STATUS OF CORAL REEF IN OUTER GULF OF KACHCHH REGION, GUJARAT

Thesis submitted in partial fulfillment
of the requirements
for the degree of

Ph. D. (Fisheries Resource Management)

By

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Dedicated to,
My respected teachers..

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ICAR-CENTRAL INSTITUTE OF FISHERIES EDUCATION
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Govt. of India.

Dated: 24th January 2022

CERTIFICATE

Certified that the thesis entitled **"STATUS OF CORAL REEF IN OUTER GULF OF KACHCHH REGION, GUJARAT"** is a record of independent bonafide research work carried out by **Mr. Katira Nareshbhai Nathabhai** during the period of study from September 2016 to August 2021 under our supervision and guidance for the degree of **Doctor of Philosophy (Fisheries Resource Management)** and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

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I hereby declare that the thesis entitled **"STATUS OF CORAL REEF IN OUTER GULF OF KACHCHH REGION, GUJARAT"** is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

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सारांश

कठिन-प्रवाल और उसकी जैवविविधता के अभ्यास हेतु, कच्छ की खाड़ी (GOK) के बाहरी क्षेत्र में प्रवाल परितंत्र की स्थिति का अध्ययन किया गया | प्रवाल जैवविविधता की स्थिति समझने हेतु, बाहरी GOK के तीन चुनिंदा स्थल, ओखा, मीठापुर, और शिवराजपुर पर प्रवाल पारितंत्र में लाईन इंटरसेप्ट ट्रांजेक्ट (LIT) क्रियाविधि, प्रश्नावली आधारित सामाजिक एवं आर्थिक विश्लेषण, एवं पर्यावरण मुल्यांकन नवंबर २०१७ से फ़रवरी २०१९ तक मासिक अंतराल पर किया गया था | शिवराजपुर में जीवित प्रवाल का उच्चतम तुलनात्मक आवरण पाया गया (७२ %), इसके बाद मीठापुर और ओखा रहें | कुल २३ कठिन-प्रवाल प्रजातियाँ १२ जाति और आठ परिवारों के अंतर्गत दर्ज हुईं | शिवराजपुर में सबसे अधिक कठिन-प्रवाल प्रजातियाँ (२३ प्रतातियाँ) मिली, उसके बाद मीठापुर और ओखा रहें | प्राप्य प्रवाल प्रजातियों में पोरीटिडे परिवार का सबसे अधिक योगदान रहा, इसके बाद फेविड़े और मेरुलिनिड़े का स्थान रहा | एक औसत सापेक्ष बहुतायत के अनुसार, GOK के बाहरी क्षेत्र में पाई जाने वाली प्रमुख प्रजाति *डीपसेस्ट्रीया फेवुस* रही जिसके बाद *प्स्युडोसाइडेस्ट्रिया टायामाई* और *गोनियोपोरा पेड्नक्यूलाटा* का स्थान रहा | प्रवाल-संलग्नित वनस्पतियों की कुल २९ प्रजातियाँ, २४ जातियां और आठ विभिन्न वरिवारों के अंतर्गत मिली | जिनमे *उल्वा लेक्ट्युका* ने कुल जैव-भार में सबसे अधिक योगदान दिया, उसके बाद *सरगासम सिनेरियम* का स्थान रहा | ओखा तट पर, सर्दियों के मौसम में सबसे अधिकतम समुद्री-शैवाल विविधता पायी गई | कुल ३५ जातियां और ३० विभिन्न परिवारों के अंतर्गत प्रवाल-संलग्नित जीवों की कुल ३९ प्रजातियाँ दर्ज हुई | जिसमे सबसे अधिक गेस्ट्रोपोड और इसके बाद क्रस्टेशियन प्राप्त हुए | प्रवाल एवं प्रवाल-संलग्नित शैवाल और जीवों की विविधता के आंकलन हेतु शैनन-वीनर सूचकांक, पिलोऊ की समता, और मार्गलिफ़ की समृधि सूचकांक लागु किये गए | कठिन-प्रवाल की उच्चतम विविधता शिवराजपुर (H'=२.५८), इसके बाद मीठापुर (H'=१.८९) और ओखा (H'=१.७८) में पाई गई | भौतिक-रासायनिक मापदंड जैसे की, पानी का तापमान, लवणता, pH, और द्राव्य ओक्सिजन बाहरी GOK के प्रवाल परितंत्र के विकास और अस्तित्व में महत्वपूर्ण भूमिका निभाते हैं | ओखा, मीठापुर, और शिवराजपुर में पानी का औसत तापमान और लवणता क्रमशः २६ °C और ३४ ppt, २६ °C और ३५ ppt, और २७ °C और ३४ ppt रहे, और औसत pH मान क्रमशः ७.७३, 7.91, और ७.८४ रहा | इसी तरह, औसत द्राव्य ओक्सिजन स्तर क्रमशः ६.५०, ६.२२ और ६.५९ mg/lit रहा | बाहरी GOK का प्रवाल परितंत्र, फिनफिश और शेलफिश उत्पादन द्वारा अधिकतम आय उत्पन्न करता है | मीठापुर में अधिकतम औसत आय प्रति मछ्वारा प्रति वर्ष आय उत्पादन हुआ (₹ १,४७,६२०), उसके बाद ओखा (₹ १,३०,३१०), और शिवराजपुर (₹ १,०९,५४०) रहें | हालाँकि, सोलह प्रवाल प्रजातियों को प्रक्षालित पाया गया, विशेष रूप से मानव-प्रेरित तनाव जैसे स्थानीय पर्यटन, पारंपरिक माछिमारी, और तट प्रदुषण के कारण यह आय असुरक्षित है | कॉलोनी स्केल ब्लीचिंग का अधिकतम तुलनात्मक आवरण *जी. पेड्नक्यूलाटा* (३४%) में देखा गया, उसके बाद *डी. फेवुस* (३१%) रहा | मीठापुर में अधिकतम सापेक्ष मृत प्रवाल आवरण (१२.६२%) पाया गया, इसके बाद ओखा (६.४५%), और शिवराजपुर (०.४१%) रहें | हालाँकि, कोरल मोर्टेलिटी इंडेक्स (CMI) के अनुसार, बाहरी GOK के प्रवाल परितंत्र को स्वस्थ माना जा सकता है | ओखा और मीठापुर के प्रवाल परितंत्र भारी मानवजनित दबाव में हैं, अतः प्रवाल का निम्नीकरण हो रहा है | फिर भी, शिवराजपुर तट काफी सुरक्षित है, जिसमें कोई पर्यटक और तटीय विकास गतिविधियाँ नहीं हैं, अतः अधिक जैवविविधता और प्रवाल आवरण मिलते हैं | पर शिवराजपुर तट पर, जनवरी-२०२१ से "ब्लू फ्लैग" समुद्र तट सौंदर्यीकरण परियोजना शुरू हुई; अतः, पर्यटन के दबाव से शिवराजपुर तट पर प्रवाल विविधता असुरक्षित हो सकती है |

ABSTRACT

The status of the coral reef ecosystem of the outer Gulf of Kachchh has been studied. To understand the status of coral reef; the Line Intercept Transect (LTI) method, questionnaire-based socioeconomic analysis, and environmental assessment were conducted monthly from November 2017 to February 2019 on three selected sites viz., Okha, Mithapur, and Shivrajpur of the outer GoK. Shivrajpur has the highest proportion of live coral cover at 72%, followed by Mithapur and Okha. A total of 23 species of Scleractinian corals were recorded under 12 genera and eight families. The highest number of Scleractinian coral species (22 species), were recorded from Shivrajpur followed by Mithapur, and Okha. The species of family Poritidae contributed the most to the assemblage, followed by the Faviidae and Merulinidae. An average relative abundance revealed that *Dipsastraea favus* formed dominant species in the outer GoK, followed by *Pseudosiderastrea tayamai* and *Goniopora pedunculata*. A total of 29 species of reef-associated flora belonging to 24 genera and 17 different families were recorded, with dominance of Phaeophyceae, followed by Rhodophyceae. *Ulva lactuca* contributed maximum to the biomass, followed by *Sargassum cinereum*. The maximum seaweed diversity was found during the post-monsoon season. A total of 39 species of reef-associated fauna belonging to 35 genera and 30 different groups are recorded. Gastropods were found to be dominant group, followed by Crustaceans. Shannon-Wiener index, Pielou's evenness, and Margalef's richness index were applied to assess the diversity of the coral reef and reef-associated flora and fauna. The highest diversity of the scleractinian corals was found at site Shivrajpur (H'=2.58), followed by Mithapur (H'=1.89). The physico-chemical parameters viz., water temperature, salinity, pH, and DO_2 play a significant role in the growth and survival of the reef ecosystem in outer GoK. The mean water temperature and salinity of Okha, Mithapur, and Shivrajpur were 26 °C and 34 ppt, 26 °C, and 35 ppt and, 27 °C and 34 ppt, respectively, and the mean pH values were 7.73, 7.91, and 7.84, respectively. Similarly, the mean dissolved oxygen levels were 6.50, 6.22, and 6.59 mg/lit, respectively. The reef ecosystem of the outer GoK generates maximum revenue by catch of finfish followed by shellfish. An average maximum revenue per annum per fisherman was generated at Mithapur reef (₹ 1,47,620) followed by Okha (₹ 1,30,310) and Shivrajpur (₹ 1,09,540). However, this revenue is under threat, since sixteen coral species were found to be bleached, especially due to human-induced stress such as local tourism, traditional fishing practices, and coastal pollution. The maximum proportion of the colony scale bleaching was observed in *G. pedunculata* (34 %) followed by *D. favus* (31%). Mithapur had the highest percentage of relative dead coral cover accounting for 12.62% of total coral cover, followed by Okha (6.45%), and Shivrajpur (0.41%). However, according to the Coral Mortality Index, reef ecosystems of the outer GoK can be deemed healthy. The reef ecosystems of Okha and Mithapur are subjected to heavy anthropogenic pressure, resulting in reef degradation; still, Shivrajpur is fairly pristine, with no tourist and coastal development activities, resulting in higher biodiversity and live coral cover. However, the "Blue Flag" beach beautification project started in January 2021 at Shivrajpur beach. Due to this, the reef diversity at site Shivrajpur could become vulnerable to tourism.

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1. INTRODUCTION

Coral reefs are one of the world's most salient, biologically rich, and economically precious ecosystems on the Earth (Biswas, 2009). This ecosystem represents a diverse group of marine invertebrates belonging to class Anthozoa and phylum Cnidaria; they were closely related to jellyfish and sea anemones. Coral reefs are large shallow water coastal ecosystems characterized by reef-building colonial marine invertebrates called coral. Coral reefs are the skeletons configuration of rocky coral polyps covered simultaneously (Veron and Smith, 2000). Corals have simple life cycle with small free-swimming larval phase known as planula and dominant larval phase known as a polyp. A planula is inhabited permanently on a hard substratum and metamorphoses into a primary polyp (Neder *et al.*, 2019). Many individual coral polyps live in massive colonies form the hard $CaCO_3$ exoskeleton and build the reef structure (Nambiar, 2015). The polyps extract calcium carbonate from the sea and build the reef structure. The corals that build the reefs are hermatypic or hard corals that construct around 1012 kg of calcium carbonate for each year in the form of aragonite globally (Milliman and Droxler, 1996). The coral species that do not build reefs are ahermatypic or soft corals that lack a calcium carbonate skeleton often similar to the plants and trees like sea fans, sea pens, sea wipes, etc. Some corals are hard but non-reef building.

The coral polyp that forms the reef survives by establishing a symbiotic association with microscopic photosynthetic algae called zooxanthellae. Polyps provide shelter to these zooxanthellae, which in turn serve food to the coral polyps through photosynthesis. These zooxanthellae use sunlight for photosynthesis and provide about 95% of the food they generate to the coral polyps (Miththapala, 2008). These types of hermatypic corals are called reef-building Scleractinian corals. There are approximately 837 living species of reef-forming Scleractinian corals in the world (Huang, 2012).

There are mainly three types of coral reefs such as fringing reefs, barrier reefs, and atolls (Veron and Smith, 2000). Fringing reefs grow in the shallow water parallel to the shoreline surrounding islands and are alienated from the shore by narrow, shallow lagoons. Fringing reefs are the most common type of reefs.

Barrier reefs correspond to the coast, most significantly alienated by deeper, wider lagoons. The Great Barrier Reef of Australia is an example of the barrier reef on the Earth. Atolls grow on an island encircled by fringing reefs sinks into the sea (Franca, 2011).

The coral reef is the most diverse ecosystem that supports more number of species per unit area than any other ecosystem (Saroj *et al.,* 2016, Ahmed *et al.*, 2005). Coral reefs are usually referred to be "*the rainforests of the sea*". Coral reefs are of substantial social, cultural, and economic importance. Corals contribute to the sustenance of the country's economy by supporting fisheries, tourism, pharmaceuticals, etc. These '*rainforests of the sea'* supply economic and ecological services to millions of people as an area of natural magnificence and recreation, source of food, employment, bio-compounds, pharmaceuticals, and shoreline protection (Knowlton *et al*., 2010, Teh *et al.* 2013, Wagner *et al.* 2020). Coral reefs are enormously significant to society and this services are valued at $30 billion and perhaps $172 billion per year (OCEAN, 2018). The economic value of reef ecosystems and services is estimated to be approximately $29.8 billion per year. Tourism and recreation account for $9.6 billion, shoreline protection for $9.0 billion, fisheries for $5.7 billion and reef-associated biodiversity for $5.5 billion (Cesar *et al*., 2003).

Apart from livelihood support, the coral reefs are of environmental importance viz., increasing shore stability, protecting against tidal surges, and offering shelter, food, and breeding grounds for the fishes, crabs, prawns, and other marine organisms **(**Parmar *et al*., 2015). They provide refuge and act as nursery ground to 25% of the marine fish species (Burke *et al.*, 2002). The coral reef ecosystem has high primary productivity. The primary productivity of the reef ecosystem is derived mainly from algae; it is estimated at 5-10 g C/m^2/Day (Sorokin, 1995). It has been found that Manauli reef produces 2500 g C/m^2/year; Minicoy reef produces 3000 g C/m^2/year and Andaman reef produces 1200 g C/m^2/year (Nair *et al.,* 1972).

Even-though immense ecologically, economically, and socially significant, the coral reef ecosystem is under intense pressure. It is anticipated that 27% of the world's coral reefs have been destroyed; an additional 30% is at risk of being lost in the coming thirty years (Wilkinson, 2008). Survival of the coral reef depends on humankind; the community obtains and sustains the awareness and capability to protect coral reefs and the related ecosystem. Coral reefs are well known to be fragile and very sensitive to fluctuations in surrounding environment, especially water temperature and sedimentation. The reefs are deteriorating rapidly due to various anthropogenic activities including overexploitation, coastal development, coastal pollution, environment alteration, and increased sea level and increased sea surface temperature (SST) (Negri and Hoogenboom, 2011). Thus, the threats to the coral reef ecosystem can be classified on local and global scales. The main local threats are destructive fishing, pollution and sedimentation, sand mining, and non-sustainable tourism (Cesar, 2000). In recent years, the bleaching of the coral reef has been a major global threat to the reef ecosystem. The elevated sea surface temperature caused widespread damage to the reef ecosystem, where corals lose their colorful symbiotic algae that leads to exposure of white exoskeleton (Wilkinson *et al.,*1999).

Reef ecosystems are distributed in the warm tropical waters between latitude 30° N and 30° S, where the temperature range is optimum, 23-29 °C (SenGupta and Deshmukhe, 2000). Coral reefs ecosystems correspond to less than 0.2% of the total oceanic environment (Ahmed *et al.,* 2005). Colonies of corals grow very gradually, at a rate of less than 1 cm to 10 cm every year (Singh *et al.,* 2006). India is blessed with substantial aquatic resources and genetic diversity. The coastline of India measures about 8129 km, spread out nine maritime states and four union territories. The Exclusive Economic Zones (EEZs) covers an area of 2.02 million km^2 enclosed within 200 nautical miles from the shore. The continental shelf area is about 0.53 million km^2 (Sathianandan, 2013).

To protect these ecologically important areas especially mangroves and coral reefs, Government of India (GOI) initiated efforts through the state governments to create a network of MPAs under the provision of the Indian Wild Life Protection Act (WPA) 1972 (Singh, 2003). Implementation of Marine Protected Areas (MPAs) is the worth strategy to protect such a valuable ecosystem. This has resulted in 980 MPAs in the world covering an area of 98,650 km^2 (18.7 %) by the world's coral reef surroundings (Mora *et al.,* 2006). Presently, there are a total of 31 Marine Protected

Areas alongside India (including the islands) that have been legitimately acknowledged for conservation and protection of coastal and marine biodiversity, which cover a total area of 6271.2 km^2 with an average size of 202.1 km^2 (Biswas, 2009, Rajagopalan, 2008, Singh, 2003). The contribution of the MNPs is only 4% of the total Protected Areas (PAs) in the country. The largest marine protected area in India is Gahirmatha Marine Sanctuary in Orissa, covering an area of 1,43,500 ha, followed by Sundarbans National Park in West Bengal spread in an area of 1,33,010 ha (Singh, 2003).

In India, the reef ecosystems are distributed in the Gulf of Kachchh, Lakshadweep, Andaman and Nicobar, Pulk bay, and Gulf of Mannar. The Gulf of Kachchh (GoK) Marine National Park (MNP) and Marine Sanctuary (MS) is the largest funnel-shaped coastal habitat of West Coast of India, situated on the Northern shore of the Jamnagar district of Gujarat at 20° 15' to 23° 35' N and 60° 05' to 70° 22' E (Chauhan *et al.,* 2006, Parasharya and Padate, 2013). The gulf area, 125 km long and 75 km wide spread from Okha to Jodiya with a core area of 163 km^2 (Michael *et al.,* 2009), has 42 islands of which 34 are enclosed by coral reefs, and most of the islands are surrounded by fringing reefs (Ramamoorthy *et al.* 2012). The GoK MNP and MS provide shelter for more than 49 species of reef-building Scleractinian corals and 23 species of soft coral species (MNPCS, 2015). Gujarat Environment and Education Foundation (GEER Foundation) reported a total of 42 species of hard corals and ten species of soft corals, along with 1,127 species of flora and fauna from the GoK including 200 species of molluscs, three species of turtles, 3 species of marine mammals including the rare and endangered sea cow, *Dugong dugon* (Singh *et al.* 2006).

The outer GoK, having an enormous potential of healthy coral reefs, was not surveyed earlier. The corals are not only subjected to high tidal fluctuations, climate change, and ocean acidification they are also highly vulnerable to, human stressors such as, local tourism, pollution, ungoverned fishing practices, sedimentation, transportation, coastal development, industrialization, etc. (Hughes *et al.* 2020). The outer gulf that includes Okha, Mithapur, and Shivrajpur are also subjected to different levels of these factors. The reef ecosystem at Okha is vulnerable to tourism, coastal construction, and traditional fishing practices on the reef ecosystem. Mithapur is also vulnerable to tourism, unregulated fishing practice, coastal construction, marine pollution, and industrialization. The TATA Chemicals Limited (TCL) plant at Mithapur, covering an area of about 6000 ha of land, is among the world's most extensive integrated salt works and inorganic chemicals industry complex. Shivrajpur site possesses rich coral reef diversity. However, after the "Blue Flag" beach beautification project started in January 2021, the reef ecosystem became vulnerable to tourism.

Though the GoK is a crucial biodiversity hotspot of Gujarat and one among India's fourth major coral reefs, except for a few studies on the marine flora and fauna of the GoK, no studies have been conducted on coral reef diversity of the outer GoK. Therefore, to generate the baseline information on the status of coral reefs and associated fauna of the GoK, the present study was carried out in the outer part of the GoK. Further, researchers focused on the MNP in the inner gulf only and, the coral reefs of this region have remained unexplored. Thus, the present study has been carried out to assess the coral reef status of outer GoK with following objectives.

(i) To study the biotic and abiotic factors affecting coral reef diversity.

(ii) To evaluate economics of the reefs diversity.

(iii) To study socioeconomic impact on coral reef diversity.

2. REVIEW OF LITERATURE

Coral reefs are distributed in warm tropical areas with rich biodiversity and economically valuable ecosystems on the Earth (Biswas, 2009). They represent a diverse group that belongs to the phylum Cnidaria and class Anthozoa. Coral reefs are often called "*the rainforest of the sea*" which sustain more species per unit area than other ecosystems (Knowlton *et al*. 2010, Saroj *et al.,* 2016,). Reef ecosystems are distributed in the warm tropical waters between latitude 30° N and 30° S, where temperature range is optimum, 23-29 °C (SenGupta and Deshmukhe, 2000).

2.1 Environmental Parameters

The coral reef ecosystem is vulnerable to changes in the environmental conditions of the surrounding environment. Some researchers have analyzed the impact of environmental parameters on the growth and survival of reef ecosystems all over the world. Aronson and Precht, (2016) reported that the physical and biological environmental factors affect coral community structure and function. They concluded that the physico-chemical properties of the reef ecosystem have a significant impact on the growth of the coral reef by affecting the population composition and associates of the reef ecosystem. The water quality of a particular marine ecosystem depends on the geographic location, weather, climate, and pollutants present. Karuppanapandian *et al.,* (2007) evaluated the physico-chemical properties of the reef ecosystem of Palk Bay. The highest mean value of temperature, pH, DO, BOD, and TOC for the experimental and control stations have been found to be 32.6 °C, 8.7, 7.07ppm, 8.29ppm, and 2.13%, and 31.5 °C, 8.3, 7.98ppm, 5.71ppm, and 048% respectively. Sridhar *et al.,* (2008) mentioned that alteration in the hydrographic factors such as salinity, DO, dissolved CO_2, and nutrients influence the functions and growth of the symbiotic organisms and the reef-associated biota of the coral reef.

2.1.1 Temperature

Temperature and pH are the most important factors affecting the growth and survival of the reef ecosystem. Wilkinson (1996) reported that global warming could raise the air temperature from 0.2 to 0.3 °C/decade, which can result in an elevated sea surface temperature, leading to increase in the bleaching incidents of coral reefs. Westmacott *et al.,* (2000) reported that, the year 1998 was the warmest year of the past 150 years due to strongest El Nino event during this period. Due to this, the high water temperature was recorded in many parts of oceans especially in tropical areas. As a result, high reef mortality was found in the reef ecosystems of India, Sri Lanka, Maldives, Kenya, Tanzania, and Seychelles with reef mortality of about 95%. Reef ecosystems in other parts of the Indian Ocean are evidence of up to 50% mortality rate (Cesar *et al.,* 2002). Subsequently, Muley *et al*. (2002) reported that dead coral reef cover has increased to about 70% in GoK, 40-60% in the GoMBR, 60-80% LI, and 80% in ANI during the bleaching event in 1998.

Vivekanandan *et al.*, (2008) studied the thermal threshold for coral bleaching prior, during, and after the 1998 coral-bleaching event in the Andaman and Nicobar Islands (ANI), Lakshadweep Islands (LI), Gulf of Mannar Biosphere Reserve (GoMBR), and GoK by acquired sea surface temperature (SST) data from NOAA/NASA. The study revealed that the annual average maximum SST at the ANI and LI, GoMBR, and GoK increased at the rate of 0.23 °C, 0.17 °C, 0.21 °C, 0.19 °C, and 0.06 °C per decade respectively. In Indian Seas, the SST value was very high during April and May 1998 owing to this, the high coral bleaching occurred during May 1998. Subsequently Marimuthu *et al.,* (2013) reported large-scale coral bleaching of about 74% to 77% of corals in the South Andaman during summer season of 2010. Abdo *et al*., (2016) reported a widespread bleaching of corals at the Abrolhos Archipelago due to a significant La Nina event during 2011 along Wastern Australian coastline. They concluded that the long-term trends of the period of 1900 to 2011, confirmed that the mean annual sea surface temperature has been increased by 0.01 °C per annum and can be considered as the most significant threat to the coral reef diversity.

McClanahan *et al.,* (2007) studied alteration in coral cover across the 1998 El Nino event on the 36 major reefs of the western Indian Ocean associated with the change in the historical sea-surface temperature (SST). They reported an average live coral cover loss in the Western Indian Ocean of 37.72 ± 31.34 %.

Temperature influenced loss in coral cover in the MPAs and an unprotected reef was explored by Selig *et al.,* (2012). The study revealed that increased ocean temperature could be considered as an important reason for coral reef degradation of the world. They also suggested a network of the MNPs could be a tool to increase reef ecosystem resistance and resilience against unfavorable climate changes.

Bignesh *et al.,* (2014) analyzed the seasonal variation of physico-chemical parameters at the reef ecosystem of Poshitra Island, Paga Reef, and Boria Reef along the southwest coast of the GoK. The study stated that coral reefs could grow at water temperature ranging from 17 °C to 30 °C, with an optimum range of 25 °C to 30 °C; however, with temperature exceeding 36.4 °C lead to coral bleaching due to physiological stress.

2.1.2 Salinity

Salinity plays a significant role in the survival of the coral reef and reef-associated flora and fauna, in addition, salinity plays a very important role in osmoregulation and other physiological processes involved for the survival of the reef ecosystem (Coles and Jokiel, 1992). The salinity range of the marine ecosystem has been recognized as the most restraining environmental factor for the growth and endurance of the reef ecosystem (Mayer, 1914; Vaughan, 1914). Coles and Jokiel (1978) reported that low salinity values of reef ecosystems result in a reduced ability of corals to expose for a short period to high light intensity.

The GoK has a negative water balance where seawater evaporation is higher than its recharge through precipitation and river runoff, because of this it leads to higher saline conditions in the GoK (Sengupta and Deshmukhe, 2000). The average seawater salinity of the GoK can be considered to be 35 ppt, sometimes well reaching up to 40 ppt (Pandey *et al.,* 2010).

Berkelmans *et al.,* (2012) studied the salinity threshold on *Acropora spp*. at the Great Barrier Reef Australia based on *in-situ* salinity revelation and coral reaction during a major flood event in 2010-11. The study revealed that north-facing reefs such as Miall Island had low mortality (5%) of *Acropora spp*. than north-facing Keppel Island (40%). Guan *et al.,* (2015) reported the global, annual average acceptance limits for the coral reefs for salinity is in the range of 28.7-40.4 ppt.

2.1.3 pH

The calcification rate of the coral reef colonies is influenced by the pH level of their surroundings. Nair (2002) reported that the seawater pH range of the GoK from 7.9-8.2, is conductive for the growth of the reef ecosystem. Due to the absorption of atmospheric carbon dioxide, the oceans are becoming more acidic (Pelejero *et al.,* 2005). Kleypas and Yates (2009) reported that the calcification ability of coral reefs is weakening due to ocean acidification. The calcification ability of reef-building organisms, corals, and calcifying macroalgae is reduced at the rate of 10 to 50% compared to pre-industrial calcifying rates. Gagliano *et al.,* (2010) studied the variation of pH on the Australian reef. They stated that ocean acidification is one of the most considerable threats to the coral reef ecosystem globally.

Mollica *et al.,* (2018) stated that the skeletal growth of coral reefs reduces because of ocean acidification. They represented an arithmetical model based on an existing coral skeletal catalog of six species of genus *Porites* collected from five different reef sites and used that framework to predict the impact of ocean acidification on the skeletal density of genus *Porites*. They also predicted that ocean acidification alone can decrease the skeletal mass of the Scleractinian corals such as *Porites spp.* up to 20.3 ± 5.4 % over 21st century throughout the world.

2.1.4 Dissolved Oxygen

Recently, Nelson and Altieri (2019) premeditated oxygen as an entire energy resource of coral reef. The study showed that oxygen is a critical factor for the survival and growth of reef ecosystems. Survival of the coral reef at accelerated oxygen and deoxygenated levels was examined by Hughes *et al.,* (2020). The study revealed that global warming and eutrophication lead to lower oxygen levels and high deoxygenation of coastal reef habitats. Thus, the extremely low oxygen levels in coastal areas can lead to mass mortality of reef flora and fauna, and mass bleaching of coral colonies.

2.2 Status of the coral reef ecosystem

2.2.1 Status of reef ecosystem work on a global level

Some of the researchers has been estimated the total reef cover area all over the world. The reef cover area varies depending upon the methodology and estimation technology, which they have followed. During the late seventies, Smith (1978) reported an approximate reef cover area of the world's ocean as 600,000 km^2. The Asiatic Mediterranean region contributed the highest reef cover area followed by the Indian Ocean with 30% and 24% respectively of the total. Klepays (1997) estimated changes in reef areas and found similar results during the estimation of the global reefs. The study reported an approximate worldwide coral cover area of about 584,000-746,000 km^2. In the same period, Spalding and Grenfell (1997) estimated the global reef cover area was about 255,000 km^2. The Southern Pacific region contributed the maximum reef area of 91,000 km^2 followed by the Asiatic Mediterranean region of 68,000 km^2. Whereas Constanza *et al.,* (1997) accounted for a worldwide coral cover area of about 920,000 km^2 through the economic valuation of the natural capital stocks of the world. Spadling *et al.,* (2001) prepared a revised estimate of the worldwide reef covering area to 284,300 km^2, with 91% of the total reef cover reported from the Indo-Pacific region.

The global diversity and distribution of hermatypic and ahermatypic corals have been studied. In earlier reports, Veron (1985) reported 350 hermatypic corals from the Great Barrier Reef, Australia of which 33 species were found to be endemic. The species richness, coral cover, and community structure of hermatypic corals were studied by DeVantier *et al.,* (2006). They have selected 599 sites on 135 reefs of the Great Barrier Reef. The study reported 362 species of Scleractinian corals belonging to 75 genera and 15 families along with three species belonging to genus *Tubastrea* were ahermatypic corals. Recently the ecological status of the reef ecosystem was assessed by Tkachenko *et al.,* (2020) on 15 selected sites of the Spratly Island in South China. They recorded 131 species of hermatypic corals belonging to 43 genera including two ahermatypic species such as octocoral *Heliopora coerulea* and hydrocoral *Millepora platyphylla*. *Acropora* contributed the highest reef cover area (27%) followed by *Porites* (17.4%) and *Pocillopora* (4.1%) with mean coral cover 36.6%.

2.2.2 Status of reef ecosystem in India

Coral reefs are one of the most primordial and vibrant ecosystems of India (Venkataraman, 2006). To protect such ecologically sensitive areas, the Indian government has initiated Marine Protected Areas (MPAs) networking programs under the provision of the Indian Wildlife (Protection) Act, 1972. Presently there are four important reef ecosystems of India viz., (1) Gulf of Mannar Marine Biosphere Reserve (GoMBR) covering 10,500 km^2 (Venkatraman and Raghuram, 2006), (2) Andaman and Nicobar Islands (ANI) covering 8,349 km^2 (Balakrishnan *et al*. 2008), (3) Lakshadweep Islands (LI) covering 28.54 km^2 (Jeyabaskaran, 2009), and (4) Gulf of Kachchh (GoK) covering 457.92 km^2 (Biswas, 2009; Pillai, 1983). The major reef ecosystems of India including Malavan Marine Sanctuary, Angria bank, and Grande island, account for a total reef cover area of 2,379 km^2 contributing less than 1% of the total reef covering area of the world (D.O.D. and S.A.C., 1997). Venkataraman *et al.,* (2004) assessed the status of the reef ecosystem of the Indian Ocean and mentioned that the total reef covering area of India is near about 2,374.9 km^2. Raghuraman *et al.,* (2012) have studied the diversity of Scleractinian corals of the ANI compared with other reef ecosystems of India. They mentioned that the total coral reef area of India is about 5,790 km^2. The spatial inventory on the reef ecosystem of the Central Indian Ocean (CIO) by using satellite data has revealed that the coral reef of the CIO, including India, Sri Lanka, Bangladesh, Maldives, and the British Indian Ocean covering an area of 18,252.13 km^2 (Bahuguna *et al.,* 2013).

Many researchers have studied the reef abundance of the Indian Ocean. In earlier studies, Pillai (1967) reported 125 species of coral belonging to 34 genera and 1 sub-genus from the GoMBR and LI. Subsequently, Pillai (1972) studied the diversity of Scleractinian corals of India. He reported 342 species of Scleractinian corals belonging to 76 genera including 253 species of ahermatypic corals belonging to 49 genera from the Indian Ocean region including Maldives, Laccadives, Ceylon (Sri Lanka), Palk Bay, GoMBR, ANI, and the Mergui Archipelago. In the year 1983, Pillai studied the genetic diversity of Scleractinian corals. He recorded 199 species of coral reefs belonging to 71 genera from four major reefs of India. Among which 155 species belonging to 50 genera were hermatypic and the rest of 44 species among 21 genera are ahermatypic. The maximum number of coral species were reported from the ANI (135 species and 59 genera) followed by the Southeast coast of India (94 species of 37 genera), LI (78 species of 31 genera), and the GoK (37 species of 24 genera). Scheer (1984) studied the distribution of coral reefs in the Indian Ocean; he reported 88 genera of hermatypic corals from all over the Indian Ocean.

Muley *et al.,* (2002) studied the status report of the reef ecosystem of India, mentioned 199 species of Scleractinian corals including 155 species of hermatypic and 44 species of ahermatypic corals that belonging to 37 genera from the four major reefs of India. Venkatraman *et al.,* (2003) reported 208 species of Scleractinian corals belonging to 60 genera and 15 families from India. The highest number of the species were reported from the ANI (177 spp.) followed by LI (91 spp.), GoMBR (82 spp.), and GoK (36 spp.). Subsequently, Ahamada *et al., (*2004) reported 320 species of Scleractinian corals including seven endemic species from the southwest Indian Ocean islands.

Zacharia *et al.,* (2008) reported 14 species of corals belonging to 11 genera along with a collection of reef fauna from the Netrani island of Karnataka. Turner *et al.,* (2009) assessed the coral reef ecosystem of the ANI and reported 197 species of corals divided among 58 genera of which 53 genera that belong to hermatypic corals. Venkataraman (2006) concluded that the Scleractinian corals of India are more diverse than any other reef ecosystem of the tropical world.

Sadhukhan and Raghunathan (2012) studied the reef diversity of Inglis island Sanctuary of the ANI. They recorded 48 species of coral belonging to 25 genera and 10 families of hermatypic corals. The average percentage of live, dead, and bleached coral cover was 27.3%, 26.5%, and 46.3% respectively. Raghuraman *et al.,* (2012) reported 424 species belonging to 89 genera and 19 families from the ANI, which contributes 89% of India's coral diversity. Subsequently, Raghuraman *et al.,* (2013) prepared an enhanced list of the diversity of Scleractinian corals of India; reported 478 species of corals belonging to 89 genera and 19 families from four major reefs of India. The maximum coral diversity has been reported from the ANI contains 424 species of corals belonging to 86 genera followed by GoMBR and Palk Bay with 117 species belonging to 40 genera, LI with 104 species belonging to 37 genera, and GoK with 49 species belong to 27 species.

Raghuraman and Raghunathan (2013) assessed the status of coral reefs from the ANI. The study reported 74 and 51 species of Scleractinian corals respectively from the Mahatma Gandhi Marine National Park (MGMNP) and Rani Jhansi Marine National Park (RJMNP). The maximum live coral cover was estimated at 40.21% from the RJMNP followed by MGMNP 33%. Raghunathan (2015) reported 327 species of Scleractinian corals belonging to 68 genera and 15 families from Rutland Island of the Andaman and Nicobar Islands. Family Acroporidae was dominantly represented by 88 species of Scleractinian corals followed by family Faviidae with 82 species.

Recently De *et al.,* (2020) published a modified checklist of Scleractinian corals from the four most important reefs of India besides other small reef ecosystems across the west coast of India, comprising 589 species that belonging to 108 genera and 22 families. The highest species diversity has been accounted from the ANI (526 species belonging to 92 genera and 22 families) followed by the GoMBR (168 species belonging to 47 genera and 16 families), the LI (167 species belonging to 56 genera and 18 families), and GoK (78 species belonging to 30 genera and 12 families).

Although being the most productive and ecologically valuable ecosystem, coral reefs face a high risk of degradation owing to various harmful anthropogenic activities (El-Naggar, 2020). Large-scale coral bleaching in the GoK during May and June 2010 was reported by Joshi *et al.,* (2014). The study revealed that coral bleaching of 19 species of Scleractinian corals and other zooxanthellae cnidarians of the GoK was due to climate-induced stress. Threats on coral reef diversity in the ANI were carried out by Majumdar *et al.,* (2018). They found 70% of the ANI reefs were destroyed due to high sea surface temperature because of El-Nino Southern Oscillation (ENSO) in 2010. Westmacott *et al.,* (2000) stated that the Indian Ocean showed reef mortality rates up to 50% during 1997-98, the strongest El Nino occurred. Although; being the most productive and biologically rich ecosystem coral reefs corresponds to less than 0.2% of the total oceanic area, in addition to being home to more than 25 % of all marine organisms (Spalding, 2001).

2.2.3. Status of reef ecosystem of the Gulf of Kachchh

Several researchers studied the occurrence of Scleractinian corals in the GoK, particularly the inner gulf areas. The first MNP, GoK having 42 islands on the northern shore of Jamnagar district Gujarat, among them Narara reef of the GoK, Poshitra, and Pirotan Islands are considered the most diverse ecosystem of the GoK. The coral reef in the outer part of the GoK region has remained unexplored (Magotra *et al*., 2008).

Pillai and Patel (1988) reported 37 species of Scleractinian corals belonging to 24 genera. Of which 20 genera with 33 species are hermatypic and the rest of four corals species were hermatypic from the GoK. Satyanarayana (2009) reported 31 species of corals belonging to 18 genera and 8 families found in the GoK. Kumar *et al.,* (2014) studied the longitudinal variation of coral reefs on 11 selected sites of the GoK. The maximum live coral cover was found from Pirotan island (36.3 %) followed by Laku point (Poshitra island) (35 %), and Mithapur (28.1 %).

A new species of Scleractinian coral *Lobophyllia hemprichii* belongs to the family Mussidae has been recorded by Kumar *et al.,* (2017) from the Poshitra reef of the MNP. In addition, they have recorded 56 species of Scleractinian corals belonging to 27 genera and 10 families from the Poshitra reef of the MNP. The coral reef structure of the Kachhigarh region at Devbhumi Dwarka district of the outer part of GoK was studied by Lakhmanpurkar & Gavali (2018). The study enumerated 24 species of Scleractinian corals divided among 14 genera. In recent studies, Parikh *et al.,* (2019) has reported 19 species of coral reef that belong to nine different families including one species of ahermatypic coral from Poshitra reef of MNP.

