area (Ojaveer and Kalejs, 2005). Habitat specificity limits the abundance of a species. Those species that thrive in specific habitats or within limited geographic boundaries will find it difficult to spread out and survive in the face of climate-induced or unnatural changes in their habitat. Habitat choice is defined by the availability of suitable biotic and abiotic conditions that favour the growth of a species. When the balance of these conditions within a habitat is upset, the species has to either adapt to the change or move on in search of similar habitats. Species that exhibit rigid habitat choices are less likely to be able to do this. An index for understanding the habitat specificity of a species is its horizontal distribution and abundance across geographic boundaries. In the current study, the availability of each species in each of the four zones was taken as the criterion to define its horizontal distribution.

Implications: Species which are available and abundant in a wider geographic range are less likely to be impacted by climate change events. Species with limited horizontal distribution, on the other hand, are likely to be more vulnerable as they are limited by their habitat specificity.

Vertical distribution

The availability of fish species in different realms of the water column, i.e., their vertical distribution, is also an indicator of their ability to withstand wide fluctuations in environmental conditions. Most pelagic species tend to remain within the three-dimensional pelagic habitat, while most demersal species move from the three-dimensional pelagic realm during the egg and larval stages to the two-dimensional habitat of the demersal stages (Rijnsdorp et al., 2009). As a fish moves across gradients in the thermocline, it is likely to encounter sudden variations in hydrographic indices like temperature, pH, dissolved oxygen etc., and is thereby endowed with a natural ability to withstand the impacts of a changing environment. Species that move and forage across pelagic, mid-water and demersal realms with ease are more likely to survive climatic variations than species which inhabit any one specific realm. Sedentary and less mobile benthic species are likely to be affected the most, particularly if they are limited by restricted horizontal distribution also, an excellent example being coral reefs. In many demersal species, the impacts may be naturally mitigated when they produce pelagic eggs and larvae, which ensure some amount of dispersal from the parent habitat. In the current study, the susceptibility to capture by depth-specific fishing gear was taken as the criterion to assess vertical distribution of a species. The more gears (defining different depth ranges) a species is likely to be caught in, the better is its vertical distribution.

Implications: Species which are available in pelagic, mid-water and demersal realms of the water column are less likely to be impacted by climate variations, while species with limited vertical distribution are prone to be more vulnerable as they are limited by their habitat specificity.

Duration of spawning

The spawning strategy adopted by a fish species is the combination of a range of adaptive traits, such as fecundity and timing of spawning, that tends to maximize the number of offspring produced (Mills, 1991; Nunn et al, 2007). The duration of spawning has long-term implications in fisheries, since stock recruitment and stock biomass are defined to a great extent by it (Holt and Byrne, 1998; Garvey et al., 2002; Beaugrand et al., 2003). Climate induced changes in the onset and duration of spawning and the spatial distribution of the spawning stock have direct implications for spawner biomass production per recruit (Tsikliras et al., 2010). The availability of spawning fishes over a protracted part of the year suggests a continuum in larval recruitment, ensuring a steady entry of 0-age classes into the stock at a frequency sufficient to put on hold a population decline from high natural or fishing mortalities.

Implications: Stocks that spawn for several months in a year are likely to be successful in a changing environment. Protracted spawning is believed to enhance offspring survival by allowing the stock to overcome adverse environmental conditions. Conversely, stocks that spawn for restricted period are likely to experience recruitment failure with potential changes in environmental conditions.

Prey specificity/No. of prey groups/Niche breadth

The successful establishment of marine species depends greatly on available food resources for the species throughout all life stages, as different species adapt to the consumption of certain forage species (Ojaveer and Kalejs, 2005). Prey abundance is one of the important factors that induces migration in several fish species and help successful larval recruitment. Cushing (1990) using the term 'match-mismatch' in order to explain the recruitment variability of fish stocks suggested that when larval recruitment matches the peak of primary or secondary production, their survival is maximised and when it does not match the abundance of prey, the recruitment and hence the stock biomass of the next year declines. Prey-predator relationship and relative abundance of either group remain more or less stable in a normal environment seldom subject to extreme climate events or detrimental externally induced alterations. Climate change impacts may alter this composition by affecting one or several species within the food web, which may have rebounding effects on the existence of every single species within that ecosystem. The resilience of species to such changes rests largely on their ability to feed on suitable prey. Prey specificity limits the survival adaptability of its predator by its own vulnerability to climate change, in addition to theirs.

Implications: Species that feed selectively on specific prey groups are less likely to adapt to a changing environment. Species which are more generalist feeders will be able to adapt to alterations in the abundance and availability of prey groups. Understanding how reliant a stock is on specific prey species could predict its ability to persist as the climate changes (Morrison et al., 2015). Diet specialists have proven to be more prone to extinction than diet generalists, as seen in mass extinction events of the past (Clavel et al., 2011).

Scoring

Based on expert opinion for each attribute the scoring was limited to a scale of 1-3, representing low, medium and high. Table 8 gives the various adaptive capacity attributes used and their scoring.

Table 8. Adaptive capacity attributes with scale limits for adaptability scoring

Attributes	Low	Medium	High
	1	2	3
Horizontal distribution	> 5 states	5 to 7 states	Distribution in 8 to 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	> 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% and more) of ripe and spawning individuals of the species in the fishery. Prey specificity/number of prey/niche breadth was defined from data collected during 2011-2015 and from published information available on Fishbase.

Vulnerability 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	Low	Medium	Low
2	Medium	High	Medium
3	High	Medium	High
4	Low	High	Medium

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 (Fig. 4).

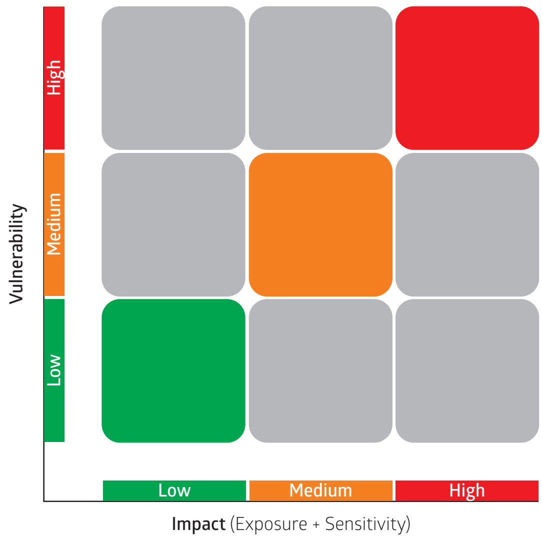


Fig. 4. Vulnerability matrix based on component scores for different attributes.

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 sustainability 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.

Limitations of the study and future scope

This study is the first of its kind in the country and provides a platform for rendering fishery management measures a climate change dimension. It is based on sets of data collated from primary and secondary sources, and care has been taken to select data sets with as much uniformity as possible. However, this study is a rapid holistic assessment of species vulnerability and does not go into in-depth models for each species. The strength of the assessment lies in the exhaustive real-time database on species-wise fishery and biology and opinion-based ranking by eighteen scientists. Nevertheless, there is still scope for improvisation and future work should be oriented towards encompassing all the commercially important species and the non-conventional resources too, which play a major role in the prey-predator web. It is not easy to single out the impacts of climate change events on a species or an ecosystem. The synergistic effect of numerous natural, human and catastrophic factors impact the balance of the marine ecosystem, with its innumerable biota, in complex ways, that create ripples within the interactive network of which they are a part. The stability of the ecosystem depends largely on the manner in which each component species responds to one change triggered by another. An important aspect that has to be incorporated in future studies is the impact of industrialisation in altering the coastal ecosystem of the country.

Synthesis and conclusion

Species vulnerability study in relation to climate change was carried out for 68 commercially important finfishes and shellfishes along the coast of India. The species belonging to different realms in the water column, could be classified as pelagic, bentho-pelagic, demersal and benthic. Considerable variation was observed in the distribution of adults and juveniles of the same species within the water column. The biology of the species was also diverse on many counts. Some species had wide distribution (seerfishes, ribbonfishes, mackerel sardine, lizardfishes, shrimps, cephalopods) and some restricted distribution (Bombay duck, some species of croakers, and shrimps). Most of the species were broadcast spawners with pelagic eggs and larvae, and occupied a range of trophic levels. Of the 68 species, 3 species were elasmobranchs, 45 teleosts, 15 crustaceans and 5 molluscs. Only one mollusc species, *Perna viridis,* was of sedentary nature.

Climate vulnerability

Increasing temperature was the most important driver in climate change. There was zone-wise differentiation in the exposure range for climatic variabilities. Except for the northeast zone, the ranking tended towards moderate vulnerability, with a scoring range of 1.33-1.73. In the northeast zone, the range was 1.66-2.21. The anomalies of climate variables were high along the northeast and northwest zone, whereas they were moderate in the other zones. Temperature anomalies were high along the northeast and southeast zones. Climate exposure ranking of pelagic species was comparatively higher than that of demersal species.

Impact on the species

Ranking of impact, an additive index of exposure and sensitivity attributes, was classified into high, medium and low for the 68 species assessed for vulnerability. There was zonal variation in the dispersion of species with respect to sensitivity and climatic vulnerability (Exposure). Mean sea surface temperature (SST) anomalies, mean upwelling index, current speed and current direction were considered to be important factors in climatic variability score. The climatic variability score was medium in all the zones. The exposure and sensitivity attributes scored high for some species in northeast. The overall climatic vulnerability scores for each zone are given in Figs. 5 a-d.

In general, most of the species showed medium vulnerability to climate along the Indian coast. In northwest zone, 23% of the species studied ranked high in sensitivity attributes

Sensitivity	Exposure: Low	Exposure: Medium		Exposure: High
High		*P. tenuispinis*	*H. imbricata*	
		L. lactarius	*O. biauritus*	
		O. cuvieri	*P. argenteus*	
		S. laticaudus	*T. tonggol*	
Medium		*A. indicus*	*C. feriata*	
		C. dussumeiri	*D. russelli*	
		E. affinis	*E. diacanthus*	
		H. nehereus	*U(L). duvaucelli*	
		M. cordyla	*M. affinis*	
		M. monoceros	*N. japonicus*	
		N. randalli	*P. diacanthus*	
		F. merguiensis	*P. niger*	
		P. polyphagus	*P. sanguinolentus*	
		P. semisulcatus	*P. stylifera*	
		R. kanagurta	*S. crassicornis*	
		S. guttatus	*S. inermis*	
		T. lepturus		
Low				

Fig. 5a. **Northwest**

Sensitivity	Exposure: Low	Exposure: Medium		Exposure: High
High		*F. indicus*	*U(L). duvaucelii*	
		S. tumbil	*L. lactarius*	
		P. tenuispinis	*P. dussumieri*	
		S. commerson	*C. limbatus*	
Medium		*S. lewini*	*R. kanagurta*	
		S. longiceps	*N. randalli*	
		N. japonicus	*T. albacares*	
		K. pelamis	*M. monoceros*	
		E. affinis	*P. viridis*	
		M. dobsoni	*T. lepturus*	
		E. devisi	*C. macrostomus*	
		S. undosquamis	*E. diacanthus*	
		D. russelli	*P. niger*	
		P. argenteus	*P. sanguinolentus*	
		P. pelagicus		
		S. obtusata		
Low				

Fig. 5b. **Southwest**

Sensitivity \ Exposure	Low	Medium		High
High		*F. indicus*	*S. commerson*	
		C. dorab	*C. limbatus*	
		M. monoceros	*M. stridulans*	
		M. dobsoni	*P. monodon*	
		P. pelagicus	*P. sanguinolentus*	
		C. limbatus	*S. lewini*	
Medium		*S. longiceps*	*R. kanagurta*	
		N. japonicus	*N. randalli*	
		K. pelamis	*T. albacares*	
		E. affinis	*T. lepturus*	
		D. russelli	*C. nudus*	
		S. jello	*S. tumbil*	
		S. undosquamis	*P. niger*	
		P. argenteus	*M. cephalus*	
		C. macrostomus	*S. obtusata*	
Low				

Fig. 5c. **Southeast**

Sensitivity \ Exposure	Low	Medium	High	
High		*P. tenuispinis*	*S. guttatus*	*S. commerson*
		U(L). duvaucelii	*T. albacares*	*K. pelamis*
			T. lepturus	*S. jello*
			N. japonicus	*S. undosquamis*
			S. tumbil	*O. ruber*
Medium		*S. aculeata*	*S. longiceps*	*S. gibbosa*
		S. pharaonis	*S. fimbriata*	*R. kanagurta*
			M. cordyla	*T. ilisha*
			N. randalli	*U. vittatus*
			U. sulphureus	*J. carutta*
			P. anea	*P. hamrur*
			M. monoceros	*F. indicus*
			P. monodon	*P. sanguinolentus*
			P. pelagicus	
Low				

Fig. 5d. **Northeast**

Fig. 5a-d. Climatic vulnerability ranking of 68 species of finfishes and shellfishes in four coastal zones of India.

while it was 30% in southwest zone, 43% in southeast and only 6% in northeast zone. In the northeast zone 31% of the species had high exposure and sensitivity ranking (seerfishes, tunas, ribbonfishes, barracudas, threadfin breams, lizardfishes and croakers). Medium sensitivity and high exposure ranking was obtained for 59% of the species studied along northeast zone (sardines, mackerel, dolphinfish, hilsa, threadfin breams, goatfishes, bullseye, shrimps and crabs).

The anomalies in climate variables in the northeast zone were high when compared to the other zones. Values of Lc/Lm and the exploitation rate which denotes the fishing pressure on individual species contributed significantly to the high vulnerability ranking of many species for sensitivity and exposure attributes.

Impact and Adaptive Capacity scoring

Vulnerability scoring for each species was done zone-wise, based on the impact and its adaptive capacity. The results indicate that the east coast species are more vulnerable to climate change when compared to west coast. About 69% of the species studied were highly vulnerable along the Indian coast. Along the east coast, 72% of the species studied were highly vulnerable in the northeast zone, while 77% were highly vulnerable in the southeast zone. In the southwest and northwest zones, 30% and 33% (of the species studied) respectively were highly vulnerable. Zone-wise dispersion of species (in numbers) based on the vulnerability assessment is given in Fig. 6.

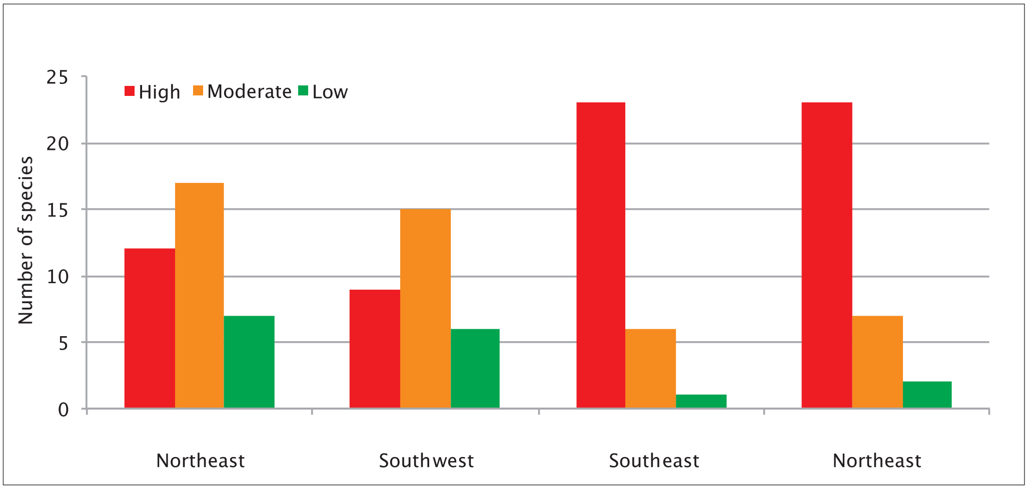


Fig. 6. Zone-wise dispersion of species (numbers) based on vulnerability assessment

About 83% of the pelagic fishes studied were highly vulnerable, followed by demersal fishes (66%), molluscs (60%) and crustaceans (53%).

Metapenaeus monoceros and catfish *Plicofollis tenuispinis* were assessed as highly vulnerable in the southwest, southeast and northeast zones. Black pomfret *Parastromateus niger* was assessed as highly vulnerable in the southwest, southeast and northeast zones. Tunas *Katsuwonus pelamis* and *Thunnus albacares*, threadfin bream *Nemipterus japonicus*, shrimp *Penaeus monodon*, lesser sardine *Sardinella gibbosa*, lizardfishes *Saurida tumbil* and *Saurida undosquamis*, seerfish *Scomberomorus commerson*, barracuda *Sphyraena jello* and ribbonfish *Trichiurus lepturus* were the species ranked as highly vulnerable in the southeast and northeast zones. These species are being exploited by trawl and the impact ranking was high while the adaptive capacity was low, rendering them vulnerable in the three zones. Oil sardine *Sardinella longiceps* was found to be highly vulnerable in the northeast zone. Along the east coast of India, upwelling and the productivity is low and hence the abundance of the resource is also low. So when exploitation increases stock become more vulnerable. Along the southwest coast, upwelling is high, which increases productivity in the area and contributes to the abundance of different resources, even though exploitation is high.

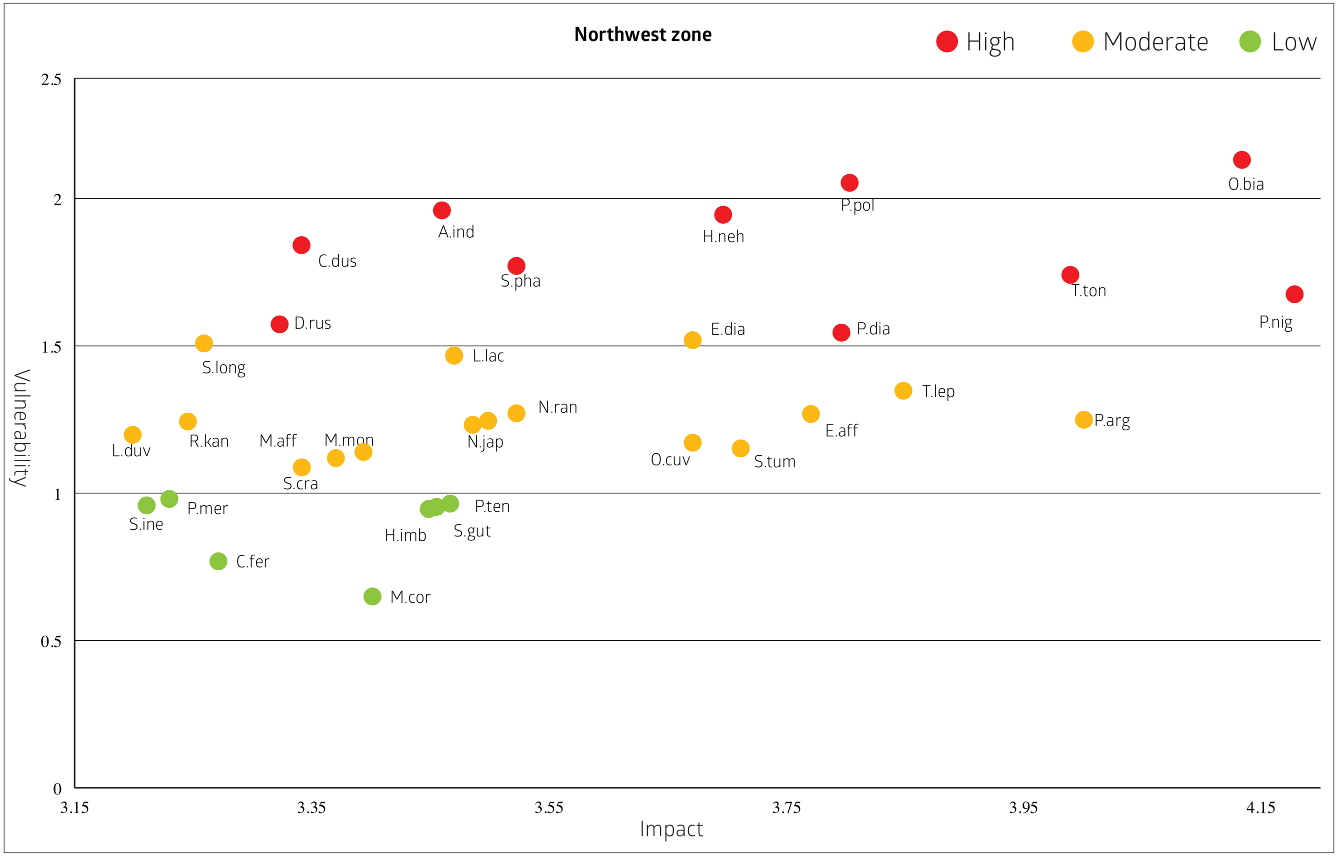
The shark *Carcharhinus limbatus* was vulnerable in the southwest and southeast zone. Impact ranking was high for this shark. Vulnerability of the stock of *Decapterus russelli* was high along the northwest and southeast zone. The stock vulnerability of different species in relation to climate change is given in Fig. 7-10.

Species with high vulnerability

Pelagic fishes

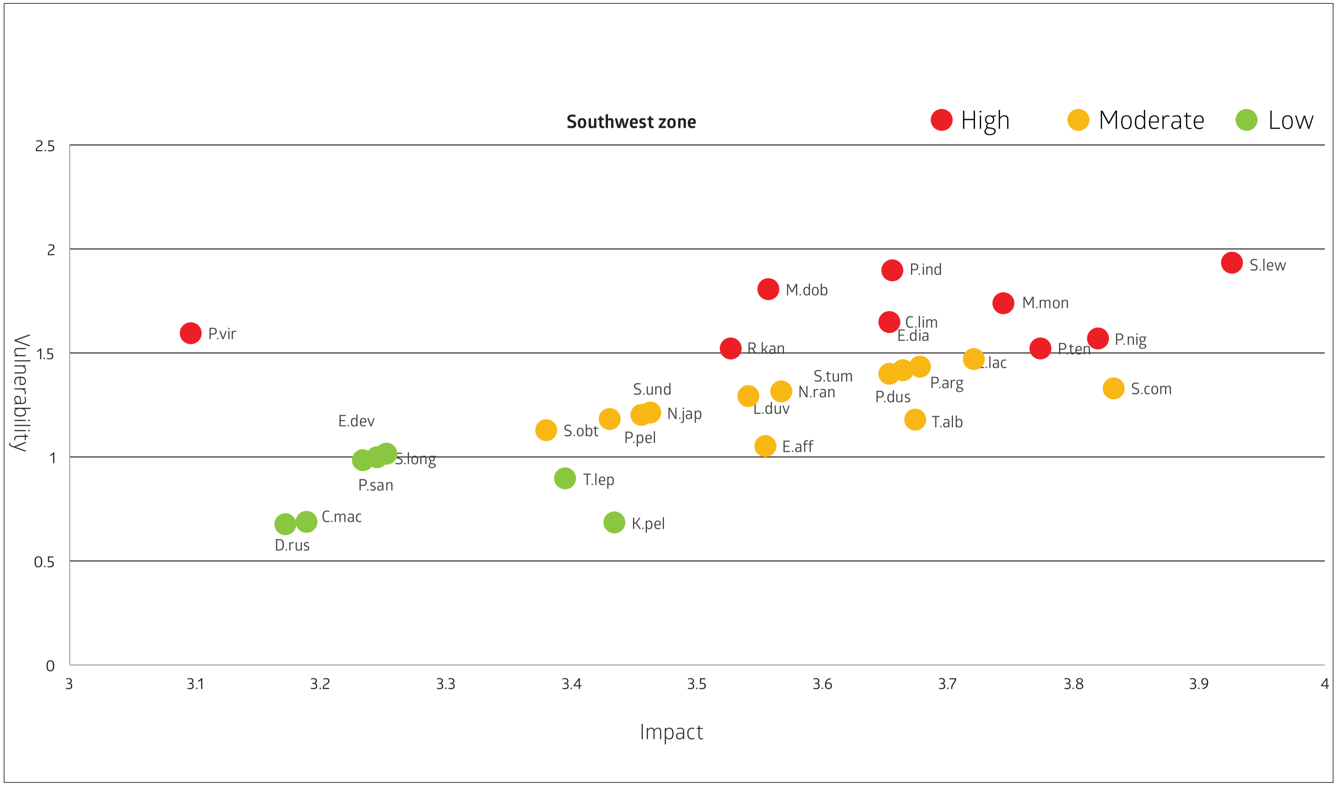
Sardines

Sardines have a wide distribution range along the Indian coast and are exploited by pelagic gears. The three sardine species ranked high in vulnerability were *Sardinella gibbosa*, *S. fimbriata* and *S. longiceps*. These species were ranked high in vulnerability along the southeast and northeast coast respectively. Although the exploitation is maximum in the southwest coast, the high productivity along the coast would have contributed to low vulnerability of the species in the region. Low productivity coupled with exploitation would have induced the species shift to highly vulnerable category along the northeast zone. These species however have high resilience and high rate of generation, and thereby, are quite efficient at making a comeback after a lull following heavy fishing pressure.



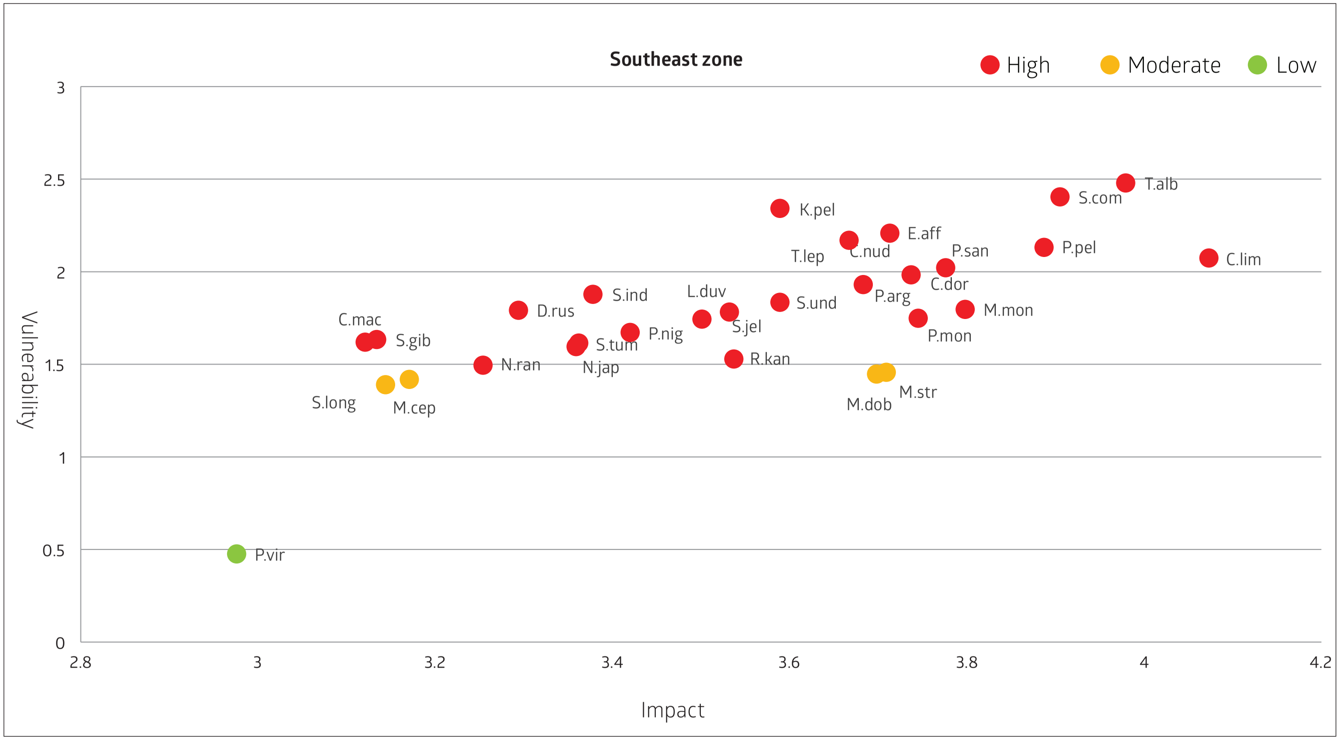
Acetes indicus (A.ind), Plicofollis tenuspinis (P.ten), Charybdis feriata (C.fer), Coilia dussumeiri (C.dus), Decapterus russelli (D.rus), Euthynnus affinis (E.aff), Epinehelus diacanthus (E.dia), Himantura imbricata (H.imb), Harpadon nehereus (H.neh), Lactarius lactarius (L.lac), Urotheuthis (Photololigo) duvaucelii (L.duv), Megalaspis cordyla (M.cor), Metapenaeus affinis (M.aff), Metapenaeus monoceros (M.mon), Nemipterus japonicus (N.jap), Nemipterus randalli (N.ran), Otolithoides biauritus (O.bia), Otolithes cuvieri (O.cuv), Pampus argenteus (P.arg), Protonibea diacanthus (P.dia), Fenneropenaeus merguiensis (P.mer), Parastromateus niger (P.nig), Panulirus polyphagus (P.pol), Portunus sanguinolentus (P.sang), Penaeus semisulcatus (P.semi), Parapeneopsis stylifera (P.sty), Rastrelliger kanagurta (R.kan), Solenocera crassicornis (S.cra), Scomberomorus guttatus (S.gut), Sepiella inermis (S.ine), Scoliodon laticaudus (S.lat), Sepia pharaonis (S.pha), Saurida tumbil (S.tum), Sardinella longiceps (S.long), Thunnus tonggol (T.ton), Trichiurus lepturus (T.lep).