2.3 Reef-associated flora of Gulf of Kachchh

Coral reefs are the precious gift of nature to humankind (Pillai, 1996). The coral reef ecosystem is the most diverse, complex, and spectacular ecosystem among all marine habitats. Since the reef ecosystem is very complex it provides home and nursery grounds to the thousands of species of marine algae and other invertebrate organisms. The coral reef is the most productive ecosystem supports more species per unit area than any other marine ecosystem. Several researchers have studied the reef diversity throughout India as well as other parts of the world.

In earlier reports, Bahuguna *et al.,* (1992) have studied the natural condition of the coral reef ecosystem of the GoK and LI. The study enumerated 120 species of marine algae from the GoK dominated by *Sargassum* followed by *Ulva*, *Enteromorpha,* and *Cladophora*. Sen Gupta *et al.,* (1999) studied ecology and threats to the biodiversity of the GoK. In addition, they reported 89 species of reef flora from three selected islands including Narara (26 spp.), Poshitra (40 spp.), and Pirotan (40). The diversity of Rhodophyceae was found high represented by 39 species followed by Chlorophyceae.

Jha *et al.,* (2009) premeditated the species diversity and distribution of marine algae from the Gujarat coast; they reported 198 species of marine algae belong to 101 genera from the Gujarat coast. Ramamoorthy *et al.,* (2012) assessed the diversity of reef flora and fauna at Pirotan Island of the GoK. They reported 31 species of reef-associated flora dominated by Ulva and Sargassum. The diversity and distribution of macroalgae from Chhad, Dedeka-Mundaka, Goose, and Narara reef of the GoK has been assessed by Roy *et al.,* (2015). The study found 70 species of macroalgae from the GoK dominated by Rhodophyta (31 spp.) followed by Chlorophyta (24 spp.), and Phaeophyta (31 spp.).

Sarkar *et al.,* (2015) assessed the genetic diversity of three different species of *Sargassum* viz., *S.swartzii S. Tenerrimum*, and *S. plagiophyllum* collected from Okha, Malwan, and Veraval respectively, from the northwest coast of India. The diversity and distribution of marine algae at the Port Okha region have been carried out by Vala *et al.,* (2016). They assessed 76 species of seaweed belonging to 47 genera and 27 families dominated by Rhodophyceae followed by Chlorophyceae and Phaeophyceae. Occurrence and biochemical assessment of marine algae from the Okha region were carried out by Kumar *et al.,* (2017). The study mentioned 70 species of seaweed from Okha dominated by Rhodophyta (51.42%) followed by Phaeophyta (25.71%) and Chlorophyta (22.58%).

Sanghvi *et al.,* (2019) have conducted a study to know the indicator species of macroalgae to analyze their onshore distribution and preferred zone of occurrence at Dwarka. A total of 97 species of seaweed has been recorded of which 49 species belonging to Rhodophyta, 27 species to Chlorophyta, and 21 species belonging to Phaeophyta. A study on biodiversity and ecological condition of Narara and Poshitra reef of MNP has been conducted by Joshi *et al.,* (2018). They reported 108 species of marine macroalgae. Afterward, Dave *et al*., (2019) studied macroalgae diversity from the intertidal zone at the Okha region. A total of 39 species of macroalgae has been found dominated with Chlorophytes (16 spp) followed by Rhodophytes (13 spp.) and Phaeophytes (10 spp.). Kalasariya *et al.,* (2020) examined the occurrence, distribution, and diversity of marine algae from the Beyt Dwarka coast find out 39 species of macroalgae dominated with red algae followed by brown and green algae. Recently, a survey on seasonal variation of seaweed diversity has been conducted by Pathak *et al.,* (2021) at Veraval and Sikka coast of Gujarat reported 28 taxa of marine algae.

2.4 Reef-associated fauna of major reefs of India

Reef distributed areas of the GoK is one of the most diverse reef ecosystems of India and comprises of 23 species of soft corals, 49 species of hard corals, 70 species of sponges, 421 species of ichthyofauna, 27 species of prawns, 30 species of crabs, 199 species of molluscs, 16 species of echinoderms, 172 species of sea birds, 108 species of marine algae, 6 species of mangroves, and three species in each of marine mammals, and sea turtles (MNPCS, 2015).

In an earlier report, the diversity and distribution of marine sponges of the GoK have been studied by Thomas *et al.,* (1996). A total of 25 species of sponges belonging to 22 genera and 15 families have been reported from the GoK. Higher diversity of marine sponges was found in the inner gulf followed by the outer GoK. The reason behind this pattern could be the anthropogenic pressure in outer part of GoK. The status of reef diversity evaluated by Dorairaj and Soundararajan (1997) reported 31 species of gastropods, 26 species of bivalves, three species of cephalopods, and 16 species of echinoderms from the MGMNP. The study revealed that gastropods (35 %) contributed maximum distribution followed by Bivalves (25 %) and echinoderms (25 %). Venkataraman *et al.,* (2002) examined the diversity of marine fauna from the GoMBR and reported 1089 faunal species belonging to 567 genera and 254 families. Subsequently, Venkatraman (2003) reported 86 species of macrophytes, ten species of anomuran crabs, 81 species of brachyuran crabs, 155 species of gastropods, 24 species of bivalves, 13 species of sea stars, six species of brittle stars, 23 species of sea cucumbers, 15 species of sea urchins, 120 species of ichthyofauna from the LI. Subba Rao and Sastry (2005) recorded 736 species of reef fauna and 180 species of flora from the GoK. Saravanakumar *et al.,* (2007) examined benthic macro-faunal groups of the mangrove ecosystem of the GoK and reported 62 species of benthic macrofauna from mangroves of the western GoK.

Diversity and habitat preference of brachyuran crabs in the GoK was investigated by Trivedi *et al.,* (2012). They reported a total of 19 species of brachyuran crabs belonging to 15 genera and eight families from Naliya, Mundra, Jodiya, Jamnagar, Sikka, Kambhaliya, Bhatia, and Poshitra region of the GoK. Of which family Ocypodidae, Grapsidae, and Portunidae contributed four species in each, family Xanthidae contributed three species while the rest of the families including Pilumnidae, Gecarcinidae, Goneplacidae, and Eriphiidae contributed only one species in each. In the same year, reef-associated biota of Pirotan reef of MNP was explored by Ramamoorthy *et al.,* (2012). They have reported 89 species of reef-associated fauna. Subsequently, Sadhukhan and Raghunathan (2012) recorded 75 species of echinoderms belonging to 13 orders and 16 families from the South Andaman region. The highest species diversity indices of echinoderms are recorded from Rutland Island (2.31) followed by Outram island (2.11).

Intertidal reef diversity of the Narara reef of MNP analyzed by Adhavan *et al.,* (2014), reported two species in each group of sponges, zoanthids, sea anemones, annelid worms, echinoderms, fishes, marine crabs, and 5 species of molluscs. Kardani *et al.,* (2014) reported 36 species of gastropods belonging to 18 families from the intertidal zone area of Mandvi, Singhi, and Mundra region of the northern part of the GoK. During the same period, Jayaprakash and Radhakrishnan (2014) have reported 1284 species of ichthyofauna, 3271 species of mulluscs, 785 species of echinoderms, 519 species of sponges, 274 species of corals, 607 species of crustaceans, and 624 species of marine algae based on the assessment made by Zoological Survey of India from Indian reefs.

Mohanraj *et al.,* (2015) reported 40 species of reef-associated gastropods belonging to 19 families from the GoMBR. The maximum species diversity was found from Vaan Island (0.968). The maximum value of species richness and evenness index were recorded from Hare Island with 0.937 and 0.942 respectively. Saxena (2015) mentioned that the coral reef composition in India includes around 180 species of microalgae, 20 species of seaweed, 20 species of sea-grass, 115 species of poriferans, 5 species of crustaceans, 110 species of echinoderms, 600 species of ichthyofauna, besides 70 species of sponges 25 species of prawns, 196 species of molluscs, and 5 species of mammals in all the reef ecosystems of India.

Shah *et al.,* (2017) carried out a comprehensive study of sea anemone diversity of the Saurashtra coast. A total of 15 species of sea anemones belonging to five families and 10 genera were recorded from Gujarat of which *Stichodactyla haddoni* and *Heteractis crispa* were first time reported from Gujarat. Crustacean diversity of the GoK was examined by Parmar *et al.,* (2018). A total of 39 species of crustaceans belonging to four different orders and 18 families including one endemic species *Metapenaeus kutchensis* were recorded from the GoK.

Rathoure (2018) reported 92 species of bivalves, 55 species of gastropods, three species of cephalopods, and two species in each of scaphopods, and amphineurans from Okha, Kandla, and Navlakhi coast of the GoK. Joshi *et al.,* (2018) assessed the bio-resources of Narara and Poshitra reef of MNP, the study reported 70 species of sponges, 421 species of ichthyofauna, 27 species of prawns, 30 species of crabs, 199 species of molluscs, 16 species of echinoderms, 172 species of sea birds and three species in each of marine mammals, and sea turtles from Narara and Poshitra reef of the GoK.

Recently, Parmar *et al.,* (2019) assessed molluscan diversity of the southern coast of the GoK, reported 108 species of molluscs, including 91 species of gastropods, 14 species of bivalves, two species of cephalopods, and one species of scaphopods. Diversity of rocky reef inhabiting echinoderms were explored by Chandrasekar *et al.,* (2019) on rocky shore areas of the southwest coast of India. This study revealed 15 species of echinoderms belonging to five classes, eight orders, 12 genera, and 10 families. In addition, they recorded 11 new species of echinoderms from Goa, and seven species from Karnataka and Tamil Nadu each. Mirza *et al*., (2019) surveyed the southern part of the GoK and reported some rare species of marine macrofauna; including two species of jellyfish (Bolinopsudae and Aequoreidae), four species of sea anemones (Stichodactylidae, Phymanthidae, and Aequoreidae), one species of polychaete (Sabellidae) from Pirotan, Goose, and Kalumbhar islands of the GoK. Recently, Shuchi *et al.,* (2020) explored the molluscan diversity of the GoK, and reported 54 molluscan species that belong to four different classes including 45 species of gastropods, seven species of bivalves, one species in each of cephalopod and polyplacophora were recorded from Poshitra, Narara, and Pirotan reef of the GoK. Subsequently, Raval *et al.,* (2020) reported 30 species of brachyuran crab belonging to nine genera and 16 families from Sikka coast the GoK.

In other Island ecosystems of India, Zacharia *et al.,* (2008) assessed the faunal diversity of the reef ecosystem from Netrani Island of Karnataka and reported 92 species of ichthyofauna, seven species of marine algae, six species of sponges, two species of jellyfish, one species of sea cucumber, seven species of nudibranchs, 15 species of bivalves, 48 species of gastropods, three species of cephalopods, 17 species of crabs, two species of shrimps four species of lobsters, 25 species of zooplankton, and 16 species of phytoplankton. Rajkumar *et al.,* (2013) studied reef diversity of the Mandapam region of Palk Bay, recorded 12 species of corals, six species of gastropods, seven species of seaweeds, five species of bivalves, three species of jellyfish, and one species in each of sponges, crab, shrimp, holothurians, brittle star.

2.5 Economics of the coral reef ecosystem

Coral reef ecosystems are distributed in coastal areas of more than 100 countries of the world. Enormously majority of the developing countries are depending on coral reefs to earn their livelihood (Salvat, 1992). Driml (1994) estimated the economics and economic worth of the Great Barrier Reef that produced $923 million annually for Australia, which contributes $682 million from tourism, $128 million through commercial fishing, $94 million from recreational fishing and boating, and $19 million through research.

The coral reef ecosystem is one of the most productive, geologically wealthy, and ecologically important unit on earth that provide valuable ecosystem services to human beings (Souter and Linden, 2000). Cesar *et al.,* (2003) reported that coral reefs provide nearly about $30 billion benefits per year to the economics of the world through tourism, fisheries, and coastal protection, in addition to the potential fisheries benefits of the coral reef ecosystem are $5.7 billion a year. The total value of reef economic goods and services on a global scale reported by Ammar (2009) was estimated to be $375 billion per year, especially coming from recreation, coastal protection, and food production with an average value of around $6075 per hectare of coral reef per year.

Economic valuation of the reef ecosystem of the GoK was carried out by Dixit *et al*., (2010). An estimated value of 1 km^2 coral corresponding area of the GoK is to the tune of ₹ 7.95 million. The highest value is attributed to fishing activities followed by coastal protection and biodiversity. Being an exceptionally valuable ecosystem, coral reefs are not only important for environmental processes but also play a vital role to support millions of people as a source of food and income. It has been anticipated that near about 3 billion people depends upon marine and coastal diversity to earn their livelihood. (FAO, 2012).

Sarkis *et al.,* (2013) estimated the Total Economic Value (TEV) of Bermuda's coral reefs. The TEV of Bermuda's coral reef has been found in the range of $488 million to $1.1 billion per year with an average of $722 million equivalent to 12% of the country's GDP. Spalding *et al.,* (2017) found that global reef-based tourism is one of the most considerable eco-tourism. The total revenue of the reef-based eco-tourism was found about US$ 36 billion per year from near about 30% of the world's reefs representing tourism value.

2.6 Socio-economic impacts on the coral reef ecosystem

Reef ecosystems are facing a high risk of decline due to anthropogenic stress worldwide. Bryant *et al.,* (1998) mentioned that 58 % of the coral reefs are under the tremendous threat of anthropogenic pressure. The status of the reef ecosystem of the world has been explored by Goldberg and Wilkinson (2004). They mentioned that the reef ecosystems are at risk of degradation worldwide, 27 % of the world's reefs are degraded through human impact. Kankara and Subramanian (2007) indicated that the coral reef, mangroves, and mudflat ecosystems of Narara and Kalubar Island of the GoK are at high risk of oil spill. Edward *et al.,* (2008) mentioned that more than 32 km^2 of the coral reef area has been declined throughout 21 reef-surrounded islands of the GoMBR.

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report stated that most of the observed increase in global average temperature since the mid-twentieth century is due to an increase in anthropogenic greenhouse gases, and concluded that significant physical and biological changes are occurring in most oceans (Parry *et al.,* 2007). Rosenzweig *et al.,* (2008) stated that the global temperature rise is not only influenced by natural climate variations but also due to anthropogenic warming over the past 50 years. Cai *et al.*, (2018) reported that the intensity and frequency of El Nino-Southern Oscillation (ENSO) could be increased under greenhouse warming. Arora *et al*., (2019) found an average of 3.9% colony scale bleaching of corals from the GoK region and attributed this to elevated sea surface temperature, *Porites lutea* contributed the maximum colony scale bleaching at Laku Point of the southern coast of the GoK. El-Naggar (2020) mentioned that the reef ecosystem is degrading due to anthropogenic activities such as overfishing, intensive tourism, urbanization, sedimentation, adverse water quality, pollution, and climate change. In some positive aspects of socio-economic impacts on the coral reef ecosystem, Kumar *et al*., (2017) transplanted 215 artificial triangles planted with 1569 fragments of Scleractinian coral species belong to eight genera at Pirotan Island of the GoK, found a 77.57% survival rate.

3. MATERIAL AND METHODS

3.1 Site selection

The study site for the research is located at the outer Gulf of Kachchh (GoK), Marine National Park (MNP), and Marine Sanctuary (MS), Gujarat, India. MNP and MS, GoK is the largest funnel-shaped coastal habitat of West Coast of India, situated on the Northern shore of the Jamnagar district of Gujarat (Plate.1), extends to a length of 170 km from Okha to Jodiya at 20° 15' to 23° 35' N and 60° 05' to 70° 22' E (Chauhan *et al.,* 2006; Parasharya and Padate, 2013). The GoK is a shallow water body, with an average depth of 30 m (Nair *et al.,* 1982). The southern part of the GoK is blessed with the most diverse ecosystems, covering 42 islands and coastal marine ecosystems sustain prosperous genetic diversity of mangroves, coral reef, sandy shores, and mudflats ecosystems (MNPCS, 2015).

The present study was conducted on three selected sites of the outer gulf including Okha, Mithapur, and Shivrajpur of Devbhumi Dwarka district located on the southern coast of the GoK. The coral reef distributing area of Port Okha, Mithapur, and Shivrajpur extending from latitude 22.32-22.40° N, and Longitude 68.94 – 69.07° E. Okha (22.46° N & 69.07° E), Mithapur (22.40° N & 69.03° E), and Shivrajpur (22.32° N & 68.94° E). (Plate.1). Port Okha is located on the narrow strip of land that is surrounded by the sea on three sides on the mouth of the GoK facing strong water currents all around the year than other coastal areas of India. The coast is characterized by rocky shore altering with some sandy patches the area is more suitable for the growth and survival of marine algae throughout the year (Barot *et al.,* 2015). Mithapur is on the extreme tip of the lower jaw of Gujarat and Shivrajpur is located near Dwarka town. The reef covering an area of Shivrajpur is towards the northern shore of Dwarka surrounded by rocky patches and sandy beaches (Padate *et al.,* 2018).

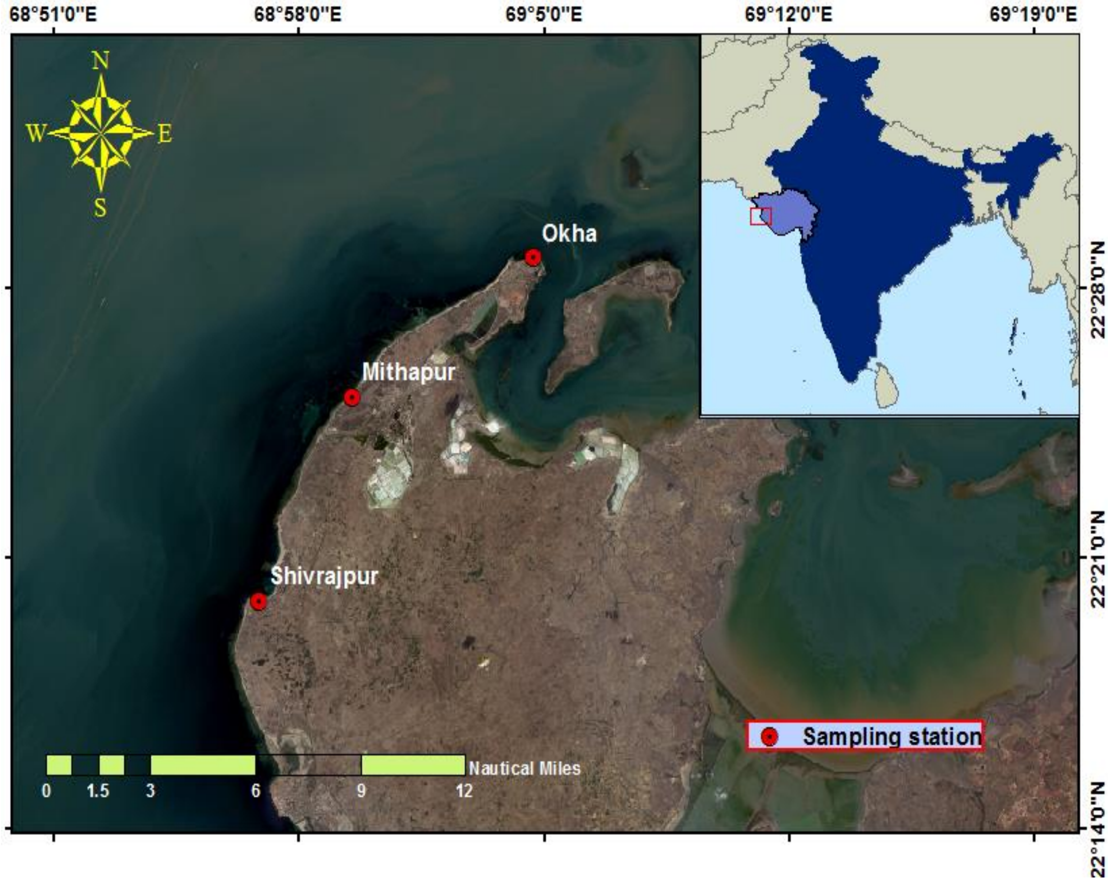


Plate 1. Map showing study area and sampling locations along the outer Gulf of Kachchh

3.2 Survey methods

3.2.1 Coral community analysis

Sampling was carried out at monthly intervals from November 2017 to February 2019 using Line Intercept Transect (LIT) method to assess coral community structure on each site (English *et al.,* 1997; Toda *et al.,* 2007).

Six transects with ten quadrates of 50X50 cm on each site covering an area of 0.25 m^2 consist 25 grids each of covering 100 cm^2 area were placed along with the three coral reef sites of the outer gulf region (Plate.2). A total of 10 quadrates per transect at an interval of 30 meters each have been placed. Total 60 quadrates on each site that covered the intertidal zone of exposed coral reef area during the low tide period have been surveyed. The survey was restricted to the intertidal reef flat due to the poor visibility of the waters. All the coral species and associated flora and fauna were recorded (i.e., seaweeds, crabs, prawns, sponges, echinoderms, nudibranchs, finfishes, shellfishes, bivalves, gastropods, and cephalopods).

All Scleractinian corals suspended by the transect were photographed, and their maximal projected size was measured based on the quadrates grid. All individual coral colonies were digitally photographed (Plate 2).

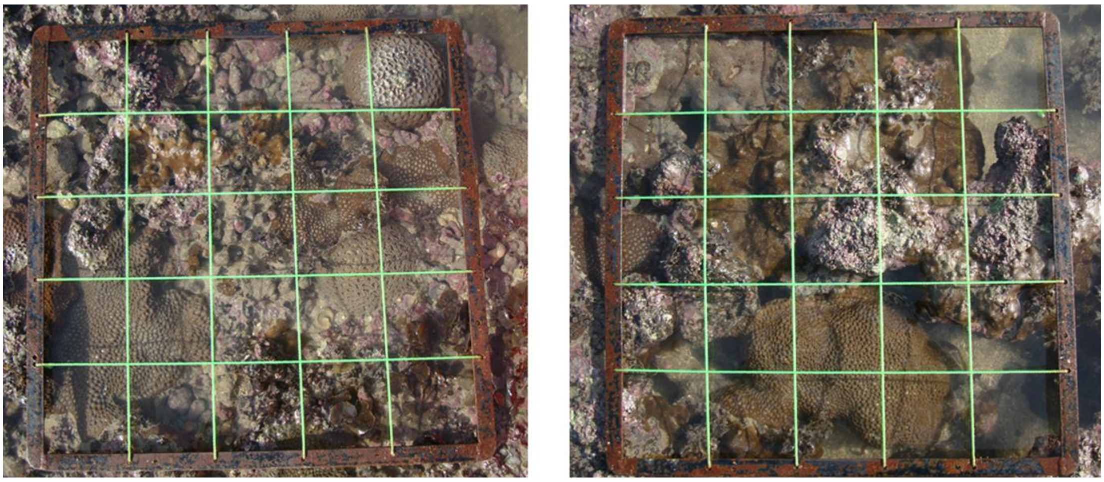


Plate. 2. Iron sampling grid (50 cm X 50 cm)

3.2.2 Reef-associated flora

To analyze the reef-associated flora, the biomass of each species of seaweed was weighted per each quadrates. The quadrate-wise seaweed biomass were stored in separate plastic polythene bags marked with the number of transects as well as the quadrate. All the species were then segregated, air-dried under sunlight, and species wise as well as quadrate wise dry weight of each species was measured on the weighing machine. The seasonal variation and availability of seaweed species on each selected site of the outer GoK were recorded. The herbaria of some dominant species were prepared. Not any species of seagrass have been recorded from the reef ecosystem of selected sites.

3.2.3 Reef-associated fauna

All the reef-associated fauna (crabs, prawns, sponges, echinoderms, nudibranchs, finfishes, shellfishes, bivalves, gastropods, and cephalopods) of the reef ecosystem were recorded as the number of individual organisms per quadrate by using Line Intercept Transect (LIT) method, during November 2017 to February 2019. Digital photography of the coral reef and reef-associated fauna was done.

3.3. Taxonomy

3.3.1 Identification of Corals

Coral reef species identification up to genus level has been made in-situ assisted by photography and morphological observation, because live coral specimen collection is illegal as they are restricted in the GoK MNP and MS. Different online databases like the digital archives of ZSI and Central Marine Fisheries Research Institute (CMFRI), And published literature has been used. The taxonomical nomenclature presented by the World List of Scleractinia (WoRMS) (Hoeksema & Cairns, 2021), and Coral Reef of the World has been used for the identification of the coral species. The distribution pattern of the recorded species is established based on an online website - corals of the world (Veron *et al.*, 2019). For coral identification, the manual of the Zoological Survey of India (Venkatraman and Satyanarayana, 2012) was followed.

3.3.2 Identification of reef-associated flora

Seaweed species were identified according to the identification key described by Jha *et al.,* (2009), and Thakur and Rao (2009). Taxonomic nomenclature of the marine algae has been carried out as per online database such as algae base (Guiry and Guiry, 2019) and WoRMS (Horton *et al.*, 2021).

3.3.3 Identification of reef-associated fauna

Identification of reef-associated fauna species has been made in-situ assisted by photography as per the marine biota identification key followed (Rao, 2010, Ramamoorthy *et al.,* 2012). Taxonomic nomenclature of the reef-associated fauna was done as per the online database such as sealifebase (Palomares and Pauly, 2019) and WoRMS (Horton *et al.*, 2021).

3.4 Water quality parameters

The water quality parameters like Temperature, Salinity, pH and Dissolve Oxygen (Do) were measured by using standard water quality parameter instruments like Thermometer, Refractometer, pH meter, and Do was measured by Winkler's method (Mohamed, H., 2016) at Fisheries Research Station, Junagadh Agricultural University, Okha.

3.5 Statistical analysis

Periodical purposive sampling has been done to collect the required data. The collected data were analyzed as per the standard statistical methods such as Diversity Indices, Multivariate analysis, coral community analysis, and Coral Health Indicator.

3.5.1 Diversity Indices

Diversity Indices have been done based on coral coverage of each species on each transects. For the reef-associated flora, quadrate-wise seaweed biomass has been taken. For the reef-associated fauna, the number of reef fauna per quadrate has been counted. Species richness index (Margalef's index), Species Diversity Indices such as Simpson Index and Shannon-Weiner diversity index, and Evenness index were calculated (Margalef, 1958; Pielou, 1975; Shannon *et al*., 1949; Simpson, 1949) by using PAST Version 3.25 (Hammer *et al.,* 2001).

A. Species Richness Indices

i) Margalef's index (R)

The Margalef's index was used as a simple measure of species richness (Margalef, 1958). The Margalef's index (R) is calculated by the following equation:

$$\textbf{Margalef's Index } (\mathbf{R}) = \frac{S-1}{ln\,\mathrm{N}}$$

Where, R = Margalef's species richness index

S = Tot al number of species

N = Total number of individuals in the sample

ln = Natural logarithm

B. Species Diversity Indices

i) A diversity index is numerical computing of species diversity based on **Simpson Index (1949)**

Species richness of a given area.

$$\textbf{Simpson index } (\boldsymbol{\lambda'}) = \sum_{i=1}^{s} \text{ni} \frac{(ni - 1)}{N(N-1)}$$

Where, λ' = Simpson index

N = Total number of the individuals in the sample

S = Total number of the species

ii) Shannon-Wiener Index (Shannon-Weaver, 1949)

The Shannon-Wiener diversity index (H') is a measure of diversity that combines species richness (the number of species in a given area) and their relative abundances. The Shannon-Wiener diversity index (H) is calculated by the following equation:

$$\textbf{Shannon} - \textbf{Wiener Index } (\mathbf{H'}) = -\sum_{\text{i}=1}^{s} (\text{pi } In \text{ pi})$$

Where, H' = Shannon-wiener index

Pi = Proportion of the individuals of the species in the sample

s = Total number of species

ln = Natural logarithm

C. Species Evenness Indices (J')

i) Evenness Index (J')

Species evenness refers to how close in numbers each species in an environment is. The evenness index (Pielou, 1975) is calculated from the following equation:

$$\textbf{Evenness Index } (\mathbf{J'}) = \frac{\text{H}'}{\text{In S}}$$

Where, H = Shannon – Wiener Diversity Index

S = Total number of species in the sample

3.5.2 Coral community analysis

The Relative abundance (RA), which is an index of commonness or uncommonness, of each coral species, was calculated (Rilov and Benayahu, 1998).

$$\textbf{Relative Abundance (RA)} = \frac{\text{Pi}}{\text{P total}} \text{X } 100$$

Where, ***Pi*** = Pooled living coverage of the i^{th} species from all transects at a given site

P total = Pooled total livening coverage of all species in all transects at a given site

The resulting values were transformed into abundance categories (%): not recorded (RA = 0), rare (RA < 0.1) uncommon (RA = 0.1 to 1), common (RA = 1 to 10), abundant (Ra = 10 to 20), and dominant (RA > 20).

3.5.3 Coral health indicator

Coral Mortality Index (CMI) was adopted to analyze the health of the coral reefs in the outer GoK (Gomez *et al.,* 1994). As opposed to measuring diversity or percent coral cover, CMI is a multivariate index, which is a simple ratio between proportions of live coral cover area to both live and dead coral cover.

Mortality Index (MI) = dead coral cover / Live coral cover + dead coral cover

If MI > 0.33, the mortality index is considered to be high and the reef is classified as sick or deteriorating.

3.5.4 Multivariate analysis

Multivariate analysis such as Principal Component Analysis (PCA), and Canonical Correspondence Analysis (CCA) was examined by pulled data of live coral cover, seaweed biomass, and number of reef fauna per quadrate of all selected sites by using PAST Version 3.25 (Hammer *et al.,* 2001). A PCA scatter plot plotted based on eigenvalue scores of a live coral cover of the selected sites. The adequacy of variables in species differentiation and classification power of the PCA model has been shown by the scatter plot. The influence of seasonal variation in the environmental variables on the abundance and species richness of the coral reef and reef associate flora has been examined by Canonical Correspondence Analysis (CCA). The contribution of species to variations has been constructed by clusters analysis by using PAST version 3.25.

To understand the seasonal influence of the environmental changes on the reef diversity Canonical Correspondence Analysis (CCA) plot has been prepared by using software PAST-Version 3.25 (Hammer *et al.,* 2001). The interrelationship of the different environmental variables has been investigated by plotting the correlation matrix by using R-Software Version 4.0.0.

3.6 Economic analysis of the coral reef ecosystem

Economic analysis of the coral reef ecosystem of the outer GoK has been done by preparing a questionnaire and evaluating traditional fishing activities at each site. All those points related to coral reef fishing directly or indirectly in all fishing season were taken into consideration. Rank Order Scaling (ROS) method and Public Opinion Scaling (POS) have been used to find out the relevance of the coral reef ecosystem and its services to the local population. The questionnaire prepared is given in Appendices.

Economic analysis was carried out by calculating fixed cost (capital cost), variable cost (marginal cost), total project cost, depreciation on a total fixed cost, total project cost, and total revenue, and finally, the annual profit (total revenue), net profit and cost-benefit ratio (CBR) were calculated as per Markad (2004).

A. Capital cost (Fixed cost)

It includes the one-time expenses such as the cost of the vessel, engine, net, and other miscellaneous items such as ropes and anchor, having more than one-year life span. In addition, other fishing equipment and related items were taken separately for analysis.

B. Variable cost (marginal cost)

Total variable cost is a part of the total cost that can change as the rate of output changes (Dewey, 1975). Daily expenditure incurred for the working of the boat is termed as operating cost or variable cost. The expenses on captured fish collecting baskets (Gumbhla), bottom painting, maintenance of the fishing vessel, engine, and fishing net, license fees, repairing and maintenance, petrol, diesel, and oil were the major components of the variable cost of the outer GoK.

C. Total project cost

Includes total operating expense of fishing activity. The total project cost was calculated by adding capital cost and variable cost.

D. Depreciation on fixed cost

Fixed cost includes depreciation, interest, and insurance. The depreciation was calculated based on the expected life, i.e. ratio of the purchase cost of an item divided by the expected life of an item.

E. Total cost

The total cost per annum was calculated by adding the fixed cost and variable cost.

F. Total revenue

Total revenue was calculated after personal inquiry for price per kilogram of fish at the landing center and obtained value was multiplied by the quantity of catch landed by the traditional fishing.

G. Annual profit

The annual profit was obtained by subtracting the total expenditure from the revenue of a unit of traditional fishing.

Annual profit = Revenue – Total expenditure

H. Net profit

The net profit has been obtained by removing the total cost from the total revenue.

Net profit = Total revenue – Total Cost

I. Cost-Benefit Ratio (CBR)

A cost-benefit ratio (CBR) is a ratio used in a cost-benefit analysis to summarize the overall relationship between the relative costs and benefits of a proposed project.

3.7 Socio-economic impact on the coral reef diversity

Socio-economic impact on coral reef diversity in the outer GoK has been done by using a Questionnaire and visual inspection on each site. All those points are taken into consideration, which can affect the reef ecosystem. Rank Order Scaling (ROS) method and Public Opinion Scaling (POS) have been used to find out the socio-economic impact on coral reef ecosystem. Important problems relating to the coral reef, public opinion to conserve the coral reef ecosystem on each site, most important uses of coral, and importance of reef ecosystem at each site of the outer GOK has been studied. The dead coral cover and the average number of people who visit coral reef sites per day also have been recorded to know the anthropogenic pressure and its impact on coral reef diversity. To find out the health status of the reef ecosystem, Coral Mortality Index (CMI) have been calculated by examining the ratio between proportions of live coral cover to both live and dead coral cover. The questionnaire used for the socio-economic impact analysis on the coral reef ecosystem is given in Appendices.

4. RESULTS

The reef covering area of the outer GoK was studied from three selected sites, Okha, Mithapur, and Shivrajpur extending from latitude 22.32-22.40° N, and Longitude 68.94 – 69.07° E. Okha (22.46° N & 69.07° E), Mithapur (22.40° N & 69.03° E), and Shivrajpur (22.32° N & 68.94° E). Site Okha is located on a narrow strip of land that projects into the sea. Mithapur is located on the extreme tip of the lower jaw of Gujarat and Shivrajpur is located near Dwarka.

The substratum and geo-morphology of the outer GoK are of limestone, rocks, and a gradual slope conducive for coral growth. The rocky substratum in the vicinity of the coral reef zone at the Okha region is surrounded by a rocky substratum and the drainage slope is from south to north. The low-lying coastal reef distributing area forms an approximately 2 km wide coastal belt. An average intertidal expanse is about 0.8 km. There are small tidal pools near about 0.5 m found in the rocky shore area. The total area surveyed was 1.6 km^2 of which coral-covered area was 0.72 km^2, which is approximately 45% of the total intertidal expanse (Plate 3). The coral reef zone of the Mithapur region is surrounded by sandy substratum in the supratidal zone and rocky substratum in the mid tidal and subtidal zone. The low-lying coastal reef distributing area forms an approximately 3 km wide coastal belt. An approximate intertidal expanse is about 1.2 km. There are about 3-to-6-meter tidal pools found in rocky shore areas. Out of a total 3.6 km^2 area, the reef covering area was about 2 km^2 which is about 55.5 % of the total intertidal expanse (Plate 4). The Shivrajpur site has mainly a rocky substratum with large and small tidal pools. The total area surveyed at this site was 3 km^2. Out of which corals were distributed on around 2.16 km^2 area covering about 72% of the total intertidal expanse (Plate 5).

Plate 3. Sampling site Okha

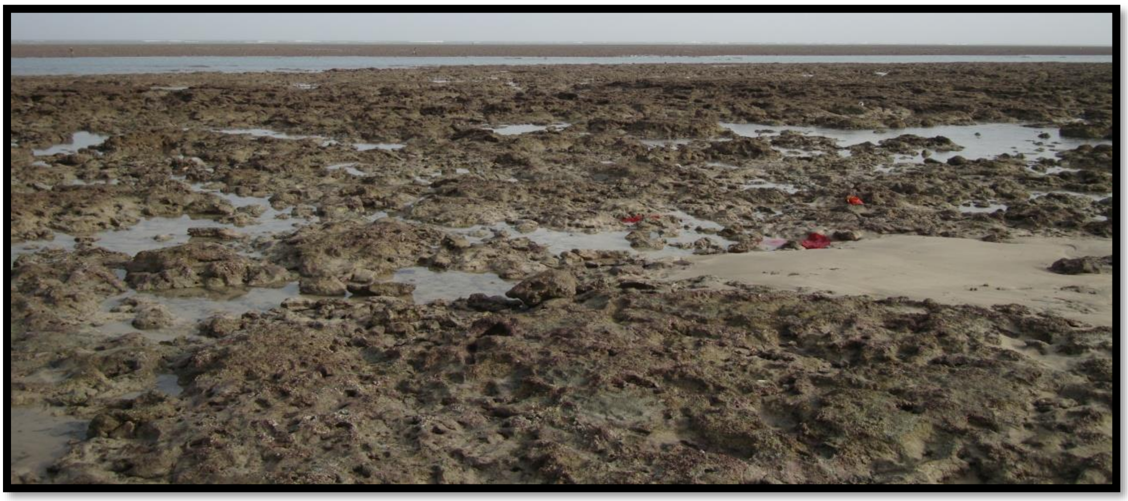


Plate 4. Sampling site Mithapur

Plate 5. Sampling site Shivrajpur

4.1 Physico-chemical characteristics

During the study period from November 2017 to February 2019, the mean water temperature and salinity of Okha, Mithapur, and Shivrajpur were 26° C and 34 ppt, 26° C and 35 ppt and, 27° C and 34 ppt respectively, and the mean pH values were 7.73, 7.91, and 7.84 respectively. The dissolved oxygen level at Okha, Mithapur, and Shivrajpur were 6.50, 6.22, and 6.59 mg/lit respectively. At Okha, the temperature was positively correlated with salinity and negatively correlated with the dissolved oxygen, whereas pH has a positive correlation with dissolved oxygen (Fig. 1). At Mithapur, the temperature was strongly positively correlated with salinity and negatively correlated with dissolved oxygen, whereas salinity and pH were negatively and positively correlated with dissolved oxygen respectively (Fig. 2). At Shivrajpur, the temperature is strongly positively correlated with salinity and strongly negatively correlated with dissolved oxygen, whereas salinity and pH were strongly negatively and positively correlated with dissolved oxygen respectively (Fig. 3).