Fig. 7. The stock vulnerability in relation to climate change along northwest coast



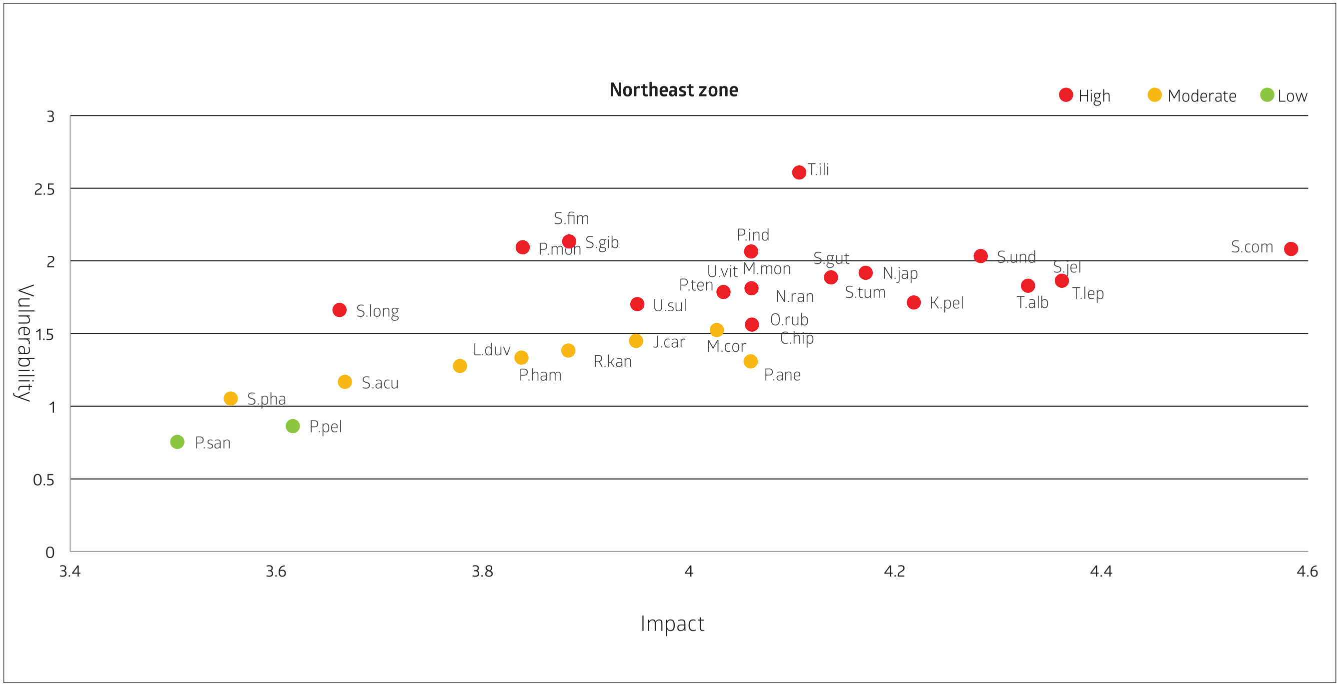
Decapterus russelli (D.rus), Encrasicholina devisi (E.dev), Euthynnus affinis (E.aff), Katsuwonus pelamis (K.pel), Rastrelliger kanagurta (R.kan), Sardinella longiceps (S.long), Scomberomorus commerson (S.com), Sphyraena obtusata (S.obt), Thunnus albacares (T.alb), Trichiurus lepturus (T.lep), Carcharhinus limbatus (C.lim), Cynoglossus macrostomus (C.mac),Epinephelus diacanthus (E.dia), Lacatrius lactrius (L.lac), Nemipterus japonicus (N.jap), Nemipterus randalli (N.ran), Pampus argenteus (P.arg), Parastromateus niger (P.nig),Plicofollis tenuispinis (P.ten),Plicofollis dussumieri (P.dus), Saurida tumbil (S.tum), Saurida undosquamis (S.und),Sphyrna lewini (S.lew), Metapenaeus dobsoni (M.dob), Metapenaeus monoceros (M.mon), Fenneropenaeus indicus (P.ind), Portunus pelagicus (P.pel), Portunus sanguinolentus (P.san), Urotheuthis (Photololigo) duvaucelii (L.duv), Perna viridis (P.vir)

Fig. 8. The stock vulnerability in relation to climate change along southwest zone



Sardinella longiceps (S.long), S.gibbosa (S.gib), Stolephorus indicus (S.ind), Rastrelliger kanagurta (R.kan), Katsuwonus pelamis (K.pel), Thunnus albacares (T.alb) , Euthynnus affinis (E.aff), Trichiurus lepturus (T.lep), Decapterus russelli (D.rus), Scomberomorus commerson (S.com), Chirocentrus dorab (C.dor), C.nudus (C.nud), Sphyraena jello (S.jel), Carcharhinus limbatus (C.lim), Saurida tumbil (S.tum), S. undosquamis (S.und), Nemipterus japonicus (N.jap), N.randalli (N.ran), Parastromateus niger (P.nig), Pampus argenteus (P.arg), Mugil cephalus (M.cep), Cynoglossus macrostomus (C.mac), Metapenaeus monoceros (M.mon), Metapenaeopsis stridulance (M.str), Metapenaeus dobsoni (M.dob), Penaeus mondon (P.mon), Portnus pelagicus (P.pel), Portunus sanguinolentus (P.san), Perna viridis (P.vir), Urotheuthis (Photololigo) duvaucelii

Fig. 9. The stock vulnerability in relation to climate change along southeast zone



Sardinella longiceps (S.long), Sardinella gibbosa (S.gib), Sardinella fimbriata (S.fim), Rastrelliger kanagurta (R.kan), Scomberomorus guttatus (S.gut), Scomberomorus commerson (S.com), Thunnus albacares (T.alb), Katsuwonus pelamis (K.pel), Coryphaena hippurus (C.hip), Trichiurus lepturus (T.lep), Sphyraena jello (S.jel),Megalaspis cordyla (M.cor), Tenualosa ilisha (T.ili), Nemipterus japonicus (N.jap), Nemipterus randalli (N.ran), Upeneus vittatus (U.vit), Upeneus sulphureus (U.sul), Saurida undosquamis (S.und), Saurida tumbil (S.tum), Otolithes ruber (O.rub), Johnius carutta (J.car),Pennahia anea (P.ane), Priacanthus hamrur (P.ham), Plicofollis tenuispinis (P.ten), Metapenaeus monoceros (M.mon), Fenneropenaeus indicus (P.ind), Penaeus monodon (P.mon) Portunus sanguinolentus (P.san), Portunus pelagicus (P.pel), Urotheuthis (Photololigo) duvaucelii (L.duv), Sepia aculeata (S.acu), Sepia pharonis (S.pha)

Fig. 10. The stock vulnerability in relation to climate change along northeast zone

Seerfishes

Among the seerfish species exploited along the Indian coast *S. commerson* ranked high in vulnerability along east coast and *S. guttatus* along the west coast. In India, seerfish is commercially very important considering its high unit value, both in the domestic and international market. As a result, there is indiscriminate harvest of both juveniles and adults by various fishing gears, and there is always the threat of overexploitation. This, together with biological features such as large body size, high size at first maturity and high trophic level, makes this species highly vulnerable. Generally, larger size groups are targeted by large meshed drift gillnet and smaller sizes are caught by trawlers.

Tunas

Exploitation of tunas is high along the east coast of India. The two tunas which are vulnerable along the east coast (southeast and northeast) were *Thunnus albacares* and *Katsuwonus pelamis*. Along southeast coast, *Euthynnus affinis* also ranked as highly vulnerable. These fishes are of large body size. Large fishes have comparatively higher longevity and also have a late age of reproductive maturity. Being large in size, they are more prone to higher exposure to fishing which in turn results in higher mortality of juveniles. Thus these species become more vulnerable when the changes in the climatic variables occur. Compared to *T. albacares* and *K. pelamis, E. affinis* is smaller in size, with faster growth rate. However, this species is more coastal in nature and thereby prone to higher fishing pressure. The high CPUE of *E. affinis* in sensitivity attributes along with the climatic variable scoring has increased its impact scoring, resulting in its inclusion among highly vulnerable species.

Ribbonfishes

Ribbonfishes are bentho-pelagic species exploited mainly by trawl. *Trichiurus lepturus* which is exploited along the coast of India is ranked highly vulnerable along the northeast and northwest zones. Although the species is exploited in all the four zones, the sensitivity attributes *viz*., exploitation and price for the species is high along the two zones which make it more vulnerable in these zones.

Barracuda

The barracuda *Sphyraena jello* which has a wide distribution along the coast of India is highly vulnerable along the east coast. This species is diurnal and solitary, and when young form schools. It feeds mainly on fishes and squid. Though the fishery for adults is throughout, there is a seasonal fishery for juveniles by trawl nets especially during July and August. The adults are caught mainly in hooks and line and gillnet. Overexploitation of this resource and the high price structure has shifted this species to highly vulnerable group along the east coast.

Wolf herrings

Chirocentrus dorab and *C. nudus* form a major fishery along the southeast zone. The exploitation is done by gillnets and trawls. Among the two, *C. dorab* dominates the fishery. The exploitation of the species is high which gives it a high ranking in the vulnerability scoring.

Anchovies

Whitebaits are exploited by trawlnet along the Indian coast. Among the whitebaits, *Stolephorus indicus* is the most dominant species exploited in southeast zone. It is regularly caught in trawls though its exploitation by other traditional gears like ring seine is seasonal. In the sensitivity attributes, exploitation of the species ranked high and this, along with the exposure attributes has given a high impact ranking, defining the resource as highly vulnerable in the southeast coast. The gold spotted anchovy *Coilia dussumieri* has restricted distribution along the northwest zone and changes in the climatic variables would have more impact on the species. The scoring was high for impact and also adaptive capacity, indicating this stock to be highly vulnerable.

Dolphinfishes

Coryphaena hippurus is the common dolphinfish which is exploited mainly by trawl in all the zones. The exploitation along the northeast zone is high when compared to the other zones. Long life span, slow growth and high exploitation rate are some of the attributes which contributed to the high score in the impact ranking making the stock highly vulnerable.

Scads

Decapterus russelli and *Megalaspis cordyla* are the two carangids which are exploited mainly by trawl. *D. russelli* has high vulnerability score in northwest and southeast zones where its exploitation is high. *M. cordyla* is ranked as highly vulnerable along northeast coast. The scoring of sensitivity attributes is high for this species as the CPUE and price scoring is high along northeast coast.

Bombay duck

The Bombay duck, *Harpadon nehereus* has a restricted distribution along northwest coast of India. This species is caught using dolnets and the exploitation is high along this coast. The high exploitation, together with high exposure attributes and low adaptive capacity has made it highly vulnerable along the coast.

Mackerel

The Indian mackerel *Rastrelliger kanagurta* is widely distributed in the Indo-Pacific region. Maximum exploitation of the resource has been recorded from the southwest (Kerala, Karnataka and Goa) coast of India using seines, gillnets and trawls. Karnataka coast is called "mackerel coast" because of its abundance and demand for the fish. The exposure attribute ranking is high because of its pelagic nature, but its adaptive capacity is also high and it has wide distribution along the coast. As the exploitation and the price for the species is high along southwest coast, it is ranked high in vulnerability along this coast.

Hilsa shad

Tenualosa ilisha is the most vulnerable fish along the northeast coast of the country. The main reason for its high vulnerability is its low adaptive capacity. The adaptive capacity is less because of limited vertical and horizontal distribution coupled with high prey specificity. This species spends most of its life in the inshore areas of the sea and undertakes extensive migration ascending the estuaries and rivers for breeding purpose. The spent fish and their progeny migrate down the river back to the seas. The hilsa fishery at present is in depleted state along the northeast zone. All these attributes have made the stock highly vulnerable along the northeast coast.

Demersal Fishes

Sharks

The species highly vulnerable along the coast were *Carcharhinus limbatus* and *Sphyrna lewini*. Their biological characteristics make them more vulnerable to climate change. The growth and maturation rates of sharks are very slow and they have very low fecundity with long gestation periods. This means that sharks have great difficulty in recovering after their populations have declined. Hence these species need special conservation strategies to cope with the climate change.

Threadfin breams

Nemipterus japonicus and *N. randalli* are the two species which have wide distribution along the Indian coast. These species are more abundant beyond a depth of 50 m and is largely exploited by trawlers. Both the juveniles and the adults are exploited along the coast. The juveniles are mainly used for fish surumi and for fish meal plants. The high scoring of the sensitivity attributes especially the CPUE and price has made it highly vulnerable along the east coast of India. This species, however, has a high resilience and high rate of generation, and thereby, is quite efficient at making a comeback inspit of perodic decline in abundance due to heavy fishing pressure.

Pomfrets

The silver pomfret *Pampus argenteus* and black pomfret *Parastromateus niger* form the major fishery along the coast and are exploited mainly by trawl and purse seine. These are considered high value food fishes and are exploited in all size ranges. The high demand for these fishes and subsequent overexploitation has resulted in the stocks becoming highly vulnerable. Black pomfret is highly vulnerable along northwest, southwest and southeast zones, while silver pomfret is highly vulnerable along southeast zone.

Croakers

The species considered in the study are *Otolithoides biauritus*, *Otolithes ruber* and *Protonibea diacanthus* which form a major fishery along the northwest coast of India. The slow growth rate, long life span, overexploitation, and high price, along with the restricted horizontal distribution has made these species highly vulnerable.

Lizardfishes

The lizardfishes *Saurida tumbil* and *S. undosquamis* are exploited mainly by trawlers along both the coasts. The exploitation of these resources is high along the entire east coast of India. This along with the low growth coefficient and higher regeneration time makes it more sensitive to climate change. Although the species have wide range of distribution in all the zones, along the east coast, the length at first capture was considerably lower than length at first maturity which also added to the high score for impact. Juvenile fishery of *S. undosquamis* is also high along the east coast.

Catfishes

The catfish *Plicofollis tenuispinis* forms a fishery in all the four zones. This species is ranked as highly vulnerable along east coast and southwest zone. Low fecundity, long life span and complexity in life cycle (mouth brooding) have contributed to high impact ranking, which, along with the low adaptive capacity has made the stock highly vulnerable.

The flatfish *Cynoglossus macrostomus*, grouper *Epinephelus diacanthus* and goatfishes *Upeneus sulphureus* and *U. vittatus* are the other demersal species assessed to have high vulnerability. Slow growth (for *E. diacanthus*), overexploitation and high CPUE has contributed for the high scoring.

Crustaceans

Among crustaceans, the shrimps *Fenneropeneaus indicus*, *Metapenaeus monoceros*, *M. dobsoni*, *Penaeus monodon* and *Acetus indicus*, crabs *Portunus pelagicus*, *P. sanguinolentus* and the spiny lobster *Palinurus polyphagus* were ranked as highly vulnerable in the assessment. The complexity in the life cycle, high CPUE, overexploitation, high price for the species have resulted in high scoring of the sensitivity attributes. This, coupled with the exposure attributes, has made these stocks vulnerable to climate change.

Molluscs

Squid *Uroteuthis (Photololigo) duvaucelii* and cuttlefish *Sepia pharoanis* were highly vulnerable in southeast and northwest zones respectively. The species are ranked in the highly vulnerable group because of complexity in life cycle (attached eggs), low fecundity, high CPUE and exploitation rate. The bivalve *Perna viridis* is ranked as highly vulnerable along southwest zone as the exploitation is high along the coast. In the other zones there is not much exploitation of this resource.

The vulnerability index of the 68 species in different zones along the Indian coast is given in Table 9.

Vulnerability assessment of Indian fish stocks to climate change indicates that the finfishes and shellfishes along the Indian coast are highly or moderately vulnerable to climate change. The species composition and exposure of the same species in different zones are variable and the study shows the extent to which abundance or productivity of a species could be impacted by climate change. In contrast to the influence of exposure factors, the influence of sensitivity attributes was more pronounced, indicating the diversity of species composition of the resources exploited along the Indian coast. Changes in species composition of the exploited resources in four different zones have been observed in this study and the changes are likely to continue in the future also. Many of the species have potential for change in distribution and distribution changes have already been observed for some species in the ecosystem and have been linked with climate change (Vivekanandan, 2011). This assessment shows that more than half of the resources will be negatively affected by climate change.

Table 9. Zone-wise vulnerability index of different species — High (red), Medium (orange), Low (green), No major fishing (grey)

Sl No	Group	Scientific Name	North west zone	South west zone	South east zone	North east zone
1	Pelagic	*Chirocentrus dorab*	No major fishing	No major fishing	High	No major fishing
2	Pelagic	*Chirocentrus nudus*	No major fishing	No major fishing	High	No major fishing
3	Pelagic	*Coilia dussumieri*	High	No major fishing	No major fishing	No major fishing
4	Pelagic	*Coryphaena hippurus*	No major fishing	No major fishing	No major fishing	High
5	Pelagic	*Decapterus russelli*	High	Low	High	No major fishing
6	Pelagic	*Encrasicholina devisi*	No major fishing	Low	Low	No major fishing
7	Pelagic	*Euthynnus affinis*	Medium	Medium	High	No major fishing
8	Pelagic	*Harpadon nehereus*	High	No major fishing	No major fishing	No major fishing
9	Pelagic	*Katsuwonus pelamis*	No major fishing	Low	High	High
10	Pelagic	*Megalaspis cordyla*	Low	No major fishing	No major fishing	High
11	Pelagic	*Mugil cephalus*	No major fishing	No major fishing	Medium	No major fishing
12	Pelagic	*Rastrelliger kanagurta*	Medium	High	Medium	Medium
13	Pelagic	*Sardinella fimbriata*	No major fishing	No major fishing	No major fishing	High
14	Pelagic	*Sardinella gibbosa*	No major fishing	No major fishing	High	High
15	Pelagic	*Sardinella longiceps*	Medium	Low	Medium	High
16	Pelagic	*Scomberomorus commerson*	No major fishing	Medium	High	High
17	Pelagic	*Scomberomorus guttatus*	Low	No major fishing	No major fishing	High
18	Pelagic	*Sphyraena jello*	No major fishing	No major fishing	High	High
19	Pelagic	*Sphyraena obtusata*	No major fishing	Medium	No major fishing	No major fishing
20	Pelagic	*Stolephorus indicus*	No major fishing	No major fishing	High	No major fishing
21	Pelagic	*Tenualosa ilisha*	No major fishing	No major fishing	No major fishing	No major fishing
22	Pelagic	*Thunnus tonggol*	High	No major fishing	No major fishing	No major fishing
23	Pelagic	*Thunnus albacares*	No major fishing	Medium	High	High
24	Pelagic	*Trichiurus lepturus*	Medium	Low	High	High
25	Demersal	*Carcharhinus limbatus*	No major fishing	High	High	No major fishing
26	Demersal	*Cynoglossus macrostomus*	No major fishing	Low	High	No major fishing
27	Demersal	*Epinephelus diacanthus*	High	Medium	No major fishing	No major fishing
28	Demersal	*Himantura imbricata*	Low	No major fishing	No major fishing	No major fishing
29	Demersal	*Johnius carutta*	No major fishing	No major fishing	No major fishing	Medium
30	Demersal	*Lactarius lactarius*	Medium	Medium	No major fishing	No major fishing
31	Demersal	*Nemipterus japonicus*	Medium	Medium	High	High
32	Demersal	*Nemipterus randalli*	Medium	Medium	Medium	High
33	Demersal	*Otolithes cuvieri*	Medium	No major fishing	No major fishing	No major fishing

34	Demersal	*Otolithes ruber*
35	Demersal	*Otolithoides biauritus*
36	Demersal	*Pampus argenteus*
37	Demersal	*Parastromateus niger*
38	Demersal	*Pennahia anea*
39	Demersal	*Plicofollis dussumieri*
40	Demersal	*Plicofollis tenuispinis*
41	Demersal	*Priacanthus hamrur*
42	Demersal	*Protonibea diacanthus*
43	Demersal	*Saurida undosquamis*
44	Demersal	*Saurida tumbil*
45	Demersal	*Scoliodon laticaudus*
46	Demersal	*Sphyrna lewini*
47	Demersal	*Upeneus sulphureus*
48	Demersal	*Upeneus vittatus*
49	Crustacean	*Acetes indicus*
50	Crustacean	*Charybdis feriata*
51	Crustacean	*Feneropenaeus merguiensis*
52	Crustacean	*Metapenaeopsis stridulans*
53	Crustacean	*Metapenaeus dobsoni*
54	Crustacean	*Metapenaeus monoceros*
55	Crustacean	*Metapenenaeus affinis*
56	Crustacean	*Panulirus polyphagus*
57	Crustacean	*Fenneropenaeus indicus*
58	Crustacean	*Penaeus monodon*
59	Crustacean	*Penaeus semisulcatus*
60	Crustacean	*Parapenaeopsis stylifera*
61	Crustacean	*Portunus pelagicus*
62	Crustacean	*Portunus sanguinolentus*
63	Crustacean	*Solenocera crassicornis*
64	Molluscs	*Perna viridis*
65	Molluscs	*Sepia aculeata*
66	Molluscs	*Sepia pharaonis*
67	Molluscs	*Sepiella inermis*
68	Molluscs	*Uroteuthis (Photololigo) duvaucelii*

Ocean temperature and current speed and direction were the climatic exposure factors which influenced the stock. Large magnitude of change is expected by 2055 for ocean temperature (Hare et al., 2016), thereby contributing most to high and very high exposure. The effects of temperature on species biology and ecology are well documented and various models on the distribution and abundance in relation to temperature have been made (Hare et al., 2010, 2012). These temperature changes would influence the changes in species distribution and composition, which in turn would influence management measures. Hence research has to continue to understand how the temperature affects the species and to parameterize these effects for inclusion in ecosystem and population models (Brown et al., 2004).

In addition to the high influence of a limited number of exposure factors, the importance of biological sensitivity attributes was more variable indicating the diversities in the life history traits of finfishes and shellfishes. Although the biological sensitivity attributes were influential in the ranking of the resources across the zones, the exploitation, Lc/Lm, CPUE are the criteria which influenced more among the sensitivity attributes, apart from the climatic attributes. The species which had complex life cycle, high exploitation and low adaptive capacity were more prone to climate change.

The fisheries in the southwest zone is predominated by pelagic fishes especially sardine and mackerel, which support the western Indian Ocean's largest coastal pelagic fishery. In the Indian Ocean, there are a number of upwelling zones associated with the southwest monsoon. One of them is the Malabar upwelling zone along the southwest coast (Krishnakumar and Bhat, 2008). This increases productivity which supports the pelagic fisheries. Moreover, discharge from rivers is also high along the southwest zone. Thus most of the pelagic fishes had low vulnerability ranking along the southwest zone while the same species had moderate or high vulnerability ranking along the east coast of India. For example, assessment of oil sardine shows that it is highly vulnerable along northeast and moderately vulnerable along the southeast while it is of low vulnerability in the southwest zone. Although the fishing pressure is high along southwest zone, high productivity sustains the fishery along the coast. On the east coast of India the fishing pressure is not recompensed by the productivity. Hence the stocks became vulnerable along northwest, northeast and southeast coast. The high catch of oil sardine along the southeast coast may not sustain for a very long time with the existing fishing pressure.

Species with restricted geographic distribution such as Bombay duck and golden anchovy are highly vulnerable to climate change. The exposure to climate variabilities, along with fishing pressure would increase the risk of the stock becoming depleted or collapsed. Fishes with larger life span, less growth rate (eg. large tunas), and low fecundity (eg. sharks) are found to be more vulnerable to climate change under present fishing pressure.

Of the attributes scored, phenology appeared to be more valuable as a measure for assessing the sensitivity of the shrimp species to climate change. Some shrimp species (eg., *Fenneropeneaus indicus*, *Penaeus monodon* etc.) have an estuarine phase in their life cycle. Any interference in the river flow and current patterns occurring due to climate change would lead to changes in the phenology of the stock. This would make the stock more vulnerable to climate change. A simulation model developed to analyse the dynamics of the Australian prawn stock for 10 years under alternative river discharge scenarios (Ives et al., 2009) indicated that both the growth and movement of prawns were affected by the rates of river discharge. Indian species such as *F. indicus* which are already highly vulnerable along southwest and northeast zones may collapse in the future if conservation measures are not initiated. Stake net fishery and estuarine pollution also affect the recruitment of this species (Pecl et al., 2014). Similar is the case of *P. monodon* along southeast and northeast zones. Moreover changes in pattern of the life cycle of the species would have significant consequences as the level of response to climate change attributes may vary across trophic levels, resulting in mismatches, e.g. between predator and prey (Edwards and Richardson, 2004). Phenology scoring is also important for finfishes and molluscs. This would be an important attribute which may override the adaptive capacity to cope positively to climate change. If current pattern and rate of phenological change are indicative of future trends (Thackeray et al., 2010), trophic mismatching may disrupt the functioning and resilience of the ecosystem, which would increase the risk of stock collapse of the species. Changes of wind speed and wind direction may lead to failure of larval survival and recruitment failure for most of the shrimp and crab species which is depending on low saline areas for their nursery phase.

Of the 69% of the stocks ranked as highly vulnerable to climate change, apart from a few species (sharks, catfishes and green mussel), all the other species are ranked as vulnerable due to overexploitation of the resource coupled with the climatic changes. The exposure to climatic changes is similar for all the species and these stocks respond differently to the change in climate and adapt to the change in environment. But the injudicious exploitation of the resources make them prone to high vulnerability.

The resilient species (sardines, mackerel, threadfin breams) with wide distribution range and high fecundity and adaptive capacity, sustains the fishery along Indian coast. Changes in the distribution, abundance and species composition of commercial resources are occurring and the fishers have generally adapted to the changes. But in future the changes will be more drastic and intense than those caused in the historical years and the stakeholders will need to adapt to these changes (Marshall et al., 2013; Hodgkinson et al., 2014). If judicious exploitation of the resources which are ranked as moderate is not done, these resources when exposed to changes in climatic condition would become vulnerable in future. Since minimizing the exposure to climate change is not possible, proper management measures for optimum exploitation of the resources has to be initiated to sustain the resources. Future management schemes will have to consider the structure and functioning of populations and ecosystems in a wider sense in order to maximise the ability of marine fauna to adapt to future climates (Planque et al., 2010). A strategic and structured approach to adaptation planning has to be undertaken by the managers and stakeholders to minimize loss.

Mitigation

Mitigation measures in the present scenario should ideally target species which are highly vulnerable in two or more coastal zones. From this study, three species were highly vulnerable in three coasts and fourteen species were highly vulnerable in two coasts (Table 10). Of this, thirteen species were highly vulnerable only along the east coast. The aim of mitigation would be to combat vulnerability attributes that may contribute towards decline or movement of stock leading to an eventual fall in fish production. The extent of impact of natural environmental fluctuations vis-à-vis climate change, fishing pressure on individual species, and habitat destruction due to anthropogenic activities are the major external influences on the ecological and biological performance of the species. Of these, implementable mitigation measures are interventions in fishing pressure and habitat destruction.

Among the seventeen species listed as highly vulnerable in at least two zones, fishing

Table 10. List of species with high vulnerability in two or more zones

	Zones	No of zones	Major influencing factor	Major gear
M. monoceros	SW, SE, NE	3	Life history and fishing pressure	Trawl
P. niger	NW, SW, SE	3	Fishing pressure (juvenile)	Trawl
P. tenuispinis	SW, SE, NE	3	Life history and fishing pressure	Trawl
C. limbatus	SW, SE	2	Life history	Trawl
D. russelli	NW, SE	2	Fishing pressure	Trawl
F. indicus	SW, NE	2	Life history and fishing pressure	Trawl
K. pelamis	SE, NE	2	Life history and fishing pressure	Gillnet
N. japonicus	SE, NE	2	Fishing pressure	Trawl
P. monodon	SE, NE	2	Life history and fishing pressure	Trawl
S. gibbosa	SE, NE	2	Fishing pressure and lack of upwelling	Gillnet
S. tumbil	SE, NE	2	Fishing pressure	Trawl
S. undosquamis	SE, NE	2	Fishing pressure	Trawl
S. commerson	SE, NE	2	Fishing pressure	Gillnet
S. jello	SE, NE	2	Fishing pressure	Trawl
T. albacares	SE, NE	2	Life history and fishing pressure	Gillnet
T. lepturus	SE, NE	2	Fishing pressure	Trawl

pressure plays a major role on stock fluctuations and reproductive output of sixteen species, the only exception being the shark *Carcharhinus limbatus*. Sharks, in general are vulnerable to stock decline due to their biological characteristics and life history traits which do not permit them to revive declining stocks naturally. Large size, high longevity, slow maturation, low fecundity, long gestation period and high trophic level put these fishes at a higher disadvantage than most other fish species. The added impetus of demand-based fishing pressure increases their vulnerability to stock depletion at a rate much faster than their capacity for natural replenishment of stocks. Strict fishery management measures including size limits, no-take zones, closed seasons and trade regulations are called for, to control population decline through overexploitation and mitigate the impacts of changing climate.

Catfishes are long-lived slow-growing, low fecund fishes (Devaraj and Vivekanandan, 1999), known to exhibit aggregating behaviour during the breeding season. These fishes were classified as a collapsed fish stock in both Kerala and Karnataka (Devaraj and Vivekanandan, 1999), probably due to large scale exploitation of eggs by seines (Mohammed et al., 2010). According to Raje and Vivekanandan (2008), males are more vulnerable to fishing, resulting in disproportionate sex ratios in the population. The capture of broodstock through targeted bottom-set gillnet fishery (Polara et al., 2002) or hooks & line fishery is a major cause for concern in the fall of catfish catches in areas where it was once abundant. The same is true in the case of large fishes like seerfish and tunas. Targeted gillnet or hooks & line fishing of breeding adults and a simultaneous removal of juveniles by indiscriminate trawl fishing together play a role in rendering the catfish *Plicofollis tenuispinis* highly vulnerable to the added impacts of climate change.

Almost all the other species, except tunas, seerfish and barracudas are exploited mainly by trawl nets. Even these resources are susceptible to capture by trawl nets during their juvenile phase. Management measures are already in force for trawl fishing in Indian waters. Strengthening of strategies like strict enforcement of cod-end mesh size regulation, increase in closed seasons relevant to the zone and strict demarcation of no-take zones. One of the major reasons for increased fishing pressure on demersal species like *Nemipterus japonicus* is the large-scale removal of juveniles. Using cod-end mesh size in keeping with suggested Minimum Legal Size (MLS) will greatly reduce this. This species is seen to be highly vulnerable along the east coast, where peak spawning is recorded during October-December. Seasonal closure of mechanised fishing along this coast, however, is observed during April-June. Lack of overlap of peak spawning months and seasonal fishing closure is an issue that needs to be looked into for many species, particularly along the east coast. There is immediate need, therefore, for judicious break or spread of seasonal closure to ensure protection of breeding stock during peak spawning months. Tsikliras et al. (2010) observed that the extended spawning of a considerable number of (Mediterranean) stocks indicates that fisheries management based on closed fishing seasons may fail to protect part of the spawning population because seasonal closures rarely coincide with the spawning period, in which case the establishment of marine protected areas (MPAs) that will protect the spawning and nursery grounds of most species, as well as ecosystem structure and function is now becoming urgent.

The Indian oil sardine is the only singular species that forms a major contributor to India's marine fish landings. Fluctuations in oil sardine landings often reflect directly as fluctuations in the total marine landings, particularly in the southern states of Kerala, Karnataka, and in recent years, Tamil Nadu. Known to be abundant in the Malabar upwelling zone off the southwest coast of India, studies on distribution patterns of oil sardine along the Indian coast have indicated a distributional extension into the southeast coast (Vivekanandan, 2011) in turn leading to a good fishery for this species along that coast also. Its short life span, high fecundity, rapid growth rate and fast generation time, coupled with the existence of upwelling zones and favourable environment, have kept the vulnerability of this species low in the southern coastal zones. However, along the northwest and northeast zones, this species is highly vulnerable, despite the lack of intensive gear-specific fishing. This is because, in recent years, high demand for this species in the southern states, particularly Kerala, has introduced a market channel for this resource, and there is a considerable increase in its landings by gillnets. The lack of upwelling zones in these regions plays a major limiting role in the recruitment of this species, thereby increasing the pressure on the fished stock.

Shrimps, known for their strategic life history migrations, are made particularly vulnerable by coastal habitat destruction, especially the estuarine zones; fishing pressure augments this vulnerability. While the present study has not focused on the extent of coastal pollution and its impact on critical habitats, future mitigation measures will depend greatly on such assessments since vulnerability status of a species is ultimately a synergistic impact of several limiting factors. The dependency of shrimps on coastal nursery grounds demands that the first mitigation step has to be towards habitat conservation and protection, for which a check on coastal industrialisation and pollution is essential. While shrimp fisheries are highly sensitive to exploitation rates (Dixon and Sloan, 2007), they are environmentally limited due to the highly variable nature of recruitment to the fishery (Huntingford et al., 2006). Strict enforcement of measures such as observing MLS for fishing and trade, release of captured live brooders back to the sea, cod-end mesh size regulation to avoid juvenile shrimp capture and demarcation of no fishing zones in known coastal nursery areas has to be initiated by State legislative bodies through regional MFRA's. Inherent patchy distribution of many shrimp species like *F. indicus* warrants specific region-based approach for resource management and mitigating the impacts of climate change induced vulnerability.

The primary approach towards mitigation must consider the vulnerability of a species as dependent on fishing pressure as much as on climate variations. However, this is not often the case, and the idea that climate and fisheries impacts can be separated is still common. Schiermeier (2004) stated that "to develop a sustainable fisheries policy, it will be crucial to determine how much of changing mortality patterns is due to fishing operations, and how much to environmental trends". Similarly, to mitigate the impacts of a changing climate, it will be crucial to safeguard the resource from the negative impacts of an unmanaged fishery. Worm and Myers (2004) stated that overfishing leads to increased sensitivity of fish populations to climate fluctuations. Fishing is often the dominant source of post-juvenile mortality for exploited species, causing direct reductions in population abundance (Myers et al., 1997; Christensen et al., 2003).

In the context of the present study, mitigation would mean directly managing the fishery of different species, singly, wherever possible, or within the limitations of a mixed fishery, as will be the case in India's marine fishery. Fortunately, several species that contribute in major to the marine fish landings in India, are highly resilient with good bounce-back potential due to their inherent reproductive and growth efficiencies. India's oil sardine fishery and threadfin bream fishery are good examples of this. On a global platform, from relatively limited and narrow uses two decades ago, the concept of vulnerability has emerged as a key dimension, often discussed and analysed along with its counterpart: resilience (Miller et al., 2010). At the ecosystem level, reduced complexity by elimination of species, such as might occur by fishing, may be destabilizing and could lead to reduced resilience to perturbations. On one hand, differential exploitation of marine resources could also promote increased turnover rates in marine ecosystems, which would exacerbate the effects of environmental changes (Planque et al., 2010). On the other hand, environmental variability and climate change also impact marine fisheries especially leading to success and failure of recruitment in most marine fish populations (Rothschild, 1986; Köster et al., 2003; Drinkwater et al., 2010). Indicators are important for identifying who is at risk so interventions can be well targeted. But it is analysis of why they are at risk that tells us what can be done about it (Miller et al., 2010). A continuous assessment of the status of stocks and changes in population parameters would be necessary for effective resource management. Often, previous estimates of population rates (growth, reproduction, recruitment) may not be appropriate for the future, and thus even well-intentioned fisheries management plans may fail because they do not account for climate-driven changes in the characteristics of exploited populations (Mackenzie et al., 2007; Rockmann et al., 2007).

Vulnerability assessments are often part of a continuum of activities that together, enable adaptive capacity and resilience to be assessed and enhanced (Lim and Spanger-

Siegfried, 2004; UNFCCC, 2011). To this means, mitigation through managing the fishery of resilient species identified as vulnerable by studies such as the present one should capitalize on the effective revival time that can be awarded to a fished stock under a judiciously limited fishing pressure. Such a measure however, would require the active cooperation of stakeholders and management implementing bodies.

Conclusion

This study was aimed to provide a broad assessment of vulnerability of fishes and shellfishes due to climate change along the Indian coast and the results will act as an effective tool in understanding the species to be prioritised zone wise and the extent to which management must be done. This assessment will help in adding a climate change perspective to management measures. Furthermore, the assessment of the resources would help fisheries managers in formulating policies related to the sustainable exploitation of resources with special attention to the species which are highly vulnerable in each zone. Efforts to reduce the fishing mortalities of the vulnerable species could be initiated. The assessment would contribute to the development of region specific ecosystem based fisheries management and it would be useful for identification of species-specific mitigation measures in relation to climate change.

The study is the first of its kind in Indian marine fisheries and the result of the study would help in prioritizing strategies for adaptation and mitigation measures to cope with climate change. In the present study, a holistic approach of pressure on the resources in terms of environmental variability and anthropological interventions are taken for vulnerability assessment. Since climate change in terms of increasing temperature, variations in current speed and directions etc., are projected with very high reliability in various IPCC scenarios, the only option left with the fishery managers for keeping the fisheries sustainable is to make needful alterations in the fishing pressure and fishing methods. The present vulnerability ranking of the species in different zones will be a handy tool to conserve the species which are ranked as highly vulnerable and also which tend to move to high vulnerability category, through policy level interventions.

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Glossary of Technical terms used in the document

Adaptive capacity	Ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (source: IPCC).
Anthropogenic	Resulting from or produced by human beings.
Anomaly	An anomaly is the deviation in a quantity from its expected value, e.g., the difference between a measurement and a mean or a model prediction.
Asymptotic length	Length the fish in a stock would attain if they were to grow for an infinitely long period. Not the largest observed size of a species (L_∞).
Asymptotic weight	A parameter of the von Bertalanffy Growth Function, q.v., expressing the mean weight the fish in a stock would attain if they were to grow for an infinitely long period (W_∞).
Benthic organisms	Which live on the bottom of a water body, in it or near it.
Biomass	The total weight of a group (stock) of living organisms in an area at a particular time.
Bloom	A rapid and localised increase in the density of plankton resulting from a nutrient rich habitat. The nutrients may come from upwelling, mixing or pollution and the bloom can kill fish populations through toxins or oxygen depletion.
Cannibalism	Eating members of one's own species
Catch	The number or weight of fish caught by a fishery, by fishing gear or by angling. May be the total amount caught, only the amount landed, or not kept but released. Usually expressed in terms of wet weight.
Climate change	Change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a

	distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (source: IPCC).
Climate prediction	A climate prediction or climate forecast is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, inter-annual or long-term time scales (source: IPCC).
Climate variability	Natural variability of the climate system, in particular on seasonal and longer time scales, which predominantly occurs with preferred spatial patterns and time scales (source: IPCC).
CMFRI	Central Marine Fisheries Research Institute, Kochi, India
Complexity in early development	The species not having viviparity or parental care, extended larval periods, require different types of ecosystems for their survival are termed as complexity in early development
Continental shelf	The area of gently sloping sea bottom from the shore out to a depth of about 200 meters. It may be only a few kilometers offshore where the sea floor descends rapidly to great depths or may be extensive and form an accessible habitat for many commercial fishes.
Continental slope	The steeply sloping sea bottom strating from continental shelf.
CSIRO	The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is the federal government agency for scientific research in Australia and is based in Canberra.
Demersal	Bottom or near-bottom of the sea; inhabiting species living at the bottom or in near-bottom waters in the commercial fishing grounds include flatfish, threadfin breams, silverbellies and shrimps.
Detritus	Debris, disintegrated material or particulate material that enters into an aquatic system. If derived from decaying organic matter it is organic detritus.
DGN/GN	Drift gillnet boats, gillnet fleet
Discard	The part of a fish catch that is thrown overboard, but which may be of important ecological or commercial value. Also the act of throwing fish overboard. The discard typically consists of “non-target” species, damaged specimens or undersized specimens. The fish may be alive or dead, whole or in parts. Estimates of discards are made by observers and logbook records. Also called discarded catch.
Ecosystem	The complex of living organisms and environmental conditions that function as a unit.

Effort	The total fishing gear in use for a specified period of time; when two or more kinds of gear are used, they must be adjusted to some standard type before being added.
Exploitation rate(E)	The proportion of a population at the beginning of a given time period that is caught during that time period (usually on a yearly basis). A catch in a year of 10 fish out of a stock of 100 is a 10% exploitation rate. Also the ratio of fish caught to total mortality (= F/Z when fishing and natural mortality take place concurrently (Ricker, 1975)). Also called rate of exploitation. Abbreviated as E.
EBFM	Ecosystem-based Fisheries Management or Ecosystem Approach to Fisheries (EAF)
ENSO (El Nino-Southern Oscillation)	A set of interacting parts of a single global system of coupled ocean-atmosphere climate fluctuations. The Pacific Ocean signatures, El Niño and La Niña produce large temperature fluctuations in surface waters of the tropical Pacific Ocean. ENSO is the most prominent known source of inter-annual variability in weather and climate around most parts of the world (~3 to 8 years).
Exclusive Economic Zone (EEZ)	This zone typically extends offshore to a distance of 200 nm from the coast, and surrounds most countries.
Exposure	Nature and degree to which a species is exposed to climatic variations.
F	Instantaneous rate of fishing mortality (mortality due to fishing)
Fisherman	A person who is engaged in fishing as a owner or labourer, and in activities related to fishing, processing and marketing at primary (landing centre) level.
Fishing effort	Effective fishing effort, abbreviated as F or f (Ricker, 1975).
GN	Gillnet
Gonadal products	The products by sexual organs, ovary and testis, producing the primary sexual products (eggs and sperm).
Greenhouse gas (GHG)	Gaseous constituents of the atmosphere, both natural and anthropogenic that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere (source: IPCC).

Growth coefficient (K)	Curvature parameter of the VBGF (increase in weight of a fish per year),denoted as K.
Habitat	The place where a species lives, defined by necessary biological and physical parameters, e.g. tidal pool, marsh, reef, continental shelf homogenous uniform.
Horizontal distribution	Distribution of species across the regional boundaries
International Comprehensive Ocean-Atmosphere Data Set (ICOADS)	ICOADS is a major update of an extensive surface marine meteorological data collection. It is maintained as a cooperative effort between National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA).
Inter-governmental Panel on Climate Change (IPCC)	The Intergovernmental Panel on Climate Change is the leading body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) for the assessment of climate change, to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences.
Km	Kilometer (0.621 mi).
L-50	length at which 50% of the fish will be vulnerable to the fishing gear
L∞	asymptotic length, i.e., the (mean) length the fish of a given stock would reach if they were to grow forever
Lc	mean length of fish at first capture; equivalent to L50
Lm	mean length first maturity (or massive maturation)
Lc/Lm	Ratio of mean length of fish at first capture to length at first maturity, which is used to understand the vulnerability of the species to particular fishing operations.
Lm/L∞	Ratio of length at first maturity to asymptotic length indicating relative reproductive costs.
Lmax	Maximum length reached by the fish of a given stock, may also be predicted from the largest specimens of several samples using the extreme value theorem.
Lmean	Mean length of a species of fish computed from L' upward in catch curve
Lopt	The length class with the highest biomass in an unfished population, where the number of survivors multiplied with their average weight reaches a maximum (Beverton 1992)

Lr	Mean length at first recruitment
Landings	The weight of a catch as fish or fish products brought to a wharf or beach. Also called landed weight. Note that the catch is different and may include discards.
Longevity/Life span	Longevity/life span is a measure of the amount of time living organisms survive between birth and death.
M	Instantaneous rate of natural mortality, i.e., death rate due to all causes except fishing.
Maturity	Fish of a given age/size capable of reproduction; attainment of first spawning.
Mechanised fishing sector	Organised sector which uses crafts fitted with in-board engines, such as purse seiner, trawler and gillnetter.
MDF	Multi-Day Fishing Fleet, Trawlers which undertake voyages lasing two days or more.
Mortality rate	The rate at which the numbers in a population decrease with time due to various causes. The proportion of the total stock (in numbers) dying each year is the annual mortality rate. To facilitate calculations, mortality is expressed as an exponential rate (called instantaneous rate) thus Nt/N0 = e-Z = e-(M+F) in which Nt/N0 is the survival rate, M the natural mortality rate, F the fishing mortality rate, and Z the total mortality rate (of deaths due to predation or disease).
Mechanised craft	A fishing boat with inboard engine.
Meridional wind (V)	Relative to lines of longitude (meridians: north south direction); the opposite is zonal.
Mitigation	An anthropogenic intervention to reduce the anthropogenic forcing of the climate system. It includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks (source:IPCC).
Motorised craft	A fishing boat with outboard motor
Multivariate ENSO Index (MEI)	Composite index of six observed variables, *viz*., sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. The MEI is calculated as the first unrotated Principal Component (PC) of all six observed fields combined. Positive MEI values are related to warm phase or El Nino events and negative values to cool phase or La Nina events.

NASA	National Aeronautics and Space Administration of USA
Nekton	Organisms of relatively large size which have fairly strong locomotory powers (as compared to plankton) and swim in the water column independent of currents, e.g. most adult fishes.
Niche overlap	An overlap in resource requirements by two species; is an overlap index which explains how a single prey (food) is shared between two predators
NOAA	The National Oceanic and Atmospheric Administration (NOAA) is an American scientific agency within the United States Department of Commerce focused on the conditions of the oceans and the atmosphere
Over-exploitation	Rate of exploitation where the resource stock is drawn down below the size that would, on average, support the long term maximum potential yield of the fishery.
PFEL	Pacific Fisheries Environment Laboratory
Population dynamics	The study of fish populations and how fishing mortality, growth, recruitment, and natural morality affect them over time.
PS	Purse seine- a seine used to encircle a school of fish in open water. It is set at speed from a large, powered vessel and the other end is anchored by a small boat. A purse line at the bottom of the net allows it to be closed like a purse.
Pelagic	Surface and subsurface of the sea; inhabiting species living at the surface or in upper ocean waters, include tunas, anchovies and sardines.
Phenology	The timing of events in an animals' life, such as when it lays eggs, migrates, or hibernates. As these events may be sensitive to climate, phenological studies may provide indirect evidence of climate impacts on biology.
Niche breadth	The niche width is defined as the parameters of this range which are determined by biotic and abiotic factors such as suitable climate and appropriate food sources.
Price	Commercial value in Indian rupees.
Recruit	An individual fish that has moved into a certain class, such as the spawning class or fishing-size class through growth, migration, etc.
Resilience	Capacity of a natural system such as a fisheries community or ecosystem to recover from heavy disturbance such as intensive fishing.

Respiration	A flow (flows) of mass or energy that is not directed toward, nor could be used by any other box (es). When Carbon is used as currency respiration appears as CO_2.
SDF	Single-Day Fishing Fleet, Trawlers which make daily trips.
Stock	The part of a fish population which is under consideration from the point of view of actual or potential utilisation; stock (noun) = a distinct genetic population, a population defined by movement pattern, part of a population potentially harvestable, i.e. an assessment or management unit, or a quantity of fish from a given area; usually isolated from other stocks of the same species and so self-sustaining. May be a total or a spawning stock.
Scalar wind (W)	Describes the speed or magnitude of the wind.
Sea level pressure	The atmospheric pressure at mean sea level, either directly measured or, most commonly, empirically determined from the observed station pressure.
Sea level rise	An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an alteration to the volume of the world ocean. Relative sea-level rise occurs where there is a net increase in the level of the ocean relative to local land movements.
Sea surface temperature	Water temperature close to the sea surface.
Sensitivity	Degree to which a species is affected, either adversely or beneficially, by climate change
Southern Oscillation Index	A measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific Ocean during El Nino and La Nina episodes. Traditionally, this index has been calculated based on the differences in air pressure anomaly between Tahiti and Darwin (Australia).
Stakeholder	A person or an organisation that has a legitimate interest in a project or entity, or would be affected by a particular action or policy.
tc	Mean age at first capture, corresponding to Lc
tmax	Longevity, approximate maximum age that fish of a given population would reach.
Trophic level	(Troph), Classification of organisms or natural communities according to their place in the food web, Trophic level = 1+ mean trophic level of the food items.

Traditional craft	A boat without any mechanical device for propulsion and fishing.
Upwelling	An upward movement of cold, nutrient-rich water from the ocean depths, often associated with great production of fish and fisheries. For fisheries, the most important types are wind-induced coastal upwelling where the upward movement is a consequence of wind stress (along shore) and Eckman transport (offshore).
United Nations Framework Convention on Climate Change (UNFCCC)	Support cooperative action by countries to combat climate change and its impacts on humanity and ecosystems. Guided by the Parties to the Convention, UNFCCC provide organisational support and technical expertise to their negotiations and institutions and facilitate the flow of authoritative information on the implementation of the Convention.
Vulnerability	Degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes (source: IPCC).
Vertical Distribution	Depth-wise distribution of a species or a group
W_∞	Asymptotic weight, i.e., the (mean) weight the fish of a given stock would reach if they were to grow forever.
Yield	Catch in weight. Catch and yield are often used interchangeably. Amount of production per unit area over a given time. The sustainable yield is the quantity of fish which can be taken from a stock (usually on an annual basis) without severely depleting or eliminating that stock.
Yield-per-recruit analysis	Analysis of how growth, natural mortality, and fishing interact to determine the best size of the fish at which to start fishing them, and the most appropriate level of fishing mortality. The yield-per-recruit models do not consider the possibility of changes in recruitment (and reproductive capacity) due to change in stock size. They also do not deal with environmental impacts.
Z	Instantaneous rate of total mortality (the sum of natural and fishing mortalities)
Zonal wind (U)	Along lines of latitude (i.e. east-west direction); the opposite of meridional.

Annexure 1

Species sheets with sensitivity and adaptability attributes

Chirocentrus dorab

Wolf herring

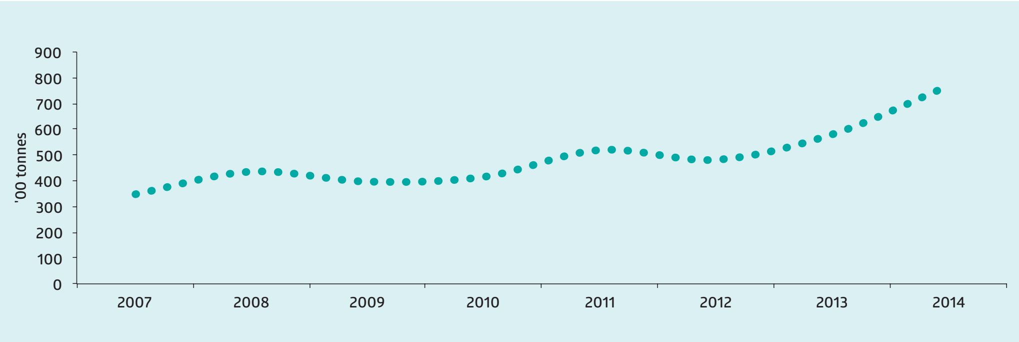
Class : Actinopterygii
Order : Clupeiformes
Family: Chirocentridae

L_{∞} (cm)	:	104.90
Annual growth coefficient (K)	:	0.73
Life span (years)	:	16.90
Lm (cm)	:	49.20
Lc/Lm	:	0.74
Absolute fecundity (in million numbers)	:	0.60

Trophic level	:	4.4
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.612
Price (₹/kg)	:	100-120

Major gears	:	Trawl, gillnet, seines

Duration of spawning (months)	:	12
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Chirocentrus nudus

Wolf herring

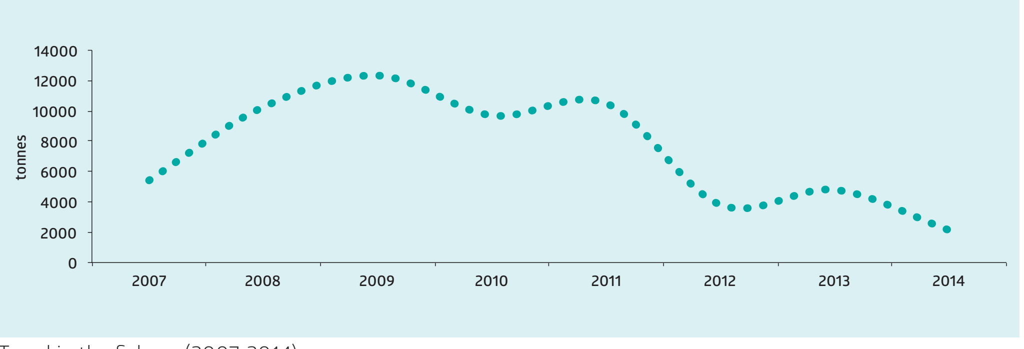
Class : Actinopterygii
Order : Clupeiformes
Family: Chirocentridae

L_∞ (cm)	:	98.7
Annual growth coefficient (K)	:	0.78
Life span (years)	:	12.00
Lm (cm)	:	43.40
Lc/Lm	:	0.80
Absolute fecundity (in million numbers)	:	0.56

Trophic level	:	4.4
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.756
Price (Rs/kg)	:	100-120

Major gears	:	Trawl, seines

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Coilia dussumieri

Golden anchovy

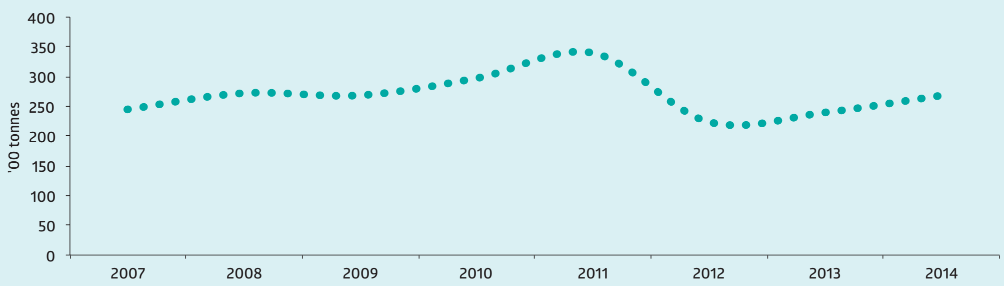
Class : Actinopterygii
Order : Clupeiformes
Family: Engraulidae

L_∞ (cm)	:	21.7
Annual growth coefficient (K)	:	1.3
Life span (years)	:	2.2
Lm (cm)	:	16.2
Lc/Lm	:	0.97
Absolute fecundity (in million numbers)	:	0.001-0.004

Trophic level	:	3.4
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.56
Price (Rs/kg)	:	52-65

Major gears	:	Trawl, bagnet

Duration of spawning (months)	:	4
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Stolephorus indicus