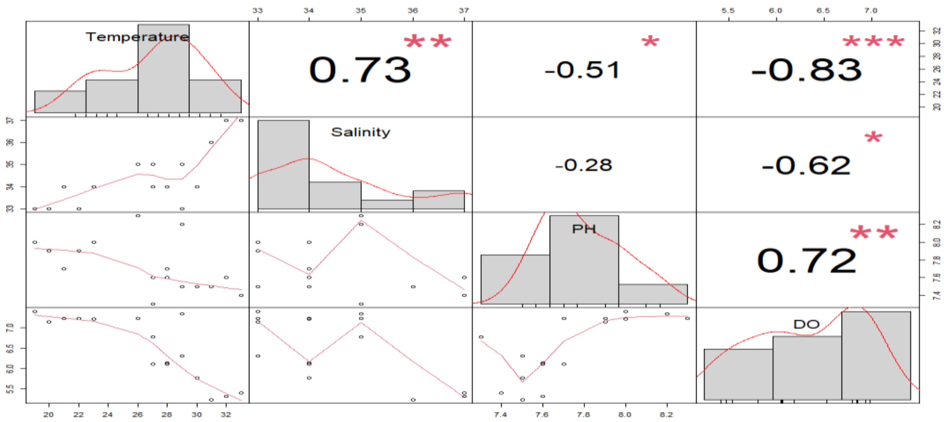


Fig. 1. Correlation matrix of environmental parameters at Okha

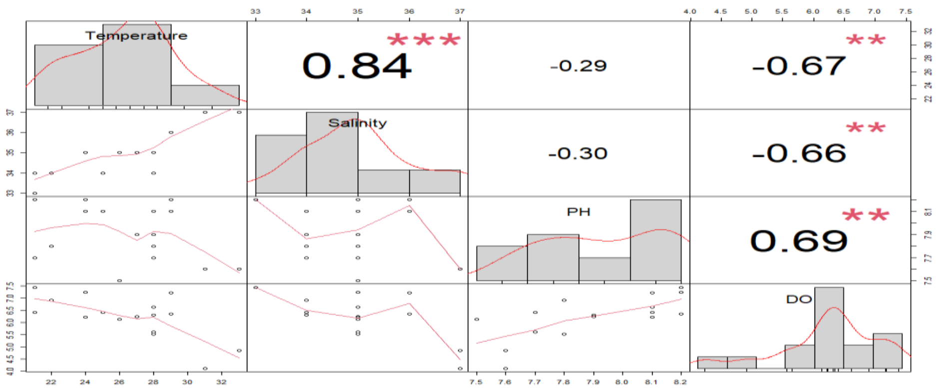


Fig. 2. Correlation matrix of environmental parameters at Mithapur

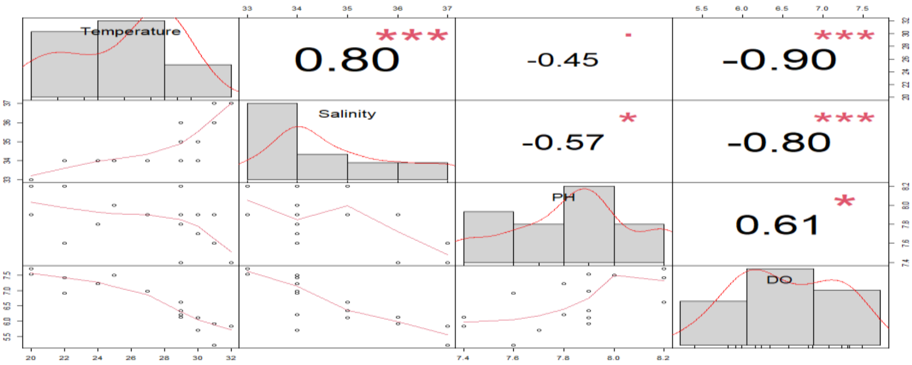


Fig. 3. Correlation matrix of environmental parameters at Shivrajpur

4.2 Diversity and distribution of coral reef in the outer GoK

A total of 23 species of Scleractinian corals belonging to eight different families, and 12 genera were recorded from three sites of the outer GoK (Table 1). The highest numbers of coral species were recorded from site Shivrajpur among three selected sites of the outer GoK. Family Poritidae contributed the highest number of Scleractinian corals followed by family Faviidae and Merulinidae. The highest number of Scleractinian corals were recorded from Shivrajpur with 22 species belonging to 12 genera followed by Mithapur with 16 species belonging to 10 genera and Okha with 12 species belonging to 8 genera (Plate 6).

Table 1. List of coral species recorded from the outer GoK.

Sr. No.	Family	Coral Reef Species	Acronyms	OKHA	MITHAPUR	SHIVRAJPUR
1	Acroporidae	*Montipora foliosa* (Pallas, 1766)	***mf***			X
2		*Montipora sp. 1*	***msp1***			X
3		*Montipora sp. 2*	***msp2***			X
4		*M. venosa* (Ehrenberg, 1834)	***mv***	X	X	X
5	Coscinaraeidae	*Coscinaraea sp.*	***csp***			X
6	Faviidae	*Dipsastraea favus* (Forskal, 1775)	***df***	X	X	X
7		*Dipsastraea sp.*	***dsp***	X		
8		*D. speciosa* (Dana, 1846)	***ds***	X	X	X
9		*Leptastrea purpurea* (Dana, 1846)	***lp***		X	X
10	Lobophylliidae	*Homophyllia bowerbanki* (Milne Edwards & Haime, 1857)	***hb***	X	X	X
11		*Lobophyllia radians* (Milne Edwards & Haime, 1849)	***lr***	X	X	X
12	Merulinidae	*Favites sp.* 1	***fssp1***	X	X	X
13		*Favites sp.* 2	***fssp2***	X	X	X
14		*Favites sp. 3*	***fssp3***		X	X

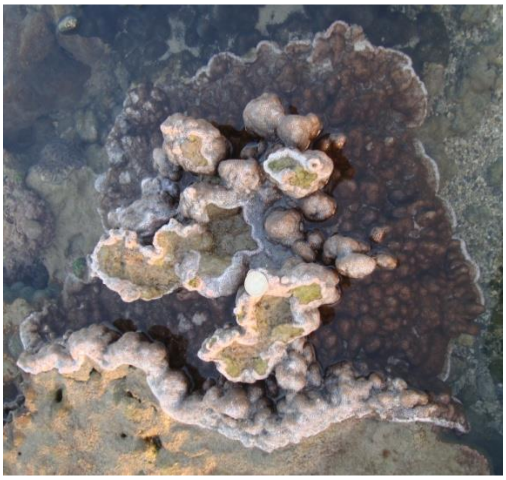
15		*F. spinosa* (Klunzinger, 1879)	***fss***	X	X	X
16	Poritidae	*Goniopora pedunculata* (Quoy & Gaimard, 1833)	***gpd***	X	X	X
17		*Goniopora sp.*	***gsp***			X
18		*Porites compressa* (Dana, 1846)	***poc***		X	X
19		*Porites sp.*	***posp***		X	X
20		*P. lutea* (Milne Edwards & Haime, 1851)	***polu***	X	X	X
21	Psammocoridae	*Psammocora sp.*	***psp***		X	X
22	Siderastreidae	*Pseudosiderastrea tayamai* (Yabe & Sugiyama, 1935)	***pt***			X
23		*Siderstrea savignayana* (Milne Edwards & Haime, 1851)	**ss**	X	X	X

Plate 6. Coral reef species recorded from the outer GoK

1. *Montipora foliosa*

2. *Montipora sp. 1*

3. *Montipora sp. 2*



4. *Montipora venosa*

5. *Coscinaraea sp.*

6. *Dipsastraea favus*

7. ***Dipsastraea sp.***

8. ***Dipsastraea speciosa***

9. ***Leptastrea purpurea***

10. ***Homophyllia bowerbanki***

11. ***Lobophyllia radians***

12. ***Favites sp.*** **1**

13. *Favites sp. 2*

14. *Favites sp. 3*

15. *Favites spinosa*

16. *Goniopora pedunculata*

17. *Goniopora sp.*

18. *Porites compressa*

19. ***Porites sp.***

20. ***Porites lutea***

21. ***Psammocora sp.***

22. ***Pseudosiderastrea tayamai***

23. ***Siderstrea savignayana***

4.2.1. Species-wise percentage contribution to the total live coral cover

The percentage contribution of the live coral cover of the outer part of the GoK is given in Fig. 4. Among the species, *Dipsastraea favus* showed the maximum percentage contribution (13 %) followed by *Pseudosiderastrea tayamai* and *Goniopora pedunculata* contributing to 9% each. The percentage contribution of *P. tayamai* and *G. pedunculata* was almost similar and together contributed to 18% of the total live coral cover of the outer GoK.

At Okha, *Porites lutea* showed the maximum percentage contribution (26 %) to the total live coral cover followed by *Siderstrea savignyana* (18 %). The percentage contribution of *D. favus* and *G. pedunculata* was almost similar and together contributed to 22 % of the total live coral cover. The minimum percentage contribution to the total live coral cover was exhibited by *Favites spinosa* followed by *Favites sp. 1* at Okha region (Fig. 5).

At Mithapur, *G. pedunculata* showed the maximum percentage contribution (23 %) to the total live coral cover followed by *D. favus* contributing to 8%. The percentage contribution of *Dipsastraea speciosa* and *S. savignyana* was almost similar and together contributed to 17 % of the total live coral cover. The minimum percentage contribution to the total live coral cover at the Mithapur region was exhibited by *F. spinosa* followed by *Lobophyllia radians* (Fig. 6).

At Shivrajpur, *P. tayamai* exhibited the maximum percentage contribution (12 %) to the total live coral cover followed by *D. favus* whereas *F. spinosa* followed by *Coscinaraea sp*. contributed minimum percentage coverage to the total live coral cover at Shivrajpur (Fig. 7).

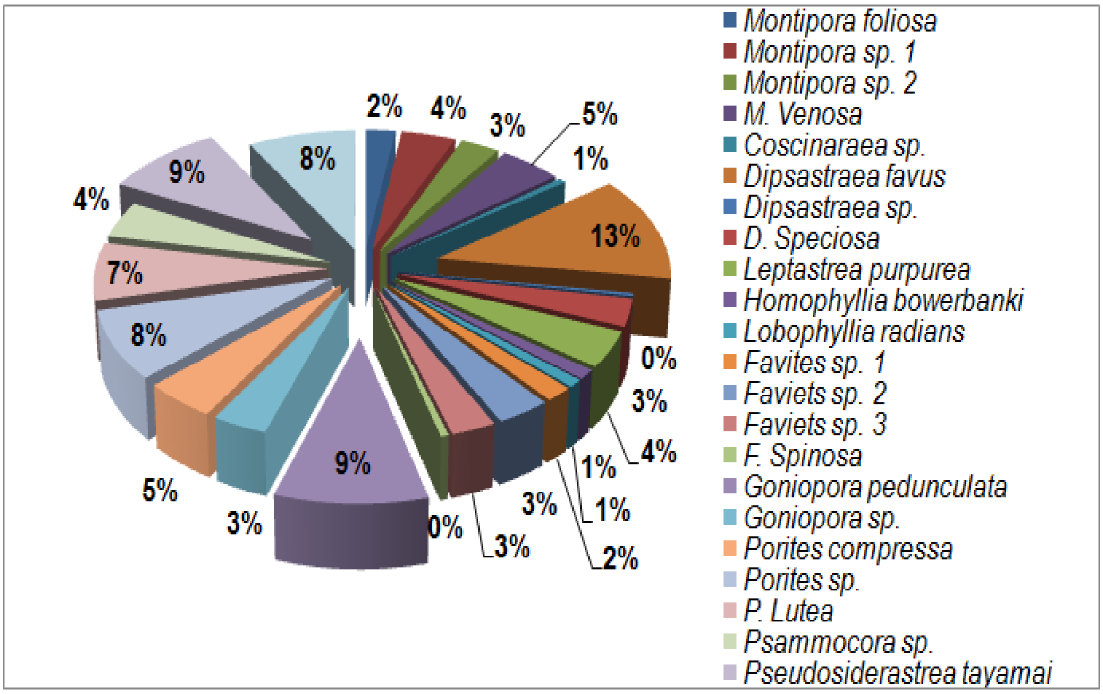


Fig. 4. Species-wise percentage contribution to the total live coral cover of the outer GoK

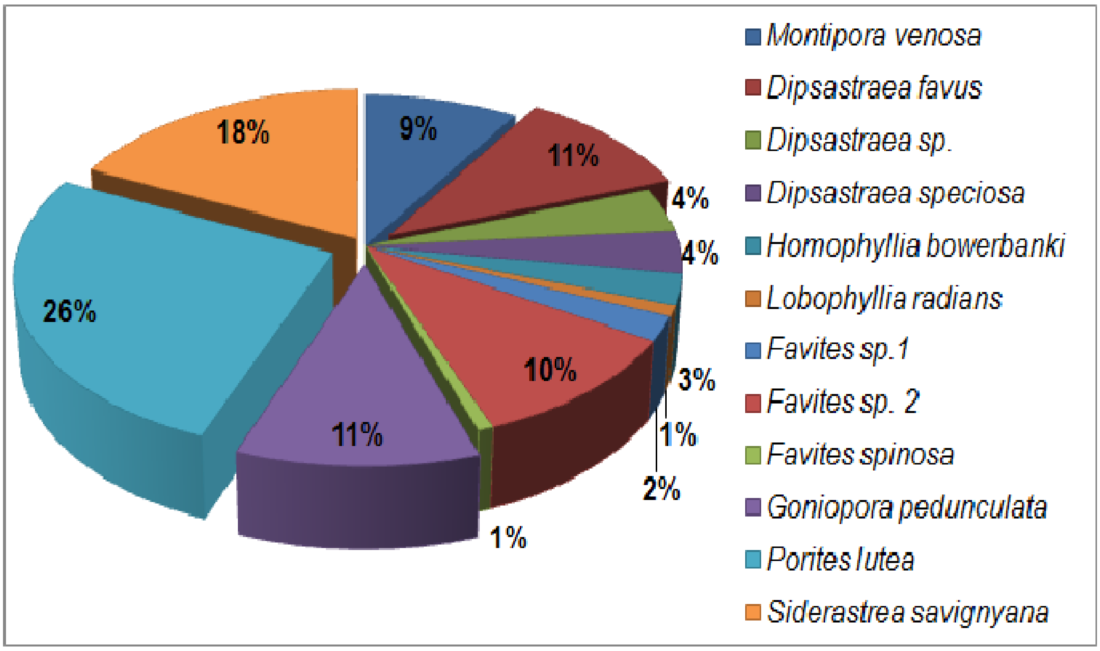


Fig. 5. Species-wise percentage contribution to the total live coral cover at Okha

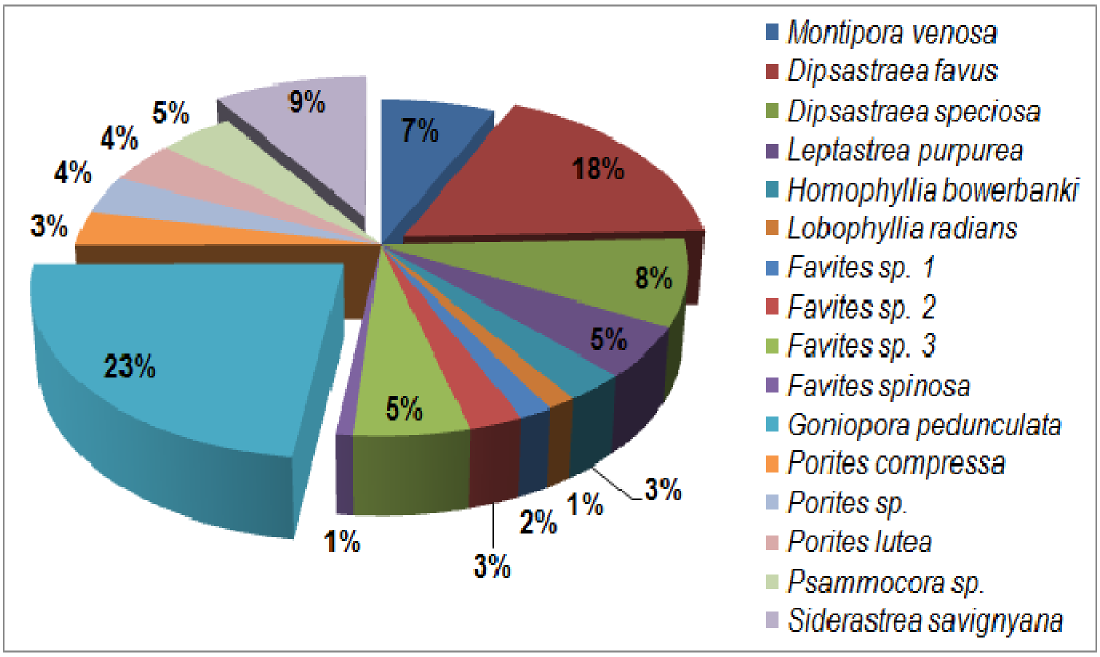


Fig. 6. Species-wise percentage contribution to the total live coral cover at Mithapur

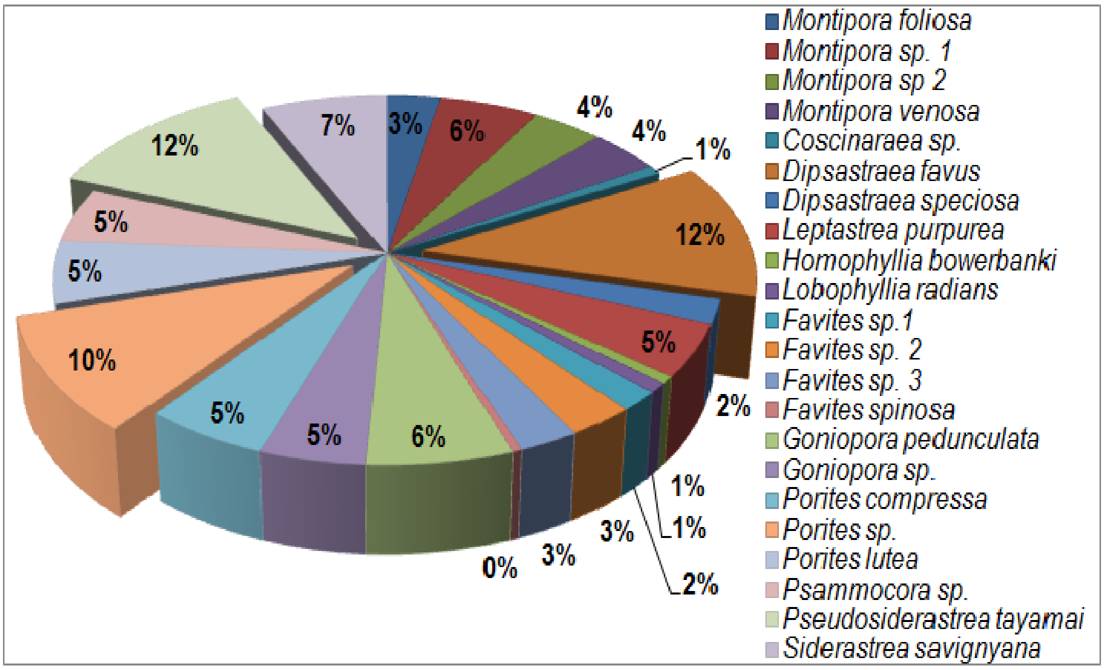


Fig. 7. Species-wise percentage contribution to the total live coral cover at Shivrajpur

4.2.2 Species diversity indices

Site Shivrajpur showed the highest number of taxa followed by Mithapur. The maximum species richness was found at Shivrajpur followed by Mithapur. Shannon-Wiener index shows that site Shivrajpur is the most diverse which is followed by Mithapur and Okha. Pielou’s evenness index was maximum at Okha followed by Mithapur and Shivrajpur (Table 2).

Table 2. Species diversity indices of coral reef of the outer GoK

Diversity Indices	Okha	Mithapur	Shivrajpur
Taxa_S	7	10	19
Individuals	19	34	109
Simpson's index (D)	0.80	0.79	0.90
Shannon-Wiener index (H’)	1.78	1.89	2.58
Evenness (J’)	0.88	0.74	0.73
Species richness (S)	2.11	2.49	3.81

4.2.3 Principal Component Analysis (PCA)

PCA scatter plot plotted based on the eigenvalue scores of a live coral cover of the selected sites. Given axis was ranked in order of important differences between the first principal component axis PCA 1 and the second principal component axis PCA 2. The important difference among the PCA 1 and PCA 2 is PCA 1 is more important than PCA 2. PCA 1 contributed the maximum (87.31 %) followed by PCA 2 (9.94 %) (Table 3). PCA analysis of all selected sites supported the statement that maximum live coral cover was found at Shivrajpur followed by Mithapur and Okha. It is also found that *D. favus* followed by *P. tayamai* were dominant species distributed all over the outer GoK. At the Okha site species such as *P. lutea*, *G. pedunculata*, *S. savignyana*, and *M. venosa* are frequently distributed. At Mithapur, *G. pedunculata* while at Shivrajpur *P. tayamai* followed by *Porites sp*. were frequently distributed (Fig. 8). The factors responsible for this pattern could be the anthropogenic pressure at these sites. Mithapur is subjected to high pollution, industrial growth, and tourism, whereas Okha site frequented tourism. Compared to these two sites, Shivrajpur is a pristine condition with no anthropogenic activities, thus supporting higher biodiversity and live coral coverage of Scleractinian corals.

Table 3. Principal components based on Eigenvalue

PC	Eigenvalue	% variance
1	967860	87.31
2	110157	9.94
3	30490	2.75

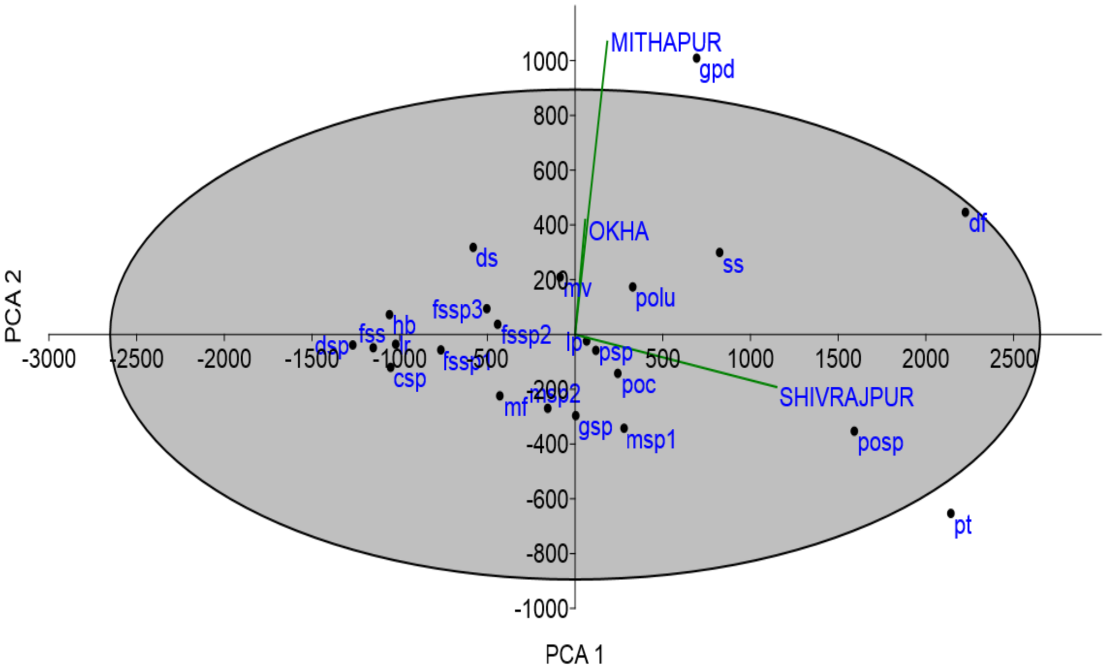


Fig. 8. PCA plot of live coral cover of the outer GoK

4.2.4 Cluster analysis

Cluster analysis based on the percentage share of coral species abundance of all selected sites of the outer GoK supported the statement that the species abundance of site Okha and Mithapur showed similar abundance whereas site Shivrajpur showed completely different species abundance than the other two sites (Fig. 9). The factor responsible for this pattern could be the anthropogenic pressure on Mithapur and Okha site showing reef degradation.

It was also found that coral species such as *Leptastrea purpurea* and *Porites sp.* exhibited the maximum similarity in abundance followed by *Coscinaraea sp*. and *Lobophyllia radians*. Dendrogram of the coral species abundance pattern of the outer GoK formed 4 different groups of the coral species based on their occurrence, of which the fourth group including *D. favus, Porites sp.*, and *P tayamai* showing completely different abundance than all other coral species. A single species *G. pedunculata* was not included in any of the groups and individually exhibited a completely different abundance pattern than all of the coral species of the outer GoK (Fig. 10).

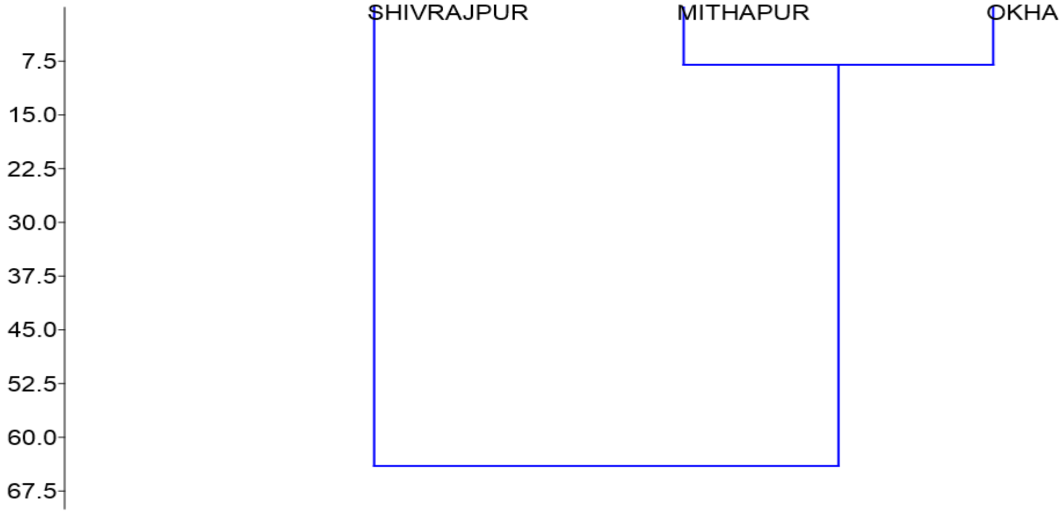


Fig. 9. Dendrogram based on the site-wise coral species abundance

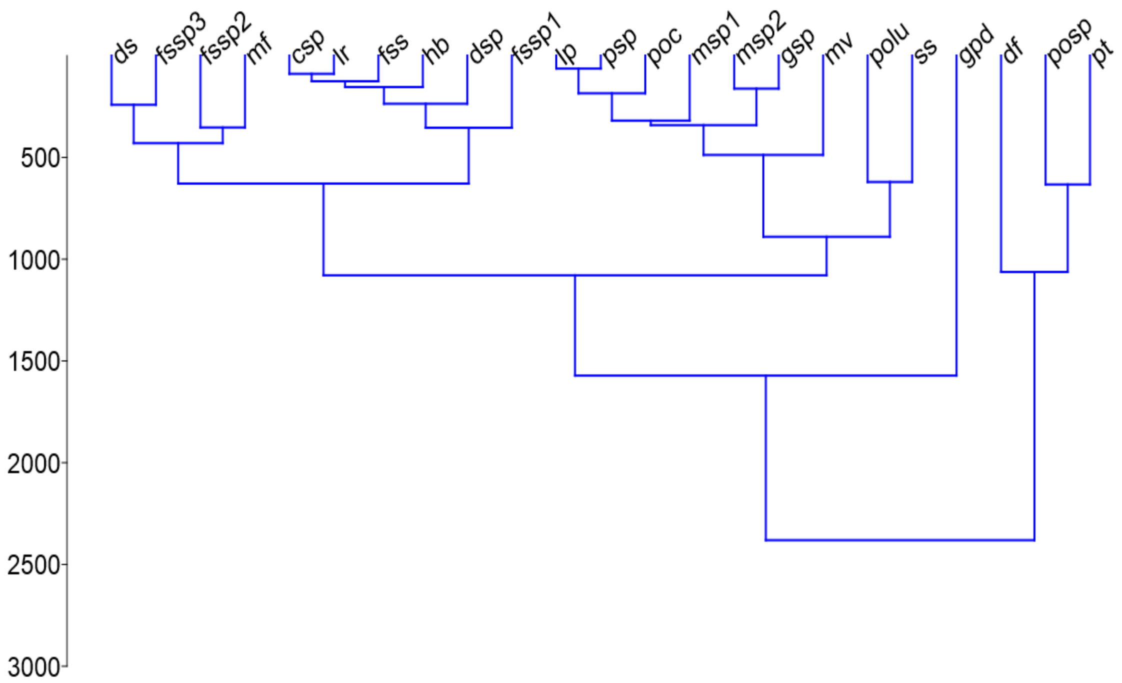


Fig. 10. Dendrogram based on the percentage share of species abundance

4.2.5 Canonical Correspondence Analysis (CCA)

CCA scatter plot plotted based on eigenvalue scores of a live coral cover associated with environmental parameters of the selected sites. Axis 1 contributed the maximum (61.72 %) followed by Axis 2 (20.75 %) (Table 4). CCA analysis of all selected sites supported the statement that environmental parameters such as temperature and salinity are negatively correlated with pH and dissolved oxygen. Some ecologically fragile species such as *G. pedunculata, Homophyllia bowerbanki,* and *Lobophyllia radians* exhibited high abundance at a higher amount of dissolved oxygen with more alkaline condition of water and lower salinity as well as temperature. Some species such as *Porites sp.* showed abundance with high saline conditions whereas *Favites sp. 3* was found at higher water temperature (Fig. 11).

Table 4. Canonical Correspondence Analysis based on Eigenvalue

Axis	Eigenvalue	%
1	0.04	61.72
2	0.01	20.75
3	0.01	17.53
4	0.00	0.00

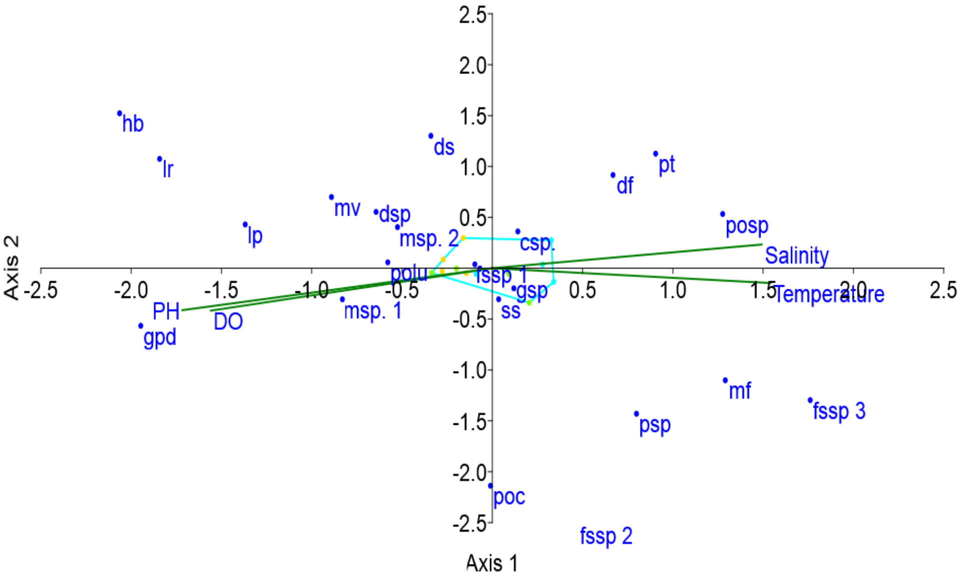


Fig. 11. CCA plot on the impact of environmental parameters on the live coral cover of the outer GoK

4.2.6. Percentage contribution of dead coral cover

The percentage contribution of the dead coral cover of the outer part of the GoK was estimated based on the species-wise dead coral cover. During the present study, reef degradation has been observed at all selected sites of the outer GoK. A total of 16 species of Scleractinian corals were found to be bleached especially due to human-induced stress such as local tourism, traditional fishing activities, and shoreline pollution. The maximum proportion of the colony scale bleaching was observed in *G. pedunculata* contributed 34 % of the total dead coral cover followed by *D. favus* contributed 31% of the total dead coral cover of the outer GoK (Fig. 12). The percentage contribution of the relative dead coral cover with the live coral cover was highest at Mithapur with 12.62 % of the total coral reef cover followed by Okha (6.45 %) and Shivrajpur (0.41 %).

At Okha, *D. favus* showed the maximum percentage contribution with 32 % to the total dead coral cover followed by *G. pedunculata* (25 %). The percentage contribution of *D. speciosa* and *Dipsastraea sp.* was almost similar and together contributed to 21 % of the total dead coral cover at Okha region. The minimum percentage contribution to the total dead coral cover was exhibited by *Favites spinosa* followed by *Favites sp. 1* at Okha region (Fig. 13). At Mithapur, *G. pedunculata* showed the maximum percentage contribution with 37 % to the total dead coral cover followed by *D. favus* contributing to 31%. The percentage contribution of *D. speciosa* and *Porites compressa* was almost similar and together contributed to 16 % of the total dead coral cover (Fig. 14). At Shivrajpur *D. favus* showed the maximum percentage contribution with 29 % to the total dead coral cover followed by *G. pedunculata* (27 %) and *P. compressa* (15 %). The percentage contribution of species such as *Goniopora sp.* and *D. speciosa* was almost similar and together contributed to 12 % of the total dead coral cover at Shivrajpur (Fig. 15).

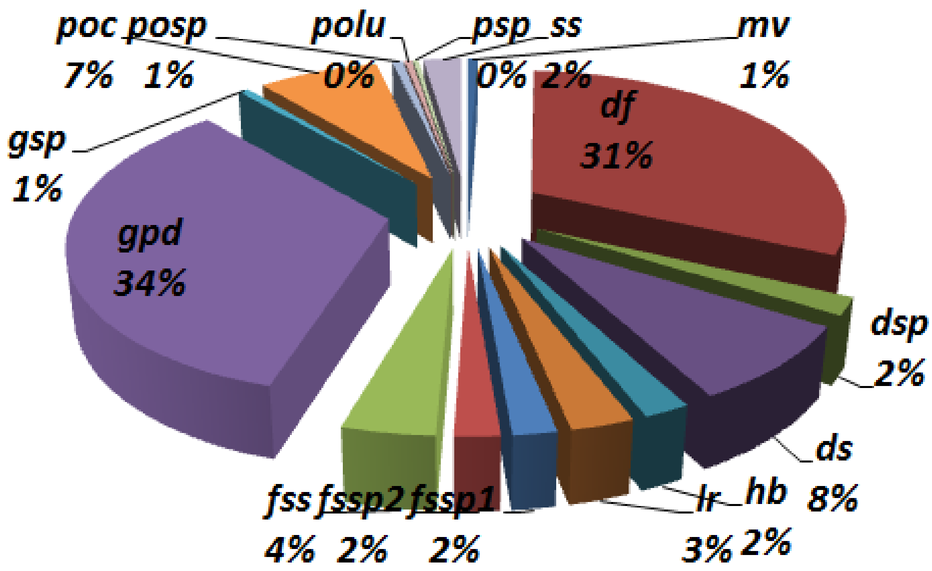


Fig. 12. Species-wise percentage contribution to the total dead coral cover of the outer GoK

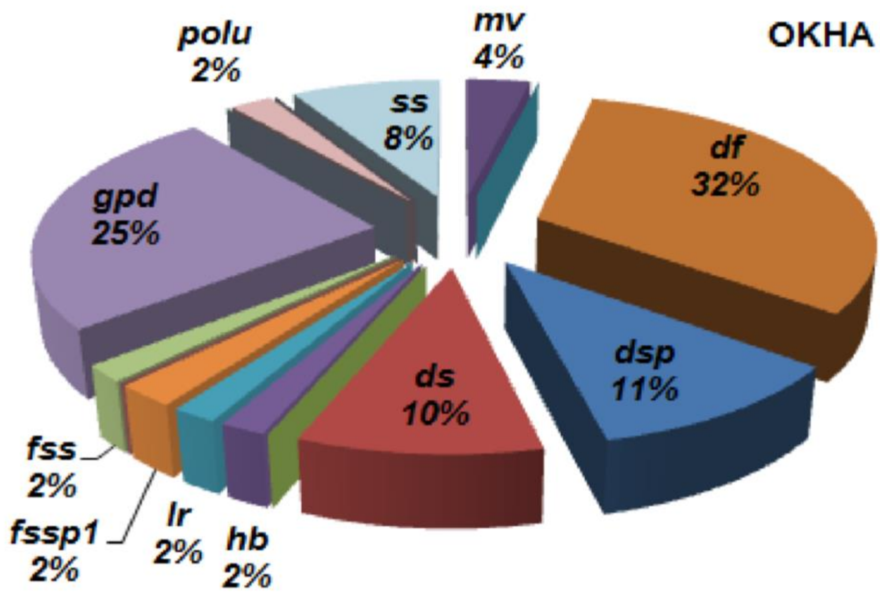


Fig. 13. Species-wise percentage contribution to the total dead coral cover at Okha

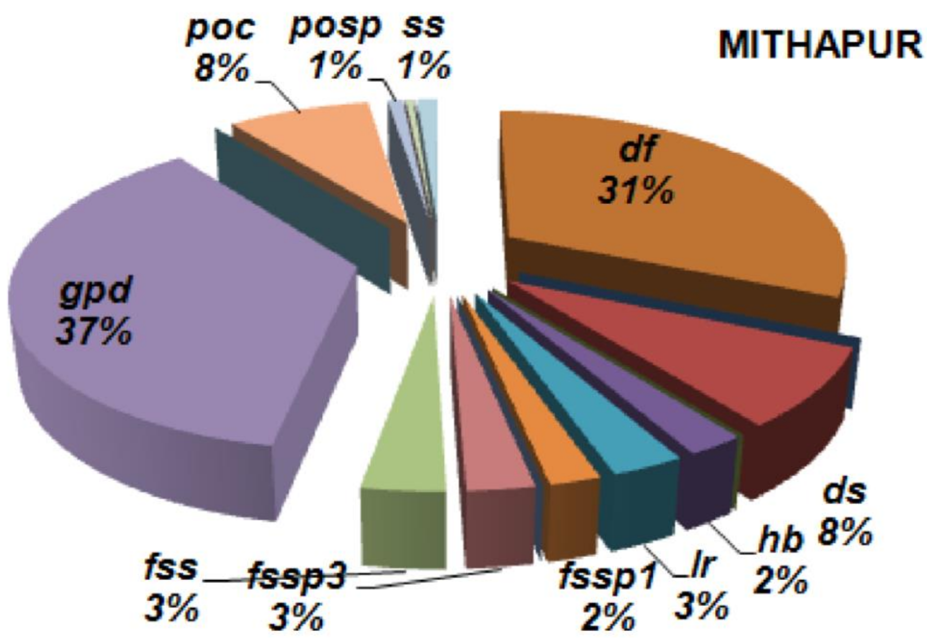


Fig. 14. Species-wise percentage contribution to the total dead coral cover at Mithapur

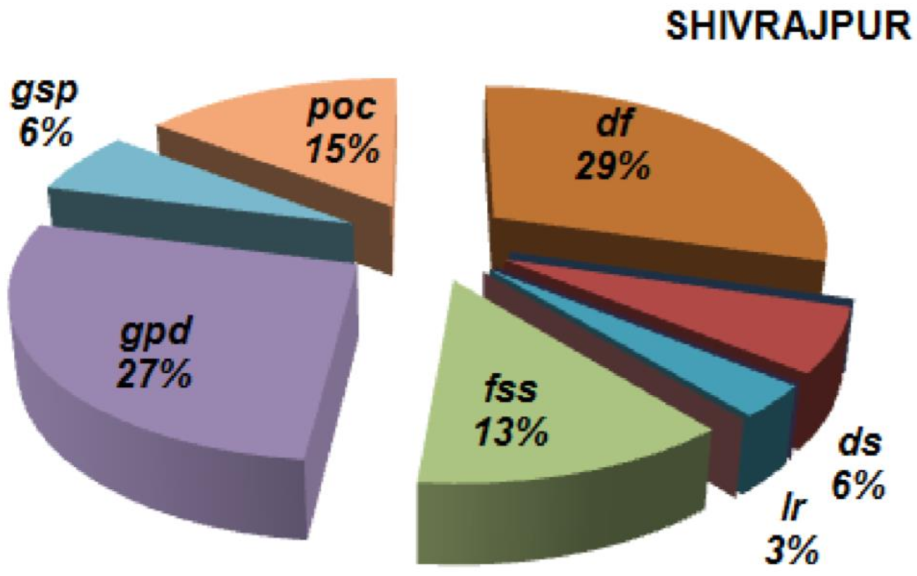


Fig. 15. Species-wise percentage contribution to the total dead coral cover at Shivrajpur

4.2.7. Cluster analysis of dead coral cover of the outer GoK

Cluster analysis based on the percentage share of the site-wise dead coral cover of all selected sites of the outer GoK supported the statement that, the dead coral cover at site Okha and Shivrajpur showed similar abundance whereas site Mithapur showed completely different species abundance than the other two sites (Fig. 16). The factor responsible for this pattern could be the anthropogenic pressure such as local tourism and traditional fishing activities on the Mithapur site showing reef degradation.

It is also found that coral species such as *Coscinaraea sp*., *M. foliosa, Montipora sp.1*, *Montipora sp.2*, and *L. purpurea* exhibited the maximum similarity in dead coral abundance followed by *Favites sp. 2* and *Psammocora sp.* Dendrogram of the dead coral cover pattern of the outer GoK formed 4 different groups of the coral species based on their dead coral cover, of which the fourth group including *D. favus* and *G. pedunculata* showed completely different abundance than all other dead coral species (Fig. 17).

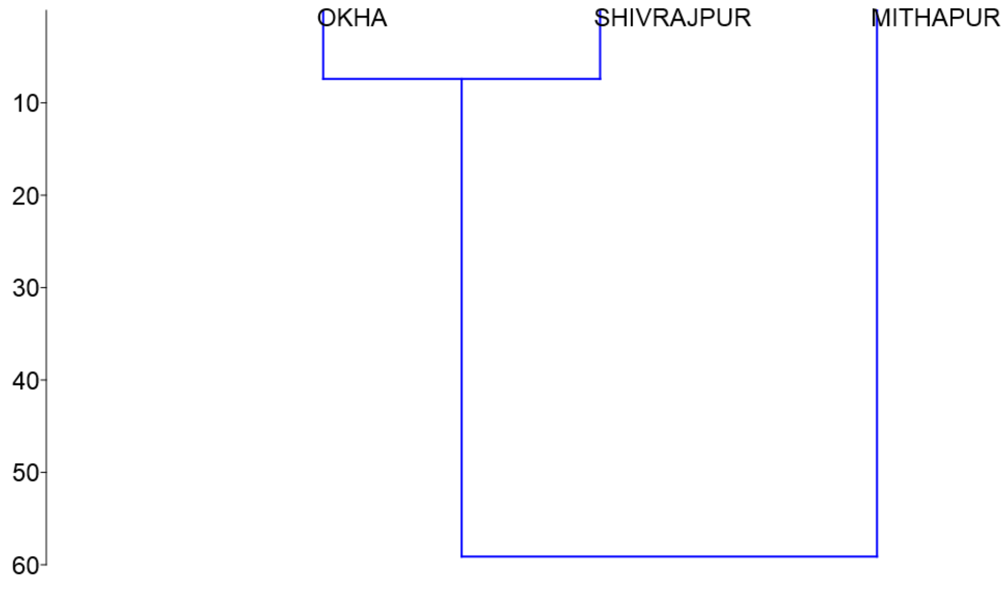


Fig. 16. Dendrogram based on the site-wise share of dead coral cover

Fig. 17. Dendrogram based on the species-wise share of dead coral cover

4.3 Reef-associated flora of the outer GoK

A total of 29 species of reef-associated flora belonging to 24 genera and 17 different families were recorded from three selected sites of the outer GoK region (Table 5). The highest number of seaweed species were recorded from Okha with 29 species belonging to 24 genera followed by Mithapur with 16 species belonging to 12 genera and Shivrajpur with 14 species belonging to 11 genera. Brown algae (Phaeophyceae) contributed the maximum species diversity with 11 species belonging to 9 genera followed by red algae (Rhodophyceae) with 10 species belonging to 9 genera and green algae (Chlorophyceae) with 8 species belonging to 6 genera (Plate 7).

Table 5. List of reef-associated flora recorded from the outer GoK.

GREEN ALGAE (Chlorophyceae)						
Sr. No.	**Family**	**Scientific Name**	**Acronyms**	**OKHA**	**MITHAPUR**	**SHIVRAJPUR**
1	Caulerpaceae	*Caulerpa racemosa (Forsskal) J.Agardh, 1873*	***cc***	X	X	X
2		*Caulerpa sertularioides* (Gmelin &.Howe, 1905)	***cs***	X	X	X
3		*Caulerpa taxifolia* (M.Vahl, C.Agardh, 1817)	***ct***	X	X	X
4	Cladophoraceae	*Cladophora glomerata* (Linnaeus, Kützing, 1843)	***clg***	X		X
5	Codiaceae	*Codium dwarkense* (Børgesen, 1947)	***cod***	X	X	X
6	Halimedaceae	*Halimeda macroloba* (Decaisne, 1841)	***hm***	X	X	X
7	Udoteaceae	*Udotea indica* (A.Gepp & E.S.Gepp, 1911)	***ui***	X	X	X
8	Ulvaceae	*Ulva lactuca* (Linnaeus, 1753)	***ull***	X	X	X
BROWN ALGAE (Phaeophyceae)						
9	Dictyotaceae	*Padina gymnospora* (Kützing, Sonder, 1871)	***pg***	X	X	X
10		*Padina tetrastromatica* (Hauck, 1887)	***pt***	X	X	X
11		*Spatoglossum asperum* (J.Agardh, 1894)	***sa***	X	X	
12		*Stoechospermum polypodioides* (Lamour. J.Agardh, 1848)	***stp***	X		
13	Sargassaceae	*Polycladia indica (Thivy & Doshi 2010)*	***poi***	X		
14		*Sargassum cinereum* (J.Agardh, 1848)	***sac***	X	X	
15		*Sargassum tenerrimum* (J.Agardh, 1848)	***sat***	X	X	X
16		*Turbinaria ornata* (Turner, J.Agardh, 1848)	***to***	X		
17	Scytosiphonaceae	*Iyengaria stellata* (Borgesen)	***Is***	X	X	X

18		*Colpomenia sinuosa* (Mertens ex Roth, Derbès & Solier, 1851)	***cols***	X		
19		*Hydroclathrus clathratus* (C.Agardh, M.A.Howe, 1920)	***hyc***	X	X	
RED ALGAE (Rhodophyceae)						
20	Bangiaceae	*Pyropia vietnamensis* (Sutherland & Monotilla, 2011)	***pyv***	X		
21	Champiaceae	*Champia indica* (Børgesen, 1933)	***chi***	X		
22	Corallinaceae	*Corallina officinalis* (Linnaeus, 1758)	***coro***	X	X	X
23	Cystocloniaceae	*Hypnea musciformis* (Wulfen, .Lamouroux, 1813)	***hypm***	X		
24	Halymeniaceae	*Grateloupia indica* (Børgesen, 1932)	***gi***	X		
25		*Halymenia maculata* (J.Agardh, 1885)	***ham***	X		
26		*Halymenia venusta* (Børgesen, 1932)	***hav***	X	X	X
27	Scinaiaceae	*Scinaia moniliformis* (J.Agardh, 1885)	***scm***	X		
28	Sebdeniaceae	*Sebdenia flabellata* (J.Agardh, Parkinson, 1980)	***sef***	X		
29	Solieriaceae	*Kappaphycus alvarezii* (Doty, Doty ex Silva, 1996)	***ka***	X		

Plate 7. List of reef-associated flora recorded from the outer GoK

1. *Caulerpa racemosa*

2. *Caulerpa sertularioides*

3. *Caulerpa taxifolia*

4. *Cladophora glomerata*

5. *Codium dwarkense*

6. *Halimeda macroloba*

7. ***Udotea indica***

8. ***Ulva lactuca***

9. ***Padina gymnospora***

10. ***Padina tetrastromatica***

11. ***Spatoglossum asperum***

12.***Stoechospermum polypodioides***

13. ***Polycladia indica***

14. ***Sargassum cinereum***

15. ***Sargassum tenerrimum***

16. ***Turbinaria ornata***

17. ***Iyengaria stellata***

18. ***Colpomenia sinuosa***

19. *Hydroclathrus clathratus*

20. *Pyropia vietnamensis*

21. *Champia indica*

22. *Corallina officinalis*

23. *Hypnea musciformis*

24. *Grateloupia indica*

25. *Halymenia maculata*

26. *Halymenia venusta*

27. *Scinaia moniliformis*

28. *Sebdenia flabellata*

29. *Kappaphycus alvarezii*

4.3.1 Species diversity and percentage contribution of seaweed biomass

The percentage contribution of seaweed biomass of the outer part of the GoK is given in Fig. 18. Among the species of seaweed, the highest percentage contribution exhibited by *Sargassum cinereum* followed by *Ulva lactuca* together contributed to 40% of the total seaweed biomass of the outer GoK. *Padina gymnospora* formed 16% of the total seaweed biomass whereas *Corallina officinalis* showed the lowest percentage contribution to the total seaweed biomass of the outer GoK (Fig. 18). Site Okha is the most diverse among the all selected sites revealed a total of 29 species of seaweed belong to 24 genera. At Okha, *S. cinereum* contributed the maximum percentage (19%) to the total seaweed biomass followed by *U. lactuca* (17%). *S. tenerrimum* (15%). Species such as *Grateloupia indica* followed by *Halymenia venusta* contributed the lowest percentage contribution to the total seaweed biomass at the Okha region (Fig. 19).

At Mithapur, *U. lactuca* showed the maximum percentage contribution (23%) to the total seaweed biomass followed by *S. tenerrimum* (18%). Species such as *P. gymnospora* and *S. cinereum* showed almost similar percentage contributions and together contributed to 31% of the total seaweed biomass at the Mithapur region. Species such as *C. officinalis* followed by *H. venusta* and *Halimeda macroloba* contributed the lowest percentage contribution to the total seaweed biomass at the Mithapur region (Fig. 20). At Shivrajpur, *P. gymnospora* and *S. tenerrimum* exhibited the maximum percentage contribution, together contributing 50% to the total seaweed biomass followed by *U. lactuca* (21%). Species such as *H. venusta* followed by *H. macroloba* contributed the lowest percentage contribution to the total seaweed biomass at the Shivrajpur region (Fig. 21).

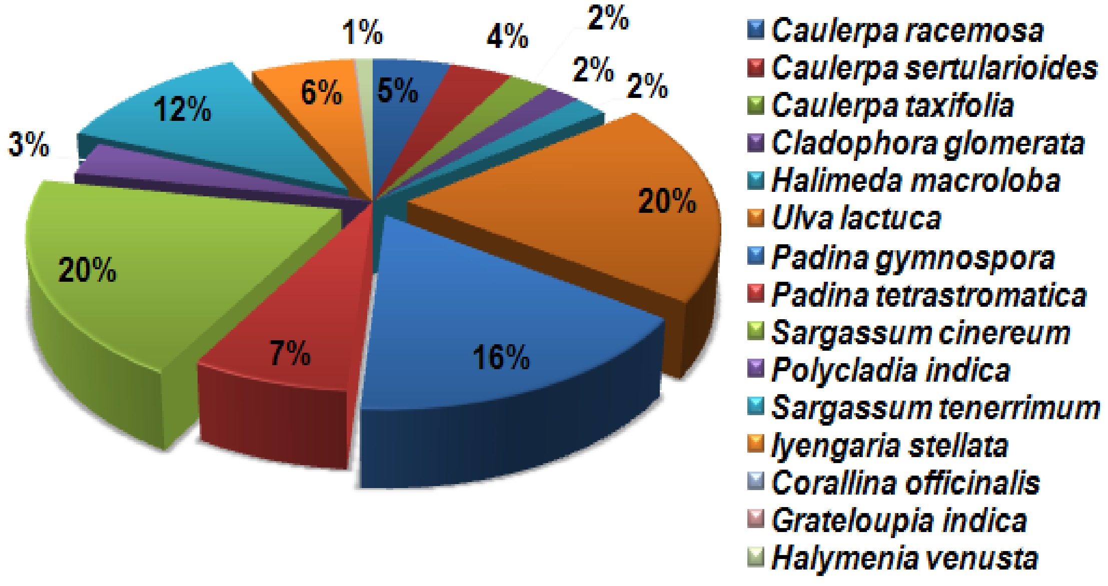


Fig. 18. Percentage contribution to the total biomass of reef-associated flora of the outer GoK

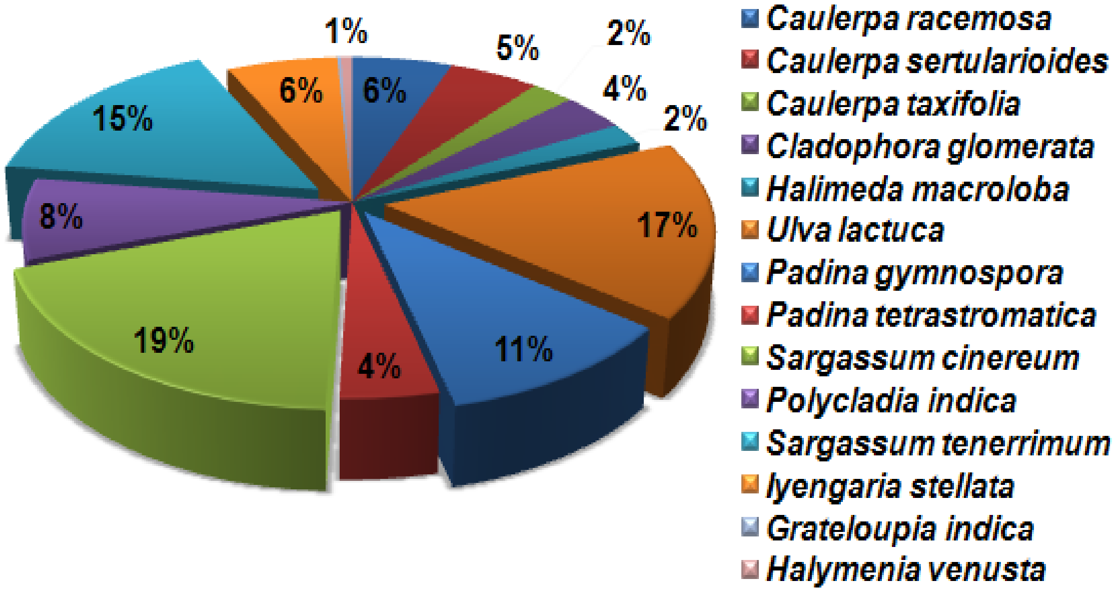


Fig. 19. Percentage contribution to the total biomass of reef-associated flora at Okha

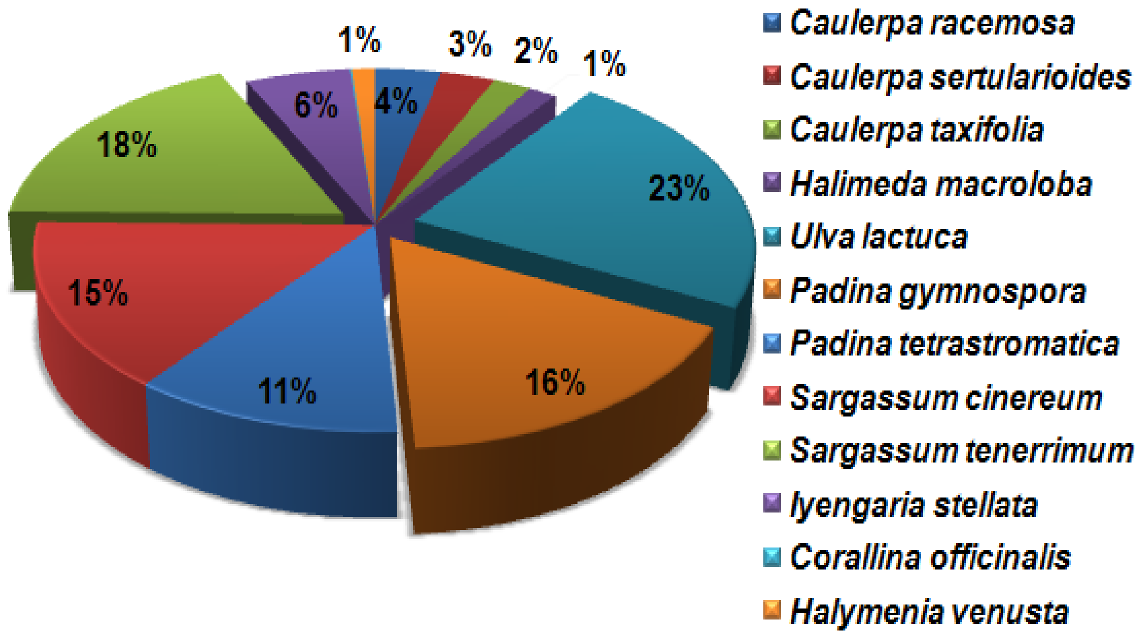


Fig. 20. Percentage contribution to the total biomass of reef-associated flora at Mithapur

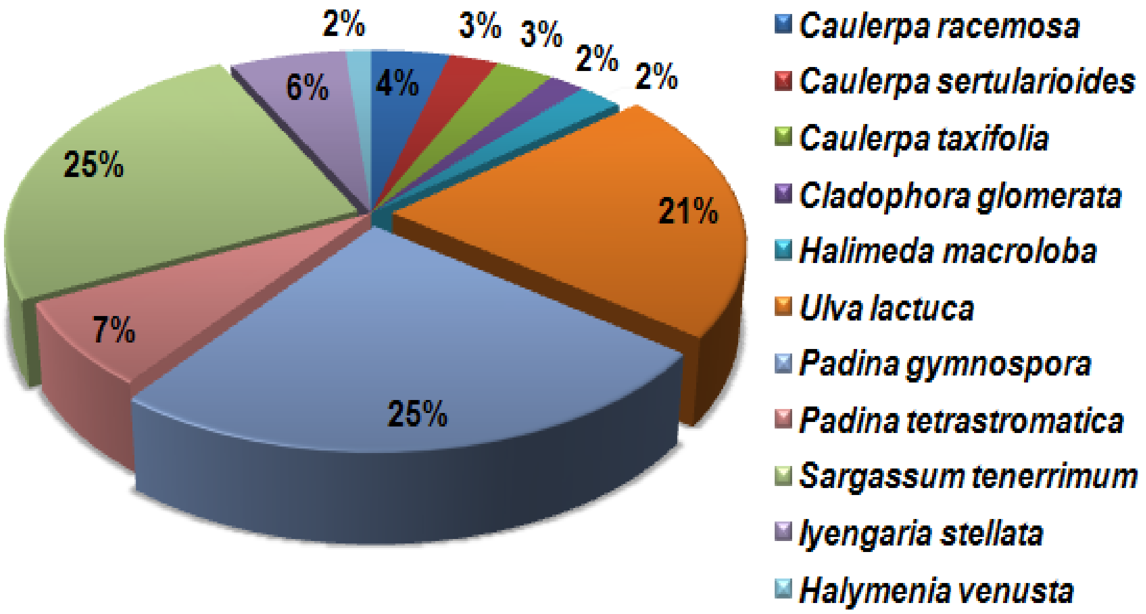


Fig. 21. Percentage contribution to the total biomass of reef-associated flora at Shivrajpur

4.3.2 Species diversity indices

Site Okha showed the highest number of taxa followed by Mithapur and Shivrajpur. The maximum species richness was found at Okha followed by Mithapur. Shannon-Wiener index shows that site Okha is the most diverse which is followed by Mithapur and Shivrajpur. Pielou's evenness index was also the maximum at Okha followed by Mithapur and Shivrajpur (Table 6).

Table 6. Species diversity indices of reef-associated flora of the outer GoK

Diversity Indices	Okha	Mithapur	Shivrajpur
Taxa_S	14	12	11
Simpson's 1ndex (D)	0.88	0.85	0.82
Shannon-Wiener index (H')	2.30	2.06	1.94
Evenness (J')	0.71	0.65	0.63
Species richness (S)	1.29	1.13	1.03

4.3.3 Principal Component Analysis (PCA)

PCA scatter plot plotted based on the eigenvalue scores of seaweed biomass of the selected sites. Given axis was ranked in order of important differences between the first principal component axis PCA 1 and the second principal component axis PCA 2. The important differences among the PCA 1 and PCA 2 is PAC 1 is more important than PCA 2. PCA 1 contributed the maximum (84.70 %) followed by PCA 2 (11.19 %) (Table 7). PCA analysis of all selected sites supported the statement that maximum seaweed biomass was found at Okha followed by Mithapur and Shivrajpur. It is also found that phaeophyceae species such as *S. tenerrimum, S. cinereum,* and *P. gymnospora* followed by chlorophyceae such as *U. lactuca,* were the dominant species, that exhibited the maximum contribution to the total seaweed biomass in the outer GoK. At the Okha site, phaeophyceae such as *S. cinereum* and chlorophyceae *U. lactuca* were found to be dominant. At Mithapur, chlorophyceae such as *U. lactuca* and phaeophyceae such as *S. tenerrimum* were found to be dominant. At Shivrajpur phaeophyceae such as *P. gymnospora, S. tenerrimum*, and *S. cinereum* were found to be dominant species (Fig. 22).

Table 7. Principal components based on Eigenvalue

PC	Eigenvalue	% variance
1	5.52E+06	84.70
2	729088	11.19
3	268022	4.11

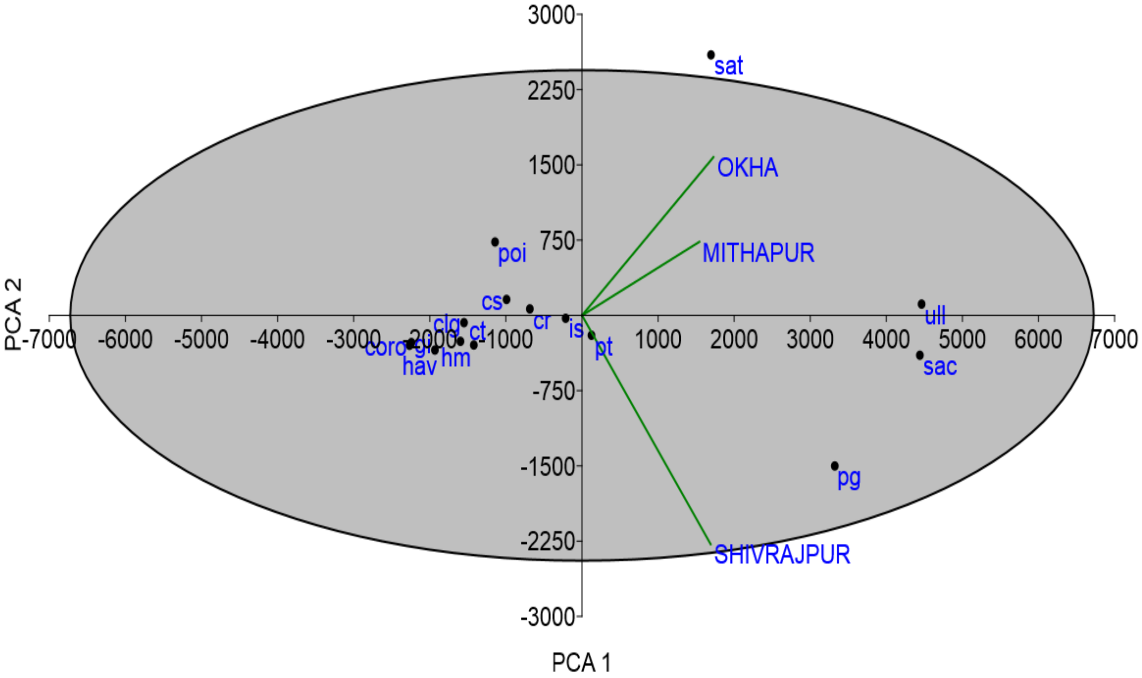


Fig. 22. PCA plot of reef-associated flora of the outer GoK

4.3.4 Cluster analysis of the reef-associated flora

Cluster analysis based on the percentage share of seaweed species biomass of all selected sites of the outer GoK supported the statement that the seaweed species biomass of site Mithapur and Shivrajpur showed similar abundance whereas site Okha showed completely different seaweed species abundance than the other two sites (Fig. 23). Cluster analysis based on the percentage share of seaweed biomass of the outer GoK supported the statement that the species such as *C. officinalis* and *G. indica* followed by *Caulerpa taxifolia* and *H. macroloba* exhibits the highest similarity in species abundance. Species such as *U. lactuca, S. cinereum,* and *P. gymnospora* showed completely different abundance than all other species.

The abundance of *Padina tetrastromatica* and *S. tenerrimum* was also different from other species (Fig. 24).

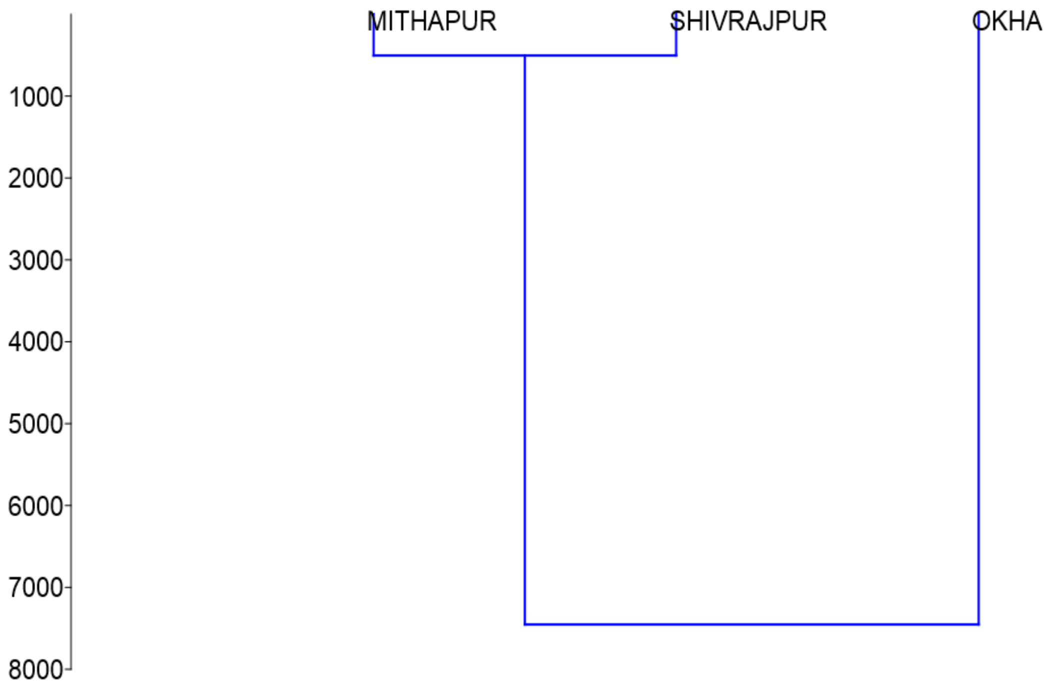


Fig. 23. Dendrogram based on the site-wise share of seaweed species abundance

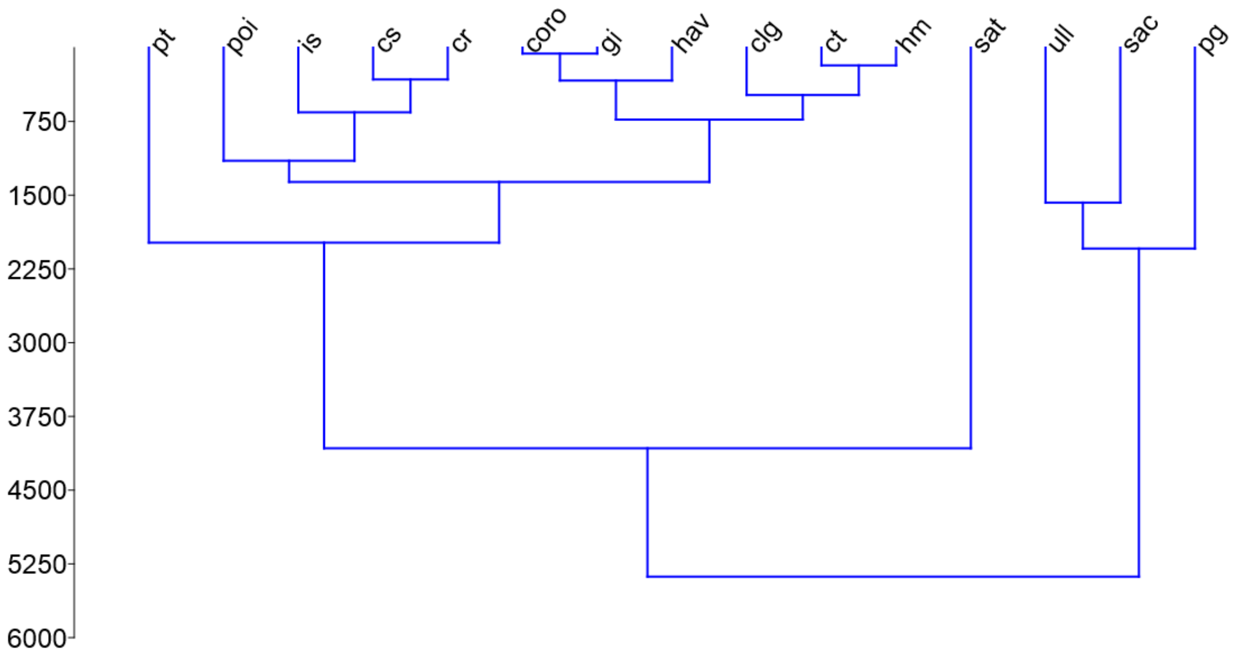


Fig. 24. Dendrogram based on the species wise share of seaweeds

4.3.5 Canonical Correspondence Analysis (CCA)

CCA scatter plot plotted based on eigenvalue scores of seaweed biomass associated with environmental parameters of the selected sites. Axis 1 contributed the maximum (73.82 %) followed by Axis 2 (23.39 %) (Table 8). CCA analysis of all selected sites supported the statement that environmental parameters such as temperature and salinity are negatively correlated with pH and dissolved oxygen. It has been found that the post-monsoon season was more productive followed by monsoon and pre-monsoon season. Chlorophyceae was found to be dominant during the post-monsoon season whereas during pre-monsoon as well as monsoon season Phaeophyceae was found to be dominant.

The CCA plot of the reef-associated flora revealed that some species of chlorophyceae such as *Caulerpa racemosa*, *H. macroloba, Caulerpa sertularioides, C. taxifolia,* and *U. lactuca* were found to be more abundant at low water temperature and salinity as well as a high amount of dissolved oxygen with the more alkaline condition of the surrounding environment. A few species of phaeophyceae such as *P. gymnospora* and *Polycladia indica* found to be grown at the high saline condition as well as high water temperature (Fig. 25).

Table 8. Canonical Correspondence Analysis based on Eigenvalue

Axis	Eigenvalue	%
1	0.06	73.82
2	0.02	23.39
3	0.00	2.79
4	0.00	0.00

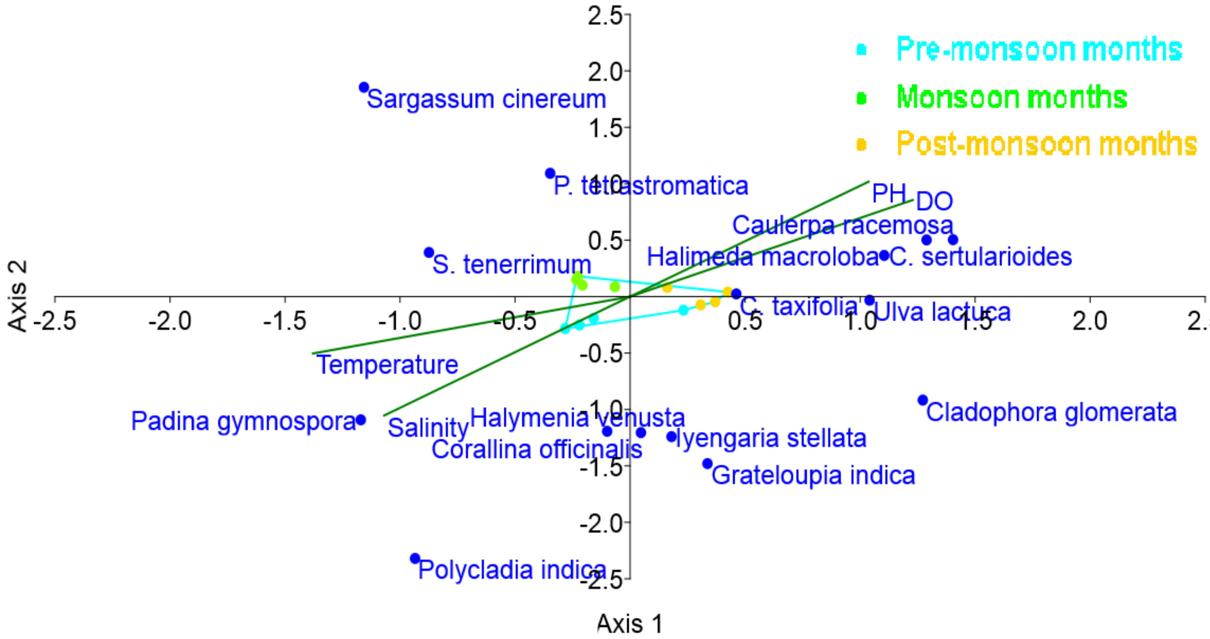


Fig. 25. CCA plot on the impact of environmental parameters on seaweed diversity of the outer GoK

4.4 Reef-associated fauna of the outer GoK

A total of 39 species of reef-associated fauna belonging to 35 genera and 30 families were recorded from the outer GoK. The highest number of reef-associated faunal species were recorded from Shivrajpur (29) followed by Okha (28) and Mithapur (23). Reef-associated fauna recorded from the outer GoK includes 5 species of sponges belonging to 3 genera and 3 families, 8 species of brachyuran crabs belonging to 7 genera and 5 families, 15 species of molluscs including 10 species of gastropods, 2 species of cephalopods, 2 species of nudibranchs and one species of polyplacophorans. A total of 6 species of cnidarians including 3 species of sea anemones, 2 species of zoantharia, and one species of scyphozoans has been recorded. Two species of polychaete worms, one species of green sea turtle, and two species of reef-associated fish species recorded from the tidal pools are blue rig angel fish reef-eating parrotfish were recorded from the reef ecosystem of outer GoK (Table 9, Plate 8).

Table 9. List of reef-associated faunal species recorded from the outer GoK.