Indian anchovy

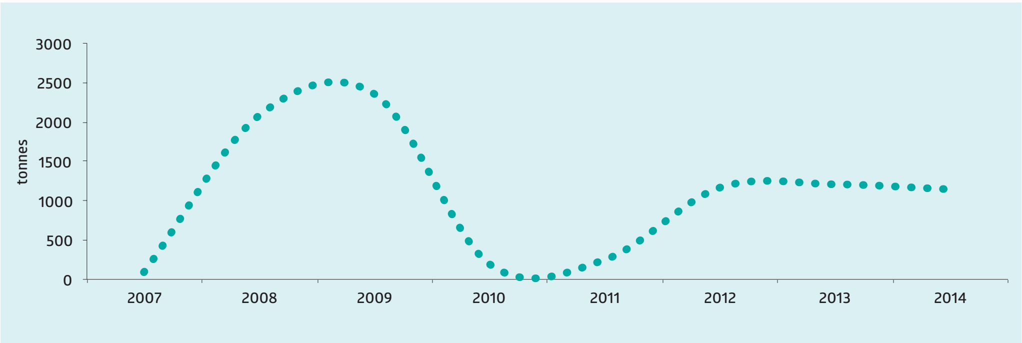
Class : Actinopterygii
Order : Clupeiformes
Family: Engraulidae

L_∞ (cm)	:	18.4
Annual growth coefficient (K)	:	1.05
Life span (years)	:	2.7
Lm (cm)	:	11.4
Lc/Lm	:	0.65
Absolute fecundity (in million numbers)	:	0.009-0.025

Trophic level	:	3.6
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.56
Price (Rs/kg)	:	50-70

Major gears	:	Trawl, seines

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Encrasicholina devisi

Devi's anchovy

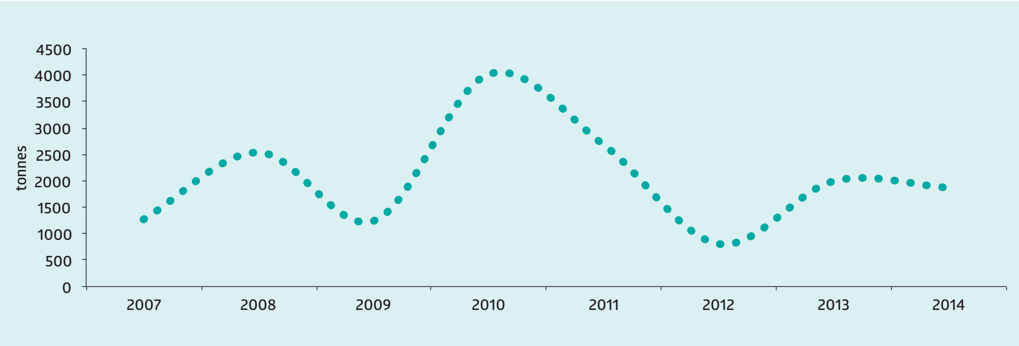
Class : Actinopterygii
Order : Clupeiformes
Family: Engraulidae

L_∞ (cm)	:	11.0
Annual growth coefficient (K)	:	1.6
Life span (years)	:	2.0
Lm (cm)	:	6.8
Lc/Lm	:	1.02
Absolute fecundity (in million numbers)	:	0.001-0.004

Trophic level	:	3.2
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.80
Price (Rs/kg)	:	30-50

Major gears	:	Trawl, bagnet

Duration of spawning (months)	:	4
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Coryphaena hippurus

Dolphinfish

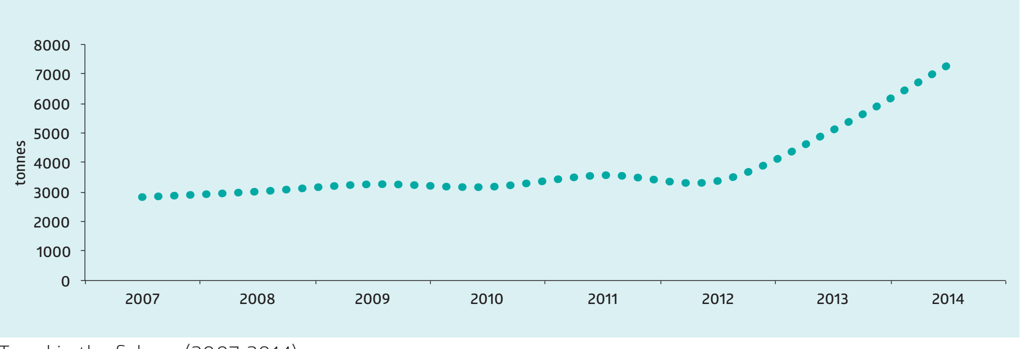
Class : Actinopterygii
Order : Perciformes
Family: Coryphaenidae

L_∞ (cm)	:	112.3
Annual growth coefficient (K)	:	1.03
Life span (years)	:	14.2
Lm (cm)	:	48
Lc/Lm	:	0.88
Absolute fecundity (in million numbers)	:	0.2-0.3

Trophic level	:	4.22
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.50
Price (Rs/kg)	:	90-110

Major gears	:	Gillnet, hooks and line

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Decapterus russelli

Indian scad

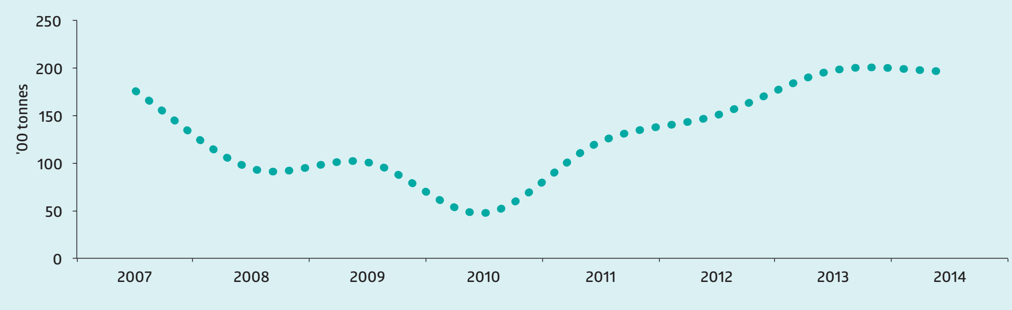
Class : Actinopterygii
Order : Perciformes
Family: Carangidae

L_∞ (cm)	:	25.6
Annual growth coefficient (K)	:	1.23
Life span (years)	:	3.1
Lm (cm)	:	18.2
Lc/Lm	:	0.70
Absolute fecundity (in million numbers)	:	0.02-0.08

Trophic level	:	3.1
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.50
Price (Rs/kg)	:	50-90

Major gears	:	Trawl, gillnet, seines

Duration of spawning (months)	:	10
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Megalaspis cordyla

Horse mackerel

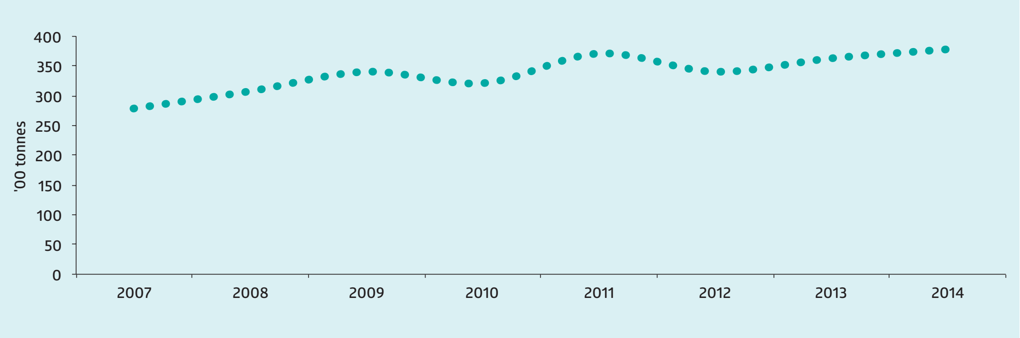
Class : Actinopterygii
Order : Perciformes
Family: Carangidae

L_∞ (cm)	:	56.0
Annual growth coefficient (K)	:	1.21
Life span (years)	:	2.4
Lm (cm)	:	25.0
Lc/Lm	:	0.82
Absolute fecundity (in million numbers)	:	0.2-0.5

Trophic level	:	4.4
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	70-85

Major gears	:	Trawl, seines, gillnet

Duration of spawning (months)	:	10
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Euthynnus affinis

Little tunny/Kawakawa

Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	81.92
Annual growth coefficient (K)	:	0.90
Life span (years)	:	4.0
Lm (cm)	:	38.0
Lc/Lm	:	1.08
Absolute fecundity (in million numbers)	:	0.3-0.5

Trophic level	:	4.1
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.45
Price (Rs/kg)	:	80-120

Major gears	:	Gillnet, hooks and lines

Duration of spawning (months)	:	3
Complexity in early development:	:	Pelagic eggs with simple larval development

Trend in the fishery (2007-2014)

Thunnus tonggol

Longtail tuna

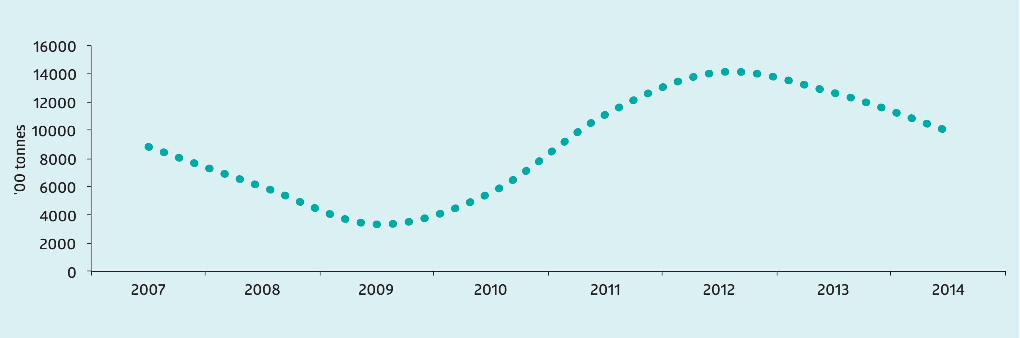
Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	123.5
Annual growth coefficient (K)	:	0.60
Life span (years)	:	8.1
Lm (cm)	:	52.5
Lc/Lm	:	0.93
Absolute fecundity (in million numbers)	:	0.1- 0.5

Trophic level	:	4.4
Niche breadth	:	Medium
Horizontal distribution	:	low
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	150-200

Major gears	:	Gillnet

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Thunnus albacares

Yellowfin tuna

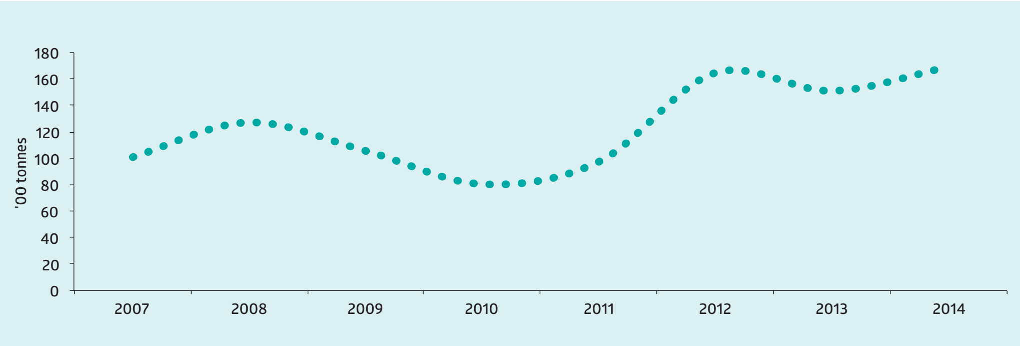
Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	209
Annual growth coefficient (K)	:	0.30
Life span (years)	:	11.1
Lm (cm)	:	70.0
Lc/Lm	:	0.77
Absolute fecundity (in million numbers)	:	3.0

Trophic level	:	4.4
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	150-200

Major gears	:	Gillnet

Duration of spawning (months)	:	2
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Katsuwonus pelamis

Skipjack tuna

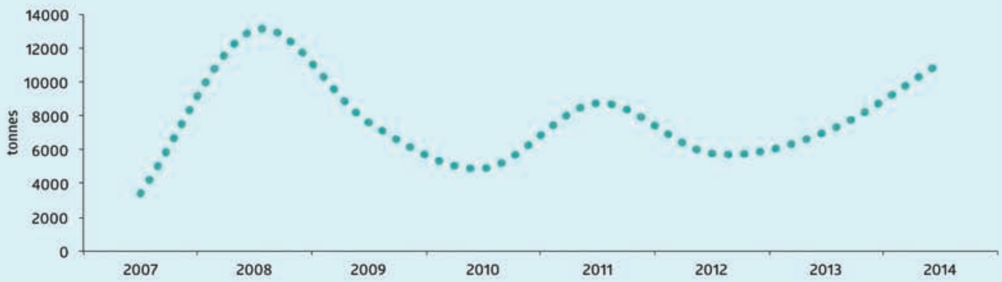
Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	78
Annual growth coefficient (K)	:	0.64
Life span (years)	:	11.1
Lm (cm)	:	40.0
Lc/Lm	:	0.77
Absolute fecundity (in million numbers)	:	3.0

Trophic level	:	4.4
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	150-200

Major gears	:	Gillnet

Duration of spawning (months)	:	2
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Harpadon nehereus

Bombay duck

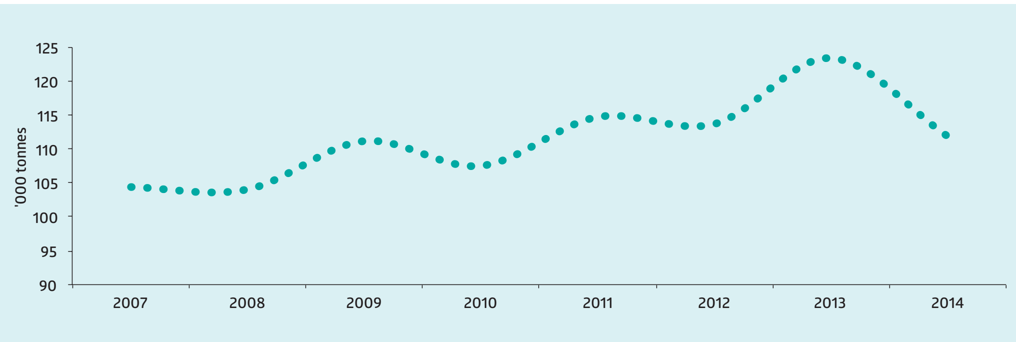
Class : Actinopterygii
Order : Perciformes
Family: Synodontidae

L_∞ (cm)	:	35
Annual growth coefficient (K)	:	0.73
Life span (years)	:	4.2
Lm (cm)	:	20.0
Lc/Lm	:	0.87
Absolute fecundity (in million numbers)	:	0.03

Trophic level	:	3.7
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.55
Price (Rs/kg)	:	25-70

Major gears	:	Bagnet, trawls

Duration of spawning (months)	:	5
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Rastrelliger kanagurta

Indian mackerel

Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	32
Annual growth coefficient (K)	:	2.2
Life span (years)	:	3.0
Lm (cm)	:	19.0
Lc/Lm	:	0.58
Absolute fecundity (in million numbers)	:	0.03-0.09

Trophic level	:	3.4
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	150-200

Major gears	:	Trawl, seines, gillnet

Duration of spawning (months)	:	3
Complexity in early development	:	Pelagic eggs with simple larval development

Trend in the fishery (2007-2014)

Sardinella longiceps

Indian oil sardine

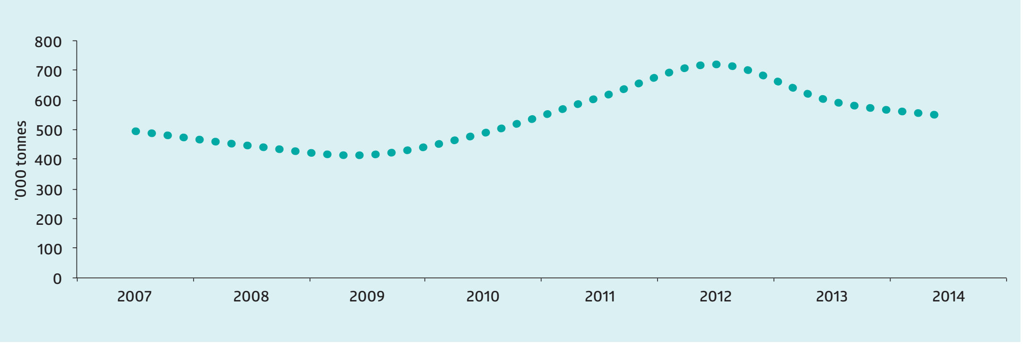
Class : Actinopterygii
Order : Clupeiformes
Family: Clupeidae

L_∞ (cm)	:	22
Annual growth coefficient (K)	:	1.8
Life span (years)	:	2.0
Lm (cm)	:	16.0
Lc/Lm	:	0.77
Absolute fecundity (in million numbers)	:	0.05

Trophic level	:	2.6
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.50
Price (Rs/kg)	:	50-70

Major gears	:	Seines, gillnet

Duration of spawning (months)	:	3
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Sardinella fimbriata

Fringe scale sardine

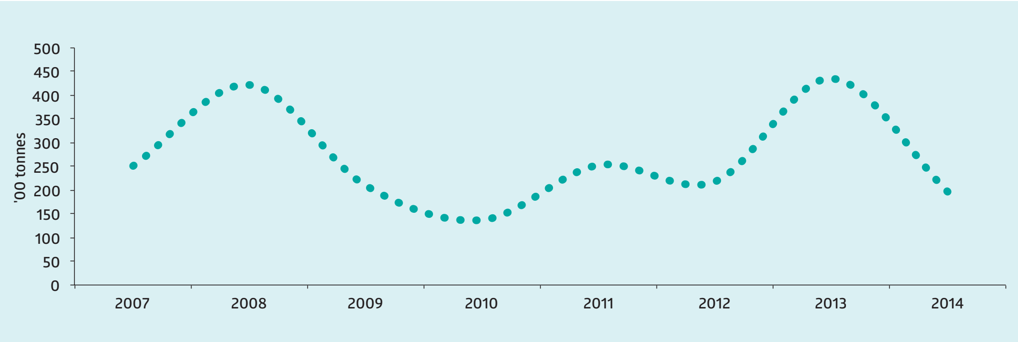
Class : Actinopterygii
Order : Clupeiformes
Family: Clupeidae

L_∞ (cm)	:	21
Annual growth coefficient (K)	:	1.3
Life span (years)	:	3.0
Lm (cm)	:	13.0
Lc/Lm	:	1.17
Absolute fecundity (in million numbers)	:	0.05

Trophic level	:	2.6
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	40-50

Major gears	:	Seines, gillnet

Duration of spawning (months)	:	6
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Sardinella gibbosa

Gold stripe sardine

Class : Actinopterygii
Order : Clupeiformes
Family: Clupeidae

L_∞ (cm)	:	21
Annual growth coefficient (K)	:	1.4
Life span (years)	:	3.1
Lm (cm)	:	13.0
Lc/Lm	:	1.14
Absolute fecundity (in million numbers)	:	0.05

Trophic level	:	2.57
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	40-50

Major gears	:	Gillnet

Duration of spawning (months)	:	6
Complexity in early development:	:	Pelagic eggs with simple larval development

Trend in the fishery (2007-2014)

Tenualosa ilisha

Hilsa shad

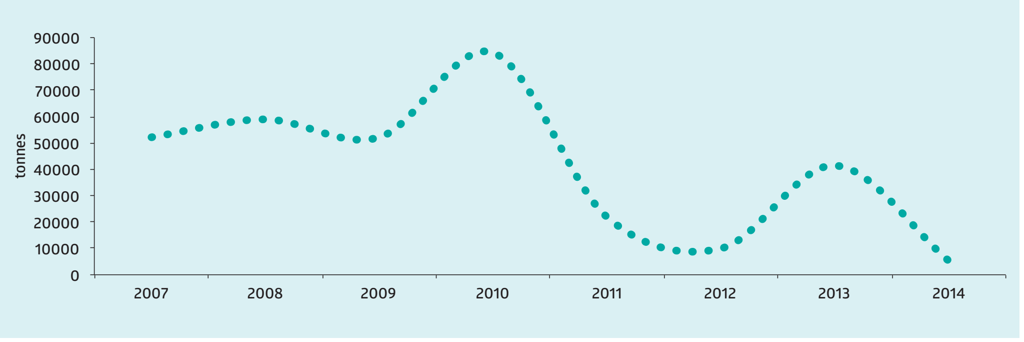
Class : Actinopterygii
Order : Clupeiformes
Family: Clupeidae

L_∞ (cm)	:	50.2
Annual growth coefficient (K)	:	0.3
Life span (years)	:	3.0
Lm (cm)	:	22.0
Lc/Lm	:	0.68
Absolute fecundity (in million numbers)	:	1.0

Trophic level	:	4.15
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.80
Price (Rs/kg)	:	90-100

Major gears	:	Gillnet

Duration of spawning (months)	:	2
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Scomberomorus commerson

Narrow barred spanish mackerel

Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	148
Annual growth coefficient (K)	:	0.8
Life span (years)	:	3.8
Lm (cm)	:	55.0
Lc/Lm	:	0.55
Absolute fecundity (in million numbers)	:	1.0

Trophic level	:	4.15
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.75
Price (Rs/kg)	:	300-800

Major gears	:	Gillnet, trawl

Duration of spawning (months)	:	6
Complexity in early development:	:	Pelagic eggs with simple larval development

Trend in the fishery (2007-2014)

Scomberomorus guttatus

Indo-Pacific king mackerel

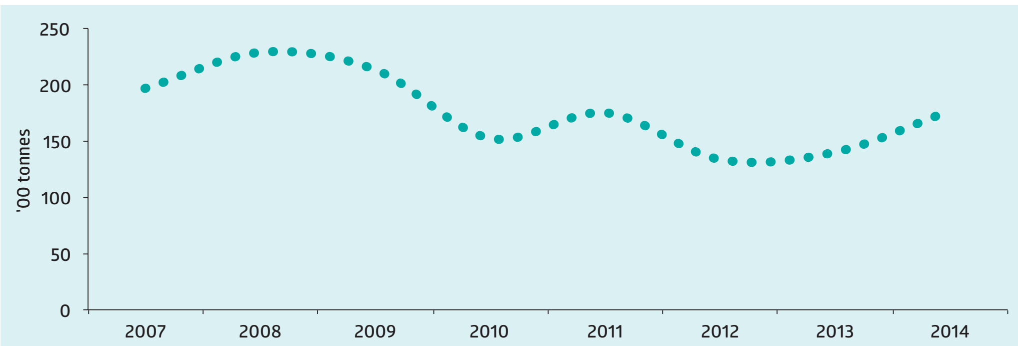
Class : Actinopterygii
Order : Perciformes
Family: Scombridae

L_∞ (cm)	:	75.5
Annual growth coefficient (K)	:	0.8
Life span (years)	:	4.9
Lm (cm)	:	40.0
Lc/Lm	:	0.63
Absolute fecundity (in million numbers)	:	0.5

Trophic level	:	3.5
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	300-800

Major gears	:	Gillnet, trawl

Duration of spawning (months)	:	6
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Sphyraena obtusata

Obtuse barracuda

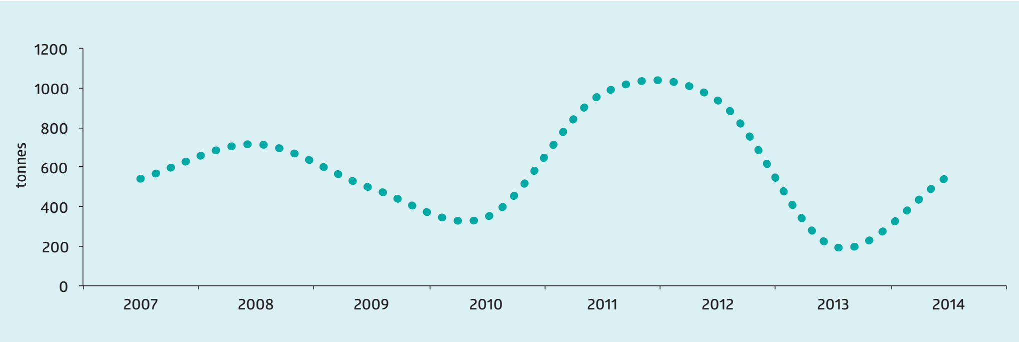
Class : Actinopterygii
Order : Perciformes
Family: Sphyraenidae

L_∞ (cm)	:	34.2
Annual growth coefficient (K)	:	0.71
Life span (years)	:	4.0
Lm (cm)	:	19.9
Lc/Lm	:	1.18
Absolute fecundity (in million numbers)	:	0.5

Trophic level	:	4.5
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.53
Price (Rs/kg)	:	80-120

Major gears	:	Gillnet, trawl

Duration of spawning (months)	:	6
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Sphyraena jello

Pickhandle barracuda

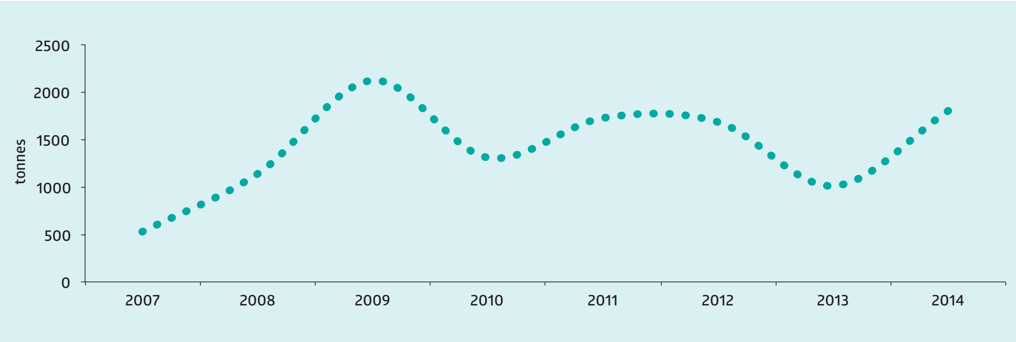
Class : Actinopterygii
Order : Perciformes
Family: Sphyraenidae

L_∞ (cm)	:	69.0
Annual growth coefficient (K)	:	0.70
Life span (years)	:	4.0
Lm (cm)	:	37.0
Lc/Lm	:	0.63
Absolute fecundity (in million numbers)	:	0.5

Trophic level	:	4.2
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	200-300

Major gears	:	Gillnet, trawl

Duration of spawning (months)	:	6
Complexity in early development	:	Pelagic eggs with simple larval development

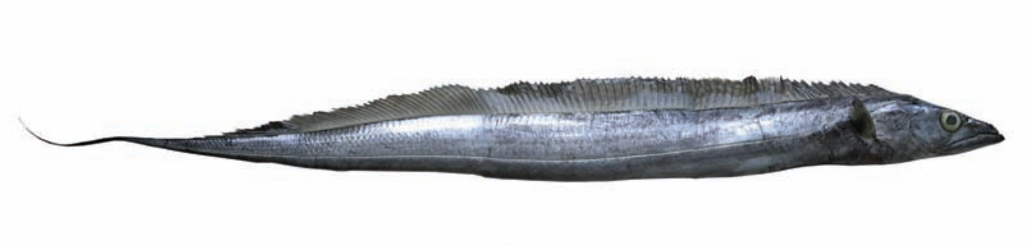


Trend in the fishery (2007-2014)

Trichiurus lepturus

Ribbonfish

Class : Actinopterygii
Order : Perciformes
Family: Trichiuridae

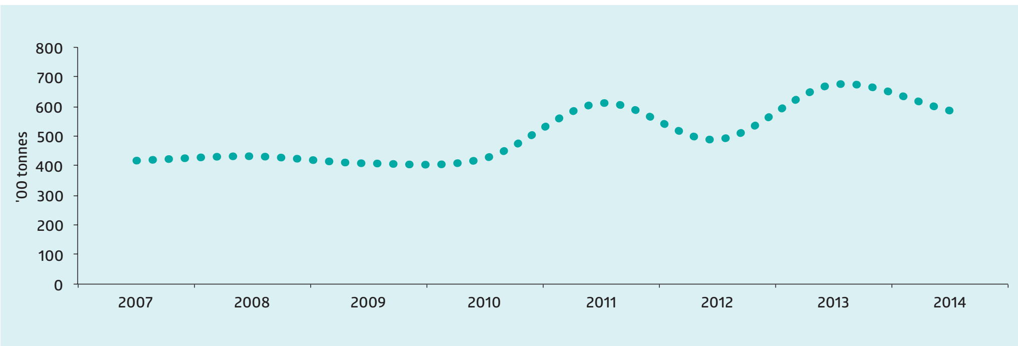


L_∞ (cm)	:	114.0
Annual growth coefficient (K)	:	0.80
Life span (years)	:	4.9
Lm (cm)	:	53.0
Lc/Lm	:	0.75
Absolute fecundity (in million numbers)	:	0.5