Sr. No.	Family	Scientific Name	OKHA	MITHAPUR	SHIVRAJPUR
Phylum : Porifera : Sponges					
1	Chalinidae	*Haliclona cinerea* (Grant, 1826)	X		X
2		*Haliclona Sp.*	X	X	
3		*Haliclona pigmentifera (Dendy, 1905)*	X		X
4	Microcionidae	*Clathria procera* (Ridley, 1884)		X	
5	Tethyidae	*Stellitethya repens* (Schmidt, 1870)	X	X	
Phylum : Arthropoda : Crustaceans					
6	Grapsidae	*Grapsus albolineatus* (Latreille in Milbert, 1812)		X	X
7	Menippidae	*Menippe rumphii* (Fabricius, 1798)			X
8	Pilumnidae	*Pilumnus vespertilio* (Fabricius, 1793)	X		
9	Portunidae	*Portunus pelagicus* (Linnaeus, 1758)	X	X	X
10		*Thranita prymna (Herbst, 1803)*	X		
11	Xanthidae	*Atergatis ocyroe (Herbst, 1801)*		X	X
12		*Atergatis integerrimus* (Lamarck, 1818)	X	X	X
13		*Etisus laevimanus* Randall, 1840	X		X
Phylum : Molusca : Gastropods, Cephalopods, Nudibranchs and Polyplacophorans					
GASTROPODA					
14	Architectonicidae	*Architectonica laevigata* (Lamarck, 1816)		X	X

15	Conidae	*Conus tessulatus* (Born, 1778)	X	X	
16	Cypraeidae	*Cypraea tigris* (Linnaeus, 1758)	X	X	X
17	Muricidae	*Chicoreus ramosus* (Linnaeus, 1758)	X	X	X
18	Onchidiidae	*Peronia verruculata (Cuvier, 1830)*			X
19	Trochidae	*Trochus stellatus* Gmelin, 1791	X	X	X
20	Neritidae	*Nerita albicilla* (Linnaeus, 1758)			X
21	Turbinellidae	*Turbinella pyrum* (Linnaeus, 1767)	X	X	X
22	Turbinidae	*Lunella coronata* (Gmelin, 1791)	X		X
23		*Turbo bruneus* (Röding, 1798)	X	X	X
CEPHALOPODS					
24	Octopodidae	*Octopus vulgaris* (Cuvier, 1797)	X	X	X
25	Sepiidae	*Sepia aculeata* (Van Hasselt, 1835)	X	X	X
NUDIBRANCH					
26	Pseudocerotidae	*Pseudoceros bolool* (Newman & Cannon, 1994)		X	X
27		*Pseudoceros susanae* (Newman & Anderson, 1997)		X	X
POLYPLACOPHORA					
28	Chitonidae	*Rhyssoplax peregrina* (Thiele, 1909)	X	X	X
Phylum : Cnidaria : Sea Anemones, Zoantharia, Scyphozoans					
29	Stichodactylidae	*Heteractis crispa* (Hemprich & Ehrenberg in Ehrenberg, 1834)	X	X	X

30		*Stichodactyla haddoni* (Saville-Kent, 1893)	X		X
31	Thalassianthidae	*Cryptodendrum adhaesivum* (Klunzinger, 1877)	X		X
ZOANTHIDS					
32	Sphenopidae	*Palythoa mutuki* (Haddon & Shackleton, 1891)	X		
33	Zoanthidae	*Zoanthus sansibaricus* (Carlgren, 1900)	X		
SCYPHOZOA					
34	Pelagiidae	*Chrysaora quinquecirrha* (Desor, 1848)		X	
Phylum : Annelida : Polychaet worms					
35	Nereididae	*Nereis zonata* (Malmgren, 1867)	X		X
36		*Alitta virens* (M. Sars, 1835)	X	X	X
Phylum : Chordata : Green sea turtle					
37	Cheloniidae	*Chelonia mydas* (Linnaeus, 1758)	X		
Ichthyofauna					
38	Labridae	*Halichoeres nigrescens* (Bloch & Schneider, 1801)	X		X
39	Pomacanthidae	*Pomacanthus annularis* (Bloch, 1787)		X	X

Plate 8. Reef-associated faunal species recorded from the outer GoK

1. ***Haliclona cinerea***

2. ***Haliclona Sp.***

3. ***Haliclona pigmentifera***

4. ***Clathria procera***

5. ***Stellitethya repens***

6. ***Grapsus albolineatus***

7. *Menippe rumphii*

8. *Pilumnus vespertilio*

9. *Portunus pelagicus*

10. *Thranita prymna*

11. *Atergatis ocyroe*

12*. Atergatis integerrimus*

13. ***Etisus laevimanus***

14. ***Architectonica laevigata***

15. ***Conus tessulatus***

16. ***Cypraea tigris***

17. ***Chicoreus ramosus***

18. ***Peronia verruculata***

19. ***Trochus stellatus***

20. ***Nerita albicilla***

21. ***Turbinella pyrum***

22. ***Lunella coronata***

23. ***Turbo bruneus***

24. ***Octopus vulgaris***

25. ***Sepia aculeata***

26. ***Pseudoceros bolool***

27. ***Pseudoceros susanae***

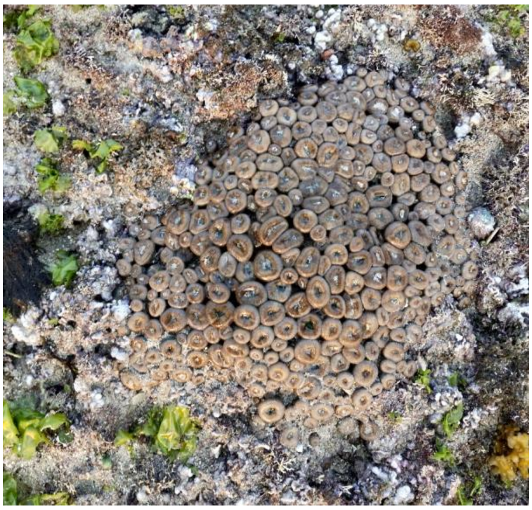
28. ***Rhyssoplax peregrina***

29. ***Heteractis crispa***

30. ***Stichodactyla haddoni***

31. ***Cryptodendrum adhaesivum***

32. ***Palythoa mutuki***



33. ***Zoanthus sansibaricus***

34. ***Chrysaora quinquecirrha***

35. ***Nereis zonata***

36. ***Alitta virens***

37. ***Chelonia mydas***

38. ***Halichoeres nigrescens***

39. ***Pomacanthus annularis***

4.4.1. Diversity and percentage contribution of reef-associated fauna

The percentage contribution of reef-associated fauna of the outer part of the GoK is given in Fig. 26. Among all the species of reef fauna, the highest percentage contribution was exhibited by gastropods followed by crustaceans and zoantharia. Nudibranchs followed by cephalopods and polychaete worms exhibited the lowest percentage contribution to the total reef diversity of the outer GoK. At Okha gastropods showed maximum percentage contribution to the total reef diversity followed by zoantharia (Fig. 27) similarly at Mithapur and Shivrajpur also, gastropods showed maximum percentage contribution to the total reef diversity followed by crustaceans (Fig. 28, 29).

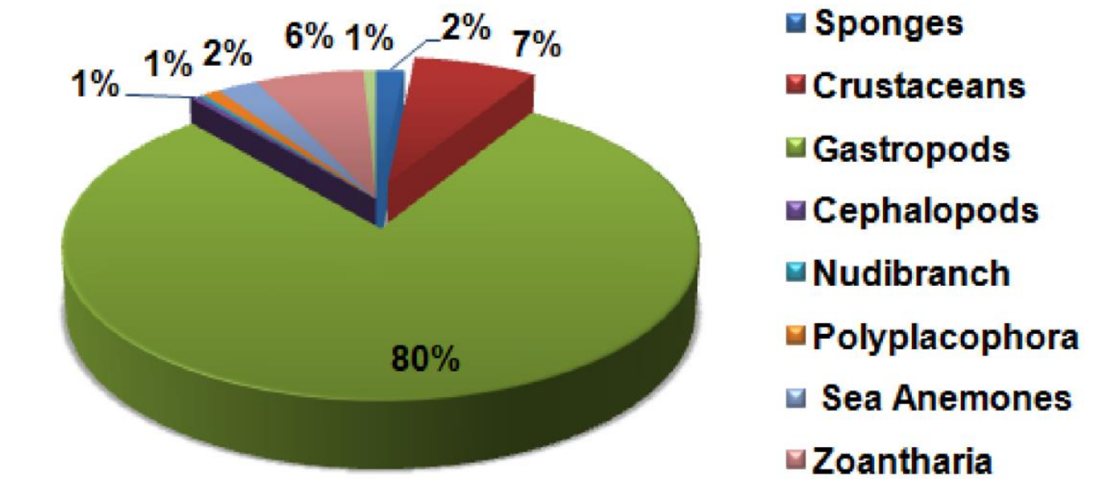


Fig. 26. Percentage contribution of group-wise reef-associated fauna of the outer GoK.

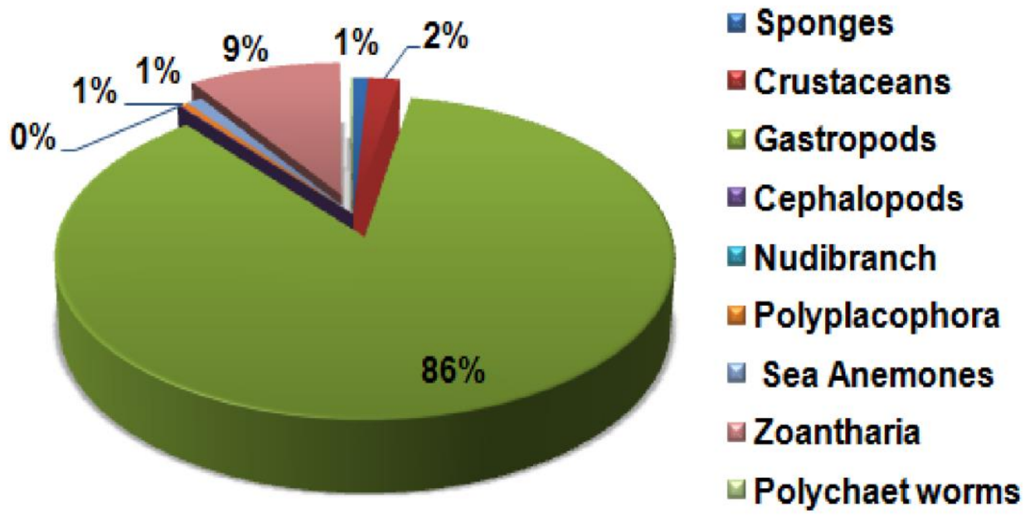


Fig. 27. Percentage contribution of group-wise reef-associated fauna at Okha.

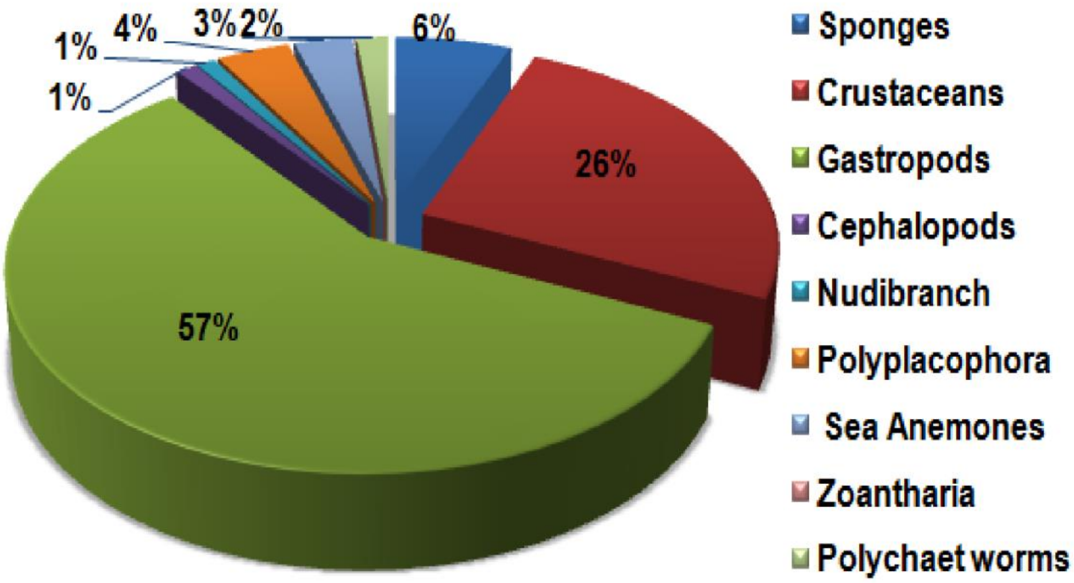


Fig. 28. Percentage contribution of group-wise reef-associated fauna at Mithapur.

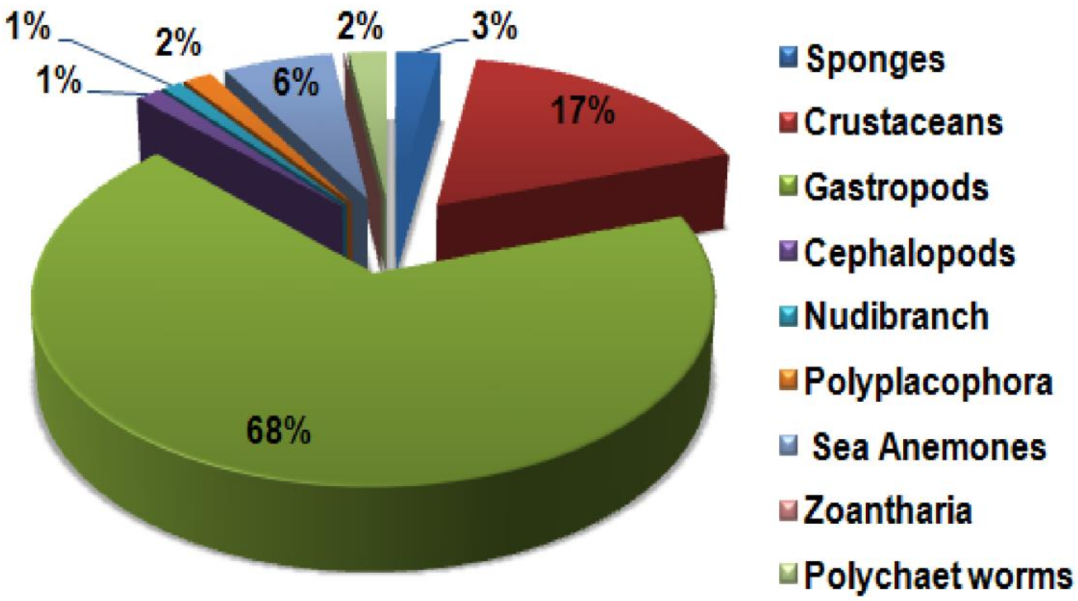


Fig. 29. Percentage contribution of group-wise reef-associated fauna at Shivrajpur.

4.4.2. Species diversity indices

Site Shivrajpur showed the highest number of taxa followed by Okha whereas a number of individuals were found maximum at Okha followed by Shivrajpur. The maximum species richness was found at Shivrajpur followed by Mithapur. Shannon-Wiener index shows that site Shivrajpur is the most diverse which is followed by Mithapur and Okha. Pielou's evenness index was the maximum at Mithapur followed by Shivrajpur and Okha (Table 10).

Table 10. Diversity indices of reef-associated fauna of the outer GoK

Diversity Indices	Okha	Mithapur	Shivrajpur
Number of Taxa	23	17	27
Individuals	552	57	187
Simpson's index (D)	0.7998	0.8944	0.9133
Shannon-Wiener index (H')	1.998	2.534	2.779
Evenness (J')	0.3208	0.7412	0.5964
Species Richness (S)	3.485	3.957	4.97

4.4.3. Cluster analysis of the reef-associated fauna

Cluster analysis based on the percentage share of reef-associated fauna of all selected sites of the outer GoK supported the statement that the reef diversity of site Mithapur and Shivrajpur showed similar abundance whereas site Okha showed completely different faunal species abundance than the other two sites (Fig. 30).

Cluster analysis based on the percentage share of group-wise reef-associated fauna of the outer GoK supported the statement that the cephalopods and nudibranchs exhibited the maximum similarity in species occurrence followed by polyplacophorans and sponges. Some groups such as gastropods and crustaceans show similar occurrence whereas zoantharia shows a completely different abundance than all other groups of reef-associated fauna of the outer GoK (Fig. 31).

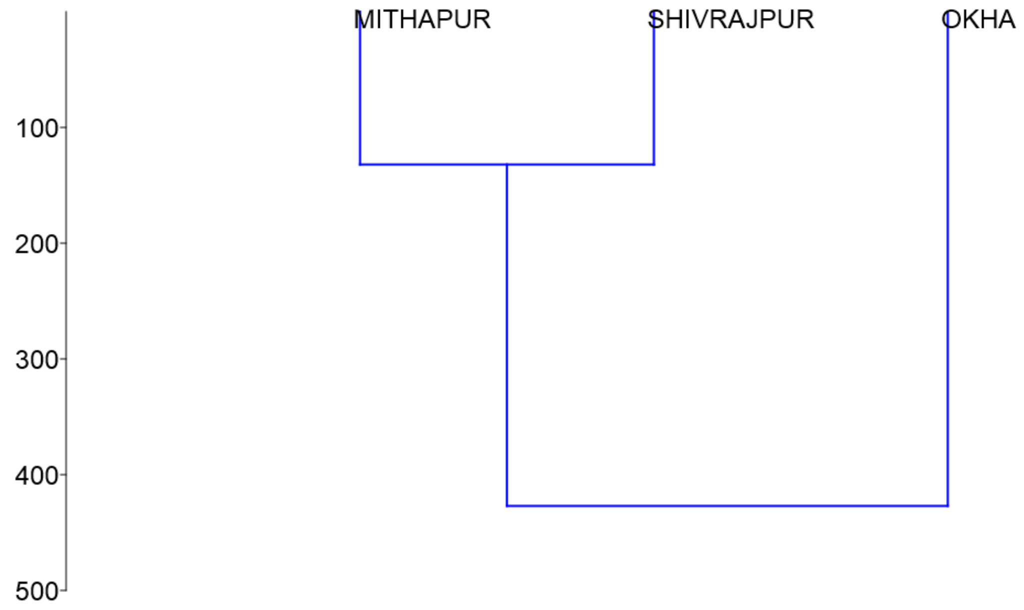


Fig. 30. Dendrogram based on the site-wise share of reef-associated fauna

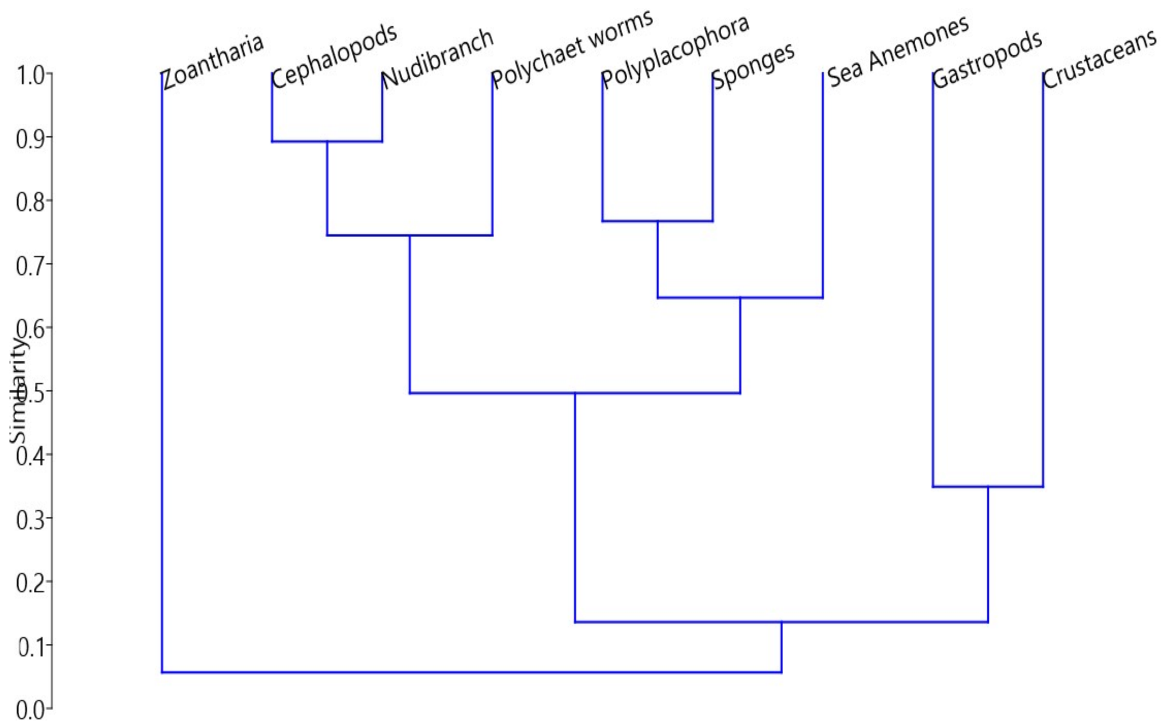


Fig. 31. Dendrogram based on the group-wise share of reef-fauna

4.4.4 Principal Component Analysis (PCA)

PCA scatter plot plotted based on the eigenvalue scores of the accordance of reef-associated fauna of the selected sites. Given axis was ranked in order of important differences between the first principal component axis PCA 1 and the second principal component axis PCA 2. The important differences among the PAC 1 and PAC 2 is, PAC 1 is more important than PCA 2. PCA 1 contributed the maximum (99.46 %) followed by PCA 2 (0.54 %) (Table 11). PCA analysis of all selected sites supported the statement that maximum diversity of the reef-associated fauna was found at Shivrajpur followed by Mithapur and Okha. Gastropods were found to be a dominant group followed by crustaceans in outer GoK. It is also found that at Shivrajpur, Okha, and Mithapur gastropods were found to be a more abundant group followed by crustaceans, sea anemones, and zoantharia respectively (Fig. 32).

Table 11. Principal components based on Eigenvalue

PC	Eigenvalue	% variance
1	26017	99.46
2	140	0.54
3	2	0.01

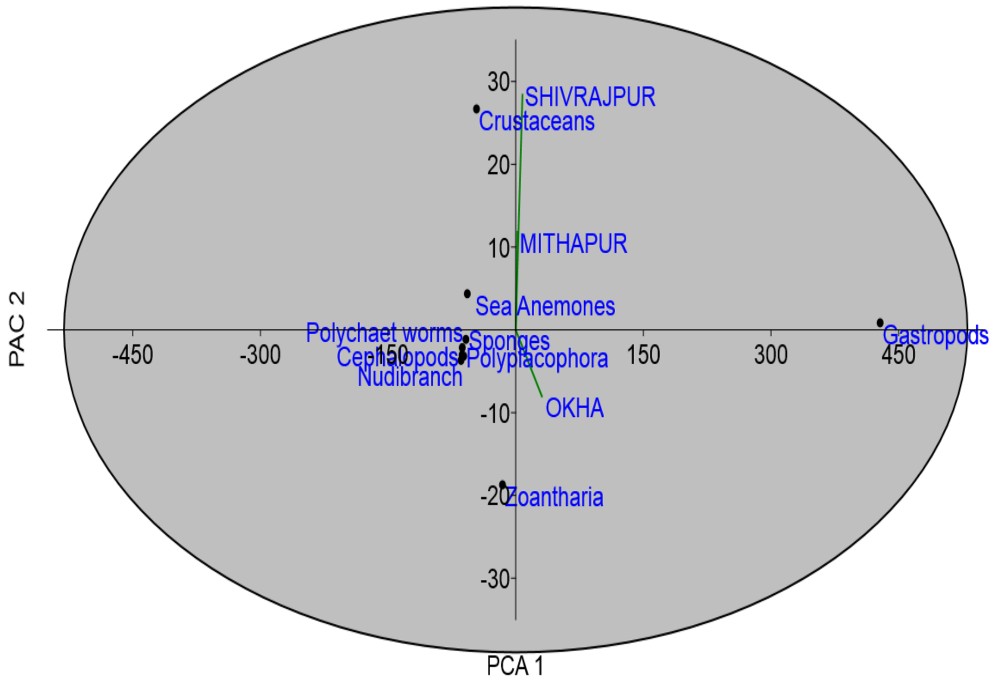


Fig. 32. PCA plot of reef-associated fauna of the outer GoK

4.5 Economic evaluation of the reefs diversity

The coral reef is one of the most productive ecosystems providing important goods and services to the society. An economic evaluation of the coral reef ecosystem of the outer GoK has been done by preparing a questionnaire and evaluating traditional fishing activities on each site. Rank Order Scaling (ROS) method and Public Opinion Scaling (POS) have been used to find out the coral reef use scenario and the importance of the coral reef ecosystem and ecosystem services of the outer GOK. The questionnaire used for the economic valuation of the coral reef ecosystem of the outer GoK during the present study is given in Appendices.

Economic analysis was done by calculating fixed cost (capital cost), variable cost (marginal cost), total project cost, depreciation on a total fixed cost, total project cost, and total revenue, and finally, the annual profit (total revenue), net profit and Cost-Benefit Ratio (CBR) were calculated as per Markad (2004).

4.5.1 The important uses of the coral reef at Okha

Table 12 represents the chart exhibiting important uses of coral reefs at the Okha region (Fig. 33). Rank order scaling based on local communities responses revealed that the coral reef ecosystem of Okha is mainly used for finfish catch followed by the shellfish collection done by the Pagadiya fishing method. Pagadiya fishing is traditional fishing method of GoK region, which can be describe as fishing without using any craft and gear.

Table. 12. Rank order scaling based on public opinion for the important use of the coral reef at Okha

Use criteria of coral reef organisms	Total	Rank
Medicine	94	III
Finfishes	177	I
Shellfish	152	II
Shoreline protection	79	V
Protection against tsunami, floods etc.	70	VI
Tourism	88	IV

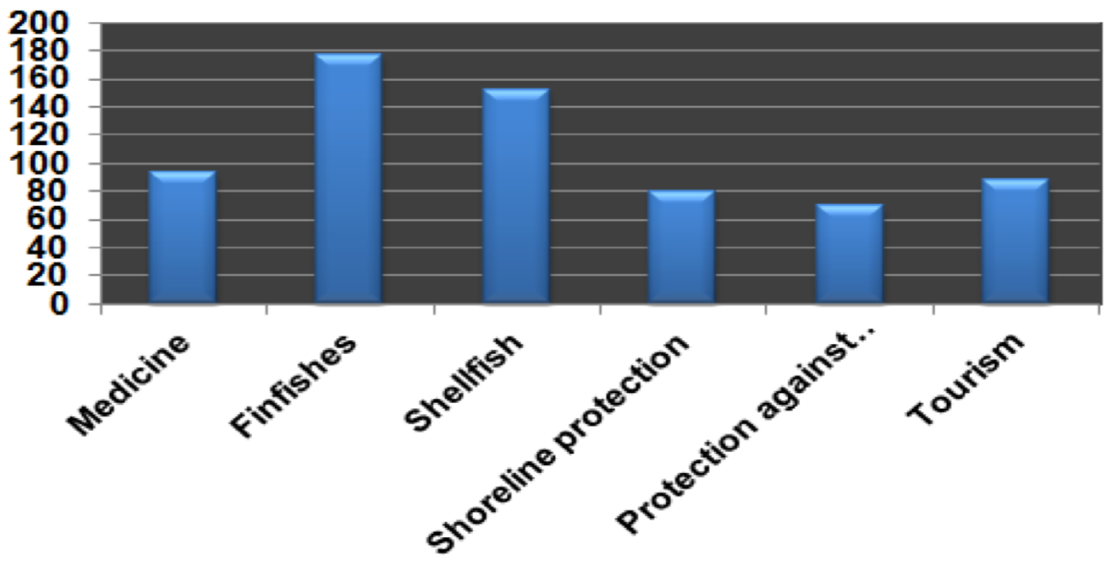


Fig. 33. Important uses of coral reef at Okha

4.5.2 The important uses of the coral reef at Mithapur

Table 13 represents the chart exhibiting important uses of coral reefs at Mithapur (Fig, 34). Public opinion for the important uses of coral reef revealed that at site Mithapur, coral reef ecosystem is mainly used for finfish catch followed by the shellfish collection by traditional Pagadiya fishing. Site Mithapur is subjected to the highest fishing pressure on the reef ecosystem than the other two sites of the outer GoK.

Table. 13. Rank order scaling based on public opinion for the important use of the coral reef at Mithapur

Use Criteria of Coral Reef	Total	Rank
Medicine	63	III
Finfishes	177	I
Shellfish	71	II
Shoreline protection	49	V
Protection against tsunami, floods etc.	45	VI
Tourism	57	IV

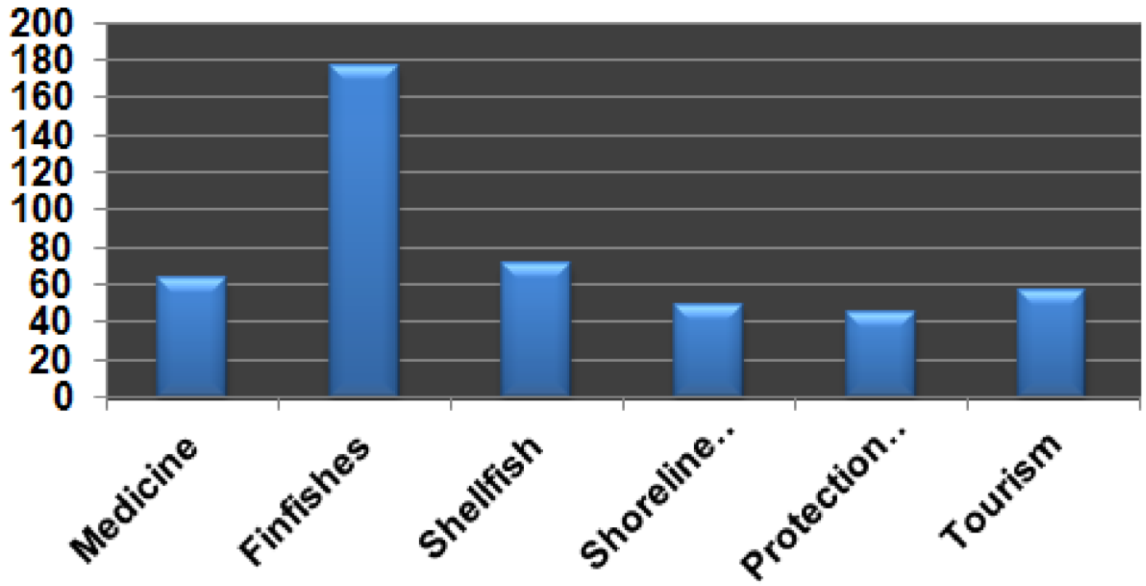


Fig. 34. Important uses of coral reef at Mithapur

4.5.3 The important uses of the coral reef at Shivrajpur

Table 14 represents the chart exhibiting important uses of coral reefs at Shivrajpur (Fig. 35). Public opinion for the important uses of coral reef revealed that at site Shivrajpur, coral reef ecosystem is mainly used for shellfish catch followed by the finfish catch by traditional fishing activities. That is because the site Shivrajpur is having less fishing pressure. Some Pagadiya fishers are doing hand-picking of crabs and gastropods.

Table. 14. Rank order scaling based on public opinion for the important use of the coral reef at Shivrajpur

Use Criteria of Coral Reef	Total	Rank
Medicine	73	IV
Finfishes	143	II
Shellfish	151	I
Shoreline protection	68	VI
Protection against tsunami, floods etc.	69	V
Tourism	126	II

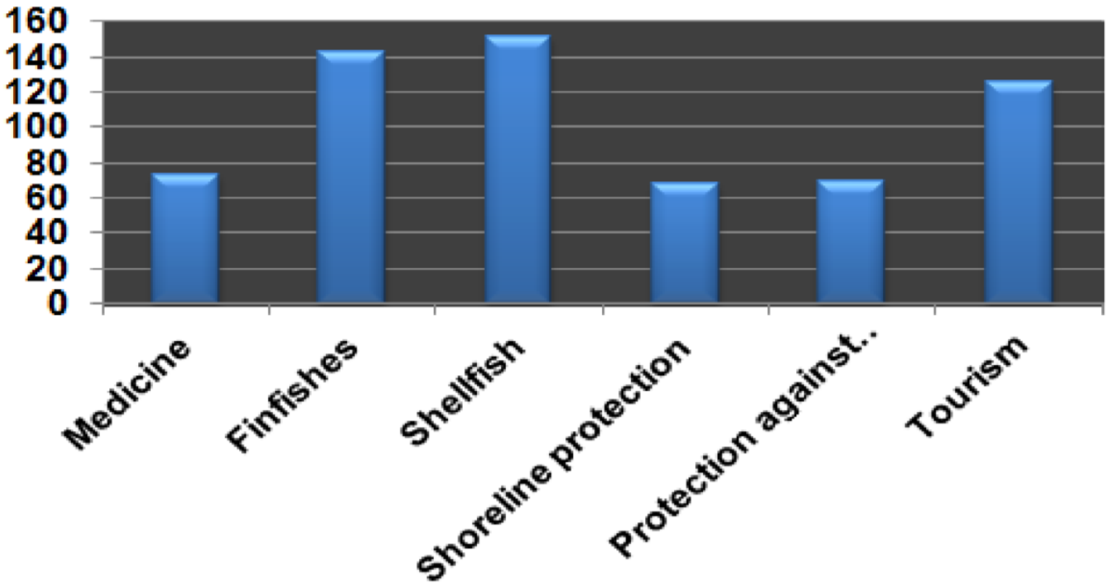


Fig. 35. Important uses of coral reef at Shivrajpur

4.5.4 Importance of coral reef in outer GoK

Scleractinian corals are forming the keystone position of the structure and function of the reef ecosystem. The coral reef is the most important coastal environment that sustains the country's economics through fisheries, ecotourism, recreation, shoreline protection from tidal surges, salinity ingression, protecting coastal areas from coastal erosion, generating employment opportunities for the local communities, supporting biodiversity, improving educational status through research and development. Conservation and survival of the reef ecosystem are mainly dependent upon the self-awareness and willingness of the local community to conserve the coral reef. Being more productive natural resources, the reef ecosystem of outer GoK is vulnerable to degradation through traditional fishing practices, coastal developments, and tourism.

Rank order scaling based on the public opinion of the coral reef ecosystem of Okha, and Mithapur exhibited a similar result. The study of coral reef importance revealed that coral reef creating more employment opportunities as alternative livelihood options for the villagers and stakeholders, was on the first rank followed by the reef ecosystem protecting the natural habitat and the diversity (Table 15, 16). The reason behind this is the local community is dependent on the coastal reef ecosystem to earn their livelihood. At Shivrajpur site, the local community mainly engaged with traditional means of exploitation like Pagadiya fishing, handpicking of crabs and gastropods, some fishermen used to make crab fishing by using an iron rod, and gill netting or entangling in tidal pools. The rank order scaling of site Shivrajpur revealed that the main importance of the coral reef is it is protecting the natural habitat and the biodiversity followed by coral reef increasing fisheries and seafood resources and farther it creating more employment opportunities as alternative livelihood options for the villagers and stakeholders (Table 17). Site Shivrajpur is pristine and has less anthropogenic impact than the other two sites of the outer GoK. Thus, the site Shivrajpur supports more diversity of reef as well as reef-associated fauna.

Table 15. Importance of coral reef and reef diversity at Okha

Importance of Coral Reef and reef diversity at Okha	Total	Rank
Enhancing Eco-tourism	62	V
Increasing fisheries and sea food resources	83	III
Protecting natural habitat and the diversity	110	II
Creating more employment opportunities as alternative livelihood options for the villagers and stakeholders	118	I
Improving educational status	77	IV

Table 16. Importance of coral reef and reef diversity at Mithapur

Importance of Coral Reef and reef diversity at Mithapur	Total	Rank
Enhancing Eco-tourism	58	IV
Increasing fisheries and sea food resources	126	II
Protecting natural habitat and the diversity	79	III
Creating more employment opportunities as alternative livelihood options for the villagers and stakeholders	130	I
Improving educational status	57	V

Table 17. Importance of coral reef and reef diversity at Shivrajpur

Importance of Coral Reef and reef diversity at Shivrajpur	Total	Rank
Enhancing Eco-tourism	71	IV
Increasing fisheries and sea food resources	110	II
Protecting natural habitat and the diversity	112	I
Creating more employment opportunities as alternative livelihood options for the villagers and stakeholders	105	III
Improving educational status	51	V

4.5.5 Economic analysis of the reef based fishing activities at Okha

At site Okha, there are about 24 active fisherman engaged in traditional fishing activities on the reef ecosystem. The traditional fisherman mainly practice traditional fishing locally called Pagadiya fishing and fisherman called Pagadiya. These Pagadiya fishers catch reef-dwelling fishes through gill netting. Some fisherman are inured to install gill nets during low tide and catch fish after one high tide. Some traditional fishers catching crabs by handpicking or by using a sharp-pointed iron rod, and some local fisherman used to catch the crabs by using scoliodon fish tied with nylon thread as bait (Plate 9). The detailed information about the fishing coast, benefits, and cost-benefits ratio of traditional fishing activities of the Okha region has been given in table 18.

A. Fixed cost

Fixed cost of traditional fishing activities at site Okha includes the cost of fishing gear and other miscellaneous items with more than one year of life span. The cost of fishing net, floats, and sinkers with more than a one-year life span has been included as the fixed cost or the capital cost. The unit cost of the fishing net alone contributed 63.02 % of the total fixed cost followed by sinkers (20.16%) and floats (16.80%). An estimated annual fixed cost of traditional fishing at the Okha site was ₹ 5950.

B. Variable cost

The total variable cost of the traditional fishing activities at Okha coast was estimated by considering expenses on traditional fishing basket locally called as Gumbhla, repairing and maintenance of the fishing net, and some fisherman are using a motorbike to reach the fishing ground therefore the average expenditure on petrol and diesel also added to the variable cost. An estimated annual variable cost was ₹ 12500. The expenditure on petrol and diesel contributed the major share 84 % of the total variable cost followed by repairing and maintenance of the fishing gear (12 %) and traditional fishing baskets (4 %).

C. Total project cost

The total project cost of the fishing at Okha was obtained by adding the total variable cost to the total fixed cost. An estimated total project cost was ₹ 18450.

D. Depreciation on fixed cost

Depreciation on the fixed cost was estimated by considering 20 % depreciation on the fishing net, sinkers, and floats. An estimated depreciation on the fixed cost was ₹ 1190.

E. Total cost

The total expenditure i. e. total cost per annum of the exploitation of the Okha reef ecosystem was estimated by adding depreciation on fixed cost to the total variable cost. An estimated total cost was ₹ 13690.

F. Total revenue

The total revenue of the exploitation of Okha reef was estimated by adding annual earning of finfishes catch and the catching of crabs during low tide. The estimated total revenue of the Okha reef ecosystem was ₹ 144000.

G. Net profit

The annual profit was obtained by subtracting the total expenditure from the revenue of a unit of traditional fishing. An estimated net profit of traditional fishing at Okha was ₹ 130310.

H. Cost benefit ratio

To summarize the overall relationship between the relative costs and benefits of traditional fishing at Okha, the cost-benefit ratio has been calculated by dividing annual net profit by total cost. An estimated cost-benefit ratio for traditional fishing at Okha was 9.52.

Table 18. Economic analysis of the reef based fishing activities at Okha

Sr. No.	Items	Amount (Rs.)
A. Fixed Cost		
1	Fishing Net	3750
2	Sinkers	1200
3	Floats	1000
Total Fixed Cost		**5950**
B. Variable Cost		
1	Basket (Gumbhla) 5 Numbers @ Rs. 100/1 No.	500
2	Maintenance of fishing net	1500
3	Diesel Total 150 Liter/Year @ 70/Liter	10500
Total Variable Cost		**12500**
C. Total Project Cost (A+B)		**18450**
D. Depreciation on Fixed Cost		
3	Fishing Net @ 20%	750
4	Sinkers @ 20%	240
5	Floats @ 20%	200
Depreciation on Total Fixed Cost		**1190**
E. Total Cost (B+D)		**13690**
F. Total Revenue		
1	Fin Fishes	96000
2	Crabs	48000
Total Revenue		**144000**
G. Net Profit		**130310**
Cost-Benefit Ratio (CBR)		**9.52**

Plate. 9. Traditional fishing activities at Okha

4.5.6 Economic analysis of the reef based fishing activities at Mithapur

At site Mithapur, there are about 42 active fisherman engaged in traditional fishing activities on the reef ecosystem. The traditional fisherman mainly practice gill netting by using small OBM fishing vessels, some local fisherman doing traditional fishing locally called Pagadiya. These Pagadiya fishers catch reef-dwelling fishes through gill netting without using any fishing craft are inured to install gill nets during low tide and catch fish after one high tide. Some traditional fishers catching reef-associated crabs by handpicking and by using a sharp-pointed iron rod (Plate 10). The detailed information about the expenditure, earnings, and cost-benefit ratio of traditional fishing activities of the Mithapur reef has been given in table 19.

A. Fixed cost

Fixed cost of the exploitation of the Mithapur reef includes the cost of the fishing vessel, engine, fishing gear, and other miscellaneous items with more than one year of life span including ropes and anchor. The cost of the fishing vessel, engine, fishing net, ropes, and anchor have more than a one-year life span has been included as the fixed cost or the capital cost. The unit cost of the fishing vessel alone contributed 80.35 % of the total fixed cost followed by engine (15.62 %) and fishing net (2.67 %). An estimated annual fixed cost of exploitation of the Mithapur reef was ₹ 224000.

B. Variable cost

The total variable cost of the traditional fishing activities at Mithapur coast was estimated by considering expenses on traditional fishing baskets locally called Gumbhla, bottom paint, maintenance of the fishing vessel, engine, and repairing and maintenance of the fishing net, license fees, kerosene, diesel, and oil. An estimated annual variable cost was ₹ 32900. The expenditure on petrol and diesel contributed the major share 53.19 % of the total variable cost followed by maintenance of the fishing vessel (15.19) and kerosene (8.35 %).

C. Total project cost

The total project cost of the fishing activities at Mithapur was obtained by adding the total variable cost to the total fixed cost. An estimated total project cost was ₹ 256900.

D. Depreciation on fixed cost

Depreciation on the fixed cost was estimated by considering 10 % depreciation on the fishing vessel and engine, 25% on the fishing net and ropes, and 10 % on anchor. An estimated depreciation of the fixed cost was ₹ 23480.

E. Total cost

The total expenditure i. e. total cost per annum of the exploitation of the Mithapur reef ecosystem was estimated by adding depreciation on fixed cost to the total variable cost. An estimated total cost was ₹ 56380.

F. Total revenue

The total revenue of the exploitation of Mithapur reef was estimated by adding annual earning of finfishes catch and the catching of crabs during low tide. The estimated total revenue of the Mithapur reef ecosystem was ₹ 204000.

G. Net profit

The annual profit was obtained by subtracting the total expenditure from the revenue of a unit of traditional fishing. An estimated net profit of traditional fishing at Mithapur was ₹ 147620.

H. Cost benefit ratio

To summarize the overall relationship between the relative costs and benefits of traditional fishing at Mithapur reef the cost-benefit ratio has been calculated by dividing annual net profit by total cost. An estimated cost-benefit ratio for traditional fishing at Mithapur was 2.62.

Table 19. Economic analysis of the reef based fishing activities at Mithapur

Sr. No.	Items	Amount (Rs.)
A. Fixed Cost		
1	Cost of Vessel	180000
2	OBM Engine	35000
3	Fishing Net	6000
4	Rope 1 Number	1200
5	Anchor 1 Number	1800
Total Fixed Cost		**224000**
B. Variable Cost		
1	Basket (Gumbhla) 5 Numbers @ Rs. 100/1 No.	500
2	Bottom Paint 2 Liter @ Rs. 300/Liter	600
3	Maintenance of fishing vessel	5000
4	Maintenance of fishing net	1500
5	Maintenance of Engine	1500
6	License fee @ Rs. 1800/Year	1800
7	Kerosene Total 50 Liter/Year @ Rs. 55/Liter	2750
8	Diesel Total 250 Liter/Year @ 70/Liter	17500
9	Oil Total 25 Liter/Year @ Rs 70/Liter	1750
Total Variable Cost		**32900**
C. Total Project Cost (A+B)		**256900**
D. Depreciation on Fixed Cost		
1	Vessel at 10%	18000
2	OBM Engine at 10%	3500
3	Fishing Net @ 25%	1500
4	Rope 1 Number @ 25%	300
5	Anchor 1 Number of @ 10%	180
Depreciation on Total Fixed Cost		**23480**
E. Total Cost (B+D)		**56380**
F. Total Revenue		
1	Fin Fishes	132000
2	Crabs	72000
Total Revenue		**204000**
G. Net Profit		**147620**
Cost-Benefit Ratio (CBR)		**2.62**

Plate 10. Traditional fishing activities at Mithapur

4.5.7 Economic analysis of the reef based fishing activities at Shivrajpur

At site Shivrajpur, there are about 21 active fisherman engaged in traditional fishing activities on the reef ecosystem. The traditional fisherman mainly practice traditional fishing locally called Pagadiya. These Pagadiya fishers catch reef-dwelling fishes through gill netting. Some traditional fishers catch crabs by handpicking, by using a sharp-pointed iron rod. Some local fisherwoman also used to collect gastropods during the low tide period (Plate 11). The detailed information about the fishing coast, benefits, and cost-benefits ratio of traditional fishing activities of the Shivrajpur region has been given in table 20.

A. Fixed cost

Fixed cost of traditional fishing activities at site Shivrajpur includes the cost of fishing gear and other miscellaneous items with more than one year of life span. The cost of fishing net, floats, and sinkers with more than a one-year life span has been included as the fixed cost or the capital cost. The unit cost of the fishing net alone contributed 62.50 % of the total fixed cost followed by sinkers (20.80%) and floats (16.70%). An estimated annual fixed cost of traditional fishing at the Shivrajpur was ₹ 4800.

B. Variable cost

The total variable cost of the traditional fishing activities at Shivrajpur coast was estimated by considering expenses on traditional fishing basket locally called as Gumbhla, repairing and maintenance of the fishing net, and some fisherman are using a motorbike to reach the fishing ground, therefore, the average expenditure on petrol and diesel also added to the variable cost. An estimated annual variable cost was ₹ 3500. The expenditure on petrol and diesel contributed the major share 57.10 % of the total variable cost followed by repairing and maintenance of the fishing gear (28.60 %) and traditional fishing baskets (14.30 %).

C. Total project cost

The total project cost of the fishing at Shivrajpur was obtained by adding the total variable cost to the total fixed cost. An estimated total project cost was ₹ 8300.

D. Depreciation on fixed cost

Depreciation on the fixed cost was estimated by considering 20 % depreciation on the fishing net, sinkers, and floats. An estimated depreciation of the fixed cost at Shivrajpur was ₹ 960.

E. Total cost

The total expenditure i. e. total cost per annum of the exploitation of the Shivrajpur coral reef ecosystem was estimated by adding depreciation on fixed cost to the total variable cost. An estimated total cost was ₹ 4460.

F. Total revenue

The total revenue of the exploitation of Shivrajpur reef was estimated by adding annual earning of finfishes catch and the catching of crabs during low tide. The estimated total revenue of the Shivrajpur reef ecosystem was ₹ 114000.

G. Net profit

The annual profit was obtained by subtracting the total expenditure from the revenue of a unit of traditional fishing. An estimated net profit of traditional fishing at Shivrajpur was ₹ 109540.

H. Cost benefit ratio

To summarize the overall relationship between the relative costs and benefits of traditional fishing at Shivrajpur reef the cost-benefit ratio has been calculated by dividing annual net profit by total cost. An estimated cost-benefit ratio for traditional fishing at Shivrajpur was 24.56.

Table 20. Economic analysis of the reef based fishing activities at Shivrajpur

Sr. No.	Items	Amount (Rs.)
A. Fixed Cost		
1	Fishing Net	3000
2	Sinkers	1000
3	Floats	800
Total Fixed Cost		**4800**
B. Variable Cost		
1	Basket (Gumbhla) 5 Numbers @ Rs. 100/1 No.	500
2	Maintenance of fishing net	1000
3	Diesel Total 150 Liter/Year @ 70/Liter	2000
Total Variable Cost		**3500**
C. Total Project Cost (A+B)		**8300**
D. Depreciation on Fixed Cost		
3	Fishing Net @ 20%	600
4	Sinkers @ 20%	200
5	Floats @ 20%	160
Depreciation on Total Fixed Cost		**960**
E. Total Cost (B+D)		**4460**
F. Total Revenue		
1	Fin Fishes	72000
2	Crabs and gastropods	42000
Total Revenue		**114000**
G. Net Profit		**109540**
Cost-Benefit Ratio (CBR)		**24.56**


Plate 11. Traditional fishing activities at Shivrajpur

4.6 Socio-economic impact on coral reef diversity

Coral reefs are the most diverse and ecologically important ecosystem of all marine environments. In addition, it supports the livelihood of many of the coastal communities, especially in developing countries. Because of that, the reef ecosystem is becoming venerable and there is an urgent need for reef management activities should be strengthened. The reef diversity of the outer GoK supports the livelihood and culture of the local community by traditional fishing activities such as gillnetting and Pagadiya fishing includes hand-picking of crabs and gastropods such as turban shells and sacred chunks. The most important anthropogenic threats to reef diversity of the outer GoK are increasing fishing pressure, ghost fishing, local tourism, dead coral collection, sand mining, coastal pollution, and industrialization.

4.6.1 Socio-economic impact on the coral reef diversity at Okha

Table 21 represents the chart exhibiting major socio-economic impacts on coral reef diversity at the Okha region (Fig. 36). Rank order scaling based on local communities revealed that the major socioeconomic impact on the coral reef diversity at Okha was habitat destruction followed by overexploitation of the reef ecosystem and global warming and climate change. Because traditional fishing activities adversely affected the reef ecosystem, some Pagadiya fishers used to lift the coral reef to find out hidden crabs will make them vulnerable directly to the sunlight exposure will result in coral bleaching.

Table 21. Major socio-economic impacts on the coral reef diversity at Okha

Sr.No.	Socioeconomic impact of coral reef ecosystem at Okha	Total	Rank
1	Global warming & Climate change	148	3
2	Water pollution	130	6
3	Habitat Destruction	167	1
4	Overexploitation of reef ecosystem	157	2
5	Declining fish catches	146	4
6	Low fish price	134	5
7	Poor conservation efforts	112	7
8	Exclusion of stakeholders in coral reef conservation and management	86	8

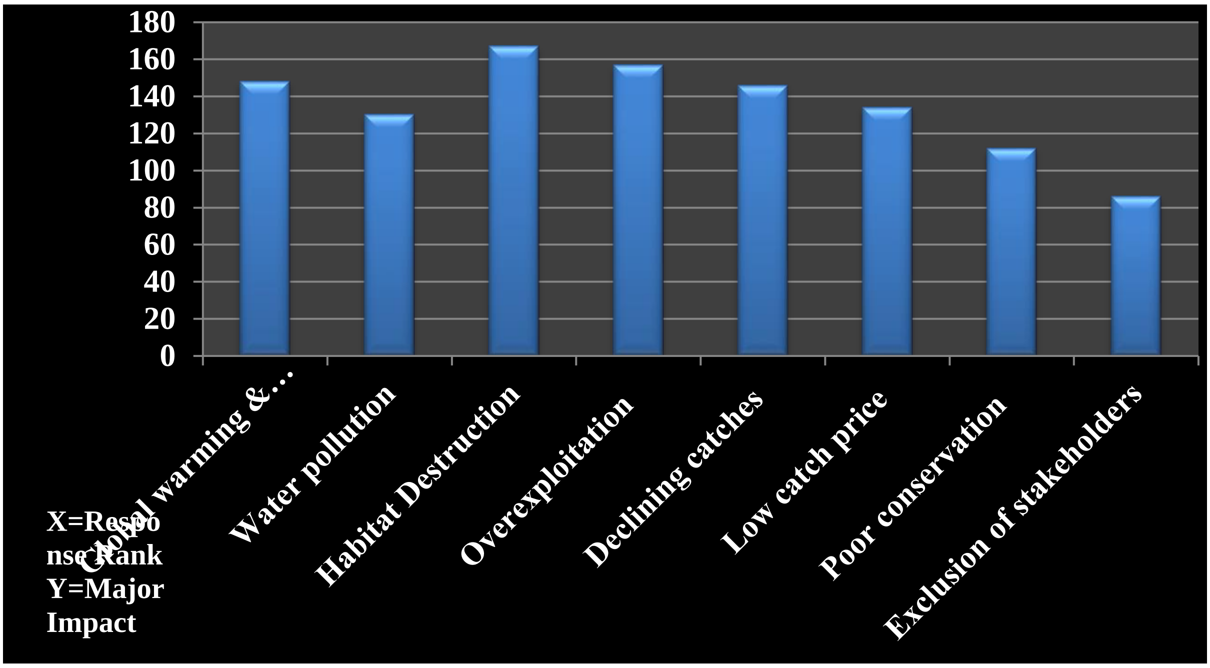


Fig. 36. Major socio-economic impact on the reef diversity at Okha

4.6.2 Socio-economic impact on the coral reef diversity at Mithapur

Table 22 represents the chart exhibiting major socio-economic impacts on coral reef diversity at the Mithapur region (Fig. 37). Rank order scaling based on local communities revealed that the major socioeconomic impact on the coral reef diversity at Mithapur was habitat destruction followed by water pollution and overexploitation of the reef ecosystem. Because site Mithapur is frequented by local tourism influencing coastal pollution, small-scale fishery in coral reef ecosystem results in habitat destruction and overexploitation.

Table 22. Major socio-economic impacts on the coral reef diversity at Mithapur

Sr.No.	Socioeconomic impact of coral reef ecosystem at Mithapur	Total	Rank
1	Global warming & Climate change	75	7
2	Water pollution	199	2
3	Habitat Destruction	218	1
4	Overexploitation of reef ecosystem	191	3
5	Declining fish catches	153	4
6	Low fish price	92	5
7	Poor conservation efforts	88	6
8	Exclusion of stakeholders in coral reef conservation and management	64	8

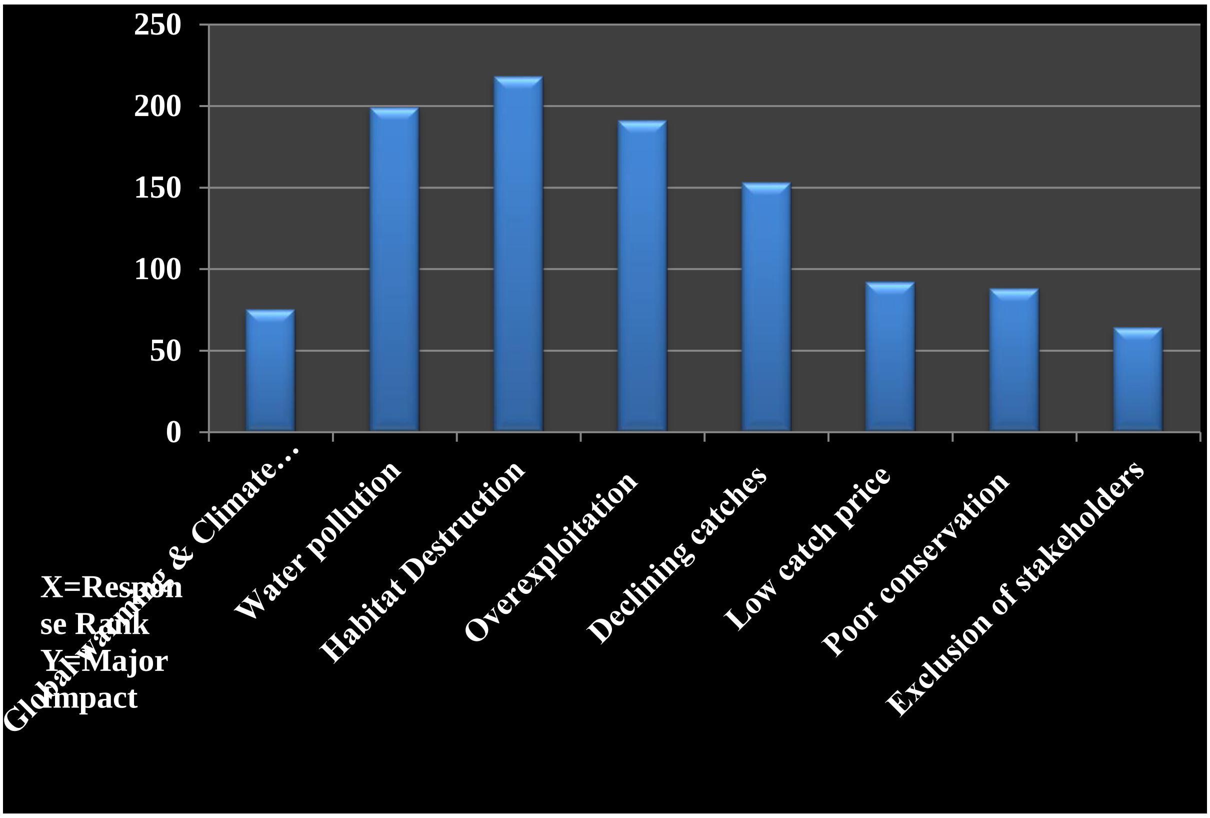


Fig. 37. Major socio-economic impact on the reef diversity at Mithapur

4.6.3 Socio-economic impact on the coral reef diversity at Shivrajpur

Table 23 represents the chart exhibiting major socio-economic impacts on coral reef diversity at the Shivrajpur region (Fig. 38). Rank order scaling based on local communities revealed that the major socioeconomic impact on the coral reef diversity at Shivrajpur was decline in fish catches followed by global warming and climate change and poor conservation efforts. Site Shivrajpur is pristine having less anthropogenic pressure than other selected sites of the outer GoK. Some local Pagadiya fishers used to collect gastropods and crabs during low tide owing to this, Shivrajpur reef ecosystem was found to be more healthy and diverse than Mithapur and Okha.

Table 23. Major socio-economic impacts on the coral reef diversity at Shivrajpur

Sr.No.	Socioeconomic impact of coral reef ecosystem at Shivrajpur	Total	Rank
1	Global warming & Climate change	175	2
2	Water pollution	119	6
3	Habitat Destruction	98	7
4	Overexploitation of reef ecosystem	89	8
5	Declining fish catches	180	1
6	Low fish price	147	4
7	Poor conservation efforts	151	3
8	Exclusion of stakeholders in coral reef conservation and management	121	5

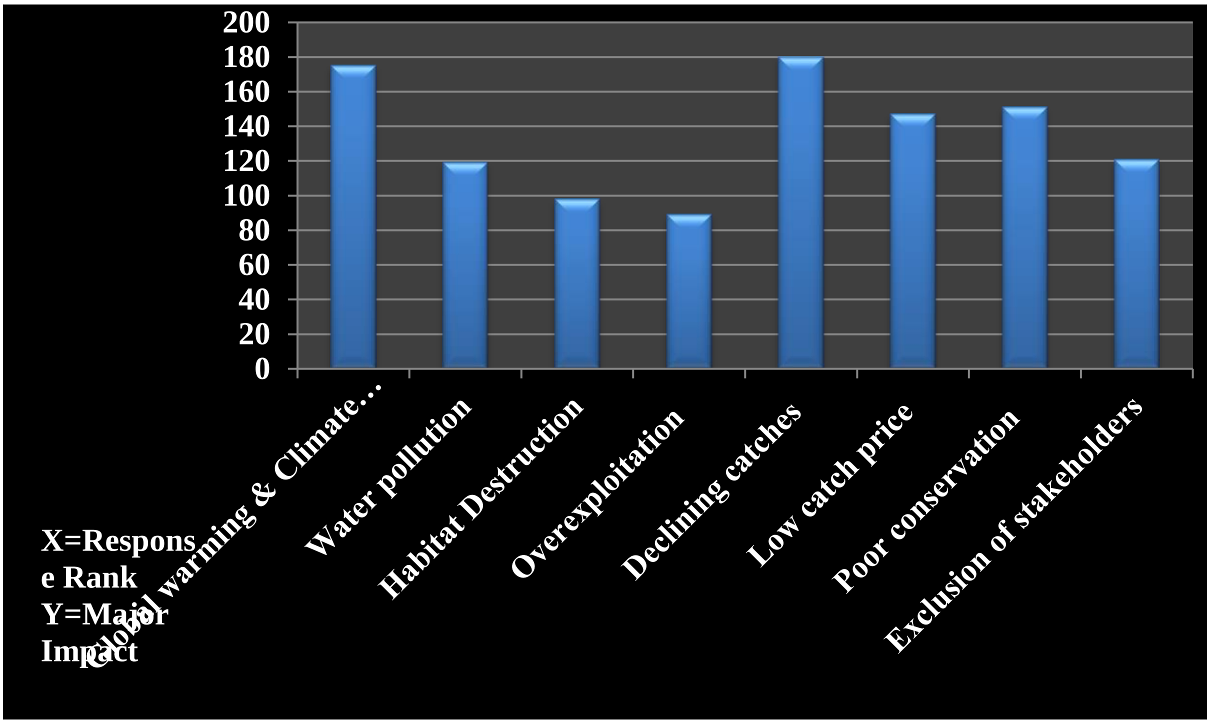


Fig. 38. Major socio-economic impact on the reef diversity at Shivrajpur

4.6.4 Important problems relating to the coral reef

The important problems relating to the growth and survival of the reef ecosystem of the outer GoK were examined by a visual inspection survey and general discussion with local fisherman. At site Okha, traditional fishing practices, ghost fishing by loss of their entangling nets (Plate. 12), local tourism, shoreline pollution, and loss of the reef diversity can be considered as the major issues, that adversely affecting the diversity and deteriorating the health status of the reef ecosystem (Table 24). At site Mithapur, ungoverned fishing practices in the coral reef ecosystem can be considered as the major problem regarding coral reef diversity and distribution. In addition, traditional fishing practices at Mithapur lead to the overexploitation of the reef ecosystem and ghost fishing in the reef ecosystem (Plate. 12). Site Mithapur is also facing a high risk of frequent tourism, coral bleaching (Plate. 13), shoreline pollution (Plate. 14), handpicking of dead corals (Plate. 15), sand mining (Plate. 16), and loss of coral reef diversity (Table 25). Site Shivrajpur was in its natural condition having no anthropogenic pressure except some local Pagadiya fishers and some traditional fishing activities. However, coastal tourism has become the main problem for the survival and growth of the reef ecosystem after the declaration of the Shivrajpur coast as the “Blue Flag” beach. The Government of Gujarat has developed the Shivrajpur beach as a tourist place under the “beach beautification project” at the collective cost of ₹ 100 cores. As a result, the coastal diversity of the reef ecosystem will became vulnerable due to tourism and shore pollution in near future (Table 26).

Table 24. Important problems relating to the coral reef at Okha

Sr. No.	Important problems relating to the coral reef – Okha	Remarks
a.	Fishing Activities	√
b.	Ghost Fishing	√
c.	Low Price Fish	
d.	Tourism	√
e.	Increasing Fishing Pressure	
f.	Shore Pollution	√
g.	Loss of Biodiversity	√
h.	Coral Reef Death	√

Table 25. Important problems relating to the coral reef at Mithapur

Sr. No.	Important problems relating to the coral reef - Mithapur	Remarks
a.	Fishing Activities	√
b.	Ghost Fishing	√
c.	Low Price Fish	
d.	Tourism	√
e.	Increasing Fishing Pressure	√
f.	Shore Pollution	√
g.	Loss of Biodiversity	√
h.	Coral Reef Death	√

Table 26. Important problems relating to the coral reef at Shivrajpur

Sr. No.	Important problems relating to the coral reef – Shivrajpur	Remarks
a.	Fishing Activities	√
b.	Ghost Fishing	
c.	Low Price Fish	
d.	Tourism	√
e.	Increasing Fishing Pressure	
f.	Shore Pollution	
g.	Loss of Biodiversity	
h.	Coral Reef Death	

Plate 12. Ghost fishing at coral reef ecosystem

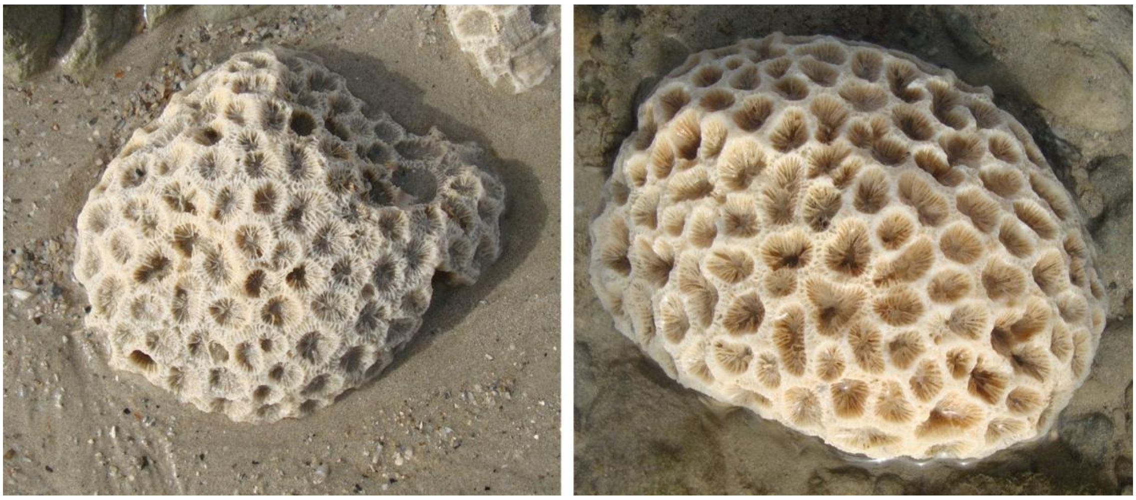


Plate 13. Coral bleaching found at Mithapur site

Plate 14. Shoreline pollution of the reef site

Plate 15. Selling of corals and reef-fauna at Beyt Dwarka temple

Plate 16. Sand mining of the shoreline at Mithapur

4.6.5 Percentage contribution of live and dead corals of the outer GoK

The site-wise dead coral cover to the live coral cover revealed that the growth and survival of the coral reef ecosystem have been greatly affected humans by disturbances such as local tourism and traditional fishing. The percentage contribution of the relative dead coral cover was maximum at site Mithapur 12.62 % followed by Okha (6.45 %) and Shivrajpur (0.41 %). The factors responsible for the higher percentage of relative dead coral cover at Mithapur and Okha were local tourism, coastal pollution, fishing activities, and sand mining. At the site, Shivrajpur the relative dead coral cover was significantly lower because Shivrajpur is a pristine reef site with less human disturbance and other anthropogenic pressure (Fig. 39). These results were found before the development of the Shivrajpur beach beautification project. Although, after the development of the “Blue Flag” beach at Shivrajpur, the diversity and distribution of the Scleractinian corals may decrease in near future. The coral reef site at site Shivrajpur is about 200 m far from the beach site became venerable to tourism and coastal pollution.

The site-wise percentage contribution of the dead coral cover revealed that the percentage contribution of the dead coral cover and the average number of people visiting the reef site per day is significantly interrelated. The percentage contribution of the dead coral cover was found maximum at site Mithapur with 73 % of the total dead coral cover of the outer GoK followed by site Okha (17 %) and Shivrajpur (Fig. 40).

The average number of people visiting coral reef sites per day was also found maximum as site Mithapur followed by Okha and Shivrajpur. At site Mithapur near about 80 to 100 people visit the coral reef site on a daily basis. At Okha about 20 to 25 people visit the coral reef site per day. Whereas at site Shivrajpur, only about 5 to 15 people visit the coral reef site per day (Table 27). The percentage contribution of the total dead coral cover was also found maximum at site Mithapur followed by Okha and Shivrajpur revealed that the human disturbance was the significant reason behind the coral bleaching in the outer GoK.

Table 27. Average number of people visiting the reef ecosystem everyday

Average number of people visits per day	
Okha	20 to 25
Mithapur	80 to 100
Shivrajpur	5 to 15

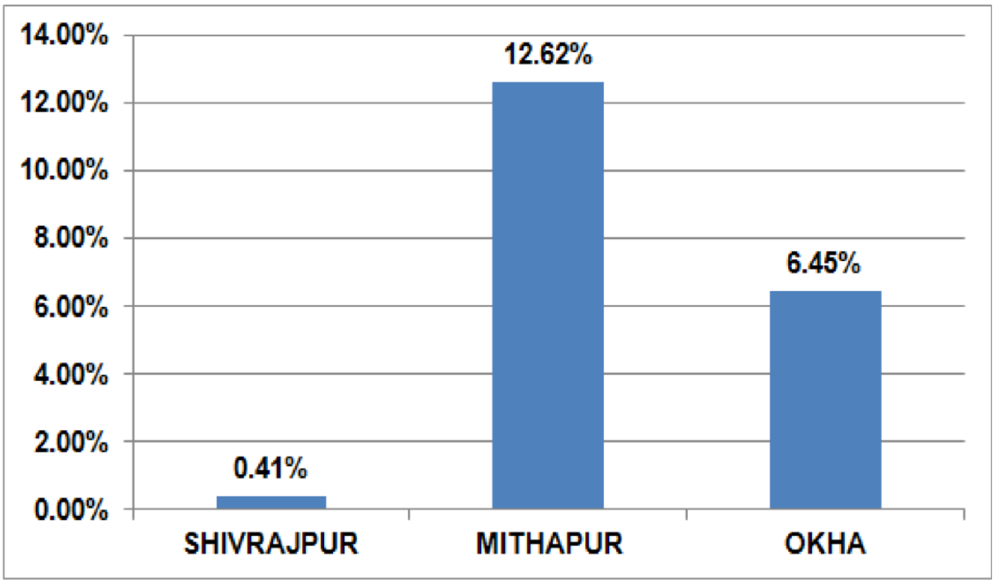


Fig. 39. Site-wise contribution of dead coral cover to the live coral cover

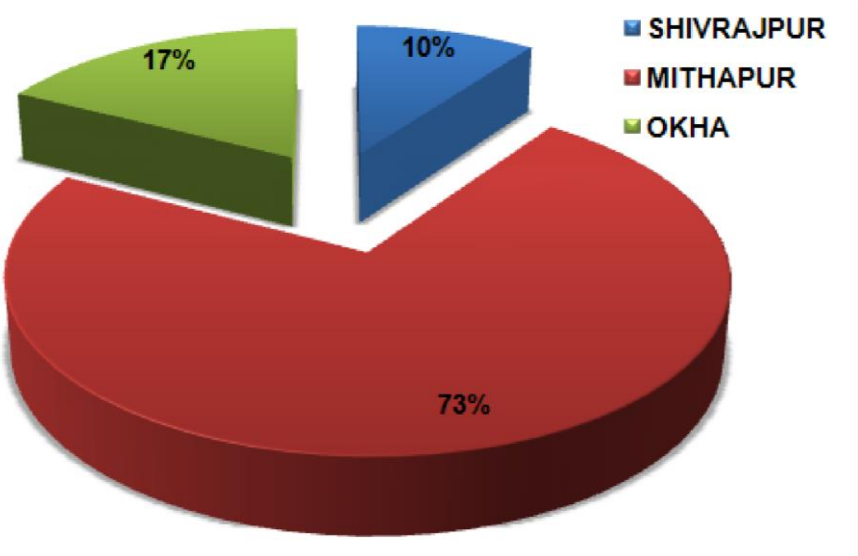


Fig. 40. Site-wise percentage contribution of the dead coral cover

4.6.6 Coral reef health indicator of the outer GoK

To find out the health status of the coral reef ecosystem of the outer GoK the coral mortality index (CMI) was analyzed by finding out the ratio between the proportions of live coral cover to both live and dead coral cover. If the coral mortality index will be more than 0.33, then the mortality index is considered to be high and the reef is classified as sick or deteriorating. The coral mortality index of the selected sites of the outer GoK is given in Table. 28. On the whole coral mortality index of the outer GoK was 0.03 in order to coral reef ecosystem of the outer GoK can be considered as healthy. Among all selected sites, the coral mortality index was found maximum at Mithapur followed by Okha and Shivrajpur. The coral mortality index at site Shivrajpur was significantly lower revealed that the reef ecosystem of the Shivrajpur site was the healthiest reef ecosystem of the selected sites of the outer GoK.

Table 28. Coral mortality index of outer GoK

OKHA	MITHAPUR	SHIVRAJPUR	OUTER GoK
0.06	0.12	0.004	0.03

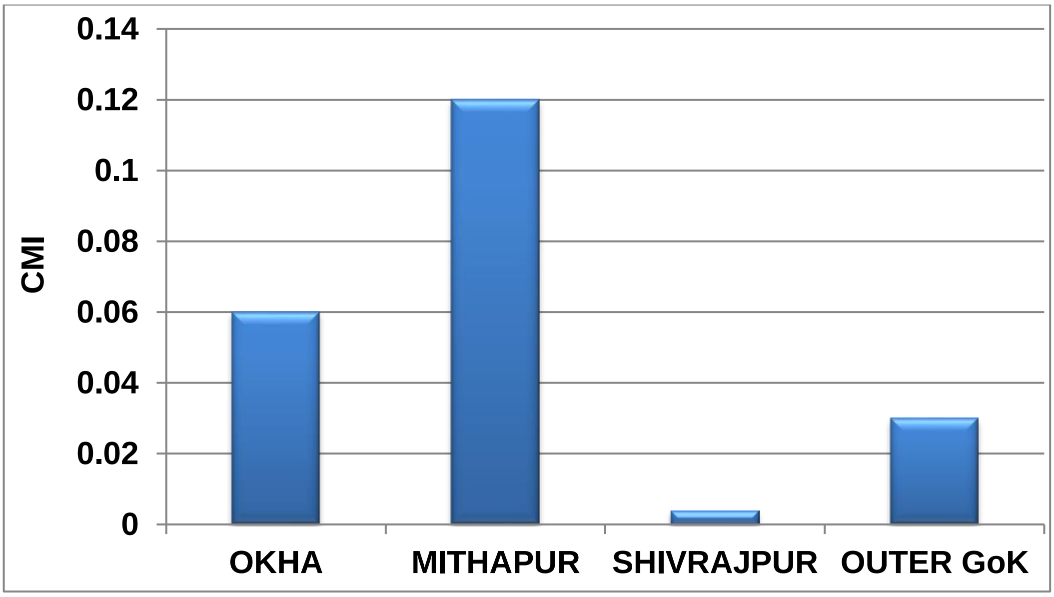


Fig. 41. Site-wise Coral Mortality Index (CMI) of the outer GoK

5. DISCUSSION

5.1. Occurrence of Scleractinian corals in the outer Gulf of Kachchh

Earlier reports have recorded 31 species of live corals belonging to eight different families and 18 genera from the Marine National Park and Marine Sanctuary of GoK. The maximum live coral cover was reported from Pirotan Island followed by Laku point (Kumar *et al.*, 2014). During the present study, 23 species of Scleractinian corals belonging to eight different families, and 12 genera were recorded from three sites of the outer Gulf of Kutch (GoK), which exhibited lesser diversity of corals in the outer part of the GoK.

Pillai and Patel (1988) reported 37 species of Scleractinian corals among 24 genera from GoK. Out of which, 20 genera with 33 species were hermatypic and the rest four genera and four species were ahermatypic. The study reported a total of 11 species of Scleractinian corals from the Okha region. Similarly, Vala *et al.,* (2016) also reported a total of 12 species of Scleractinian corals belonging to 11 genera and eight families from port Okha. Among all recorded species, eight species of Scleractinian corals viz., *Montipora foliosa, Dipsastraea favus, Dipsastraea sp., Goniopora pedunculata, Porites lutea,* and *Siderstrea savignyana* show similarity with the present study. During the present study, 12 species of Scleractinian corals belonging to eight genera were reported from the Okha region, showing stagnant growth of corals and no decline in the coral reef ecosystem of the outer GoK.

A total of eight species of Scleractinian corals belonging to five different families from the Porbandar coast of the outer part of the GoK were recorded (Parasharya and Padate, 2014). Among which six species of corals such as *M. foliosa, D. favus, Favites sp., G. pedunculata, P. lutea,* and *Pseudosiderastrea tayamai* were reported during the present study while two species viz., *Tubastrea aurea* and *Turbinaria peltata* were not found during the present study.

Recently, De *et al.,* (2020) presented a revised checklist of Scleractinian corals from the four major Indian reefs including other small reefs across the West coast of India representing a total of 585 species that belong to 95 genera and 25 families. They have reported a total of 76 species of Scleractinian corals belonging to 30 genera and 12 families from the GoK. According to the reports, 56 species of coral reef belonging to 27 genera and 10 families were reported from the GoK of which 44 species were hard corals (Kumar *et al.,* 2017). This report exhibits lesser diversity of corals in the outer GoK.