Trophic level	:	3.5
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	100-150

Major gears	:	Trawl

Duration of spawning (months)	:	6
Complexity in early development:	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Mugil cephalus

Grey mullet

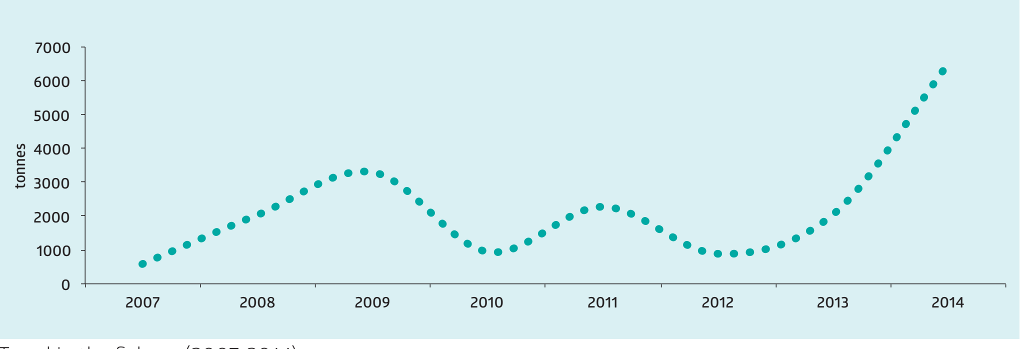
Class : Actinopterygii
Order : Perciformes
Family: Mugilidae

L_∞ (cm)	:	59.0
Annual growth coefficient (K)	:	0.27
Life span (years)	:	11.1
Lm (cm)	:	31.5
Lc/Lm	:	1.11
Absolute fecundity (in million numbers)	:	0.04-2.12

Trophic level	:	2.2
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.25
Price (Rs/kg)	:	100-250

Major gears	:	Gillnet

Duration of spawning (months)	:	3
Complexity in early development	:	Pelagic eggs with simple larval development



Trend in the fishery (2007-2014)

Nemipterus japonicus

Japanese threadfin bream

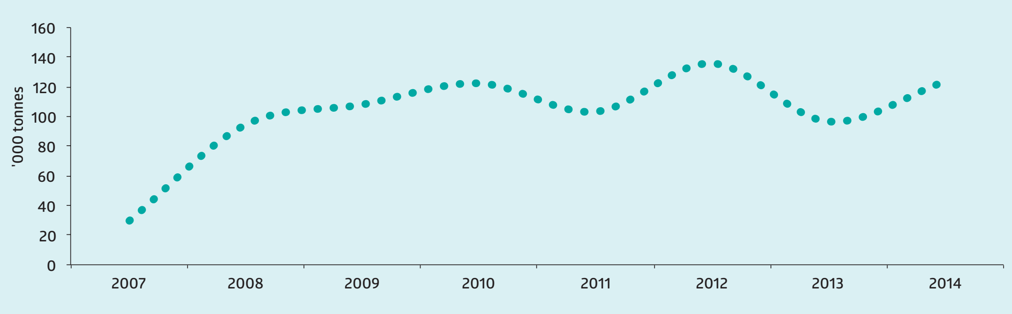
Class : Actinopterygii
Order : Perciformes
Family: Nemipteridae

L_∞ (cm)	:	33.5
Annual growth coefficient (K)	:	0.85
Life span (years)	:	3.5
Lm (cm)	:	21.8
Lc/Lm	:	0.97
Absolute fecundity (in million numbers)	:	0.003-0.044

Trophic level	:	3.8
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.74
Price (Rs/kg)	:	80-190

Major gears	:	Trawl

Duration of spawning (months)	:	7
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Nemipterus randalli

Randall's threadfin bream

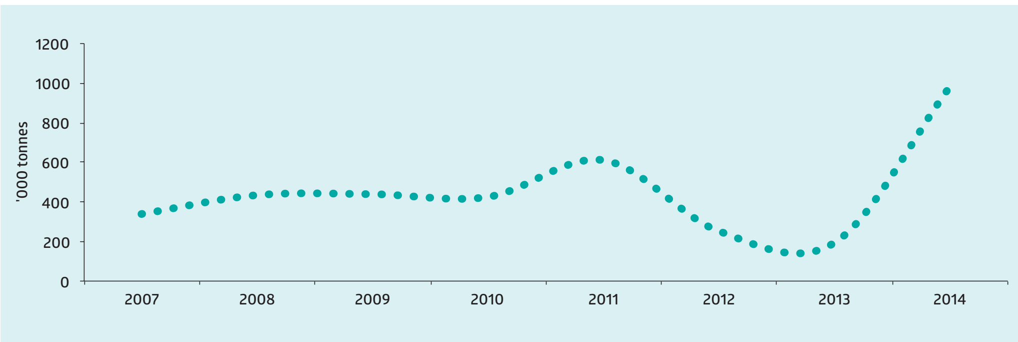
Class : Actinopterygii
Order : Perciformes
Family: Nemipteridae

L_∞ (cm)	:	31
Annual growth coefficient (K)	:	0.86
Life span (years)	:	3.5
Lm (cm)	:	18.4
Lc/Lm	:	0.473
Absolute fecundity (in million numbers)	:	0.005-0.06

Trophic level	:	3.8
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.61
Price (Rs/kg)	:	50-160

Major gears	:	Trawl

Duration of spawning (months)	:	4
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Saurida tumbil

Greater lizard fish

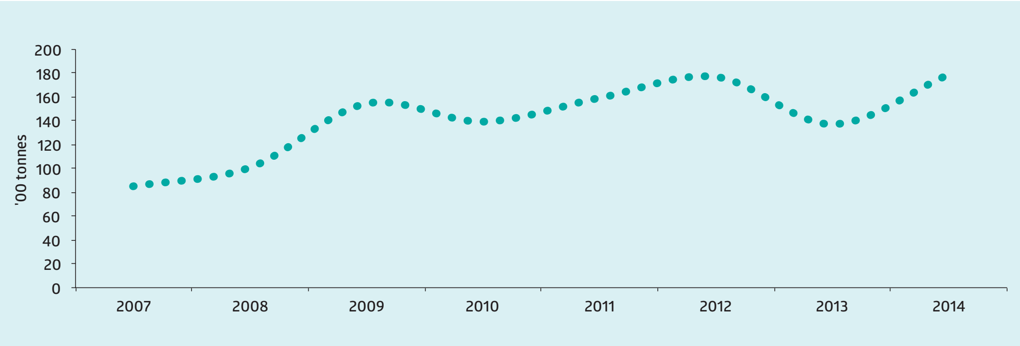
Class : Actinopterygii
Order : Aulopiformes
Family: Synodontidae

L_∞ (cm)	:	60.5
Annual growth coefficient (K)	:	0.73
Life span (years)	:	4.1
Lm (cm)	:	20.5
Lc/Lm	:	0.763
Absolute fecundity (in million numbers)	:	0.024-0.172

Trophic level	:	3.8
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.73
Price (Rs/kg)	:	60-130

Major gears	:	Trawl

Duration of spawning (months)	:	6
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Saurida undosquamis

Brushtooth lizard fish

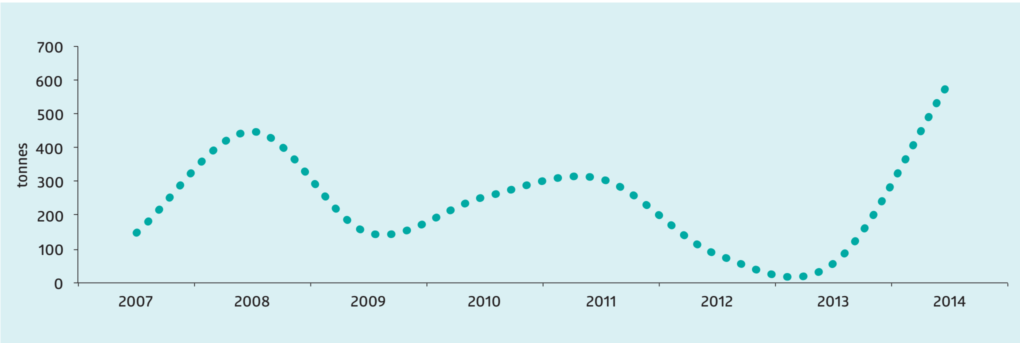
Class : Actinopterygii
Order : Aulopiformes
Family: Synodontidae

L_∞ (cm)	:	45.6
Annual growth coefficient (K)	:	0.64
Life span (years)	:	4.7
Lm (cm)	:	29.5
Lc/Lm	:	0.966
Absolute fecundity (in million numbers)	:	0.024-0.172

Trophic level	:	4.14
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.58
Price (Rs/kg)	:	50-130

Major gears	:	Trawl

Duration of spawning (months)	:	6
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Cynoglossus macrostomus

Malabar sole

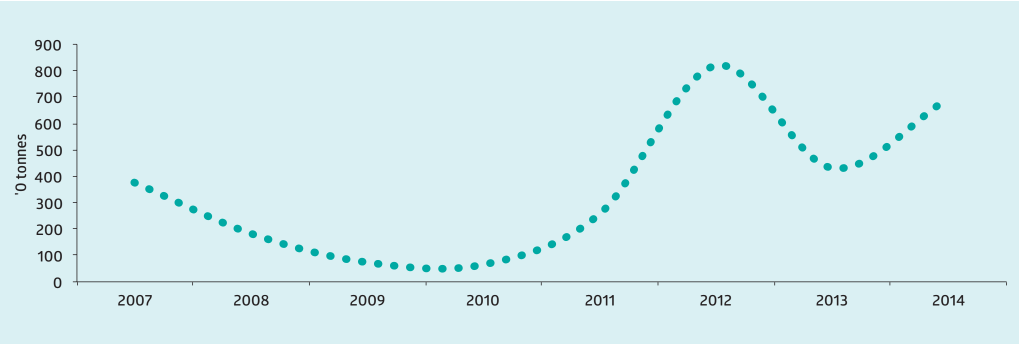
Class : Actinopterygii
Order : Pleuronectiformes
Family: Cynoglossidae

L_∞ (cm)	:	17.8
Annual growth coefficient (K)	:	0.95
Life span (years)	:	3.2
Lm (cm)	:	11.1
Lc/Lm	:	1.17
Absolute fecundity (in million numbers)	:	0.0050-0.0644

Trophic level	:	2.55
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.72
Price (Rs/kg)	:	50-100

Major gears	:	Trawl

Duration of spawning (months)	:	7
Complexity in early development:	:	Nonguarders



Trend in the fishery (2007-2014)

Epinephelus diacanthus

Spinycheek grouper

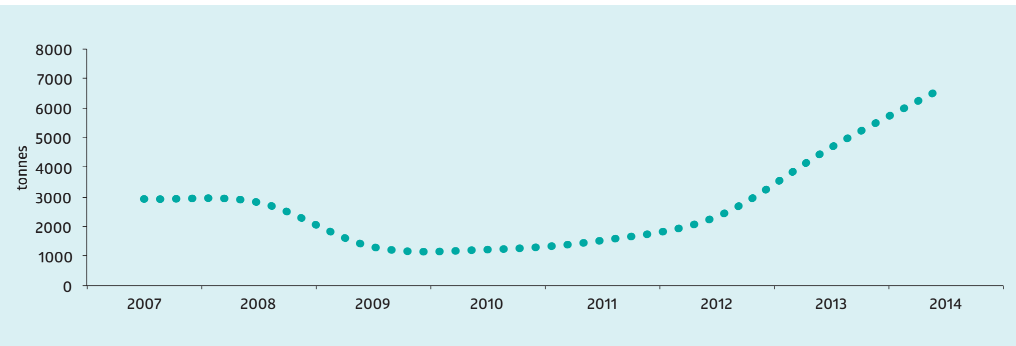
Class : Actinopterygii
Order : Perciformes
Family: Serranidae

L_{∞} (cm)	:	61
Annual growth coefficient (K)	:	0.65
Life span (years)	:	4.6
Lm (cm)	:	28.1
Lc/Lm	:	0.398
Absolute fecundity (in million numbers)	:	0.13-0.145

Trophic level	:	4.14
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.58
Price (Rs/kg)	:	90-180

Major gears	:	Trawl

Duration of spawning (months)	:	6
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Lactarius lactarius

False trevally

Class : Actinopterygii
Order : Perciformes
Family: Lactariidae

L_∞ (cm)	:	29
Annual growth coefficient (K)	:	1
Life span (years)	:	4
Lm (cm)	:	19.4
Lc/Lm	:	0.539
Absolute fecundity (in million numbers)	:	0.007-0.053

Trophic level	:	4
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.6
Price (Rs/kg)	:	140-200

Major gears	:	Trawl

Duration of spawning (months)	:	5
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers

Trend in the fishery (2007-2014)

Plicofollis tenuispinis

Thinspine catfish

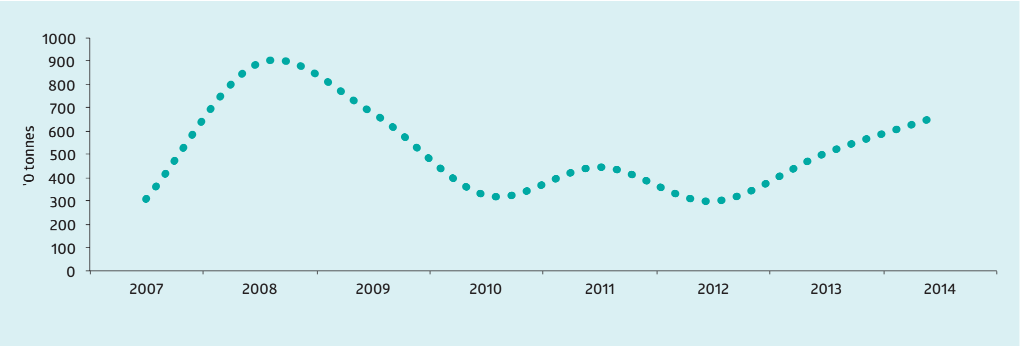
Class : Actinopterygii
Order : Siluriformes
Family: Ariidae

L_∞ (cm)	:	59
Annual growth coefficient (K)	:	0.22
Life span (years)	:	13.6
Lm (cm)	:	39.1
Lc/Lm	:	0.53
Absolute fecundity (in million numbers)	:	0.000072-0.000089

Trophic level	:	4
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.55
Price (Rs/kg)	:	100-150

Major gears	:	Trawl, purseseine

Duration of spawning (months)	:	5
Complexity in early development:	:	Guarders/male incubate egg in the mouth



Trend in the fishery (2007-2014)

Plicofollis dussumieri

Blacktip sea catfish

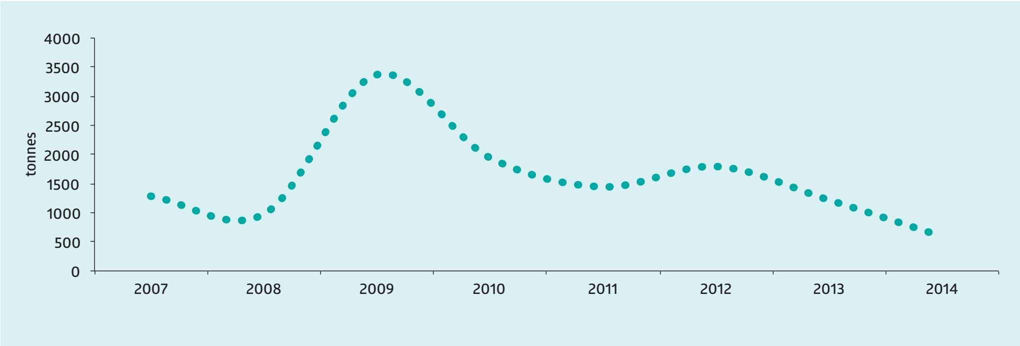
Class : Actinopterygii
Order : Siluriformes
Family: Ariidae

L_∞ (cm)	:	102.7
Annual growth coefficient (K)	:	0.41
Life span (years)	:	6
Lm (cm)	:	36
Lc/Lm	:	0.586
Absolute fecundity (in million numbers)	:	0.000072-0.000089

Trophic level	:	4
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.55
Price (Rs/kg)	:	100-180

Major gears	:	Trawl, purseseine

Duration of spawning (months)	:	4
Complexity in early development:	:	Guarders/male incubate egg in the mouth

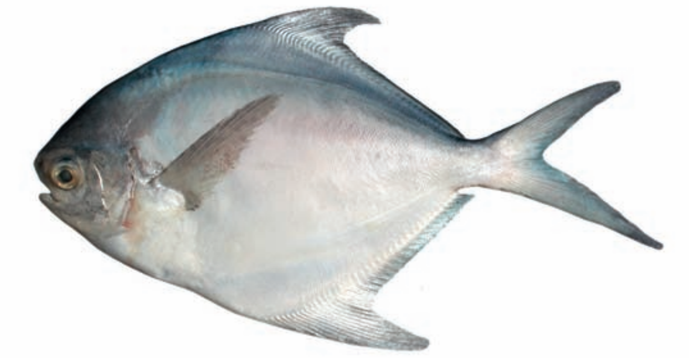


Trend in the fishery (2007-2014)

Pampus argenteus

Silver pomfret

Class : Actinopterygii
Order : Perciformes
Family: Stromateidae



L_∞ (cm)	:	41.57
Annual growth coefficient (K)	:	0.64
Life span (years)	:	4.7
Lm (cm)	:	23.7
Lc/Lm	:	0.426
Absolute fecundity (in million numbers)	:	0.093

Trophic level	:	3.3
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.64
Price (Rs/kg)	:	350-1300

Major gears	:	Trawl, gillnet

Duration of spawning (months)	:	4
Complexity in early development:	:	Non guarders, open waters

Trend in the fishery (2007-2014)

Parastromateus niger

Black pomfret

Class : Actinopterygii
Order : Perciformes
Family: Carangidae

L_∞ (cm)	:	46.0
Annual growth coefficient (K)	:	0.59
Life span (years)	:	5.1
Lm (cm)	:	26.0
Lc/Lm	:	0.527
Absolute fecundity (in million numbers)	:	0.0743

Trophic level	:	2.9
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.75
Price (Rs/kg)	:	350- 600

Major gears	:	Trawl, gillnet

Duration of spawning (months)	:	7
Complexity in early development:	:	Non guarders, open waters

Trend in the fishery (2007-2014)

Protonibea diacanthus

Blackspotted croaker

Class : Actinopterygii
Order : Perciformes
Family: Sciaenidae

L_∞ (cm)	:	145.3
Annual growth coefficient (K)	:	0.14-0.31
Life span (years)	:	4.2-9.3
Lm (cm)	:	85.0
Lc/Lm	:	0.82
Absolute fecundity (in million numbers)	:	0.182-0.50

Trophic level	:	3.5
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.5
Price (Rs/kg)	:	275

Major gears	:	Trawl, gillnet

Duration of spawning (months)	:	5
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers

Trend in the fishery (2007-2014)

Otolithoides biauritus

Bronze croaker

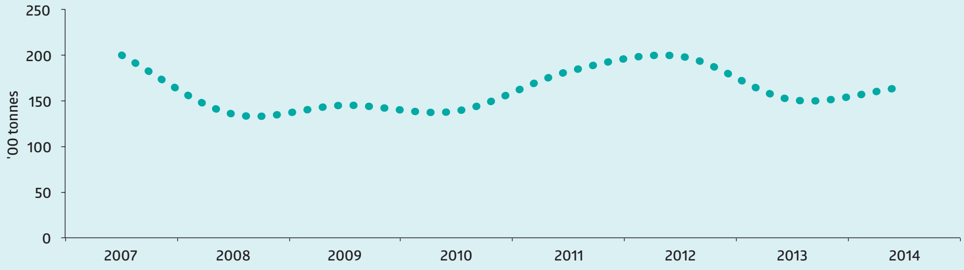
Class : Actinopterygii
Order : Perciformes
Family: Sciaenidae

L_∞ (cm)	:	160
Annual growth coefficient (K)	:	0.48
Life span (years)	:	15.3
Lm (cm)	:	120
Lc/Lm	:	0.92
Absolute fecundity (in million numbers)	:	0.182-0.50

Trophic level	:	3.5
Niche breadth	:	Medium
Horizontal distribution	:	Low
Vertical distribution	:	High
Exploitation rate (E)	:	0.71
Price (Rs/kg)	:	420

Major gears	:	Trawl, gillnet, Dolnet

Duration of spawning (months)	:	4
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Otolithes cuvieri

Lesser tigertooth croaker

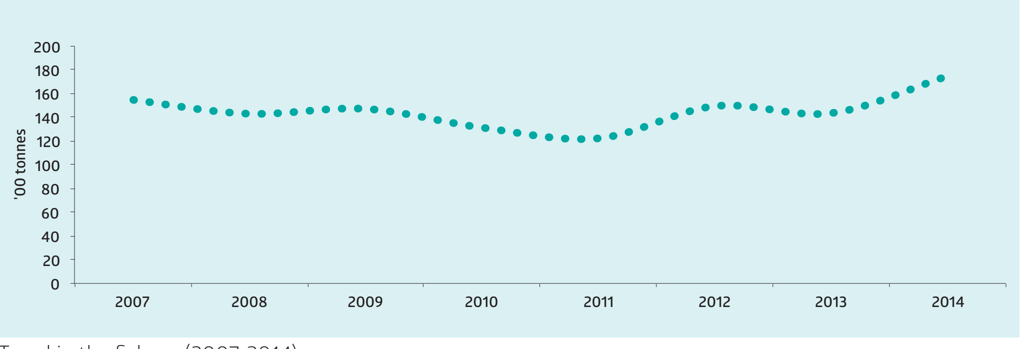
Class : Actinopterygii
Order : Perciformes
Family: Sciaenidae

L_∞ (cm)	:	38.2
Annual growth coefficient (K)	:	0.48-0.78
Life span (years)	:	4.4
Lm (cm)	:	23.9
Lc/Lm	:	0.61
Absolute fecundity (in million numbers)	:	0.1125-0.50

Trophic level	:	3.5
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	90-100

Major gears	:	Trawl

Duration of spawning (months)	:	4
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Otolithes ruber

Tigertooth croaker

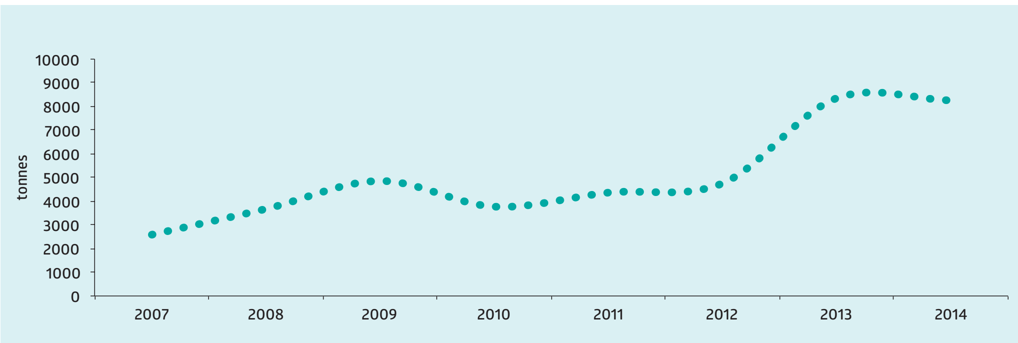
Class : Actinopterygii
Order : Perciformes
Family: Sciaenidae

L_∞ (cm)	:	47.0
Annual growth coefficient (K)	:	0.65
Life span (years)	:	4.97
Lm (cm)	:	20.0
Lc/Lm	:	0.8
Absolute fecundity (in million numbers)	:	0.3

Trophic level	:	3.35
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.70
Price (Rs/kg)	:	200

Major gears	:	Trawl, Gillnet

Duration of spawning (months)	:	7
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Pennahia anea

Donkey croaker

Class : Actinopterygii
Order : Perciformes
Family: Sciaenidae

L_∞ (cm)	:	33.0
Annual growth coefficient (K)	:	0.7
Life span (years)	:	4.26
Lm (cm)	:	16.6
Lc/Lm	:	0.93
Absolute fecundity (in million numbers)	:	0.2

Trophic level	:	3.58
Niche breadth	:	Broad
Horizontal distribution	:	Low
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.68
Price (Rs/kg)	:	150

Major gears	:	Trawl, gillnet

Duration of spawning (months)	:	9
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers

Trend in the fishery (2007-2014)

Upeneus sulphureus

Sulphur goatfish

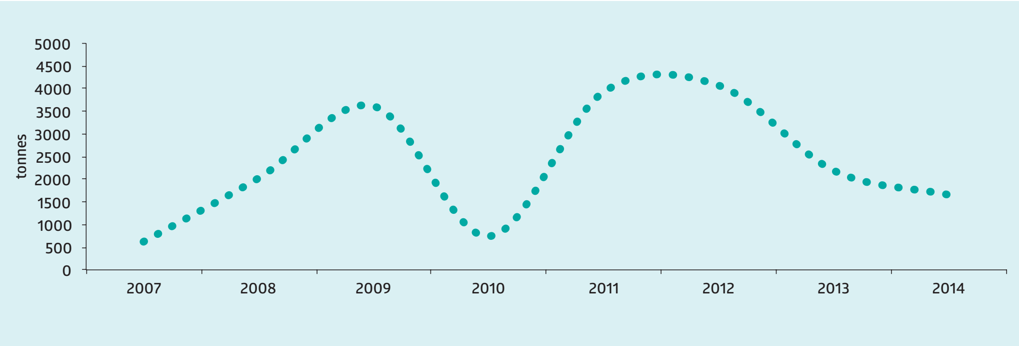
Class : Actinopterygii
Order : Perciformes
Family: Mullidae

L_∞ (cm)	:	20.2
Annual growth coefficient (K)	:	0.65
Life span (years)	:	4.56
Lm (cm)	:	13.1
Lc/Lm	:	0.66
Absolute fecundity (in million numbers)	:	0.03

Trophic level	:	3.24
Niche breadth	:	Broad
Horizontal distribution	:	Low
Vertical distribution	:	High
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	100

Major gears	:	Trawl

Duration of spawning (months)	:	5
Complexity in early development:	:	Nonguarders/open water/substratum egg scatterers



Trend in the fishery (2007-2014)

Carcharhinus limbatus

Blacktip shark

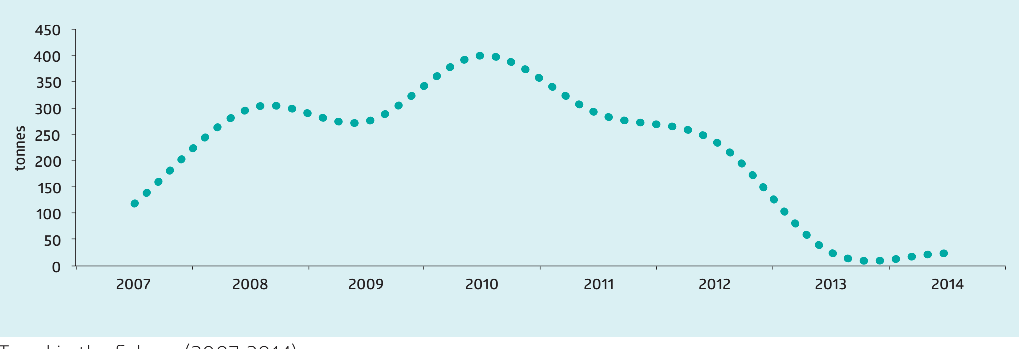
Class : Elasmobranchii
Order : Carcharhiniformes
Family: Carcharhinidae

L_∞ (cm)	:	218.5
Annual growth coefficient (K)	:	0.27
Life span (years)	:	11.1
Lm (cm)	:	105.2
Lc/Lm	:	0.675
Absolute fecundity (in million numbers)	:	1-10 litter

Trophic level	:	4.4
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.6
Price (Rs/kg)	:	110-325