Sreenath (2015) reported 31 species of Scleractinian corals that belong to 20 genera and nine families from GoK, in addition to the new record of *G. djiboutiensis*, *G. stokesii*, and *Hydnophora pilosa*. It shows similarity accept the new records were not reported during the present study. Kumar *et al.*, (2014) reported two species of soft coral, *Carijoa riisei* and *Subergorgia suberosa* belonging to families Clavulariidae and Subergorgiidae, respectively from GoK for the first time. During the present study, soft coral species have not been recorded. The reason behind that can be the high anthropogenic pressure in the outer part of the GoK results in the decline of soft coral diversity.

Lakhamnpurkar and Gavali, (2018) reported 24 species of Scleractinian corals belonging to 14 different genera from the Kachhigarh near Shivrajpur region of the outer GoK. During the present study, a total of 22 species of Scleractinian corals were reported from site Shivrajpur which is almost similar to the previous studies. They showed similar results between *Favia*, *Favites*, and *Porites* species in this area.

A longitudinal variation of coral reef in the GoK was studied Kumar *et al.,* (2014). The study revealed that a maximum live coral cover was found at Pirotan Island followed by Laku point and Mithapur. The present study exhibits maximum live coral cover at Shivrajpur followed by Mithapur and Okha. The reason behind this pattern can be the increasing anthropogenic pressure at the Mithapur and Okha sites of the outer GoK.

Venkatraman *et al*., (2003) reported a total of 36 species of Scleractinian coals that belong to 20 genera and eight different families from the GoK. Raghuraman *et al*., (2012) recorded a total of 49 species of Scleractinian corals belonging to 27 genera and 10 different families while George and Jasmine (2015) reported a total of 37 species of Scleractinian corals belonging to 24 genera from GoK. During the present study, a total of 23 species of Scleractinian corals belonging to 12 genera and eight different families were recorded, which revealed that the outer GoK supports less diversity and distribution of coral reef. Some factors that might be responsible for the degradation of the reef ecosystem in the outer GoK can be coastal pollution, sand mining activities, local tourism, industrialization, traditional fishing activities, lack of self-awareness of the local communities, and poor conservation majors for the reef ecosystem.

The diversity indices of the present study showed that the value of Simpson's and Shannon's diversity index was found maximum at Shivrajpur which was 0.90 and 2.58 respectively, while the Pielou's evenness index was found maximum at site Okha with the value of 0.88. A study based on community structure and spatial patterns of Scleractinian corals in the Kilakarai group of islands in the GoM reported the highest value of the Shannon diversity index in the reef of Mulli Island (2.53) and the lowest values in Anaipar Island (1.72). Simpson's richness index also followed the same trend with values of 0.91 and 0.81, respectively, for Mulli and Anaipar island reefs. Pielou's evenness value was the maximum (0.88) in Mulli island reefs and the minimum (0.81) in the Valimunai island reef (Sukumaran *et al.,* 2008). Which exhibited similarity with the diversity and distribution of the coral reef of the outer GoK region.

Rajan *et al*., (2015) studied the diversity indices of the coral reef of the GoK. The value of Simpson's index was found maximum at the Bural island 0.63 followed by Laku Point 0.57, Shannon's diversity index was found maximum at Mundeka island 2.14 followed by Pirotan island 2.03, and the evenness index was found maximum at Narara reef of the GoK 0.90 followed by Mundeka island 0.89. The diversity indices of the present study showed similarity with the earlier report showed maximum value of Simpson's and Shannon's diversity index at Shivrajpur which was 0.90 and 2.58 respectively, while the Pielou's evenness index was found maximum at site Okha with the value of 0.88.

Principal component analysis of the present study supported the statement that the maximum live coral cover was found at Shivrajpur followed by Mithapur and Okha. Species such as *P. tayamai, D. favus, Porites sp. G. pedunculata*, and *S. savignyana* were found to be dominant in the outer part of the GoK. A similar study had been done by Kumar *et al.,* (2014) at 11 selected sites of

MNP GoK from West to East to assess the status of live coral cover with their associates. Multivariate analysis of this study supported that the contribution of live coral cover was more at Pirotan Island and Laku Point at Poshitra Island. It is also indicated that the availability of coral species such as *Paracyathus*, *Polycyathus*, *Goniastrea*, *Goniopora*, and *Turbinaria* sp. was more at Laku Point than on the other selected sites.

Marimuthu *et al*., (2016) analyzed the coral community at 11 selected sites of Palk Bay. PCA of the coral reef diversity showed that the major contributions of coral reef species were found at the northern part of Rameswaram island viz., Vliiuditheertham, Thangatchimadam, and Vadakaud, the species abundance of the corals included *Favites*, *Favia*, *Platygyra*, *Astreopora*, *Turbinaria*, *Siderastrea*, *Hydnophora*, *Symphyllia*, *Montastrea*, and *Syphastrea*. Principal component analysis of the present study revealed that the maximum live coral cover was found at Shivrajpur followed by Mithapur and Okha. Species such as *P. tayamai, D. favus, Porites sp. G. pedunculata*, and *S. savignyana* were found to be dominant in the outer part of the GoK, of which, *D. favus* were also found dominant during the earlier reports. The reason responsible for this pattern can be the ecological and geographical variations among the selected site of the present studies and earlier reports because the selected sites of the outer GoK viz., Okha, Mithapur, and Shivrajpur are the coastal ecosystem whereas the Laku Point site is the island ecosystem with no human interruption.

Kumar *et al.,* (2014) also prepared a cluster based on the coral species abundance. The live coral cover at site Mithapur exhibited a completely different abundance than all other selected sites of the GoK. During the present study, the live coral cover was found similar at Mithapur and Okha whereas site Shivrajpur exhibited a completely different abundance of live coral. It is also found that coral species such as *L. purpurea* and *Porites sp.* exhibited the maximum similarity in abundance followed by *Coscinaraea sp.* and *L. radians*. The dissimilarities of the present study and earlier reports revealed that the anthropogenic pressure at site Mithapur and Okha is the limiting factor for the growth and the survival of the reef ecosystem.

5.2. Reef-associated flora of the outer GoK

During the present study, a total of 29 species of the reef-associated flora of 24 genera belonging to 17 different families were recorded from three selected sites of the outer GoK region. The highest number of seaweed species were recorded from Okha with 29 species belonging to 24 genera followed by Mithapur with 16 species belonging to 12 genera and Shivrajpur with 14 species belonging to 11 genera. Brown algae (Phaeophyceae) contributed the maximum species diversity with 11 species belonging to nine genera followed by red algae (Rhodophyceae) with 10 species belonging to nine genera and green algae (Chlorophyceae) with eight species belonging to six genera.

In earlier reports, Bahuguna *et al.,* (1992) reported a total of 120 species of marine algae from the GoK, dominated by *Sargassum* followed by *Ulva*, *Enteromorpha*, and *Cladophora*. Sen Gupta *et al*., (1999) reported a total of 89 species of reef-associated flora from three selected sites of the GoK viz., Narara, Poshitra, and Pirotan reef of MNP. The study revealed that 26 species of seaweed have been reported from Narara whereas Pirotan and Poshitra exhibited similar species abundance with 40 species of marine algae. It is also found that the species of Rhodophyceae were dominant followed by Chlorophyceae. During the present study, Phaeophyceae were found to be dominant followed by Rhodophyceae exhibited dissimilarity with the species abundance of reef flora in the outer GoK.

Ramamoorthy *et al.,* (2012) reported a total of 31 species of reef-associated flora from Pirotan Island of the GoK. The study revealed that *Ulva* and *Sargassum* were found to be dominant species at Pirotan Island. An almost similar number of seaweed species was found from the outer part of the GoK during the present study (29 species) as compared to the earlier report (31 species). However, the species diversity was found to be dissimilar from the present study. Kumar *et al*., (2014) reported 121 species of the marine algae 74 genera, and 36 families dominated by Rhodophyceae followed by Chlorophyceae from Beyt Dwarka and Okha coast of Gujarat. Barot *et al.,* (2015) reported a total of 70 species of marine macroalgae dominated by Rhodophyceae followed by Phaeophyceae and Chlorophyceae from the Okha coast. During the same period, Roy *et al*., (2015) also reported 70 species of seaweed from Chhad, Goose, Narara, and Dedeka-Mundeka reef of the GoK, which was dominated by Rhodophyta, represented 31 species followed by Chlorophyta with 24 species and Phaeophyta with 15 species. In addition, Vala *et al*., (2016) reported a total of 76 species of seaweed belonging to 47 genera and 27 families from the Okha region of the outer GoK. The results of this studies exhibited dissimilarities in abundance and species diversity of seaweed with the present study. The factor responsible for that can be the impact of coastal pollution and traditional fishing activates of the coastal areas at the Okha and Mithapur influencing the loss of seaweed diversity.

The higher diversity of marine algae was reported from the Dwarka region by Sanghvi *et al.,* (2019). A total of 97 species of seaweed has been recorded during earlier reports from the Dwarka region. It is also found that the maximum species diversity was found of Rhodophyta with 49 species followed by Chlorophyta with 27 species and Phaeophyta with 21 species. During the same period, Kumar *et al.,* (2017) has reported a total of 70 species of seaweed from Okha. The percentage contribution of the seaweed biomass was dominated by Rhodophyta contributed 51.42 % of the total seaweed biomass followed by Phaeophyta with 25.71 % and Chlorophyta 22.58 %. During the present study, brown algae contributed the maximum species diversity with 11 species belonging to nine genera followed by red algae with 10 species belonging to nine genera, and green algae with eight species belonging to six genera.

Joshi *et al.,* (2018) reported 108 species of marine algae from the Narara and Poshitra reef of the GoK. During the same period, Dave *et al.,* (2019) reported 39 species of seaweed from the Okha region. The study also revealed that Chlorophyceae contributed the maximum species diversity with 16 species followed by Rhodophyceae and Phaeophyceae. The present study exhibited significant contrast with these reports. The recent studies based on seaweed diversity of the outer part of GoK reported a total of 39 species of marine algae from the Beyt Dwarka region. The study also revealed that Rhodophyceae followed by Phaeophyceae and Chlorophyceae exhibited the maximum species diversity (Kalsariya *et al*., 2020). During the same year, Sanghvi *et al.,* (2020) reported a total of 27 species of Chlorophyceae that belong to 13 different genera from Dwarka. The outcomes of the earlier reports are not similar to the present study. Findings of the earlier reports exhibit higher species diversity of the reef-associated flora in the inner GoK than the outer part of the GoK. The reason for the decline in diversity and distribution of reef-associated flora in the outer GoK can be the highly turbid water during high tide. Due to this, marine algae could not have an adequate amount of sunlight exposure to grow well.

Seaweed diversity and abundance were found more in the post-monsoon season. Chlorophyceae was found to be dominant during the post-monsoon season whereas during pre-monsoon as well as monsoon season Phaeophyceae was found to be dominant. Similar findings have been discovered Gohil and Kundu, (2012) reported that the Chlorophyceae was found to be prevailing during the post-monsoon season and Rhodophyceae was found dominant during the monsoon and post-monsoon season at Gujarat coast. Ishakani *et al.,* (2016) also revealed a similar outcome; the study reported a total of 67 species of marine algae from the Veraval coast, of which Chlorophyceae was found to be dominant during the post-monsoon months in addition the post-monsoon season was the most productive season than the monsoon and pre-monsoon season.

In a recent study, Pathak *et al*., (2021) reported 28 taxa of marine algae from the Veraval and Sikka coast of Gujarat. They reported that during the post-monsoon season green algae were found to be dominant contributing to 64.12% of the total density of the algal biomass followed by pre-monsoon season. The present study shows similarities with the earlier reports that the post-monsoon season was the most productive season for the growth of marine algae. The monsoon season exhibited the least abundance of marine algae because of the high turbidity, water currents, and less amount of sunlight.

The species richness index of the outer GoK was found in the range of 1.29 to 1.03. The Shannon-Wiener index shows the range between 2.30 to 1.94, and the evenness was in the range of 0.71 to 0.63. The maximum species richness and Shannon-Wiener index were found at Okha followed by Mithapur. In earlier reports, Ishakani *et al.,* (2016) stated that the value of species richness of the marine algae of Veraval coast, Gujarat was found in the range of 1.82 to 13.66 and the Shannon-Wiener index was in the range of 0.60 - 1.74. The range of species richness of the seaweed diversity during the present study was found between 1.29 to 1.03 and the

Shannon-Wiener index was in the range between 2.30 to 1.94. viewing the significant difference between the seaweed diversity between the outer GoK and Saurashtra coast. Recently, Roy, (2020) studied the seaweed diversity of the Rameshwaram coast. The Shannon-Wiener index was in the range of 1.16 to 3.60, the Simpson index was in the range of 0.60 to 0.96, and the evenness was between 0.72 to 0.90 can be considered as the average similarity with the present study.

The multivariate analysis of the reef-associated flora such as PCA and CCA analysis of the present study supported the statement that maximum seaweed biomass was found at Okha followed by Mithapur and Shivrajpur. PCA 1 contributed the maximum (84.70 %) followed by PCA 2 (11.19 %). It is also found that Phaeophyceae species such as *S. tenerrimum, S. cinereum,* and *P. gymnospora* followed by Chlorophyceae such as *U. lactuca,* were the dominant species that exhibited the maximum contribution to the total seaweed biomass in the outer GoK. At the Okha site, Phaeophyceae such as *S. cinereum* and Chlorophyceae *U. lactuca* were found to be dominant. At Mithapur, Chlorophyceae such as *U. lactuca* and Phaeophyceae such as *S. tenerrimum* were found to be dominant. At Shivrajpur Phaeophyceae such as *P. gymnospora, S. tenerrimum*, and *S. cinereum* were found to be dominant species. The CCA analysis based on biomass of marine macroalgae associated with environmental parameters of the selected sites revealed that the post-monsoon season was found to be most productive and favorable for the growth and survival of marine algae. Axis 1 contributed the maximum (73.82 %) followed by Axis 2 (23.39 %). it is also found that the Chlorophyceae was found to be dominant during the post-monsoon season whereas during pre-monsoon as well as monsoon season Phaeophyceae was found to be dominant.

Similar multivariate analysis used to evaluate the habitat preference of seaweed diversity was studied by Zainee *et al.,* (2019) at a tropical Island of southern Malaysia. The study revealed that seaweed communities prefer rocky substratum to survive according to their ecological and environmental needs. The substratum and geo-morphology of the outer GoK are of limestone, rocks, and a gradual slope conducive for the growth and survival of marine algae. Seasonal abundance of microalgae associated with physic-chemical parameters of river Noyyal a tributary of Kaveri were studied (Kumar and Thomas, 2019). The PCA analysis of the study revealed that the post-monsoon season was the most productive followed by pre-monsoon and monsoon. The CCA analysis also exhibited that seasonal variation in the abundance of microalgae species significantly depends upon the environmental parameters. Species such as *Brachysiraceae*, *Oscillatoriaceae*, *Selenastraceae*, *Chlorococcaceae*, and *Chlorellaceae* were found to be more abundant during the post-monsoon season. During pre-monsoon season, species viz. *Chlorellaceae*, *Scenedesmaceae*, *Chlorococcaceae*, and *Bacillariaceae* preferred nitrate and ammonia for their growth and survival. The results of the diversity and abundance of microalgae of the river ecosystem exhibited similarity with the diversity and abundance of macroalgae of the reef ecosystem of the present study. The reason behind this pattern could be the environmental influences on the growth and survival of marine algae.

The dendrogram based on the site-wise and species-wise percentage share of seaweed biomass of the present study supported the statement that the seaweed species biomass of site Mithapur and Shivrajpur showed similar abundance whereas site Okha showed a completely different abundance of marine algae than the other two sites. The species such as *C. officinalis* and *G. indica* followed by *C. taxifolia* and *H. macroloba* exhibited the highest similarity whereas *U. lactuca, S. cinereum,* and *P. gymnospora* showed completely different abundance than all other species. The abundance of *P. tetrastromatica* and *S. tenerrimum* was also different from other species. Dave *et al*., (2019) prepared a major cluster based on different zones that exhibited 60.40% similarity of zone I and zone II of the outer GoK. While zone III had exhibited 32.43 % similarity to zone I. Zone II and III showed 62.61 % similarity. Besides, this pattern also revealed that water-flooded coastal areas are the most favorable for the growth of Phaeophyceae and Rhodophyceae. A similar result has been found during the present study, the water-flooded areas are the most productive for the growth and survival of the brown and red algae. Because the water-flooded areas of the coastal ecosystems have, more clear water with high sunlight penetration for the photosynthesis of the marine algae and face lesser pressure of water currents.

5.3. Reef-associated fauna of the outer GoK

A total of 39 species of reef-associated fauna belonging to 35 genera and 30 families were recorded from the outer GoK. The earlier reports accounted, a total of 25 species of sponges belonging to 22 genera and 15 different families from the GoK (Thomas *et al*., 1996). During the present study, five species of sponges have been reported from the outer GoK. The reason behind this degradation in the diversity of the sponges can be the intense anthropogenic pressure on the coastal areas of the outer GoK. Thivakaran and Kundu, (2011) studied the ecology of the macro-benthos from the coastal region of the GoK and had reported 42 macro-benthic infaunal species belonging to five major groups. Crustaceans were found to be the dominant group that contributed 78% of the total marine fauna followed by the gastropods. The present study revealed an almost similar number of reef-associated fauna, but the species composition was found to be dissimilar from the earlier reports. During the present study, gastropods were found to be the dominant group of the reef-associated fauna contributing 80% of the total reef-associated faunal diversity followed by crustaceans.

Trivedi *et al*., (2012) reported 19 species of brachyuran crabs belonging to 15 genera and eight families from 16 different locations included two locations in each site viz., Naliya, Mundra, Jodiya, Jamnagar, Sikka, Khambhaliya, Bhatiya, and Poshitra reef of GoK. During the present study, a total of eight species of brachyuran crabs belonging to seven genera, and five different families were reported from outer GoK. Reduced diversity of the brachyuran crabs was due to the traditional “Pagadiya fishing” of crabs in outer the outer GoK.

Kardani *et al.,* (2014) reported a total of 36 species of gastropods belonging to 18 different families from Mandavi, Singhi, and Mundra sites of the northern part of the GoK. There are a total of 10 species of gastropods have been reported during the present study exhibits the lowered gastropod diversity in the outer GoK. Whereas Adhavan *et al.,* (2014) reported two species in each group of sponges, zoanthids, sea anemones, annelid worms, echinoderms, fishes, marine crabs, and five species of mollusks from the Narara reef of GoK. During the present study, five species of sponges, two species of zoanthids, three species of sea anemones, two species of polychaete worms, two species of reef-associated ichthyofauna, two species of brachyuran crabs, and 15 species of mollusks have been reported. The present study revealed that the reef ecosystem of the outer GoK is more diverse than the Narara reef of the inner Gulf.

Vadher *et al.,* (2014) reported a total of 69 species of marine molluscs belonging to 31 different families from the Chorwad coast of Gujarat. Recently Bhatt *et al*., (2020) reported a total of 54 species of marine molluscs belonging to four different classes including 45 species of gastropods, seven species of bivalves, one species of cephalopod, and Polyplacophora from Poshitra, Pirotan, and Narara reef of the GoK. During the present study, only 15 species of molluscs including 10 species of gastropods showing lesser molluscan diversity while two species of cephalopods, two species of nudibranchs, and one species of polyplacophorans showed similarity with the earlier reports.

During the present study, a total of six species of cnidarians including three species of sea anemones, two species of zoantharia, and one species of scyphozoans has been recorded from the outer GoK. High diversity of cnidarians has been reported in earlier reports by Shah *et al*., (2017), a total of 15 species of sea anemones belonging to 10 genera, and five different families have been recorded from Sutrapada, Vadodra Jhala, Okha, Shivrajpur, and Mithapur sites of Saurashtra and the outer region of GoK. Additionally, seven, three, and one species of sea anemone were found from Okha, Shivrajpur, and Mithapur respectively. Out of the seven species reported in earlier reports from Okha only three species viz., *Heteractis crispa, Stichodactyla haddoni,* and *Cryptodendrum adhaesivum* has been reported during the present study. Barely a single species of sea anemone was reported from Mithapur and three species from Shivrajpur. The reason behind the loss of diversity of sea anemones at the Okha site can be the increasing fishing pressure, shoreline pollution, local tourism, and coastal development.

In some recent studies, a total of 92 species of bivalves, 55 species of gastropods, three species of cephalopods, and two species in each of scaphopods and amphineurans reported from Okha, Kandla, and Navlakhi coast of GoK by Rathore (2018). Coral reef diversity of the outer GoK during the present study reported a total of 15 species of mollusks, including 10 species of gastropods and two species of cephalopods, two species of nudibranchs, and one species of polyplacophorans. That revealed the destruction of the reef diversity in the outer part of the GoK. Subsequently, Joshi *et al*., (2018) reported 70 species of sponges, 421 species of fishes, 27 species of prawns, 30 species of crabs, 199 species of molluscs, 16 species of echinoderms, 172 species of ea-birds, three species of sea mammals, and three species of a sea turtle from the Narara and Poshitra island of the GoK.

Parmar *et al.,* (2018) reported a total of 39 species of crustaceans belonging to 18 families and four different orders including one endemic species, *Metapenaeus kutchensis*. Out of 39 species of crustaceans, species such as *Etisus laevimanus, Portunus pelagicus,* and two species of genus *Atergatis* were reported during the present study, with a total of eight species of brachyuran crabs belonging to seven genera and five families. The study revealed that the inner gulf is more diverse and suitable for the growth and survival of the reef diversity.

A total of six species of cnidarians including three species of sea anemone belonging to three genera and two different families, two species of zoanthids belonging to two genera, and one species of jellyfish from the outer GoK during the present study. Mirza *et al.,* (2019) reported an almost similar number of species from the Pirotan, Goose, and Kalumbhar islands of the GoK. Nevertheless, the species abundance is not similar to the present study. In earlier reports, two species of jellyfish, four species of sea anemones, and one species of polychaete worm have been reported.

Parmar *et al*.*,* (2019) reported 108 molluscs from the southern coast of the GoK, which includes 91 species of gastropods, 14 species of bivalves, two species of cephalopods, and one species of scaphopods from GoK. The present study showed lesser diversity among the groups of molluscs than the earlier report except the cephalopods and scaphopods exhibited similarity with the present study.

The diversity indices of the reef-associated fauna of the present study showed that the value of Simpson's and Shannon’s diversity index was found maximum at Shivrajpur which was 0.91 and 2.78 respectively, while the Pielou’s evenness index was found maximum at site Mithapur with the value of 0.74. Saravankumar *et al*., (2007) reported a total of 62 species of benthic macrofauna belonging to five major groups viz., 18 species of crustaceans, 17 species of gastropods, 16 species of bivalves, nine species of polychaete worms, and two species of reef fishes from the mangrove ecosystem of the GoK. In addition, the study also revealed that species diversity was found in the range of 1.84 to 2.45, species richness varied from 0.82 to 0.98, and the evenness was between 0.64 to 0.81. Shannon's diversity index and the species evenness index of the present study were found similar to the earlier reports but the value of species richness was found higher during the present study.

Mohanraj *et al*., (2010) analyzed the diversity indices of the coral reef-associated gastropods from the Tuticorin coast of GoMBR. The maximum value of Shannon's diversity index was 1.4. The Shannon's diversity index of the present study was found in the range of 1.99 to 2.77, which is higher than the previous report. Sadhukhan and Raghunathan, (2012) estimated the species diversity index of echinoderms at the south Andaman Sea. The maximum value of species diversity index was found at Rutland island 2.31 followed by Outram island 2.11. The value of the Species diversity indices of the present study found maximum at Shivrajpur followed by Mithapur, exhibited similarity with the previous reports.

Parmar *et al*., (2015) prepared the site-wise cluster of reef-associated ichthyofauna of the GoK. The Dendrogram showed maximum similarity between the port Okha and Dwarka followed by Goose and Narara reef of the GoK, whereas site Poshitra showed completely different species abundance than all other sites. Kumar *et al*., (2014) prepared four major clusters based on the availability of ten different groups of the reef fauna with 78 % similarity. The cluster analysis of the present study revealed that site Mithapur and Shivrajpur exhibited maximum similarity in species diversity and abundance whereas site Okha showed completely different abundance.

Recently Ramesh *et al.,* (2020) studied the reef diversity of the Mandapam group of islands. The PCA analysis of the study showed maximum diversity of reef-associated ichthyofauna from Here, Manoli, and Pullivasal islands followed by Shingle, Nanoliputii, and Krusadai islands. During the present study, the multivariate analysis showed the maximum reef diversity was found at Shivrajpur followed by Mithapur and Okha.

5.4. Environmental parameters affecting the reef diversity

The environmental parameters during the study period revealed that the mean water temperature and salinity of Okha, Mithapur, and Shivrajpur were 26 °C and 34 ppt, 26 °C, and 35 ppt and, 27 °C and 34 ppt respectively, and the mean pH values were 7.73, 7.91, and 7.84 respectively. The dissolved oxygen level at Okha, Mithapur, and Shivrajpur was 6.50, 6.22, and 6.59 mg/lit respectively. At Okha, the temperature was positively correlated with salinity and strongly negatively correlated with dissolved oxygen, whereas pH has a positive correlation with dissolved oxygen. At Mithapur, the temperature was strongly positively correlated with salinity and negatively correlated with dissolved oxygen, whereas salinity and pH negatively and positively correlated with dissolved oxygen respectively. At Shivrajpur, the temperature is strongly positively correlated with salinity and strongly negatively correlated with dissolved oxygen, whereas salinity and pH were strongly negatively and positively correlated with dissolved oxygen respectively.

Thivakaran and Kundu, (2011) reported temperature, salinity, dissolved oxygen, and pH in the range of 21 to 31.9 °C, 36 to 39 ppt, 3.3 to 4.8 mg/l, and 7.7 to 8.2 respectively from coastal waters of GoK. The average temperature, salinity, and pH value of the present study exhibited similarity with the previous study but the dissolved oxygen level were found significantly higher during the present study. Bignesh *et al*., (2014) also reported almost similar ranges of the water quality parameters from the reef-ecosystem of the Poshitra reef of the GoK.

Joshi *et al*., (2014) observed the mass coral bleaching incidents due to climate change affected a total of 19 species of scleractinian corals including other zooxanthellate cnidarians at the Narara and Poshitra reef of the GoK. The species of *Porites* colonies were found to be most affected. While in the present study a total of 16 species of the Scleractinian corals were found to be bleached. Site Mithapur contributed maximum relative dead coral cover of about 12.62 % of the total live coral cover followed by Okha and Shivrajpur. Because of that, the outer part of the GoK can be considered a moderate reef degradation region. Species of corals such as *G. pedunculata* and *D. favus* were found to be most affected. The major damaging impact on the coral reef of the outer GoK was the anthropogenic impact. A similar percentage contribution of the dead corals to the total coral cover was found at

Pirotan reef of GoK which was in the mean range of 12 to 15% during the years 1998, 2000, and 2005 (Sharma *et al.,* 2008).

Rathoure (2018) stated that the temperature range of the GoK region was 20 °C to 30 °C with localized higher temperatures raised to 35 °C. The average dissolved oxygen level was reported significantly higher (35 mg/L) than the present study with most of the times in the range of 0.1 – 6.3 which is indicating good oxidizing conditions in the inner part of the GoK than the outer GoK. As the diversity and distribution of the coral reef ecosystem are based on the physicochemical properties of the surrounding environment including geographic location, water quality, tidal amplitude, depth, etc., the coral reef ecosystem of the outer GoK found less diverse than the inner gulf.

Joshi *et al*., (2018) determined the seasonal variation of oceanographic conditions in the Narara and Poshitra reef of the GoK. The environmental variables were found in the ranges of, viz., temperature 30.34±1.33 °C, pH 7.90±0.19, Salinity 32.89±0.97 ppt, and the dissolved oxygen 6.17±0.69 mg/lit. The temperature was strongly positively correlated with salinity and strongly negatively correlated with dissolved oxygen whereas the correlation between dissolved oxygen level and pH was found significantly positive. The water parameters ranges and the correlation between the different water quality variables were found almost similar during the present study. Panseriya *et al*., (2021) reported that water quality was found to be moderate in summer, worst in monsoon, and best in post-monsoon season in GoK. The present study also revealed parallel findings with the previous studies because the post-monsoon season was found the most productive followed by pre-monsoon and monsoon.

5.5. Economic analysis of the coral reef diversity

The rank order scaling analysis based on the public opinion of the local communities during the present study revealed that at site Okha and Mithapur the most important uses of the coral reef ecosystem were for the finfish catch followed by shellfish collection by traditional fishers. However, at site Shivrajpur the shellfish catch formed the major use of coral reef ecosystem followed by finfish catch. The reason behind this could be traditional Pagadiya fishers used to collect shellfish species during low tide period.

The reef ecosystem's goods and services to the human population either directly or indirectly from the ecosystem functions viz., food and fisheries, medical advances, rich minerals, coastal protection, water filtration, air quality maintenance, tourism, recreation, aesthetic services, and intrinsic cultural heritage value (Costanza *et al.,* 1997). Ahamada *et al.,* (2004) reported that coral reef fishing is one of the main uses of the coral reef of the south East Indian islands ecosystems. Charles, (2005) accounted that coral reefs are extremely important to grant necessary goods and services to humankind such as fisheries, coastal security, recreation, and tourism.

Venkatraman (2006) revealed that the reef ecosystem of India supports the growth and survival of the marine flora and fauna, protecting the shoreline against tidal surges, and offering livelihood and support to the coastal communities of the country. Subha, (2013) stated that the reef ecosystem plays a vital role in biosphere protection, climatic and environmental ecology. Besides, the coral reefs are especially valuable for meditational, beautification, and commercial fishing purposes. In recent studies, Mirza *et al*., (2019) also reported that the coral reef ecosystem is highly productive in terms of diverse flora and fauna, which supports the livelihood and survival of local fisherman communities.

The present study revealed that the reef ecosystem of the outer GoK supports traditional fishing activities followed by local tourism. In addition, the reef ecosystem of the outer GoK exhibited that the coral reef ecosystem of the outer GoK is most important for creating more employment opportunities as an alternative livelihood option for the villagers and stakeholders followed by the reef ecosystem protecting the natural habitat and biodiversity.

Economic analysis of the reef ecosystem from the outer GoK in the present study revealed that finfishes followed by shellfishes catch by the local communities generated maximum revenue. The highest annual revenue was found from the Mithapur reef that was ₹1,47,620 followed by Okha (₹ 1,30,310) and

Shivrajpur (₹ 1,09,540). The Coast-Benefit Ratio (CBR) was found highest at Shivrajpur that was 24.56 followed by Okha (9.52) and Mithapur (3.62).

Driml, (1994) estimated that the Great Barrier Reef of Australia generates a value of UU$ 923 million per year for the country. Cesar *et al*., (2003) evaluated the economics of the coral reef of the world. The study revealed that the reef ecosystem provides nearly about US$ 30 billion benefits annually to the economics of the world. Ammar, (2009) estimated the value of the coral reef ecosystem of the world was US$ 375 billion with an average value of around US$ 6075 per hectare of the coral annually. In recent years, Spalding *et al.,* (2017) mentioned that global reef-based tourism is one of the most significant natural tourism, earning total revenue of US$ 35.8 billion per annum.

Dixit *et al*., (2010) have done the economic evaluation of the reef ecosystem of the GoK. The study revealed that an estimated value of one km^2 of coral reef covering area of the GoK was found to the tune of ₹ 7.95 million. The study also mentioned that the maximum value of the reef ecosystem has been found from the fisheries activities followed by coastal protection and biodiversity benefits. Subsequently, Dixit *et al*., (2010) also reported that the net annual benefits of the coral reef ecosystem of the GoK were ₹ 1799 million of which fisheries contributed the maximum revenue of ₹ 1284 million followed by coastal protection of ₹ 422 million, and biodiversity benefits were of ₹ 46 million. During the present study, it has been found that finfishes followed by shellfishes catch by the local communities generated maximum revenue. The highest annual revenue of the reef diversity was found from the Mithapur reef that was ₹1,47,620 followed by Okha (₹ 1,30,310) and Shivrajpur (₹ 1,09,540). The Coast-Benefit Ratio (CBR) was found highest at Shivrajpur that was 24.56 followed by Okha (9.52) and Mithapur (3.62).

5.6. Socio-economic impact on the coral reef diversity

Coral reefs are the most diverse and ecologically important ecosystem of all marine environments. In addition, it supports the livelihood of many of the coastal communities, especially in developing countries. Because of that, the reef ecosystem is becoming venerable. The reef diversity of the outer GoK supports the livelihood and culture of the local community by traditional fishing activities such as gillnetting, and Pagadiya fishing includes handpicking of crabs and gastropods. The most important anthropogenic threats to reef diversity of the outer GoK are increasing fishing pressure, ghost fishing, local tourism, dead coral collection, sand mining, coastal pollution, and industrialization. The major socio-economic impact on the coral reef diversity of site Okha was habitat destruction followed by overexploitation of the reef ecosystem and global warming and climate change. At Mithapur habitat destruction was found to be a major socio-economic impact on the reef diversity followed by coastal pollution and overexploitation of the reef ecosystem. While at site Shivrajpur, declining in fish catches was found to be a major socioeconomic impact on the coral reef diversity followed by global warming and climate change, and poor conservation efforts.

In earlier reports, it has been found that the commercial exploitation of the coral reef by the cement industry was the major cause of the destruction of the reef ecosystem (GEC., 1997). Nambiar *et al*., (1995) reported that fishing activities cause major stress on the coral reef because the unsustainable practices such as poisoning, fixing of the fishing net on the coral reef distributing areas, handpicking of the shells, and crabs. Ngoile, (1998) estimated the global coral reef degradation. The study has been reported that the global reef covering the area was 6,00,000 km^2 out of that 60,000 km^2 are degraded and 1,80,000 km^2 are under threats to be decline. It has been reported that the coastal reef ecosystem of the Indian Ocean faces a high risk of degradation due to high anthropogenic impacts and sedimentation (Arthur, 2000; Rajasuriya and white, 1995). Rodwell and Roberts (2000) revealed that the reef ecosystem faces a significant risk of degradation due to the overexploitation of the coral reef diversity.

Muley *et al*., (2002) reported that the anthropogenic pressures and interference were the major issue regarding the health of the coral reef ecosystem of India, followed by sedimentation, dredging, and coral mining. Kankara and Subramanian, (2007) indicated that the coral reef, mangroves, and mudflat ecosystems at the Narara and Kalubar reef of the GoK is at a high risk of an oil spill. Mangotra *et al.,* (2008) reported that the most important socioeconomic threats to the GoK are the rapid growth of industries in coastal areas and human interference such as coral mining, dredging, siltation, and pollution. Subsequently, Nayak *et al*., (2017) reported that the coastal habitats of the GoK face a high risk of productivity loss due to coastal development, habitat alteration, and salt production. In previous studies researchers were also concluded that the anthropogenic activities such as coastal development, traditional fishing activities, and tourism were the major threats to the coral reef ecosystems in GoK, that exhibiting similarities with the results of the present study.

Recently, Baswapoor and Irfan, (2018) listed out the natural and anthropogenic threats to the coral reef ecosystem of the Indian Ocean. The natural threats included predation by the crown of thrones (a reef-eating fish species), direct exposure to the sunlight for a long period, natural breakdown by the reef-associated faunas, and tidal surges. Whereas the anthropogenic threats to the reef diversity of the GoK can be coral mining, destructive fishing activities, and anchors of the boat, collection of the corals, mangrove destructions, unstable tourism, and coastal and industrial pollution. It has been also mentioned that due to climate change the reef ecosystem facing a high risk of coral bleaching due to sea-level rise, storms, ocean acidification, and ozone layer depletion.

During the present study, the major anthropogenic threats to the coral reef ecosystem viz., increasing fishing pressure, ghost fishing, local tourism, dead coral collection, sand mining, coastal pollution, and industrialization. Some important problems regarding the growth and survival of the reef ecosystem of the outer GoK included traditional fishing practices, ghost fishing by loss of their entangling nets, local tourism, shoreline pollution, and loss of the reef diversity at Okha. At site Mithapur, ungoverned fishing practices in the coral reef ecosystem can be considered as the major problem regarding coral reef diversity and distribution. Site Shivrajpur was in its natural condition having less anthropogenic pressure except some local Pagadiya fishers and some traditional fishing activities.

Arora *et al*., (2019) found bleaching events in 13 species of corals and other cnidarians from the Laku Point reef near the Poshitra region of the GoK. The study revealed that the maximum colony scale bleaching was found in *P. lutea* species with an average of 3.9%. In another report bleached coral species viz., *D. favus, D. lacuna, D. speciosa, F. halicora, F. flexuosa, P. compressa,* and *P. lichens* have been found from the Pirotan reef of GoK (Adhavan *et al.,* 2014). During the present study, the maximum contribution to the total dead coral cover was found in *G. pedunculata* with 34 % of the total dead cover followed by *D. favus* (31 %). Nearly about 30% of live corals of the GoK were lost after the large-scale coral bleaching event in 1998 (Wafar, 1999). During the present study, the maximum percentage contribution of the dead coral cover was found at site Mithapur with 73 % followed by site Okha (17 %) and Shivrajpur. This was directly proportional to the average number of people visiting the reef site.

The health status of the coral reef ecosystem of the outer GoK was examined by using the CMI of each selected site. The overall coral mortality index of the outer GoK was 0.03 indicated that the coral reef of the outer GoK can be considered healthy. Among all selected sites, the coral mortality index was found maximum (0.12) at Mithapur followed by Okha (0.06) and Shivrajpur (0.004). The coral mortality index at site Shivrajpur was significantly lower revealed that the reef ecosystem of the Shivrajpur site was the healthiest reef ecosystem of the selected sites of the outer GoK. A similar study has been done by Shreenath *et al*., (2015) at Agatti Island, Lakshadweep. The study reported a total of 71 species of Scleractinian corals dominated by *Acropora formosa* contributed 18.3 % of the total abundance followed by *Porites lutea* (14.8%). The total live coral cover was 48.6 % and the coral mortality index was 0.29. This was higher than the present study but considered the coral reef ecosystem healthy.

The outer part of GoK is can be considered healthy with a highly diverse reef ecosystem, which requires to be protected from anthropogenic pressure and deterioration. Increasing fishing pressure, ghost fishing, local tourism, dead coral collection, sand mining, coastal pollution, and industrialization together increase pressure on the coral reef ecosystem of the outer GoK with natural disturbances and global climate change. Due to this, the reef ecosystem of the outer GoK needs attention and self-awareness among the local communities.