Major gears	:	Trawl, gillnet

Duration of spawning (months)	:	once in a year
Complexity in early developmen	:	Viviparous, with a yolk-sac placenta, Gestation period is 10 to 12 months



Trend in the fishery (2007-2014)

Sphyrna lewini

Scalloped hammerhead shark

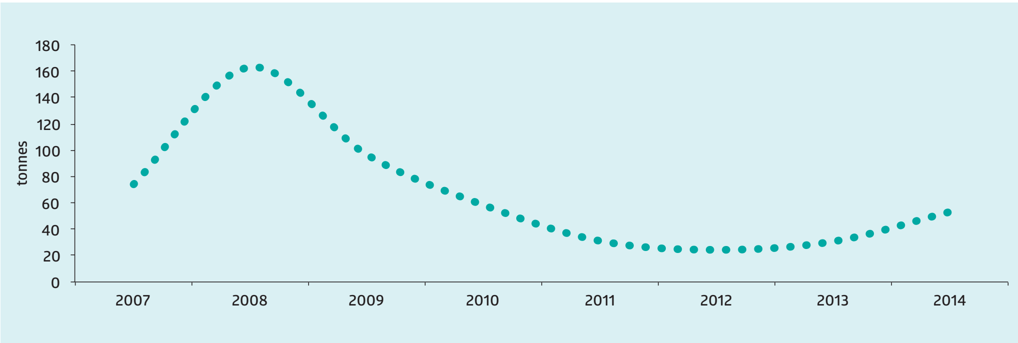
Class : Elasmobranchii
Order : Carcharhiniformes
Family: Sphyrnidae

L_∞ (cm)	:	450
Annual growth coefficient (K)	:	0.07
Life span (years)	:	42.8
Lm (cm)	:	180
Lc/Lm	:	0.283
Absolute fecundity (in million numbers)	:	21-40 litter

Trophic level	:	4.1
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.8
Price (Rs/kg)	:	150-400

Major gears	:	Trawl

Duration of spawning (months)	:	once in a year
Complexity in early development	:	Viviparous, with a yolk-sac placenta, Gestation period is 9-10 months



Trend in the fishery (2007-2014)

Scoliodon laticaudus

Spadenose shark

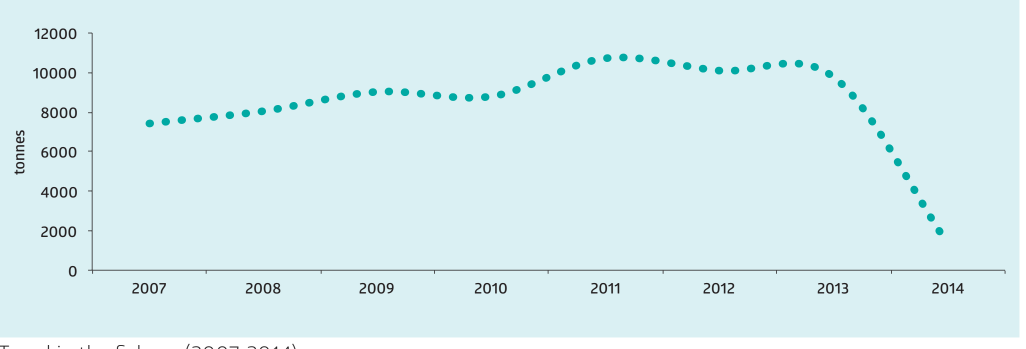
Class : Elasmobranchii
Order : Carcharhiniformes
Family: Carcharhinidae

L_∞ (cm)	:	71.5
Annual growth coefficient (K)	:	0.5-0.74
Life span (years)	:	4.1-4.4
Lm (cm)	:	38.0
Lc/Lm	:	1.07
Absolute fecundity (in million numbers)	:	2-16 litter

Trophic level	:	4.0
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.69
Price (Rs/kg)	:	80-100

Major gears	:	Trawl, Dolnet

Duration of spawning (months)	:	12
Complexity in early developmen	:	Viviparous, with an unusual columnar placenta



Trend in the fishery (2007-2014)

Himantura imbricata

Scaly stingray

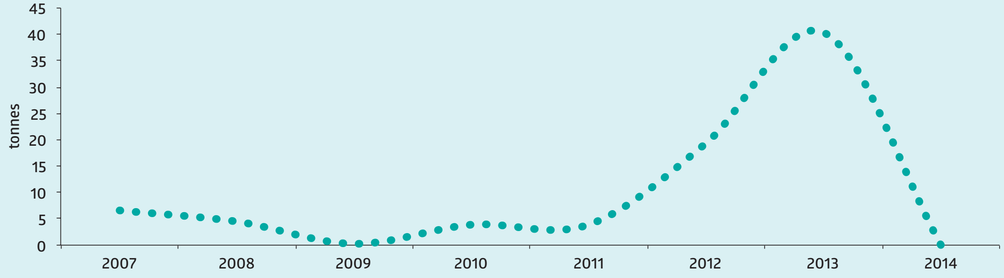
Class : Elasmobranchii
Order : Myliobatiformes
Family: Dasyatidae

L_∞ (cm)	:	26.3
Annual growth coefficient (K)	:	0.4-0.59
Life span (years)	:	5.1
Lm (cm)	:	15.7
Lc/Lm	:	0.82
Absolute fecundity (in million numbers)	:	1-2 pups

Trophic level	:	3.58
Niche breadth	:	Medium
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.95
Price (Rs/kg)	:	65-70

Major gears	:	Trawl, gillnet, dolnet

Duration of spawning (months)	:	12
Complexity in early development	:	Exhibit ovoviparity



Trend in the fishery (2007-2014)

Acetes indicus

Jawala paste shrimp

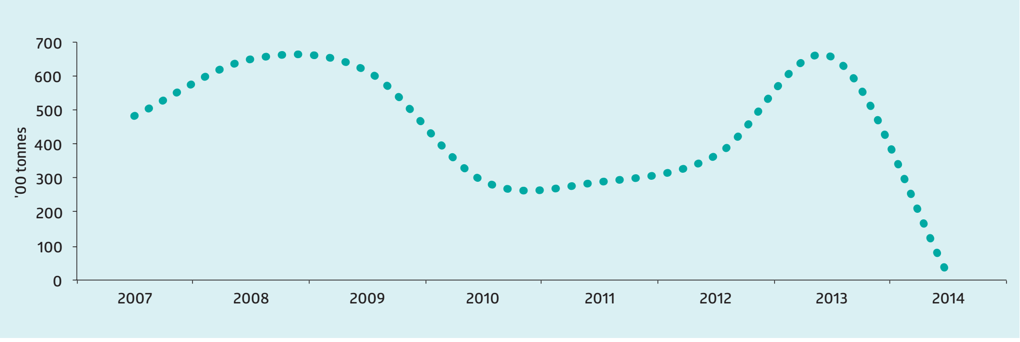
Class : Malacostraca
Order : Decapoda
Family: Sergestidae

L_∞ (cm)	:	3.96
Annual growth coefficient (K)	:	3.22
Life span (years)	:	0.6
Lm (cm)	:	2.0
Lc/Lm	:	1.33
Absolute fecundity (in million numbers)	:	0.045-0.105

Trophic level	:	2.51
Niche breadth	:	Narrow
Horizontal distribution	:	Low
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.65
Price (Rs/kg)	:	15-25

Major gears	:	Trawl, Dolnet

Duration of spawning (months)	:	3
Complexity in early developmen	:	Pelagic eggs



Trend in the fishery (2007-2014)

Metapenaeus affinis

Jinga prawn

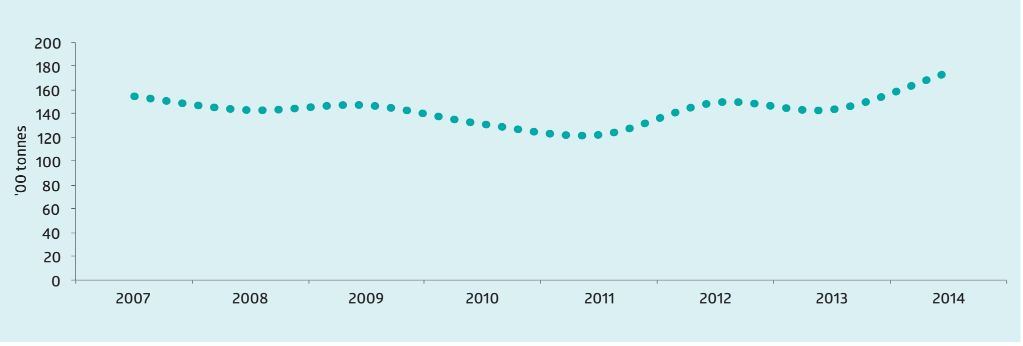
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	20.4
Annual growth coefficient (K)	:	1.9
Life span (years)	:	1.7
Lm (cm)	:	12.02
Lc/Lm	:	1.29
Absolute fecundity (in million numbers)	:	0.5

Trophic level	:	2.50
Niche breadth	:	Narrow
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	300-400

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early development	:	Pelagic eggs with complex larval phase

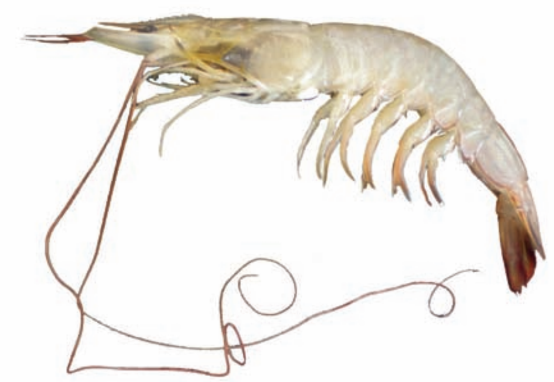


Trend in the fishery (2007-2014)

Metapenaeus dobsoni

Kadal shrimp

Class : Malacostraca
Order : Decapoda
Family: Penaeidae

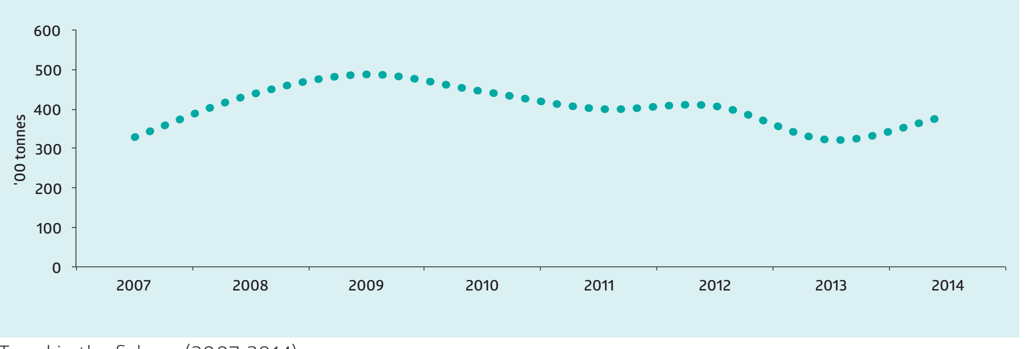


L_∞ (cm)	:	13.0
Annual growth coefficient (K)	:	1.0
Life span (years)	:	2.5
Lm (cm)	:	7.1
Lc/Lm	:	0.69
Absolute fecundity (in million numbers)	:	0.4 -1.6

Trophic level	:	3.02
Niche breadth	:	Narrow
Horizontal distribution	:	Medium
Vertical distribution	:	Low
Exploitation rate (E)	:	0.74
Price (Rs/kg)	:	200

Major gears	:	Trawl

Duration of spawning (months)	:	4-7
Complexity in early development	:	Pelagic eggs with complex larval phase



Trend in the fishery (2007-2014)

Metapenaeus monoceros

Speckled shrimp

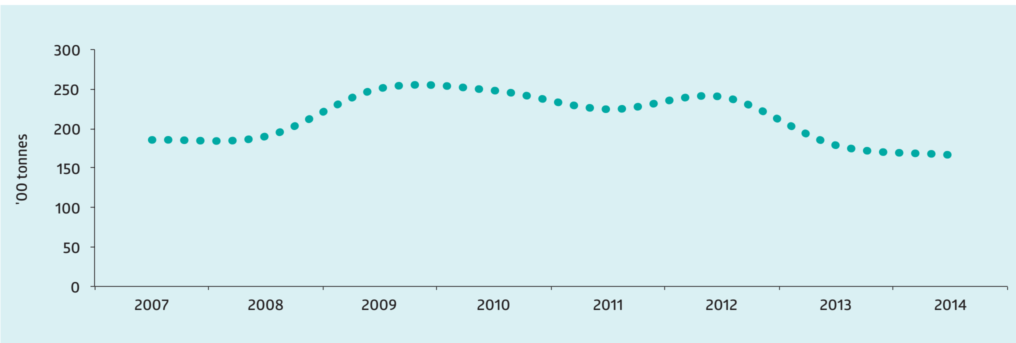
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	20.4
Annual growth coefficient (K)	:	1.8
Life span (years)	:	2.5
Lm (cm)	:	9.5
Lc/Lm	:	0.72
Absolute fecundity (in million numbers)	:	0.05 -0.4

Trophic level	:	3.02
Niche breadth	:	Narrow
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.75
Price (Rs/kg)	:	350-400

Major gears	:	Trawl

Duration of spawning (months)	:	4-7
Complexity in early development	:	Pelagic eggs with complex larval phase



Trend in the fishery (2007-2014)

Metapenaeopsis stridulans

Fiddler shrimp

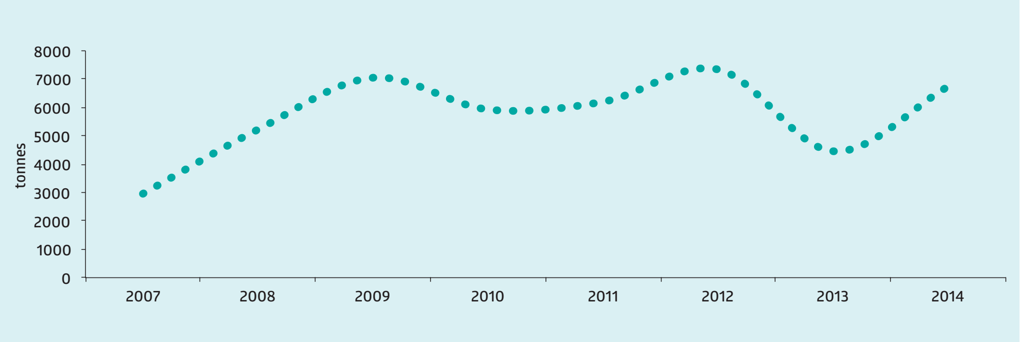
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	12.5
Annual growth coefficient (K)	:	1.1
Life span (years)	:	2.7
Lm (cm)	:	7.5
Lc/Lm	:	0.85
Absolute fecundity (in million numbers)	:	0.04 -0.4

Trophic level	:	2.9
Niche breadth	:	Narrow
Horizontal distribution	:	Low
Vertical distribution	:	Low
Exploitation rate (E)	:	0.66
Price (Rs/kg)	:	100-200

Major gears	:	Trawl

Duration of spawning (months)	:	4
Complexity in early developmen	:	Pelagic larval phase



Trend in the fishery (2007-2014)

Parapenaeopsis stylifera

Kiddi shrimp

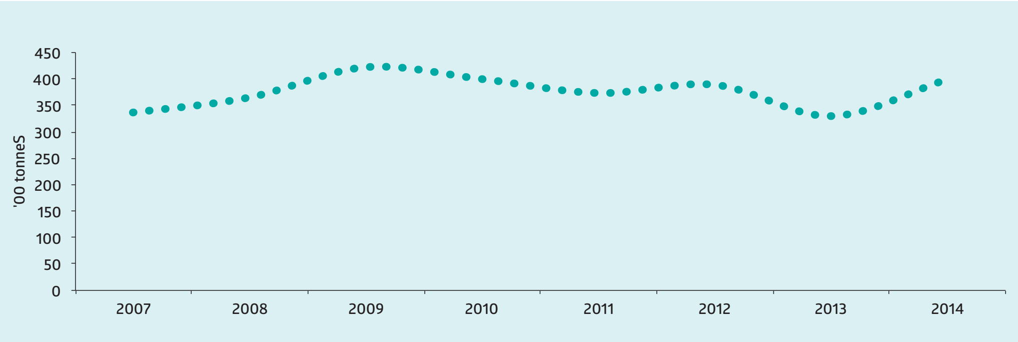
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	13.2
Annual growth coefficient (K)	:	2.4
Life span (years)	:	2.5
Lm (cm)	:	6.8
Lc/Lm	:	1.06
Absolute fecundity (in million numbers)	:	0.24

Trophic level	:	2.5
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.60
Price (Rs/kg)	:	150

Major gears	:	Trawl

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic larvae, complex larval phase



Trend in the fishery (2007-2014)

Solenocera crassicornis

Coastal mud shrimp

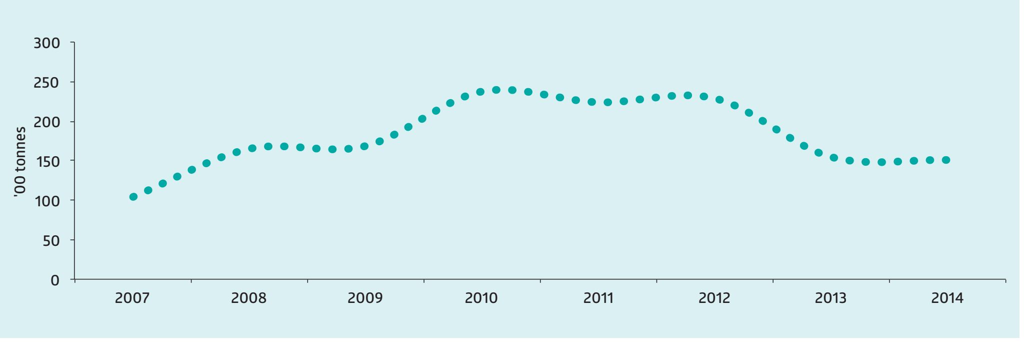
Class : Malacostraca
Order : Decapoda
Family: Solenoceridae

L_∞ (cm)	:	10.5
Annual growth coefficient (K)	:	1.2
Life span (years)	:	2.5
Lm (cm)	:	5.3
Lc/Lm	:	0.94
Absolute fecundity (in million numbers)	:	0.028- 0.1

Trophic level	:	2.5
Niche breadth	:	Narrow
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.63
Price (Rs/kg)	:	150

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early developmen	:	Pelagic larvae, complex larval phase



Trend in the fishery (2007-2014)

Fenneropenaeus indicus

Indian white prawn

Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	18.3
Annual growth coefficient (K)	:	1.2
Life span (years)	:	2.5
Lm (cm)	:	11.4
Lc/Lm	:	1.44
Absolute fecundity (in million numbers)	:	0.68 -0.73

Trophic level	:	3.02
Niche breadth	:	Narrow
Horizontal distribution	:	Medium
Vertical distribution	:	Low
Exploitation rate (E)	:	0.78
Price (Rs/kg)	:	400-500

Major gears	:	Trawl

Duration of spawning (months)	:	7
Complexity in early development	:	Pelagic eggs with complex larval phase

Trend in the fishery (2007-2014)

Fenneropenaeus merguiensis

Banana prawn

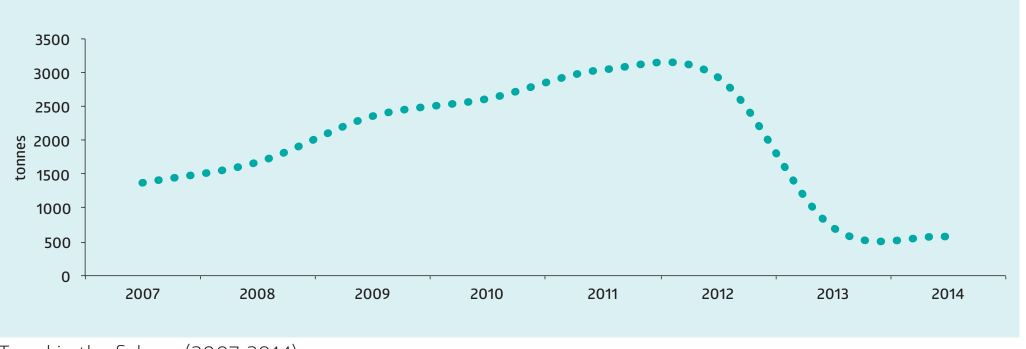
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	20.3
Annual growth coefficient (K)	:	2.15
Life span (years)	:	2.3
Lm (cm)	:	15.7
Lc/Lm	:	1.23
Absolute fecundity (in million numbers)	:	0.5 -0.75

Trophic level	:	2.5
Niche breadth	:	Narrow
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.55
Price (Rs/kg)	:	250-300

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early development	:	Pelagic eggs with complex larval phase



Trend in the fishery (2007-2014)

Penaeus monodon

Tiger prawn

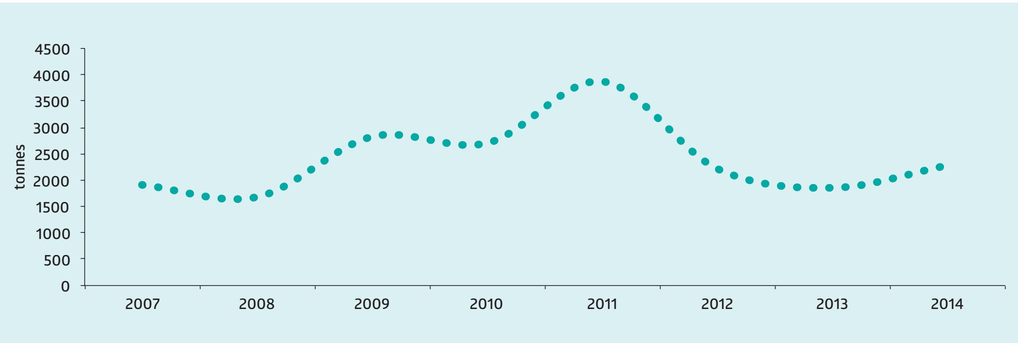
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	33.1
Annual growth coefficient (K)	:	1.59
Life span (years)	:	1.88
Lm (cm)	:	13.0
Lc/Lm	:	0.77
Absolute fecundity (in million numbers)	:	0.6 -1.00

Trophic level	:	2.9
Niche breadth	:	Narrow
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.65
Price (Rs/kg)	:	400-800

Major gears	:	Trawl

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic eggs with complex larval phase



Trend in the fishery (2007-2014)

Penaeus semisulcatus

Green tiger prawn

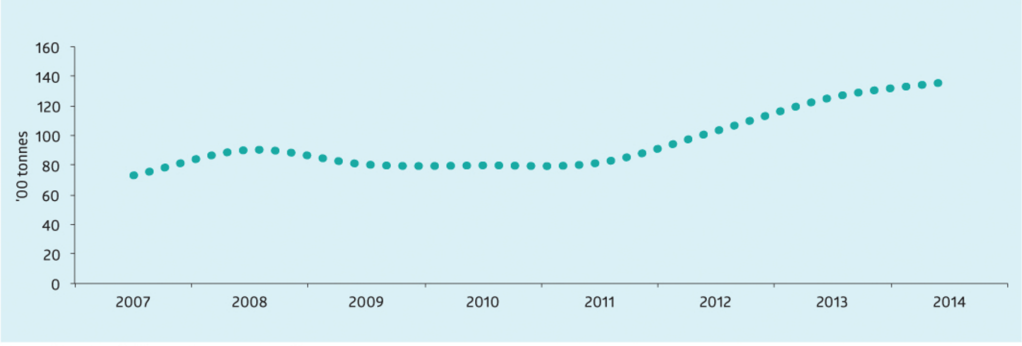
Class : Malacostraca
Order : Decapoda
Family: Penaeidae

L_∞ (cm)	:	26.1
Annual growth coefficient (K)	:	1.3
Life span (years)	:	2.2
Lm (cm)	:	13.2
Lc/Lm	:	0.88
Absolute fecundity (in million numbers)	:	0.5 -0.75

Trophic level	:	3.0
Niche breadth	:	Narrow
Horizontal distribution	:	Low
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.71
Price (Rs/kg)	:	350-400

Major gears	:	Trawl

Duration of spawning (months)	:	4
Complexity in early development	:	Pelagic eggs with complex larval phase



Trend in the fishery (2007-2014)

Charybdis feriata

Crucifix crab

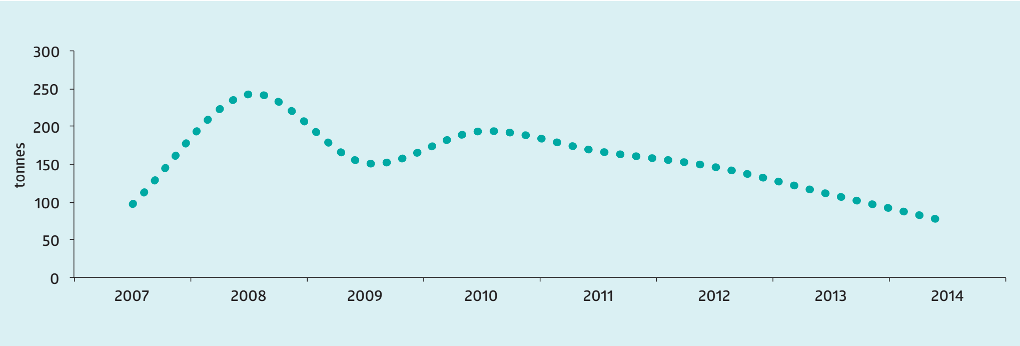
Class : Malacostraca
Order : Decapoda
Family: Portunidae

L_∞ (cm)	:	17.3
Annual growth coefficient (K)	:	0.88
Life span (years)	:	2.9
Lm (cm)	:	8.73
Lc/Lm	:	1.09
Absolute fecundity (in million numbers)	:	0.029- 0.97

Trophic level	:	2.7
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Medium
Exploitation rate (E)	:	0.62
Price (Rs/kg)	:	100

Major gears	:	Trawl

Duration of spawning (months)	:	10
Complexity in early development	:	Complex life cycle with different larval stages



Trend in the fishery (2007-2014)

Portunus pelagicus

Flower crab

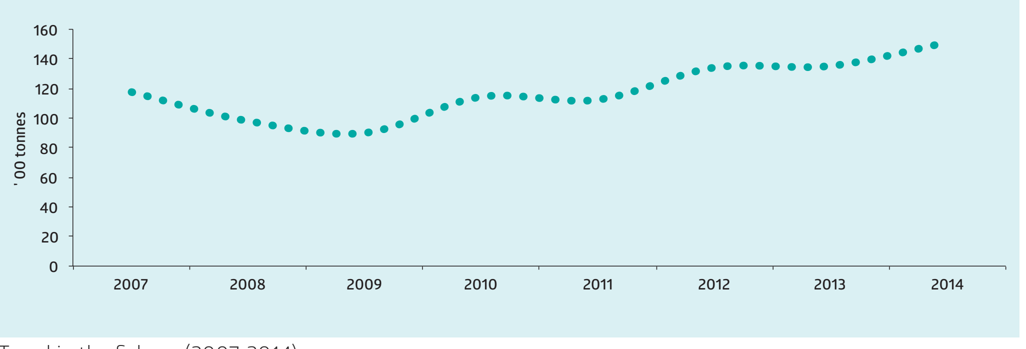
Class : Malacostraca
Order : Decapoda
Family: Portunidae

L_∞ (cm)	:	17.4
Annual growth coefficient (K)	:	1.2
Life span (years)	:	2.5
Lm (cm)	:	9.6
Lc/Lm	:	0.61
Absolute fecundity (in million numbers)	:	0.06-1.98

Trophic level	:	2.89
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.8
Price (Rs/kg)	:	100-200

Major gears	:	Trawl

Duration of spawning (months)	:	10
Complexity in early development	:	Complex life cycle with different larval stages



Trend in the fishery (2007-2014)

Portunus sanguinolentus

Blood spotted crab

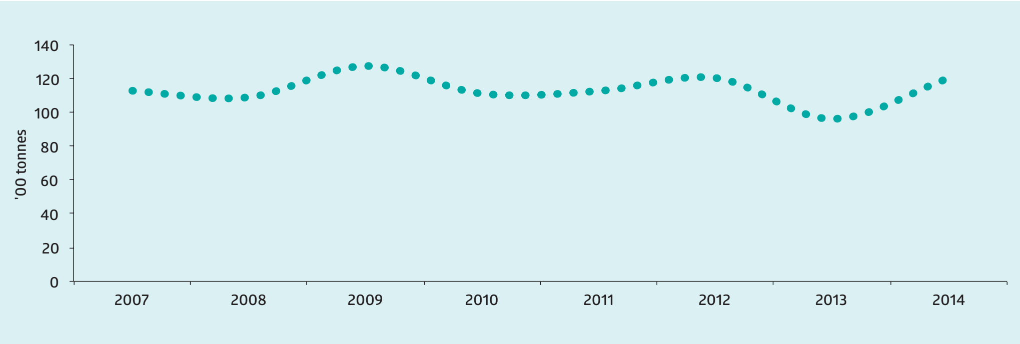
Class : Malacostraca
Order : Decapoda
Family: Portunidae

L_∞ (cm)	:	16.3
Annual growth coefficient (K)	:	1.2
Life span (years)	:	2.5
Lm (cm)	:	9.3
Lc/Lm	:	0.63
Absolute fecundity (in million numbers)	:	0.03- 0.07

Trophic level	:	2.89
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.86
Price (Rs/kg)	:	100-200

Major gears	:	Trawl

Duration of spawning (months)	:	3
Complexity in early development	:	Complex life cycle with different larval stages



Trend in the fishery (2007-2014)

Panulirus polyphagus

Mud spiny lobster

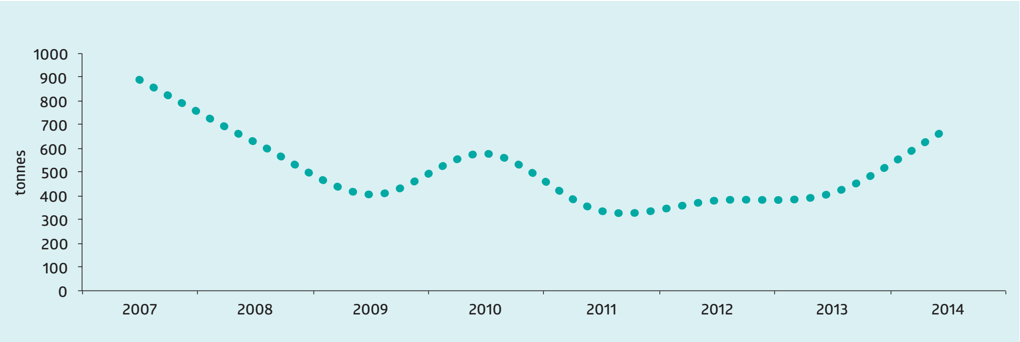
Class : Malacostraca
Order : Decapoda
Family: Palinuridae

L_∞ (cm)	:	40.0
Annual growth coefficient (K)	:	1.5
Life span (years)	:	2.0
Lm (cm)	:	20.0
Lc/Lm	:	0.55
Absolute fecundity (in million numbers)	:	0.143-0.472

Trophic level	:	3.2
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	High
Exploitation rate (E)	:	0.62
Price (Rs/kg)	:	1200-1400

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early development	:	Complex life cycle with different larval stages



Trend in the fishery (2007-2014)

Uroteuthis (Photololigo) duvauceli

Indian squid

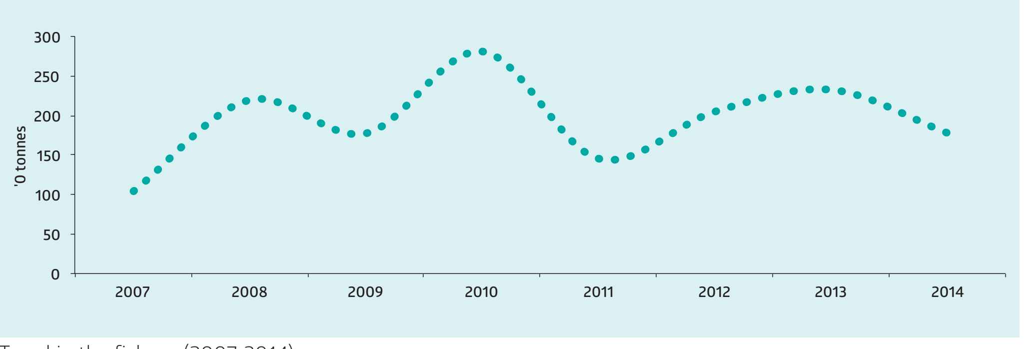
Class : Cephalopoda
Order : Teuthida
Family: Loliginidae

L_∞ (cm)	:	20.5
Annual growth coefficient (K)	:	1.3
Life span (years)	:	4.6
Lm (cm)	:	10.8
Lc/Lm	:	0.46
Absolute fecundity (in million numbers)	:	0.05

Trophic level	:	3.84
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.7
Price (Rs/kg)	:	250

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early development	:	Simple



Trend in the fishery (2007-2014)

Sepia aculeata

Needle cuttlefish

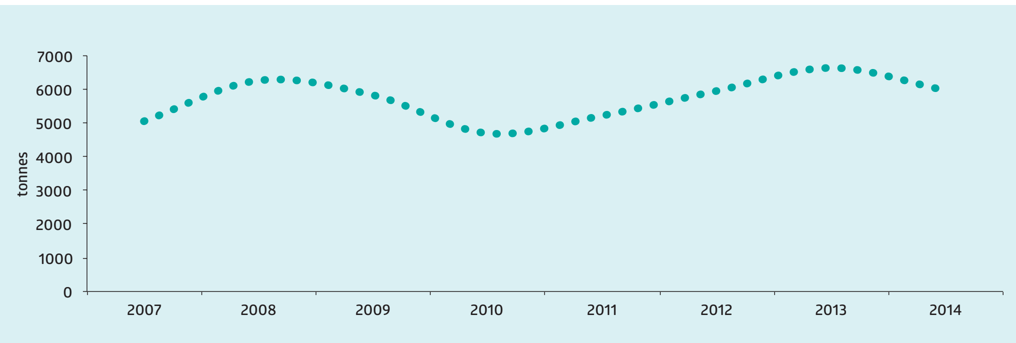
Class : Cephalopoda
Order : Sepiida
Family: Sepiidae

L_∞ (cm)	:	20.3
Annual growth coefficient (K)	:	0.9
Life span (years)	:	6.0
Lm (cm)	:	10.2
Lc/Lm	:	0.78
Absolute fecundity (in million numbers)	:	0.0015

Trophic level	:	3.84
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.65
Price (Rs/kg)	:	250

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early developmen	:	Simple



Trend in the fishery (2007-2014)

Sepia pharaonis

Pharaoh cuttlefish

Class : Cephalopoda
Order : Sepiida
Family: Sepiidae

L_∞ (cm)	:	32.0
Annual growth coefficient (K)	:	0.5
Life span (years)	:	6.3
Lm (cm)	:	12.0
Lc/Lm	:	0.83
Absolute fecundity (in million numbers)	:	0.0015

Trophic level	:	3.84
Niche breadth	:	Broad
Horizontal distribution	:	High
Vertical distribution	:	Low
Exploitation rate (E)	:	0.65
Price (Rs/kg)	:	250

Major gears	:	Trawl

Duration of spawning (months)	:	12
Complexity in early development	:	Simple

Trend in the fishery (2007-2014)

Perna viridis

Green mussel

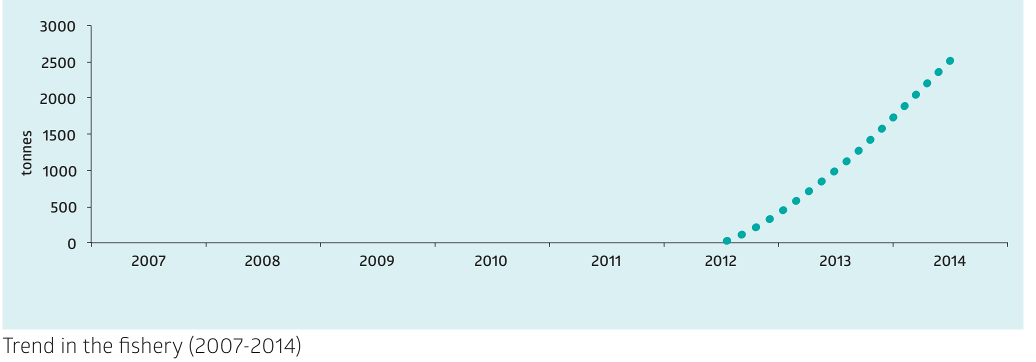
Class : Bivalvia
Order : Mytiloida
Family: Mytilidae

L_∞ (cm)	:	10.2
Annual growth coefficient (K)	:	1.5
Life span (years)	:	2.0
Lm (cm)	:	2.8
Lc/Lm	:	1.42
Absolute fecundity (in million numbers)	:	0.05

Trophic level	:	2
Niche breadth	:	Medium
Horizontal distribution	:	Medium
Vertical distribution	:	Low
Price (Rs/kg)	:	100-200

Major gears	:	Manual collection

Duration of spawning (months)	:	5
Complexity in early development	:	Pelagic larvae, different larval stages



Trend in the fishery (2007-2014)
*All India data available from 2013 onwards

Annexure 2

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Appendix 1

Attributes and scoring along different zones

Appendix 1 a. Exposure attributes and scoring along northwest zone

Species	SST	Rainfall	Current Speed	Current direction	Upwelling Index	Chlor conc	Avg Score
Coilia dussumieri	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Decapterus russelli	2.14	1.37	2.85	3.16	0.75	1.43	1.95
Euthynnus affinis	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Harpadon nehereus	1.43	1.37	1.43	1.58	0.75	1.43	1.33
Megalaspis cordyla	1.43	1.37	1.43	1.58	0.75	1.43	1.33
Rastrelliger kanagurta	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Sardinella longiceps	2.14	1.37	2.85	3.16	0.75	1.43	1.95
Scomberomorus guttatus	1.64	1.37	1.43	1.58	0.75	1.43	1.37
Thunnus tonggol	2.14	1.37	2.85	3.16	0.75	1.43	1.95
Trichiurus lepturus	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Epinephelus diacanthus	1.78	1.37	2.48	3.04	0.75	1.43	1.81
Himantura imbricata	2.14	1.37	2.85	3.16	0.75	1.43	1.95
Lactarius lactarius	1.43	1.37	1.43	1.58	0.75	1.43	1.33
Nemipterus japonicus	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Nemipterus randalli	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Otolithes cuvieri	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Otolithoides biauritus	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Pampus argenteus	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Parastromateus niger	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Plicofollis tenuispinis	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Protonibea diacanthus	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Saurida tumbil	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Scoliodon laticaudus	1.43	1.37	1.43	3.16	0.75	1.43	1.59
Fenneropenaeus merguiensis	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Metapenaeus monoceros	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Metapenaeus affinis	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Penaeus semisulcatus	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Parapenaeopsis stylifera	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Solenocera crassicornis	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Panulirus polyphagus	1.78	1.37	2.85	3.16	0.75	1.43	1.89
Charybdis feriata	1.43	1.37	1.43	1.58	0.75	1.43	1.33
Portunus sanguinolentus	1.43	1.37	2.85	3.16	0.75	1.43	1.83
Sepia pharaonis	1.78	1.37	1.43	1.58	0.75	1.43	1.39
Sepiella inermis	1.43	1.37	2.85	1.58	0.75	1.43	1.57
Uroteuthis (Photololigo) duvauceli	1.78	1.37	2.85	3.16	0.75	1.43	1.89

Appendix 1 b. Sensitivity attributes and scoring northwest zone

Species	Fecundity	Complex life cycle	Growth Coefficient	Trophic level	Longevity	Lc/Lm	Explo.rate	CPUE	Price	Avg Score
Coilia dussumieri	1	3	1	1	1	2	1.97	1	1	1.44
Decapterus russelli	2	1	1	2	1	2	1.53	1	1	1.39
Euthynnus affinis	2	1	2	3	2	2	1.47	2	2	1.94
Harpadon nehereus	3	1	3	2	3	3	2.13	1	1	2.13
Megalaspis cordyla	2	2	2	2	2	2	1.83	1	2	1.87
Rastrelliger kanagurta	1	3	1	1	1	2	1.83	1	2	1.54
Sardinella longiceps	2	1	1	2	1	1	1.67	1	1	1.30
Scomberomorus guttatus	3	2	1	2	2	2	1.60	1	2	1.85
Thunnus tonggol	2	1	1	1	2	1	1.80	1	1	1.31
Trichiurus lepturus	2	1	2	3	3	3	1.90	1	2	2.10
Epinephelus diacanthus	2	1	1	3	1	2	1.63	1	1	1.52
Himantura imbricata	2	2	2	2	2	2	1.73	1	1	1.75
Lactarius lactarius	2	1	3	2	3	2	1.27	3	2	2.14
Nemipterus japonicus	1	3	1	1	1	1	1.87	1	3	1.54
Nemipterus randalli	2	1	2	2	2	2	1.70	1	1	1.63
Otolithes cuvieri	2	1	2	2	2	2	1.80	1	1	1.64
Otolithoides biauritus	2	2	3	2	3	3	1.73	1	3	2.30
Pampus argenteus	2	2	2	2	2	2	1.57	2	1	1.84
Parastromateus niger	2	2	3	2	3	1	1.70	1	2	1.97
Plicofollis tenuispinis	2	3	1	2	1	1	1.23	3	3	1.92
Protonibea diacanthus	1	3	1	1	1	2	1.90	1	3	1.66
Saurida tumbil	1	3	1	1	1	2	1.60	1	2	1.51
Scoliodon laticaudus	2	1	2	3	2	2	1.87	1	2	1.87
Fenneropenaeus merguiensis	2	2	2	2	2	2	1.57	2	1	1.84
Metapenaeus monoceros	2	1	1	3	1	1	1.60	2	1	1.51
Metapenaeus affinis	1	3	1	1	1	1	1.60	1	3	1.51
Penaeus semisulcatus	1	3	1	1	1	1	1.60	1	2	1.40
Parapenaeopsis stylifera	2	2	2	3	2	3	1.60	2	3	2.29
Solenocera crassicornis	2	2	2	3	2	2	1.40	1	1	1.82
Panulirus polyphagus	2	2	2	2	2	2	2.00	2	3	2.11
Charybdis feriata	3	1	2	2	3	2	2.07	3	1	2.12
Portunus sanguinolentus	1	3	1	1	1	2	2.07	1	2	1.56
Sepia pharonis	3	1	2	3	2	2	1.97	1	1	2.11
Sepiella inermis	2	2	2	2	2	2	1.60	1	3	1.96
Uroteuthis (Photololigo) duvauceli	2	1	2	3	3	2	1.63	1	2	1.96

Appendix 1 c. Adaptive capacity scoring of species along northwest zone

Species	Horizontal Distribution	Vertical Distribution	Duration of Spawning Season	Prey Specificity	Average Score
Coilia dussumieri	3	1	3	3	2.5
Decapterus russelli	1	1	2	2	1.5
Euthynnus affinis	3	2	2	3	2.5
Harpadon nehereus	3	1	3	3	2.5
Megalaspis cordyla	3	1	1	3	2
Rastrelliger kanagurta	3	1	3	2	2.25
Sardinella longiceps	3	2	2	1	2
Scomberomorus guttatus	2	1	3	3	2.25
Thunnus tonggol	3	1	2	1	1.75
Trichiurus lepturus	2	2	2	3	2.25
Epinephelus diacanthus	3	1	2	1	1.75
Himantura imbricata	1	1	2	3	1.75
Lactarius lactarius	2	2	2	2	2
Nemipterus japonicus	3	1	3	2	2.25
Nemipterus randalli	3	1	2	3	2.25
Otolithes cuvieri	3	1	2	3	2.25
Otolithoides biauritus	2	2	1	3	2
Pampus argenteus	3	1	2	3	2.5
Parastromateus niger	2	3	1	3	2.25
Plicofollis tenuispinis	1	2	2	2	1.75
Protonibea diacanthus	3	1	3	2	2.25
Saurida tumbil	3	1	3	2	2.25
Scoliodon laticaudus	3	2	2	3	2.5
Fenneropenaeus merguiensis	3	2	1	3	2.25
Metapenaeus monoceros	3	2	3	3	2.75
Metapenaeus affinis	3	1	3	2	2.25
Penaeus semisulcatus	3	1	3	2	2.25
Parapenaeopsis stylifera	3	2	2	3	2.5
Solenocera crassicornis	3	1	2	3	2.5
Panulirus polyphagus	3	2	3	3	2.75
Charybdis feriata	3	2	2	3	2.5
Portunus sanguinolentus	3	1	3	2	2.25
Sepia pharonis	3	2	3	3	2.25
Sepiella inermis	2	1	1	3	1.75
Uroteuthis (Photololigo) duvauceli	3	1	3	3	2.5

Appendix 1 d. Vulnerability scoring of species along northwest zone

Species	Exposure score	Sensitivity score	Adaptive capacity Score	Vulnerability score
Coilia dussumieri	1.83	1.44	2.5	0.77
Decapterus russelli	1.95	1.39	1.5	1.84
Euthynnus affinis	1.83	1.94	2.5	1.27
Harpadon nehereus	1.33	2.13	2.5	0.96
Megalaspis cordyla	1.33	1.87	2	1.20
Rastrelliger kanagurta	1.83	1.54	2.25	1.12
Sardinella longiceps	1.95	1.30	2	1.25
Scomberomorus guttatus	1.37	1.85	2.25	0.96
Thunnus tonggol	1.95	1.31	1.75	1.51
Trichiurus lepturus	1.89	2.10	2.25	1.74
Epinephelus diacanthus	1.81	1.52	1.75	1.57
Himantura imbricata	1.95	1.75	1.75	1.95
Lactarius lactarius	1.33	2.14	2	1.47
Nemipterus japonicus	1.83	1.54	2.25	1.12
Nemipterus randalli	1.89	1.63	2.25	1.27
Otolithes cuvieri	1.89	1.64	2.25	1.28
Otolithoides biauritus	1.83	2.30	2	2.13
Pampus argenteus	1.83	1.84	2.5	1.17
Parastromateus niger	1.83	1.97	2.25	1.55
Plicofollis tenuispinis	1.89	1.92	1.75	2.05
Protonibea diacanthus	1.83	1.66	2.25	1.24
Saurida tumbil	1.83	1.51	2.25	1.09
Scoliodon laticaudus	1.593	1.87	2.5	0.97
Fenneropenaeus merguiensis	1.83	1.84	2.25	1.42
Metapenaeus monoceros	1.89	1.51	2.75	0.65
Metapenaeus affinis	1.83	1.51	2.25	1.09
Penaeus semisulcatus	1.83	1.40	2.25	0.98
Parapenaeopsis stylifera	1.89	2.29	2.5	1.68
Solenocera crassicornis	1.83	1.82	2.5	1.15
Panulirus polyphagus	1.89	2.11	2.75	1.25
Charybdis feriata	1.33	2.12	2.5	0.95
Portunus sanguinolentus	1.83	1.56	2.25	1.14
Sepia pharonis	1.389	2.11	2.25	1.25
Sepiella inermis	1.567	1.96	1.75	1.77
Uroteuthis (Photololigo) duvauceli	1.89	1.96	2.5	1.35

Appendix 2 a. Exposure attributes and scoring along southwest zone

Species	SST	Rainfall	Current speed	Current direction	Upwelling index	Chlor conc.	Avg score
Decapterus russellii	1.73	1.54	2	1.6	0.5	2.56	1.65
Encrasicholina devisi	2.07	1.54	2	1.6	0.5	2.56	1.71
Euthynnus affinis	2.07	1.54	2	1.6	0.5	2.56	1.71
Katsuwonus pelamis	2.07	1.54	2	1.6	0.6	2.56	1.73
Rastrelliger kanagurta	2.07	1.54	2	1.6	0.5	2.56	1.71
Sardinella longiceps	2.07	1.54	2	1.6	0.5	2.56	1.71
Scomberomorus commerson	1.73	1.54	2	1.6	0.5	2.56	1.65
Sphyraena obtusata	1.73	1.54	2	1.6	0.5	2.56	1.65
Thunnus albacares	2.07	1.54	2	1.6	0.6	2.56	1.73
Trichiurus lepturus	1.73	1.54	2	1.6	0.6	2.56	1.67
Carcharhinus limbatus	1.73	1.54	1	0.8	0.6	2.56	1.37
Cynoglossus macrostomus	1.38	1.54	2	1.6	0.5	2.56	1.60
Epinephelus diacanthus	1.38	1.54	2	1.6	0.5	2.56	1.60
Lactarius lactarius	1.73	1.54	2	1.6	0.5	2.56	1.65
Nemipterus japonicus	1.38	1.54	2	1.6	0.5	2.56	1.60
Nemipterus randalli	1.38	1.54	2	1.6	0.5	2.56	1.60
Pampus argenteus	1.73	1.54	2	1.6	0.5	2.56	1.65
Parastromateus niger	1.38	1.54	2	1.6	0.5	2.56	1.60
Plicofollis dussumieri	1.38	1.54	1	0.8	0.5	2.56	1.30
Plicofollis tenuispinis	1.38	1.54	1	0.8	0.5	2.56	1.30
Saurida tumbil	1.38	1.54	2	1.6	0.5	2.56	1.60
Saurida undosquamis	1.38	1.54	2	1.6	0.5	2.56	1.60
Sphyrna lewini	1.73	1.54	1	0.8	0.6	2.56	1.37
Metapenaeus monoceros	1.38	1.54	2	1.6	0.5	2.56	1.60
Metapenaeus dobsoni	1.38	1.54	2	1.6	0.5	2.56	1.60
Fenneropenaeus indicus	1.38	1.54	2	1.6	0.5	2.56	1.60
Portunus pelagicus	1.38	1.54	2	1.6	0.5	2.56	1.60
Portunus sanguinolentus	1.38	1.54	2	1.6	0.5	2.56	1.60
Perna viridis	1.38	1.54	2	1.6	0.5	2.56	1.60
Uroteuthis (Photololigo) duvauceli	1.73	1.54	1	0.8	0.5	2.56	1.35

Appendix 2 b. Sensitivity attributes and scoring along southwest zone

Species	Fecundity	Complex life cycle	Growth cofficient	Trophic level	Longevity	Lc/Lm	Explo.rate	CPUE	Price	Avg score
Decapterus russellii	2	1	2	2	2	1	1	1.67	1	1.52
Encrasicholina devisi	2	1	1	2	1	1	3	1.87	1	1.54
Euthynnus affinis	2	1	2	3	3	1	1	1.58	2	1.84
Katsuwonus pelamis	1	1	2	3	2	2	1	1.35	2	1.71
Rastrelliger kanagurta	2	1	1	2	1	3	3	1.33	2	1.81
Sardinella longiceps	2	1	1	1	1	2	2	1.8	2	1.53
Scomberomorus commerson	2	1	2	3	2	2	3	1.6	3	2.18
Sphyraena obtusata	2	1	1	3	2	1	2	1.53	2	1.73
Thunnus albacares	1	1	3	3	3	2	1	1.5	2	1.94
Trichiurus lepturus	2	1	2	3	2	1	2	1.52	1	1.72
Carcharhinus limbatus	3	1	3	3	3	2	2	1.53	2	2.28
Cynoglossus macrostomus	2	1	2	1	2	1	3	1.33	1	1.59
Epinephelus diacanthus	2	1	2	3	2	3	2	1.53	2	2.06
Lactarius lactarius	2	1	2	3	2	3	2	1.6	2	2.07
Nemipterus japonicus	2	1	2	2	2	1	3	1.79	2	1.87
Nemipterus randalli	2	1	2	2	2	3	2	1.73	2	1.97
Pampus argenteus	2	1	2	2	2	3	2	1.2	3	2.02
Parastromateus niger	2	1	2	1	3	3	3	2	3	2.22
Plicofollis tenuispinis	3	1	3	3	3	3	2	2.29	2	2.48
Plicofollis dussumieri	3	1	3	3	3	3	2	1.2	2	2.07
Saurida tumbil	2	1	2	3	2	2	3	1.6	2	2.07
Saurida undosquamis	2	1	2	3	2	1	2	1.73	2	1.86
Sphyrna lewini	3	1	3	3	3	3	3	2	2	2.56
Metapenaeus dobsoni	2	3	1	2	1	2	3	1.64	2	1.96
Metapenaeus monoceros	2	3	1	2	1	2	3	2.35	3	2.15
Fenneropenaeus indicus	1	3	1	2	1	3	3	1.53	3	2.06
Portunus pelagicus	2	3	1	1	1	2	3	1.5	2	1.83
Portunus sanguinolentus	2	3	1	1	1	0.64	3	1.1	2	1.64
Perna viridis	1	3	1	1	1	1	1		3	1.50
Uroteuthis (Photololigo) duvauceli	2	2	2	3	2	2	3	1.67	2	2.19

Appendix 2 c. Adaptive capacity attribute and scoring along southwest zone

Species	Horizontal distribution	Vertical distribution	Duration of spawning season	Prey specificity	Average score
Decapterus russellii	3	1	3	3	2.5
Encrasicholina devisi	3	1	2	3	2.25
Euthynnus affinis	3	3	1	3	2.5
Katsuwonus pelamis	3	2	3	3	2.75
Rastrelliger kanagurta	3	2	1	2	2
Sardinella longiceps	3	2	2	2	2.25
Scomberomorus commerson	3	2	2	3	2.5
Sphyraena obtusata	3	1	2	3	2.25
Thunnus albacares	3	3	1	3	2.5
Trichiurus lepturus	3	1	3	3	2.5
Carcharhinus limbatus	3	1	1	3	2
Cynoglossus macrostomus	3	1	3	3	2.5
Epinephelus diacanthus	3	1	2	3	2.25
Lactarius lactarius	3	1	2	3	2.25
Nemipterus japonicus	3	1	2	3	2.25
Nemipterus randalli	3	1	2	3	2.25
Pampus argenteus	3	1	2	3	2.25
Parastromateus niger	3	1	2	3	2.25
Plicofollis tenuispinis	3	1	2	3	2.25
Plicofollis dussumieri	3	1	2	3	2.25
Saurida tumbil	3	1	2	3	2.25
Saurida undosquamis	3	1	2	3	2.25
Sphyrna lewini	3	1	1	3	2
Metapenaeus dobsoni	2	1	2	2	1.75
Metapenaeus monoceros	3	1	2	2	2
Fenneropenaeus indicus	2	1	2	2	1.75
Portunus pelagicus	3	1	2	3	2.25
Portunus sanguinolentus	3	1	2	3	2.25
Perna viridis	2	1	2	1	1.5
Uroteuthis (Photololigo) duvauceli	3	1	2	3	2.25

Appendix 2 d. Vulnerability scoring of species along southwest zone

Species	Exposure score	Sensitivity score	Adaptive capacity Score	Vulnerability score
Decapterus russellii	1.65	1.52	2.5	0.67
Encrasicholina devisi	1.71	1.54	2.25	1.00
Euthynnus affinis	1.71	1.84	2.5	1.05
Katsuwonus pelamis	1.73	1.71	2.75	0.68
Rastrelliger kanagurta	1.71	1.81	2	1.53
Sardinella longiceps	1.71	1.53	2.25	0.99
Scomberomorus commerson	1.65	2.18	2.5	1.33
Sphyraena obtusata	1.65	1.73	2.25	1.13
Thunnus albacares	1.73	1.94	2.5	1.17
Trichiurus lepturus	1.67	1.72	2.5	0.90
Carcharhinus limbatus	1.37	2.28	2	1.65
Cynoglossus macrostomus	1.60	1.59	2.5	0.69
Epinephelus diacanthus	1.60	2.06	2.25	1.41
Lactarius lactarius	1.65	2.07	2.25	1.47
Nemipterus japonicus	1.60	1.87	2.25	1.21
Nemipterus randalli	1.60	1.97	2.25	1.32
Pampus argenteus	1.65	2.02	2.25	1.43
Parastromateus niger	1.60	2.22	2.25	1.57
Plicofollis tenuispinis	1.30	2.48	2.25	1.52
Plicofollis dussumieri	1.30	2.36	2.25	1.40
Saurida tumbil	1.60	2.07	2.25	1.41
Saurida undosquamis	1.60	1.86	2.25	1.21
Sphyrna lewini	1.37	2.56	2	1.93
Metapenaeus dobsoni	1.60	1.96	1.75	1.81
Metapenaeus monoceros	1.60	2.15	2	1.75
Fenneropenaeus indicus	1.60	2.06	1.75	1.91
Portunus pelagicus	1.60	1.83	2.25	1.18
Portunus sanguinolentus	1.60	1.64	2.25	0.98
Perna viridis	1.60	1.50	1.5	1.60
Uroteuthis (Photololigo) duvauceli	1.35	2.19	2.25	1.29

Appendix 3 a. Exposure attributes and scoring along southeast zone

Species	SST	Rainfall	Current speed	Upwelling index	Chlor conc.	Avg score
Sardinella longiceps	2.07	1.5	2	1	1.9	1.69
Sardinella gibbosa	2.07	1.5	2	1	1.9	1.69
Stolephorus indicus	2.07	1.5	2	1	1.9	1.69
Rastrelliger kanagurta	2.07	1.5	2	1	1.9	1.69
Katsuwonus pelamis	2.07	1.5	2	1	1.9	1.69
Thunnus albacares	2.07	1.5	2	1	1.9	1.69
Euthynnus affinis	2.07	1.5	2	1	1.9	1.69
Trichiurus lepturus	1.73	1.5	2	1	1.9	1.63
Decapterus russelli	1.73	1.5	2	1	1.9	1.63
Scomberomorus commerson	1.73	1.5	2	1	1.9	1.63
Chirocentrus dorab	2.07	1.5	2	1	1.9	1.69
Chirocentrus nudus	2.07	1.5	2	1	1.9	1.69
Sphyraena jello	1.73	1.5	2	1	1.9	1.63
Carcharinus limbatus	1.73	1.5	1	1	1.9	1.43
Saurida tumbil	1.38	1.5	2	1	1.9	1.56
Saurida undosquamis	1.38	1.5	2	1	1.9	1.56
Nemipterus japonicus	1.38	1.5	2	1	1.9	1.56
Nemipterus randalli	1.38	1.5	2	1	1.9	1.56
Parastromateus niger	1.73	1.5	2	1	1.9	1.63
Pampus argenteus	1.73	1.5	2	1	1.9	1.63
Mugil cephalus	1.38	1.5	2	1	1.9	1.56
Cynoglossus macrostomus	1.38	1.5	2	1	1.9	1.56
Metapenaeus monoceros	1.38	1.5	2	1	1.9	1.56
Metapenaeus stridulans	1.38	1.5	2	1	1.9	1.56
Metapenaeus dobsoni	1.38	1.5	2	1	1.9	1.56
Penaeus monodon	1.38	1.5	2	1	1.9	1.56
Portunus pelagicus	1.38	1.5	2	1	1.9	1.56
Portunus sanguinolentus	1.38	1.5	2	1	1.9	1.56
Perna viridis	1.38	1.5	2	1	1.9	1.56
Uroteuthis (Photololigo) duvauceli	1.73	1.5	1	1	1.9	1.43

Appendix 3 b. Sensitivity attributes and scoring along southeast zone

Species	Fecundity	Complex life cycle	Growth cofficient	Trophic level	Longevity	Lc/Lm	Explo.rate	CPUE	Price	Avg score
Sardinella longiceps	2	1	1	1	1	2	2	1.2	1	1.36
Sardinella gibbosa	2	1	1	1	1	1	1	2.1	2	1.34
Stolephorus indicus	2	1	1	2	1	1	2	2.3	2	1.59
Rastrelliger kanagurta	2	1	1	2	1	3	2	1.7	2	1.74
Katsuwonus pelamis	1	1	2	3	2	2	2	1.2	2	1.80
Thunnus albacares	1	1	3	3	3	2	3	1.7	2	2.19
Euthynnus affinis	1	1	2	3	3	1	2	2.3	2	1.92
Trichiurus lepturus	2	1	2	3	2	1	2	1.9	2	1.88
Decapterus russelli	2	1	2	2	2	1	1	2.3	1	1.59
Scomberomorus commerson	2	1	2	3	2	2	3	1.8	3	2.20
Chirocentrus dorab	2	1	2	3	2	2	3	1.3	2	2.03
Chirocentrus nudus	2	1	2	3	2	1	3	1.5	2	1.94
Sphyraena jello	2	1	1	3	2	1	2	1.4	2	1.71
Carcharinus limbatus	3	1	3	3	3	2	2	2.3	2	2.37
Saurida tumbil	2	1	2	3	2	2	1	1.7	2	1.86
Saurida undosquamis	2	1	2	3	2	2	2	1.7	2	1.97
Nemipterus japonicus	2	1	2	2	2	1	2	1.7	2	1.74
Nemipterus randalli	2	1	2	2	2	1	1	1.7	2	1.63
Parastromateus niger	2	1	2	2	2	1	2	1.2	3	1.80
Pampus argenteus	2	1	2	2	2	2	2	1.8	3	1.98
Mugil cephalus	2	1	3	1	1	1	1	1.2	2	1.47
Cynoglossus macrostomus	2	1	2	2	2	1	1	1.5	1	1.50
Metapenaeus monoceros	2	3	1	2	2	2	2	2.6	3	2.18
Metapenaeus stridulans	2	3	1	2	2	3	2	1.8	2	2.09
Metapenaeus dobsoni	2	3	1	2	2	2	2	2.7	2	2.08
Penaeus monodon	2	3	1	2	2	2	2		3	2.13
Portunus pelagicus	2	3	2	2	2	2	3	2.4	2	2.27
Portunus sanguinolentus	2	3	2	2	2	2	2	2.4	2	2.16
Perna viridis	1	3	1	1	1	1	1	1.2	2	1.36
Uroteuthis (Photololigo) duvauceli	2	2	2	3	2	2	1	1.2	2	1.91

Appendix 3 c. Adaptive capacity attribute and scoring along southeast zone

Species	Horizontal distribution	Vertical distribution	Duration of spawning season	Prey specificity	Average score
Sardinella longiceps	1	2	2	2	1.75
Sardinella gibbosa	1	2	1	2	1.5
Stolephorus indicus	1	3	1	1	1.5
Rastrelliger kanagurta	1	2	3	2	2
Katsuwonus pelamis	1	2	1	1	1.25
Thunnus albacares	1	1	3	1	1.5
Euthynnus affinis	1	1	3	1	1.5
Trichiurus lepturus	1	3	1	1	1.5
Decapterus russelli	1	3	1	1	1.5
Scomberomorus commerson	1	2	2	1	1.5
Chirocentrus dorab	1	2	2	2	1.75
Chirocentrus nudus	1	2	2	2	1.75
Sphyraena jello	1	2	2	2	1.75
Carcharinus limbatus	1	3	3	1	2
Saurida tumbil	1	3	2	1	1.75
Saurida undosquamis	1	3	2	1	1.75
Nemipterus japonicus	1	3	2	1	1.75
Nemipterus randalli	1	3	2	1	1.75
Parastromateus niger	1	3	2	1	1.75
Pampus argenteus	1	3	2	1	1.75
Mugil cephalus	1	2	2	2	1.75
Cynoglossus macrostomus	1	3	1	1	1.5
Metapenaeus monoceros	1	3	2	2	2
Metapenaeus stridulans	2	3	2	2	2.25
Metapenaeus dobsoni	2	3	2	2	2.25
Penaeus monodon	1	3	2	2	2
Portunus pelagicus	1	3	2	1	1.75
Portunus sanguinolentus	1	3	2	1	1.75
Perna viridis	2	3	2	3	2.5
Uroteuthis (Photololigo) duvauceli	1	3	2	1	1.75

Appendix 3 d. Vulnerability scoring of species along southeast zone

Species	Exposure score	Sensitivity score	Adaptive capacity Score	Vulnerability score
Sardinella longiceps	1.69	1.36	1.75	1.30
Sardinella gibbosa	1.69	1.34	1.50	1.54
Stolephorus indicus	1.69	1.59	1.50	1.78
Rastrelliger kanagurta	1.69	1.74	2.00	1.44
Katsuwonus pelamis	1.69	1.80	1.25	2.24
Thunnus albacares	1.69	2.19	1.50	2.38
Euthynnus affinis	1.69	1.92	1.50	2.12
Trichiurus lepturus	1.63	1.88	1.50	2.00
Decapterus russelli	1.63	1.59	1.50	1.71
Scomberomorus commerson	1.63	2.20	1.50	2.33
Chirocentrus dorab	1.69	2.03	1.75	1.98
Chirocentrus nudus	1.69	1.94	1.75	1.89
Sphyraena jello	1.63	1.71	1.75	1.59
Carcharinus limbatus	1.43	2.37	2.00	1.79
Saurida tumbil	1.56	1.86	1.75	1.66
Saurida undosquamis	1.56	1.97	1.75	1.77
Nemipterus japonicus	1.56	1.74	1.75	1.55
Nemipterus randalli	1.56	1.63	1.75	1.44
Parastromateus niger	1.63	1.80	1.75	1.68
Pampus argenteus	1.63	1.98	1.75	1.85
Mugil cephalus	1.56	1.47	1.75	1.27
Cynoglossus macrostomus	1.56	1.50	1.50	1.56
Metapenaeus monoceros	1.56	2.18	2.00	1.73
Metapenaeus stridulans	1.56	2.09	2.25	1.40
Metapenaeus dobsoni	1.56	2.08	2.25	1.38
Penaeus monodon	1.56	2.13	2.00	1.68
Portunus pelagicus	1.56	2.27	1.75	2.07
Portunus sanguinolentus	1.56	2.16	1.75	1.96
Perna viridis	1.56	1.36	2.50	0.41
Uroteuthis (Photololigo) duvauceli	1.43	1.91	1.75	1.59

Appendix 4 a. Exposure attributes and scoring along northeast zone

Species	SST	Rainfall	Current speed	Current direction	Upwelling index	Chlor conc.	Exposure score
Sardinella longiceps	2.82	1.64	2	2	1	2.18	2.22
Sardinella gibbosa	2.82	1.64	2	2	1	2.18	2.22
Sardinella fimbriata	2.82	1.64	2	2	1	2.18	2.22
Rastrelliger kanagurta	2.82	1.64	2	2	1	2.18	2.22
Scomberomorus guttatus	2.35	1.64	2	2	1	2.18	2.14
Scomberomorus commerson	2.35	1.64	2	2	1	2.18	2.14
Thunnus albacares	2.82	1.64	2	2	1	2.18	2.22
Katsuwonus pelamis	2.82	1.64	2	2	1	2.18	2.22
Coryphaena hippurus	2.35	1.64	2	2	1	2.18	2.14
Trichiurus lepturus	2.35	1.64	2	2	1	2.18	2.14
Sphyraena jello	2.35	1.64	2	2	1	2.18	2.14
Megalaspis cordyla	2.35	1.64	2	2	1	2.18	2.14
Tenulosa ilisha	2.82	1.64	2	2	1	2.18	2.22
Nemipterus japonicus	1.88	1.64	2	2	1	2.18	2.06
Nemipterus mesoprion	1.88	1.64	2	2	1	2.18	2.06
Upenues vittatus	1.88	1.64	2	2	1	2.18	2.06
Upeneus sulphureus	1.88	1.64	2	2	1	2.18	2.06
Saurida undosquamis	1.88	1.64	2	2	1	2.18	2.06
Saurida tumbil	1.88	1.64	2	2	1	2.18	2.06
Otolithes ruber	1.88	1.64	2	2	1	2.18	2.06
Johnius carutta	1.88	1.64	2	2	1	2.18	2.06
Pennahia anea	1.88	1.64	2	2	1	2.18	2.06
Priacanthus hamrur	1.88	1.64	2	2	1	2.18	2.06
Plicofollis tenuispinis	1.88	1.64	1	1	1	2.18	1.59
Metapenaeus monoceros	1.88	1.64	2	2	1	2.18	2.06
Fenneropenaeus indicus	1.88	1.64	2	2	1	2.18	2.06
Penaeus monodon	1.88	1.64	2	2	1	2.18	2.06
Portunus sanguinolentus	1.88	1.64	2	2	1	2.18	2.06
Portunus pelagicus	1.88	1.64	2	2	1	2.18	2.06
Uroteuthis (Photololigo) duvauceli	2.35	1.64	1	1	1	2.18	1.67
Sepia aculeata	2.35	1.64	1	1	1	2.18	1.67
Sepia pharonis	2.35	1.64	1	1	1	2.18	1.67

Appendix 4 b. Sensitivity attributes and scoring along northeast zone

Species	Fecundity	Complexity in early development	Growth coefficient (K)	Trophic level	Longevity	Lc/Lm	Exploitation rate	Price (Rs)	CPUE	Sensitivity score
Sardinella longiceps	2	1	1	1	2	1	1	1	3	1.44
Sardinella gibbosa	2	1	2	1	2	1	2	1	3	1.67
Sardinella fimbriata	2	1	2	1	2	1	2	1	3	1.67
Rastrelliger kanagurta	2	1	2	1	2	1	1	2	3	1.67
Scomberomorus guttatus	1	1	2	2	2	2	2	3	3	2.0
Scomberomorus commerson	1	1	3	3	3	3	2	3	3	2.44
Thunnus albacares	1	1	3	3	3	2	2	1	3	2.11
Katsuwonus pelamis	1	1	3	3	3	1	2	1	3	2.00
Coryphaena hippurus	2	1	3	3	3	1	1	1	2	1.89
Trichiurus lepturus	2	1	3	2	3	2	2	2	3	2.22
Sphyraena jello	1	1	3	3	3	2	2	2	3	2.22
Megalaspis cordyla	1	1	2	2	2	1	3	2	3	1.89
Tenulosa ilisha	1	1	2	1	2	2	3	3	2	1.89
Nemipterus japonicus	2	1	2	2	2	2	3	2	3	2.11
Nemipterus mesoprion	2	1	2	2	2	2	2	2	3	2.00
Upenues vittatus	2	1	2	2	2	2	3	1	3	2.00
Upeneus sulphureus	2	1	2	2	2	2	2	1	3	1.89
Saurida undosquamis	2	1	3	2	3	2	2	2	3	2.22
Saurida tumbil	2	1	2	3	2	2	2	2	3	2.11
Otolithes ruber	2	1	2	2	2	1	3	2	3	2.00
Johnius carutta	2	1	2	2	2	1	2	2	3	1.89
Pennahia anea	2	1	2	2	2	1	3	2	3	2.00
Priacanthus hamrur	1	1	2	2	2	2	2	1	3	1.78
Plicofollis tenuispinis	3	3	3	2	3	1	2	2	3	2.44
Metapenaeus monoceros	2	2	1	1	1	2	3	3	3	2.00
Fenneropenaeus indicus	2	2	1	1	1	2	3	3	3	2.00
Penaeus monodon	1	2	1	1	1	2	2	3	3	1.78
Portunus sanguinolentus	1	2	1	1	1	1	2	2	2	1.44
Portunus pelagicus	1	2	1	1	1	2	2	2	2	1.56
Uroteuthis (Photololigo) duvauceli	2	1	1	2	2	3	3	2	3	2.11
Sepia aculeata	2	1	2	2	3	2	2	2	2	2.00
Sepia pharonis	2	1	2	2	3	1	2	2	2	1.89

Appendix 4 c. Adaptive capacity attribute and scoring along northeast zone

Species	Horizontal distribution	Vertical distribution	Duration of spawning season	Prey specificity	Average
Sardinella longiceps	2	2	2	2	2
Sardinella gibbosa	2	1	2	2	1.75
Sardinella fimbriata	2	1	2	2	1.75
Rastrelliger kanagurta	3	3	2	2	2.5
Scomberomorus guttatus	2	2	2	3	2.25
Scomberomorus commerson	3	2	2	3	2.5
Thunnus albacares	3	2	2	3	2.5
Katsuwonus pelamis	3	2	2	3	2.5
Coryphaena hippurus	3	2	2	3	2.5
Trichiurus lepturus	3	2	2	3	2.5
Sphyraena jello	3	2	2	3	2.5
Megalaspis cordyla	3	2	2	3	2.5
Tenulosa ilisha	1	1	2	2	1.5
Nemipterus japonicus	3	1	2	3	2.25
Nemipterus mesoprion	3	1	2	3	2.25
Upenues vittatus	3	1	2	3	2.25
Upeneus sulphureus	3	1	2	3	2.25
Saurida undosquamis	3	1	2	3	2.25
Saurida tumbil	3	1	2	3	2.25
Otolithes ruber	3	2	2	3	2.5
Johnius carutta	3	2	2	3	2.5
Pennahia anea	3	2	3	3	2.75
Priacanthus hamrur	3	2	2	3	2.5
Tachysurus tenuispinis	2	2	2	3	2.25
Metapenaeus monoceros	3	1	2	2	2
Fenneropenaeus indicus	3	1	2	2	2
Penaeus monodon	2	1	2	2	1.75
Portunus sanguinolentus	3	2	3	3	2.75
Portunus pelagicus	3	2	3	3	2.75
Uroteuthis (Photololigo) duvauceli	3	1	3	3	2.5
Sepia aculeata	3	1	3	3	2.5
Sepia pharonis	3	1	3	3	2.5

Appendix 4 d. Vulnerability scoring of species along northeast zone

Species	Exposure score	Sensitivity score	Adaptive capacity score	Vulnerability score
Sardinella longiceps	2.22	1.44	2.00	1.66
Sardinella gibbosa	2.22	1.67	1.75	2.13
Sardinella fimbriata	2.22	1.67	1.75	2.13
Rastrelliger kanagurta	2.22	1.67	2.50	1.38
Scomberomorus guttatus	2.14	2.00	2.25	1.89
Scomberomorus commerson	2.14	2.44	2.50	2.08
Thunnus albacares	2.22	2.11	2.50	1.83
Katsuwonus pelamis	2.22	2.00	2.50	1.72
Coryphaena hippurus	2.14	1.89	2.50	1.53
Trichiurus lepturus	2.14	2.22	2.50	1.86
Sphyraena jello	2.14	2.22	2.50	1.86
Megalaspis cordyla	2.14	1.89	2.50	1.53
Tenulosa ilisha	2.22	1.89	1.50	2.61
Nemipterus japonicus	2.06	2.11	2.25	1.92
Nemipterus mesoprion	2.06	2.00	2.25	1.81
Upenues vittatus	2.06	2.00	2.25	1.81
Upeneus sulphureus	2.06	1.89	2.25	1.70
Saurida undosquamis	2.06	2.22	2.25	2.03
Saurida tumbil	2.06	2.11	2.25	1.92
Otolithes ruber	2.06	2.00	2.50	1.56
Johnius carutta	2.06	1.89	2.50	1.45
Pennahia anea	2.06	2.00	2.75	1.31
Priacanthus hamrur	2.06	1.78	2.50	1.34
Plicofollis tenuispinis	1.59	2.44	2.25	1.78
Metapenaeus monoceros	2.06	2.00	2.00	2.06
Fenneropenaeus indicus	2.06	2.00	2.00	2.06
Penaeus monodon	2.06	1.78	1.75	2.09
Portunus sanguinolentus	2.06	1.44	2.75	0.75
Portunus pelagicus	2.06	1.56	2.75	0.87
Uroteuthis (Photololigo) duvauceli	1.67	2.11	2.50	1.28
Sepia aculeata	1.67	2.00	2.50	1.17
Sepia pharonis	1.67	1.89	2.50	1.06

Appendix 2

Personnel involved

Working Group members for evolving criteria for consultation

1. Dr. P. U. Zacharia, Principal Scientist & Head, Demersal Fisheries Division, CMFRI, Kochi
2. Dr A.P. Dineshbabu, Principal Scientist, Crustacean Fisheries Division, Mangalore Research Centre of CMFRI, Mangalore
3. Dr. Sujitha Thomas, Principal Scientist, Demersal Fisheries Division, Mangalore Research Centre of CMFRI, Mangalore
4. Dr. Shoba Joe Kizhakudan, Principal Scientist, Demersal Fisheries Division, Madras Research Centre of CMFRI, Chennai
5. Dr. S. Lakshmi Pillai, Principal Scientist, Crustacean Fisheries Division, CMFRI, Kochi
6. Dr. M. Sivadas, Principal Scientist, Pelagic Fisheries Division , Madras Research Centre of CMFRI, Chennai
7. Dr. Shubhadeep Ghosh, Senior Scientist, Pelagic Fisheries Division, Visakhapatnam Regional Centre of CMFRI, Visakhapatnam
8. Dr. U. Ganga, Principal Scientist, Pelagic Fisheries Division, CMFRI, Kochi
9. Dr. K.M. Rajesh, Senior Scientist, Pelagic Fisheries Division, Mangalore Research Centre of CMFRI, Mangalore
10. Dr. Rekha J. Nair, Principal Scientist, Demersal Fisheries Division, CMFRI, Kochi
11. Dr. T.M. Najmudeen, Senior Scientist, Demersal Fisheries Division, CMFRI, Kochi
12. Shri. Mohammed Koya, Scientist, Pelagic Fisheries Division, Veraval Regional Centre of CMFRI, Veraval
13. Dr. Anulekshmi Chellappan, Scientist, Pelagic Fisheries Division, Mumbai Research Centre of CMFRI, Mumbai
14. Shri. Gyanranjan Dash, Scientist, Crustacean Fisheries Division, Veraval Regional Centre of CMFRI, Veraval
15. Smt. Indira Divipala, Crustacean Fisheries Division, Madras Research Centre of CMFRI, Chennai
16. Dr. K.V. Akhilesh, Scientist, Demersal Fisheries Division, Mumbai Research Centre of CMFRI, Mumbai
17. Smt. M. Muktha, Scientist, Demersal Fisheries Division, Visakhapatnam Regional Centre of CMFRI, Visakhapatnam
18. Smt. Swathipriyanka Sen Dash, Scientist, Demersal Fisheries Division, Veraval Regional Centre of CMFRI, Veraval

National Consultant

Dr. E. Vivekanandan, Principal Scientist (Retd.), CMFRI, Kochi

National and Zonal Resource Group

Principal Investigator

Dr. P.U. Zacharia, Principal Scientist

National Coordinator

Dr. A.P. Dineshbabu, Principal Scientist

Northwest zone

Shri. Mohammed Koya, Scientist - Team Leader

Dr. Anulekshmi Chellappan, Scientist

Shri. Gyanranjan Dash, Scientist

Dr. K.V. Akhilesh, Scientist

Smt. Swathipriyanka Sen Dash, Scientist

Ms. Sonia Kumari, Research Associate

Mr. Bala L. Mhadgut, Senior Research Fellow

Southwest zone

Dr. Sujitha Thomas, Principal Scientist - Team Leader

Dr. S. Lakshmi Pillai, Principal Scientist

Dr. U. Ganga. Principal Scientist

Dr. Rekha J. Nair, Principal Scientist

Dr. T.M. Najmudeen, Senior Scientist

Dr. K.M Rajesh, Senior Scientist

Ms. V. Suprabha, Research Associate

Dr. G. Rojith, Research Associate

Ms. V. H. Sajna, Senior Research Fellow

Shri. T.V. Ambrose, Senior Research Fellow

Ms. Shailaja Salian, Senior Research Fellow

Shri. Subhankar Biswas, Senior Research Fellow

Ms. Vinny Johny, Senior Research Fellow

Southeast zone

Dr. M. Sivadas, Principal Scientist - Team Leader

Dr. Shoba Joe Kizhakudan, Principal Scientist

Smt. Indira Divipala, Scientist

Dr. M. Shanthi, Research Associate

Dr. K. Kannan, Senior Research Fellow

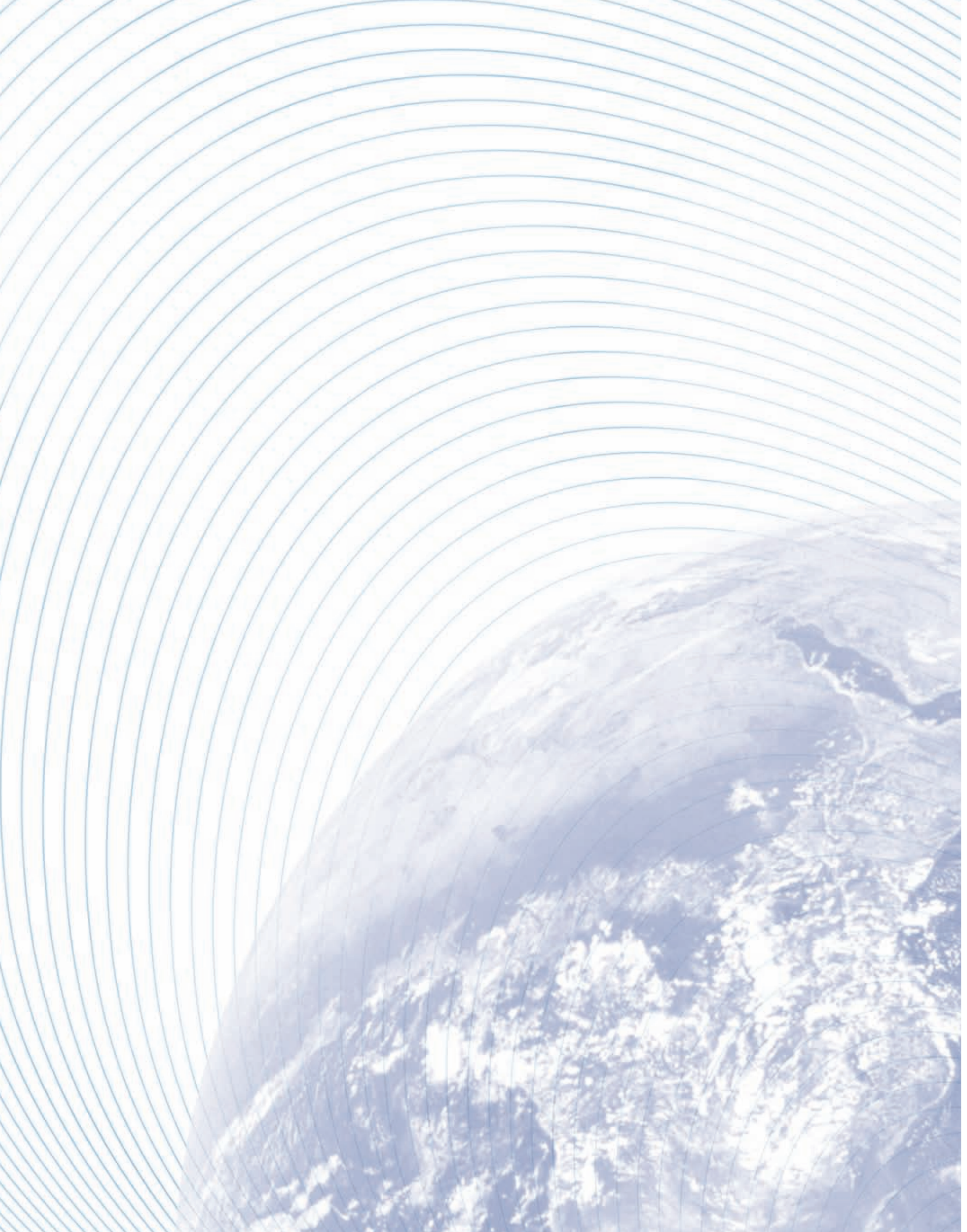
Northeast zone

Dr. Shubhadeep Ghosh, Senior Scientist - Team Leader

Smt. M. Muktha, Scientist

Shri. V. Hanumantha Rao, Senior Research Fellow

Shri. Uma Mahesh, Senior Research Fellow



Relative vulnerability assessment of
Indian marine fishes to climate change
using impact and adaptation attributes

Vulnerability assessments can be used for different purposes, including improving adaptation planning (designing of policies and interventions), raising awareness of risks and opportunities, and advancing scientific research. This book is the result of the study on vulnerability of Indian fish stocks to climate change conducted on identified priority species that contribute significantly to the fishery along the Indian coast, and on which substantial biological information was 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.

भाकृअनुप
ICAR

Indian Council of Agricultural Research
Central Marine Fisheries Research Institute
Ernakulum North. P.O, No.1603, Kochi-682 018, Kerala, India.

सी एम एफ आर आइ
CMFRI