SUMMARY

The present study was aimed to assess the biotic and abiotic factors, socioeconomic impact on reef diversity, and economic evaluation of the coral reef ecosystem of the outer Gulf of Kachchh. The mean water temperature and salinity of Okha, Mithapur, and Shivrajpur were 26 °C and 34 ppt, 26 °C and 35 ppt and, 27 °C and 34 ppt respectively, while the mean pH values were 7.73, 7.91, and 7.84, respectively. Similarly, the dissolved oxygen level at Okha, Mithapur, and Shivrajpur were 6.50, 6.22, and 6.59 mg/lit, respectively.

During the study, 23 species of Scleractinian corals belonging to 12 genera and eight different families have been recorded. Among all the species of Scleractinian coral, *Dipsastraea favus* showed the maximum percentage contribution to the coral cover followed by *Pseudosiderastrea tayamai.* The maximum species richness was found at Shivrajpur followed by Mithapur. PCA analysis of all selected sites indicated maximum live coral cover found at Shivrajpur followed by Mithapur and Okha. It is also found that *Dipsastraea favus* followed by *Pseudosiderastrea tayamai* were the dominant species distributed all over the outer GoK. CCA analysis of the selected sites revealed that some ecologically fragile coral species such as *Goniopora pedunculata, Homophyllia bowerbanki,* and *Lobophyllia radians* exhibit high abundance at a higher value of dissolved oxygen with the more alkaline condition of water and lower salinity as well as temperature. Cluster analysis based on the percentage share of coral species indicated maximum similarity in abundance between *Leptastrea purpurea* and *Porites sp.* followed by *Coscinaraea sp*. and *Lobophyllia radians*.

Altogether 29 species of reef-associated flora belonging to 24 genera and 17 families were recorded from all the sites. The highest number of seaweed species were recorded from Okha followed by Mithapur. Among seaweed species, the highest percentage contribution was exhibited by *Sargassum cinereum* followed by *Ulva lactuca*. The maximum species richness was found at Okha followed by Mithapur. PCA analysis of the selected sites indicated maximum seaweed biomass at Okha followed by Mithapur and Shivrajpur sites. The CCA plot of the reef-associated flora revealed the post-monsoon season to be more productive followed by the pre-monsoon season. Some species of Chlorophyceae such as *Caulerpa racemosa*, *Halimeda macroloba, Caulerpa sertularioides, Caulerpa taxifolia,* and *Ulva lactuca* were found to be more abundant at low water temperature and salinity but at high dissolved oxygen.

A total of 39 species of reef-associated fauna belonging to 35 genera and 30 families were recorded from the outer GoK. The highest percentage contribution to the total reef diversity was made by gastropods followed by crustaceans and zoantharia. The maximum species richness was found at Shivrajpur followed by Mithapur. Cluster analysis of the reef-associated fauna of the outer GoK highlighted maximum similarity in species abundance of cephalopods and nudibranchs followed by polyplacophorans and sponges. Similarly, PCA analysis of all selected sites exhibited the maximum diversity of the reef-associated fauna at Shivrajpur followed by Mithapur and Okha.

The study on the importance of coral reef revealed that coral reefs generate employment opportunities and alternative livelihood options for the villagers and stakeholders. At Okha, about 24 active fisherman engaged in traditional fishing activities on fishery resources of the reef ecosystem. An estimated annual total cost of traditional fishing at the Okha site was ₹ 13690. The estimated total revenue was ₹ 144000, which generates a net profit of ₹ 130310 with a cost-benefit ratio of 9.52 per annum. At Mithapur, 42 active fisherman engaged in traditional fishing activities on the reef ecosystem. An estimated annual total cost of traditional fishing was ₹ 56380. The estimated total revenue was ₹ 204000, which generates a net profit of ₹ 147620 with a cost-benefit ratio of 2.62 per annum. There are about 21 active fisherman engaged in traditional fishing activities on the reef ecosystem at site Shivrajpur. An estimated annual total cost of traditional fishing was ₹ 4460. The estimated total revenue was ₹ 114000, which generates a net profit of ₹ 109540 with a cost-benefit ratio of 24.56 per annum.

The most important threats to reef diversity of the outer GoK are anthropogenic activities such as increasing fishing pressure, ghost fishing, local tourism, dead coral collection, sand mining, industrialization, and coastal pollution. A total of 16 species of Scleractinian corals were found to be bleached. The maximum proportion of the colony scale bleaching was observed in *Goniopora pedunculata* followed by *Dipsastraea favus*. The percentage contribution of the relative dead coral cover with the live coral cover was highest at Mithapur followed by Okha. The coral mortality index of the outer GoK was 0.03 pointing that the reef ecosystem of the outer GoK is healthy.

The information generated from the present study can be helpful to understand the status of the coral reef ecosystem and be used as baseline data to create awareness among the local communities. The results from this study indicate that the outer GoK has great potential for reef diversity, which yet remained unexplored. The coral reef in the outer GoK could be considered healthy because the coral mortality index is 0.03. The health status of the coral reef ecosystem is deteriorating due to anthropogenic factors; especially site Mithapur is highly vulnerable due to local tourism, traditional fishing, and industrialization. It is recommended that such kind of regular assessment should be done for monitoring of the coral reef. To protect the coral reef ecosystem in the outer GoK, reef management activities should be strengthened and anthropogenic pressure should be minimized. Especially after the development of the “Blue Flag”, beach beautification project at site Shivrajpur. It is also essential to undertake protection and conservation measures to protect the reef from future exploitation, local tourism, coastal development, and industrialization.

REFERENCES

Abdo, D. A., Bellchambers, L. M. and Evans, S. N. 2012. Turning up the heat: increasing temperature and coral bleaching at the high latitude coral reefs of the Houtman Abrolhos Islands. *Plos one*, 7(8): 43878.

Adhavan, D., Kamboj, R. D., Chavdaand, D. V., and Bhalodi, M. M. 2014. Status of intertidal biodiversity of Narara Reef Marine National Park, Gulf of Kachchh, Gujarat. *Journal of Marine Biology & Oceanography*, 3(3): 2.

Adhavan, D., Kamboj, R. D., Marimuthu, N. and Bhalodi, M. M. 2014. Seasonal Variation and Climate Change Influence Coral Bleaching in Pirotan Island, Gulf of Kachchh Marine National Park, Gujarat. *Current Science,* 107(11): 1780-1781.

Ahamada, S., Bijoux, J., Bigot, L., Cauvin, B., Kooonjul, M., Maharavo, J., Meunier, S., Moine-Picard, M., Quod, J. and Pierre-Louis, R. 2004. Status of the coral reefs of the South-West Indian Ocean island states. Status of coral reefs of the world, pp. 189-212.

Ahmed, M., Chong, C. and Balasubramanian, H. 2005. An Overview of Problems and Issues of Coral Reef Economic Valuation and Policy Priorities for Sustainable Management of Coral Reef, Second Edition, World Fish Centre, Malaysia, pp. 2-11.

Ammar, M. S. A. 2009. Coral reef restoration and artificial reef management, future and economic. *The Open Environmental Engineering Journal*, 7(20): 37- 49.

Aronson, R.B. and Precht, W.F., 2016. Physical and biological drivers of coral-reef dynamics. In *Coral reefs at the crossroads* (pp. 261-275). Springer, Dordrecht.

Arora, M., Chaudhury, N. R., Gujrati, A., Kamboj, R. D., Joshi, D., Patel, H. and Patel, R. 2019. Coral bleaching due to increased sea surface temperature in Gulf of Kachchh Region, India, during June 2016. *Indian Journal of Geo-Marine Sciences*, 48(3): 327-332.

Arthur, R. 2000. Coral bleaching and mortality in three Indian reef regions during an El Nino southern oscillation event. *Current Science*, 79(12): 1723-1729.

Bahuguna, A., Chaudhury, R. N., Bhattji, N. and Navalgund, R. R. 2013. Spatial inventory and ecological status of coral reefs of the Central Indian Ocean using Resourcesat-1. *Indian Journal of Geo-Marine Sciences*, 42(6): 684-696.

Bahuguna, A., Ghosh, A., Nayak, S., Patel, A. and Aggarwal, J. P. 1992. Ecological status of the coral reefs of the Gulf of Kachchh and Lakshadweep. Proc. Nat. Sym. on Rem. Sens. for Sustainable Development, ISRS, Lucknow, pp. 57-61.

Balakrishnan, M., Srivastava, R.C. and Pokhriyal, M., 2008. Biodiversity of Andaman and Nicobar Islands. *Biobytes*, *3*, pp.9-12.

Barot, M., Kumar, N. J. I. and Kumar, R. N. 2015. Seaweed Species Diversity in Relation to Hydro Chemical Characters of Okha Coast, Western India*. International Journal of Research and Review,* 8(3): 16-28.

Baswapoor, S. and Irfan, Z. B. 2018. Current Status of Coral Reefs in India: Importance, Rising Threats and Policies for its Conservation and Management, Madras School of Economics*,* 175 pp.

Berkelmans, R., Jones, A. M. and Schaffelke, B. 2012. Salinity thresholds of *Acropora spp*. on the Great Barrier Reef. *Coral Reefs*, 31(4): 1103-1110.

Bhatt, S., Joshi, D. and Kamboj, R. D. 2020. Diversity of Marine Mollusca in Gulf of Kachchh, Gujarat. *Environment and Ecology*, 38(1): 17-23.

Bignesh, T., Chetan, C. and Harshad, S. 2014. Winter Season Variations In Physicochemical Parameters Of Marine Water Characteristics Of Coral Reef Of The Poshitra Coast, Paga Reef And Boria Reef Of Southwest Gulf Of Kachchh, India. *International journal of scientific and technology research*, 3(7): 270-273.

Biswas, N. 2009. Gulf of Katch Marine National Park and Sanctuary: a case Study, International Collective in Support of Fishworkes, Chennai, pp. 1-33.

Bryant, D., Burke, L., McManus, J. and Spalding, M. 1998. Reefs at risk: a map-based indicator of threats to the world's coral reefs, *Springer*, 56 pp.

Burke, L., Selig, L. and Spalding, M. 2002. Reefs at Risk in Southeast Asia- A spatial analysis of threats protection and vulnerability, In Proceedings of the Ninth international Coral Reef Symposium, Bali, pp. 1033-1039.

Cai, W., Wang, G., Dewitte, B., Wu, L., Santoso, A., Takahashi, K., Yang, Y., Carréric, A. and McPhaden, M. J. 2018. Increased variability of eastern Pacific El Niño under greenhouse warming. *Nature*, 564(7735): 201-206.

Cesar, H. S. 2000. Coral reefs: their functions, threats and economic value, collected essays on the economics of coral reefs, CORDIO, Kalmar University, pp. 14-39.

Cesar, H. S. J., Westmacott, S., Pet-Soede, L. I. D. A. and Lindén, O. L. O. F. 2002. Coral Bleaching in the Indian Ocean: Socio-Economic Assessment of Effects, pp. 94-106.

Cesar, H., Burke, L. and Pet-Soede, L. 2003. The economics of worldwide coral reef degradation, 23 pp.

Chandrasekar, S., Lazarus, S., Chandran, R., Nisha, J. C., Rajan, G. C. and Satyanarayana, C. 2019. In situ observations increase the diversity records of Rocky-reef inhabiting Echinoderms along the South West Coast of India. *Indian Journal of Geo-Marine Sciences*, 48(10): 1528-1533.

Charles, M., Groot, D., Chancerelle, Y. and Leemans, R. 2005. Functions and socio-economic importance of coral reefs and lagoons and implications for sustainable management. Master's thesis, Wageningen University, 147 pp.

Chauhan, O. S., Jayakumar, S., Menezes, A. A. A., Rajawat, A. S. and Nayak, S. R. 2006. Anomalous inland influx of the river Indus, Gulf of Kachchh, India. *Marine Geology*, 229(1-2): 91-100.

Coles, S. L. and Jokiel, P. L. 1978. Synergistic effects of temperature, salinity and light on the hermatypic coral *Montipora verrucosa*. *Marine Biology*, 49(30): 187-195.

Coles, S. L. and Jokiel, P. L. 1992. Effects of salinity on coral reefs. Pollution in tropical aquatic systems, pp.147-166.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R. V., Paruelo, J. and Raskin, R. G., 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387(6630): 253-260.

D. O. D., S. A. C. 1997. Coral reef maps of India. Department of Ocean Development and Space Application Centre, Ahmadabad, India.

Dave, T. H., Vaghela, D. T. and Chudasama, B. G. 2019. Status, distribution, and diversity of some macroalgae along the intertidal coast of Okha, Gulf of Kachchh, Gujarat in India. *Journal of Entomology and Zoology Studies*, 7(3): 327-331.

De, K., Venkataraman, K. and Ingole, B. 2020. The hard corals (Scleractinia) of India: A revised checklist. *Indian Journal of Geo-Marine Sciences*, 49(10): 1651-1660.

DeVantier, L. M., De'Ath, G., Turak, E., Done, T. J. and Fabricius, K. E. 2006. Species richness and community structure of reef-building corals on the near-shore Great Barrier Reef. *Coral reefs*, 25(3): 329-340.

Dewey, D. 1975. Production, in Microeconomics- The analysis of price in markets, Oxford University Press, 65 pp.

Dixit, I. A. M., Kumar P., Kumar, L., Pathak, K. D. and Patel, M. I. 2010. Economic Valuation of Coral Reef Systems in Gulf of Kachchh, Gujarat Ecology Commission, Gandhinagar, 143 pp.

Dixit, I. A. M., Kumar, L. and Kumar, P. 2010. Valuing the services of coral reef systems for sustainable coastal management: A case study of the Gulf of Kachchh, India. In Valuation of Regulating Services of Ecosystems, pp. 187-210.

Dixit, I. A. M., Kumar, P., Kumar, L., Pathak, K. D. and Patel, M. I. 2010. Economic Valuation of Coral Reef Systems in Gulf of Kachchh. Final Report. World Bank Aided Integrated Coastal Zone Management (ICZM) Project.

Dorairaj, K. and Soundararajan, R. 1997. Status of coral reefs of Mahatma Gandhi Marine National Park, Wandoor, Andamans. In Proceeding Regional workshop on the Conservation of Sustainable Management of Coral Reefs, pp. 55-63.

Driml, S. M. 1994. Protection for profit: economic and financial values of the Great Barrier Reef World Heritage Area and other protected areas. Great Barrier Reef Marine Park Authority, 83 pp.

Edward, J. P., Mathews, G., Patterson, J., Ramkumar, R., Wilhelmsson, D., Tamelander, J. and Linden, O. 2008. Status of coral reefs of the Gulf of Mannar, southeastern India. Coastal oceans research and development in the Indian Ocean, 45 pp.

El-Naggar, H. A. 2020. Human Impacts on Coral Reef Ecosystem, In: Natural Resources Management and Biological Sciences, (Edited by Rhodes, E.R. & Naser, H.) IntechOpen, London, pp. 91-108.

English, S., Wilkinson, C., and Baker, V. 1997, Survey Manual for Tropical Marine Resources, 2nd Edition. Townsville: Australian Institute of Marine Science, 354 pp.

FAO, F. 2012. The state of world fisheries and aquaculture. Opportunities and challenges. Food and Agriculture Organization of the United Nations, 223 pp.

Franca, A. 2011. Encyclopedia of Modern Coral Reefs: Structure, Form and Process. *Springer,* 25(8): 39-40.

G.E.C. 1997 "Coastal Marine Environment of Gujarat: a bench mark Survey - Report I Gulf of Kutch," Gujarat Ecology Commission, Vadodara, India.

Gagliano, M., McCormick, M. I., Moore, J. A. and Depczynski, M. 2010. The basics of acidification: baseline variability of pH on Australian coral reefs. *Marine Biology*, 157(8): 1849-1856.

George, R. M. and Jasmine, S. 2015. Scleractinian coral diversity in Indian reefs, their threats and conservation. CMFRI, Cochi, Kerala, pp. 33-37.

Gohil, B. and Kundu, R. 2012. Diversity of the intertidal macrofauna at west coast of Gujarat, India, *Life Sciences Leaflets*, 34(12): 135-145.

Goldberg, J. and Wilkinson, C. 2004. Global threats to coral reefs: coral bleaching, global climate change, disease, predator plagues and invasive species. Status of coral reefs of the world, pp. 67-92.

Gomez, E. D., Alino, P. M., Yap, H. T. and Licuanan, W. Y. 1994. A review of the status of Philippines reef. *Marine Pollution Bulletin*, 29(1-3): 62-68.

Guan, Y., Hohn, S. and Merico, A. 2015. Suitable environmental ranges for potential coral reef habitats in the tropical ocean. *PLoS One*, 10(6): e0128831.

Guiry, M. D. & Guiry, G. M. 2019. *AlgaeBase,* Worldwide electronic publication, National University of Ireland, Galway. 5/19 https://www.algaebase.org

Hammer, Ø., Harper, D. A. T. and Ryan, P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis, *Palaeontologia Electronica* 4(1): 9.

Hoeksema, B. W. and Cairns, S. 2021. World List of Scleractinia, 9/19 http://www.marinespecies.org/scleractinia

Horton, T., Kroh, A., Ahyong, S., Bailly, N. *et al.,* 2021. *World Register of Marine Species*, 9/19. https://www.marinespecies.org/

Huang, D., 2012. Threatened reef corals of the world. *PLoS One*, *7*(3): 34459.

Hughes, D. J., Alderdice, R., Cooney, C., Kühl, M., Pernice, M., Voolstra, C. R. and Suggett, D. J. 2020. Coral reef survival under accelerating ocean deoxygenation. *Nature Climate Change*, 10(40: 296-307.

Ishakani, A. H., Joshi, N. H., Ayaz, M., Sumara, K. and Vadher, K. H. 2016. Assessment of seaweed diversity at Veraval coast, Gujarat. *Journal of Experimental Zoology, India*, 19(2): 863-868.

Jayaprakas, V. and Radhakrishnan, R. 2014. Indian coral reefs: diversity, anthropogenic influences and conservation measure*, International Journal of Humanities , Arts, Medicine and Sciences* , 2(4): 25-36.

Jeyabaskaran, R., 2009. New records of corals from Lakshadweep Islands. *Records of the Zoological Survey of India*, *109*(1), pp.53-64.

Jha, B., Reddy, C. R. K., Thakur, M. C. and Rao, M. U. 2009. Seaweeds of India: the diversity and distribution of seaweeds of Gujarat coast, Springer Science & Business Media, 215 pp.

Joshi, A., Desai, A. Y., Bhatt, A. J. and Dave, T. H. 2018. Bio-resources and Environmental Status in Narara and Poshitra Islands at Marine National Park, Gulf of Kachchh, Gujarat. *International Journal of Bio-resource and Stress Management*, 9(2): 262-268.

Joshi, A., Desai, A. Y., Bhatt, A. J., Kardani, H. K. and Yusufzai, S. I. 2018. Seasonal variations of oceanographic conditions along Marine National Park and Sanctuary, Gulf of Kachchh, Gujarat, *Journal of Experimental Zoology India*, 20(2): 879-884.

Joshi, D., Munjpara, S., Banerji, U. and Parasharya, D. 2014. Coral bleaching observations in the Gulf of Kachchh, India–a climate induced stress on the Scleractinians. *Journal of Aquatic biology and Fisheries*, 2:106-113.

Kalasariya, H., Patel, V., Patel, R., Patel, N. and Rathwa, S. 2020. Seaweeds diversity study of selected Beyt Dwarka coast in Gujarat, India. *International Journal of Botany Studies*, 5(1): 141-145.

Kankara, R. S. and Subramanian, B. R. 2007. Oil spill sensitivity analysis and risk assessment for Gulf of Kachchh, India, using integrated modeling. *Journal of Coastal Research*, 23(5): 1251-1258.

Kardani, H. K., Mankodi, P. C. and Thivakaran, G. A. 2014. Diversity and distribution of gastropods of intertidal region of northern gulf of Kachchh, Gujarat, India. *Ecology Environment and Conservation*, 20(1): 105-110.

Karuppanapandian, T., Karuppudurai, T. and Kumaraguru, A. K. 2007. A preliminary study on the environmental condition of the coral reef habitat. *International Journal of Environmental Science & Technology*, 4(3): 371-378.

Kleypas, J. A. 1997. Modeled estimates of global reef habitat and carbonate production since the last glacial maximum. *Paleoceanography*, 12(4): 533-545.

Kleypas, J. A. and Yates, K. K. 2009. Coral reefs and ocean acidification. *Oceanography*, 22(4): 108-117.

Knowlton, N., Brainard, R.E., Fisher, R., Moews, M., Plaisance, L., Caley, M.J. and McIntyre, A.D., 2010. Life in the World's Oceans: Diversity, Distribution, and Abundance. *Blackwell Publishing Ltd, Oxford. doi*, *10*. 384 pp.

Kumar, J. S. Y., Satyanarayana, C. S., and Venkataraman, K., A. 2017. New Scleractinian coral *Lobophyllia hemprichii* (Family Mussidae) reported first time from the Marine National Park, Gulf of Kachchh, India, *Indian Journal of Geo-Marine Sciences*, 46(4): 738-741.

Kumar, J. S., Y., Satyanarayana, C. S., Venkataraman, K. A., Beleem, I. B., Arun, G., Chandran, R., Ramkumaran, K. and Kamboj, R.D. 2017. Coral reefs transplantation and restoration experience in Pirotan Island, Marine National Park, and Gulf of Kachchh, India. *Indian Journal of Geo-Marine Sciences*, 46(4): 299-303.

Kumar, J. Y. S., Geetha, S., Satyanarayana, C. H., Venkataraman, K. and Kamboj, R. D. 2014. New species of soft corals (Octocorallia) on the reef of Marine National Park, Gulf of Kachchh. *Journal of Pharmaceutical and Biological Research*, 2(10): 50-55.

Kumar, J. Y., Marimuthu, N., Geetha, S., Satyanarayana, C., Venkataraman, K. and Kamboj, R. D. 2014. Longitudinal variations of coral reef features in the Marine National Park, Gulf of Kachchh. *Journal of Coastal Conservation*, 18(3): 167-175.

Kumar, M., Magotra, R., Parikh, J., and Rajawat, A. S. 2017. Changing Landscape of Marine National Park and Sanctuary, Gulf of Kachchh: Ecological Assessment of Mangroves and Coral reefs*, Proc. Nat. Acad. Sci., India Section A: Physical Sciences*, 87(4): 889-900.

Kumar, N. J. I. 2014. An assessment of biochemical compounds in relation with environmental constituents and Phylogenetic relationship and bar coding of different seaweeds from Okha coast of Gujarat, India. Performa for submission of information at the time of sending the final report of the work done on the project, 104 pp.

Kumar, N. J. I., Barot, M. and Kumar, R. N. 2017. Distribution and biochemical constituents of different seaweeds collected from Okha coast, Gujarat, India. *Indian Journal of Geo-Marine Sciences*, 46(2): 349-357.

Kumar, P. S. and Thomas, J. 2019. Seasonal distribution and population dynamics of limnic microalgae and their association with physico-chemical parameters of river Noyyal through multivariate statistical analysis. *Scientific Reports*, 9:1-14.

Lakhamapurkar, J. and Gavali, G. 2018. Coral reef structure at Kachhigarh, Gujarat. *Indian Journal of Geo-Marine Sciences*, 47(2): 503-508.

Magotra R., Kumar, M., Pandey, P., Kaushik, A., Vyas, S. and Gupta, M. K. 2008. Review of Status of Marine National Park, Jamnagar: Evolving a Vision Statement for Management of MNP CMPA Technical Series No. 53, Indo-German Biodiversity Programme, GIZ – India, New Delhi. 107 pp.

Majumdar, S. D., Hazra, S., Giri, S., Chanda, A., Gupta, K., Mukhopadhyay, A. and Roy, S. D. 2018. Threats to coral reef diversity of Andaman Islands, India: A review. *Regional Studies in Marine Science*, 24:237-250.

Margalef, R. 1958. Information theory in biology. General Systems Yearbook - 3. pp 36-71.

Marimuthu, N., Jerald Wilson, J., Vinithkumar, N.V. and Kirubagaran, R., 2013. Coral reef recovery status in South Andaman Islands after the bleaching event 2010. *Journal of Ocean University of China*, *12*(1), pp.91-96.

Marimuthu, N., Ramachandran, P., Robin, R. S., Tudu, D., Hariharan, G. and Ramesh, R. 2016. Spatial variation in the health of coral reef communities of Palk Bay, southeast coast of India. *Aquatic Ecosystem Health & Management*, 19(4): 360-367.

Markad, T. A. 2004. Catch composition and economic analysis of gillnetters operating off Ratnagiri coast. A thesis submitted to Dr. B. S. Konkan Krishi Vidhyapeeth, Dapoli, Maharashtra. pp. 1-98.

McClanahan, T. R., Ateweberhan, M., Muhando, C., Maina, J. and Mohammed, S. M. 2007. Climate change and spatio-temporal variation in seawater temperature effects on coral bleaching and mortality. *Ecological Monograph*, 77:503-525.

Meyer, A. G. 1914. The effects of temperature upon marine animals. *Marine Laboratories of the Tortugas*, 183(6): 1-24.

Michael, L., Rao, D. G., Krishna, K. S. and Vora, K. H. 2009. Late Quaternary seismic sequence stratigraphy of the Gulf of Kachchh, northwest of India. *Journal of Coastal Research*, 25(2): 459-468.

Milliman, J. D. and Droxler, A. W. 1996. Neritic and pelagic carbonate sedimentation in the marine environment: ignorance is not blis. *Geologische Rundschau*, 85(3): 496-504.

Mirza, R., Viradiya, A., Salunke, S. and Hoek, G. 2019. Some important sightings of marine fauna in Southern Gulf of Kachchh, Gujarat, India. *Journal of Entomology and Zoology Studies*, 7(4): 410-416.

Miththapala, S. 2008. Coral reefs: Coastal Ecosystems Series, Ecosystems and Livelihoods Group, (Vol. 1). IUCN. 36 pp.

MNPCS, 2015, Gujarat Marine National Park and Marine Sanctuary, 18(6):2017. https://mnpcs.gov.in/

Mohamed, H. 2016. Winkler Method for Do Determination, Monica Z. Bruckner, Montana State University, 1 pp.

Mohanraj, J., Chelladurai, G., Balakrishnan, S. and Kuam, I. V. 2015. Gulf of Mannar Island coral reef associated gastropods assemblages: Distribution and diversity pattern. *Journal of Coastal Life Medicine,* 3(9): 691-695.

Mohanraj, J., Johnson, J. A., Ranjan, R., Johnson, L., Pandi, U. and Shunmugaraj, T. 2010. Coral reef associated gastropods in Tuticorin coast of Gulf of Mannar biosphere reserve, India. *Indian Journal of Science and Technology*, 3(2): 204-206.

Mollica, N. R., Guo, W., Cohen, A. L., Huang, K. F., Foster, G. L., Donald, H. K. and Solow, A. R. 2018. Ocean acidification affects coral growth by reducing skeletal density. *Proceedings of the National Academy of Sciences*, 115(8): 1754-1759.

Mora, C., Andrefouet, S., Costello, M. J., Kranenburg, C., Rollo, A., Veron, J., Gaston, K. J. and Myers, R. A. 2006. Coral reefs and the global network of marine protected areas. Science-New York then Washington, 1750 pp.

Muley, E. V., Venkataraman, K., Alfred, J. R. B. and Wafar, M. V. M. 2002. Status of coral reefs of India. In Proceedings of the Ninth International Coral Reef Symposium, Bali, pp. 847-853.

Nair, P. V., Ramachandran and Pillai, C. S. G. 1972*. Primary productivity of some coral reefs in the Indian seas.* In: Proceedings of the First International Symposium on Corals and Coral Reefs, Marine Biological Association of India, Mandapam, pp. 33-42.

Nair, R. R., Hashimi, N. H. and Rao, V. P. 1982. On the possibility of high-velocity tidal streams as dynamic barriers to longshore sediment transport: evidence from the continental shelf off the Gulf of Kutch, India. *Marine Geology*, 47(1-2): 77-86.

Nair, V. R. 2002. Status of Flora and fauna of Gulf of Kachchh, India. National Institute of Oceanography, 157 pp.

Nambiar, G. 2015. Corals in Gujarat: a review. *International journal of applied and pure science and agriculture*, 1(7): 2394-5532.

Nambiar, P., Oza G. M. and Khacher L. 1995, “Gulf of Kutch Marine National Park in RGICS Project: No. 7 “Protecting Endangered National Parks, Rajiv Gandhi Institute for Contemporary studies. New Delhi.

Nayak, D. P. and Fulekar, M. H. 2017. Coastal geomorphological and land use and land cover study on some sites of Gulf of Kachchh, Gujarat, and West Coast of India using multi-temporal remote sensing data. *International Journal of Advanced Remote Sensing & GIS*, 6(1): 2192-2203.

Neder, M., Laissue, P. P., Akiva, A., Akkaynak, D., Alberic, M., Spaeker, O., Politi, Y., Pinkas, I. and Mass, T. 2019. Mineral formation in the primary polyps of pocilloporoid corals. *Acta Biomaterialia*, 96: 631-645.

Negri, A. P. and Hoogenboom, M. O., 2011. Water contamination reduces the tolerance of coral larvae to thermal stress. *PLoS One*, 6(5): e19703.

Nelson, H. R. and Altieri, A. H. 2019. Oxygen: the universal currency on coral reefs. *Coral Reefs*, 38(2): 177-198.

Ngoile, M. 1998. Coral reef biodiversity loss. 21(4):2020. https://aquadocs.org/handle/1834/449

OCEAN, 2018. Ocean fined your blue, 21(4):2020. https://ocean.si.edu/

Padate, G., Viradiya, A., Salunke, S. and Mirza, R. 2018. Additional records of macrobenthic fauna in and around Marine National Park and Sanctuary, Gujarat, India. *Journal of Marine Biology & Oceanography*, 7(1): 1-5.

Palomares, M. L. D. and Pauly, D. 2019 SealifeBase World Wide Web electronic publication, 04/19, www.sealifebase.org

Pandey, C. N., Raval, B. R., Parasharya, D., Munjpara, S., Joshi, D. and Banerji, U. 2010. Recruitment and growth study of coral reefs of the Gulf of Kachchh. Gujarat Ecological Education and Research (GEER) Foundation, 146 pp.

Panseriya, H. Z., Gosai, H. B., Vala, A. K., Gavali, D. J. and Dave, B. P. 2021. Assessment of surface water of Gulf of Kachchh, west coast of India: A chemometric approach. *Marine Pollution Bulletin*, 1(170): 112589.

Parasharya, D. and Padate, G. 2013. Status of Scleractinian corals of Narara reef in the Gulf of Kachchh, western India. *Jalplavit*, 4(3): 49-59.

Parasharya, D. and Padate, G. 2014. Additional record of Scleractinian corals on Porbandar coast, Gujarat, India. *Journal of Threatened Taxa*, 6(6): 5900-5904.

Parikh, H., Jadeja, J.K. and Mankodi, P. C. 2019. Diversity and distribution of corals at Poshitra, Gulf of Kachchh, Gujarat. *International Association of Biologicals and Computational Digest,* 4(2): 232-244.

Parmar, H., Anand, Y., Joshi, J., Munjapara, S., Kamboj, R. D. and Salvi, H. 2018. Crustacean Diversity of the Gulf of Kachchh, Gujarat, India. *International Journal of Ecology and Environmental Sciences*, 44(2): 165-169.

Parmar, H., Barad, D. and Parasharya, D. 2015. Reef dependent ichthyofauna of the Gulf of Kachchh, Gujarat, Western India. *International Journal of Fisheries and Aquatic Studies*, 2(6): 33-37.

Parmar, H., Kamboj, R. D., Anand, J., Joshi, D., Munjpara, S. and Salvi, H. 2019. Molluscan Diversity of the Gulf of Kachchh, Gujarat, India. *G.J.B.B.,* 8(2): 129-135.

Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E. 2007. IPCC Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK. pp. 7-22

Pathak, S., Dubey, S., Sharma, M., Mishra, P. and Mahajan, S. K. 2021. Seasonal variation on the density of seaweed species from Veraval and Sikka coast, Gujarat. *Journal of Entomology and Zoology Studies*, 9(1): 1510-1515.

Pelejero, C., Calvo, E., McCulloch, M. T., Marshall, J. F., Gagan, M. K., Lough, J. M. and Opdyke, B. N. 2005. Preindustrial to modern interdecadal variability in coral reef pH. *Science*, 309(5744): 2204-2207.

Pielou, F. D., 1975. Ecological diversity Wiley Intescieco. New York, 165 pp.

Pillai C. S. G. 1967. Studies on corals, Ph.D. thesis, University of Kerala, Trivandrum, India.

Pillai, C. S. G. 1972. Stony corals of the seas around India. Proceedings of Symposium on Corals and Coral reefs, Marine Biological Association of India, pp. 191-216.

Pillai, C. S. G. 1983. Structure and generic diversity of recent Scleractinia of India. *Journal of the Marine Biological Association of India*, 25(1&2): 78-90.

Pillai, C. S. G. 1996. Coral reefs of India, their conservation and management, CMFRI, Cochi, pp. 16-31.

Pillai, C. S. G. and Patel, P. I. 1988. Scleractinian corals from the Gulf of Kachchh. *Journal of the Marine Biological Association of India*, 30(1 & 2): 54-74.

Raghunathan, C. 2015. Diversity of Reef Associated Macrofauna of Rutland Island, Andaman and Nicobar Islands. Records of Zoological Survey of India, Kolkata, 370: 1-152.

Raghuraman, R. and Raghunathan, C. 2013. Status of coral reefs in marine national parks of Andaman Islands, India. *Journal of the Andaman Science Association*, 18(2): 186-191.

Raghuraman, R., Raghunathan, C. and Venkataraman, K. 2013. Present status of coral reefs in India. In ecology and conservation of tropical marine faunal communities. *Springer*, 23: 351-379.

Raghuraman, R., Sreeraj, C. R., Raghunathan, C. and Venkataraman, K. 2012. Scleractinian coral diversity in Andaman Nicobar Island in comparison with other Indian reefs. Proceedings of International day for Biological Diversity: Marine Biodiversity, pp. 75-92.

Rajagopalan, R. 2008. Marine protected areas in India. International Collective in Support of Fishworkers, Chennai, 69 pp.

Rajan, R., Satyanarayana, C., Raghunathan, C., Koya, S. S., Ravindran, J., Manikandan, B. and Venkataraman, K. 2015. Status and review of health of Indian coral reefs. *Journal of Aquatic Biology & Fisheries*, 3:1-14.

Rajasuriya, A. and White, A. T. 1995. Coral reefs of Sri Lanka: review of their extent, condition, and management status. *Coastal Management*, 23(10): 77-90.

Rajkumar, M., Aravind, R. and Pandey, A. K. 2013. Flora and fauna of coral reef habitats excluding fishes. *Ecology, Environment and Conservation ,* 19(4): 1073-1078.

Ramamoorthy, K., Sankar, G. and Sakkaravarthi, K. 2012. Assessment of Reef Associated Biota in the Pirotan Island, Gulf of Kachchh, Gujarat, India. *European Journal of Experimental Biology*, 2(3): 551-561.

Ramesh, C. H., Koushik, S., Shunmugaraj, T., & Murthy, M. R. 2020. Current biodiversity of Mandapam group of Islands in Gulf of Mannar Marine Biosphere Reserve, Southeast coast of Tamil Nadu, India. *Regional Studies in Marine Science*, 39: 101429.

Rao, D.V., 2010. Field guide to corals and coral associates of Andaman and Nicobar Islands. Zoological Survey of India, Kolkata, 283 pp.

Rathoure, A. K. 2018. Marine biodiversity of Gulf of Kutch located in Northeastern Arabian Sea. *International Journal of Avian & Wildlife Biology*, 3(4): 312-318.

Raval, J. V., Chauhan, S. K., Kardani, H. K. and Vadher, P. J. 2020. Diversity of marine brachyuran crabs from the Sikka coast, Gujarat, India. *Journal of Experimental Zoology,* 23(2): 1463-1471.

Rilov, G. and Benayahu, Y. 1998. Vertical artificial structures as an alternative habitat for coral reef fishes in distributed environments. *Marine Environmental Research,* 45(4-5): 431-451.

Rodwell, L. D. and Roberts, C. M. 2000. Economic implications of fully protected marine reserves for coral reef fisheries. 21(4):2020. https://aquadocs.org/handle/1834/556

Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A., Root, T.L., Estrella, N., Seguin, B. and Tryjanowski, P. 2008.

Attributing physical and biological impacts to anthropogenic climate change. *Nature*, 453(7193): 353-357.

Roy, S. 2020. Seaweed diversity within intertidal zone of Olaikuda and Vadakkadu, Rameshwaram, southeast coast of India. *Heliyon*, 6(7): e04585.

Roy, S., Salvi, H., Brahmbhatt, B., Vaghela, N., Das, L. and Pathak, B. 2015. Diversity and distribution of seaweeds in selected reefs and island in Gulf of Kachchh. *Seaweed Res. Utiln.*, 37(1): 12-19.

Sadhukhan, K. and Raghunathan, C. 2012. A study on diversity and distribution of reef associated Echinoderm fauna in South Andaman, India. *Asian Journal of Experimental Biological Sciences*, 3(1): 187-196.

Sadhukhan, K. and Raghunathan, C. 2012. Studies on scleractinian coral diversity in Inglis Island sanctuary Andaman and Nicobar Islands, India. *World Journal of Fish and Marine Sciences*, 4(1): 31-36.

Salvat, B. 1992. Coral reefs a challenging ecosystem for human societies. *Global Environmental Change*, 2(1): 12-18.

Sanghvi, D., Chaudhury, N. R. and Jain, B. 2020. Species and Thallus structure diversity of Chlorophyta in shore platform of Dwarka (Gujarat coast, India). *Transylvanian Review of Systematical and Ecological Research,* 22(1): 29-42.

Sanghvi, D., Chaudhury, N. R. and Jain, B. K. 2019. Macroalgae as indicator species for shore platform zones of Dwarka, Gujarat, India. *Indian Journal of Geo-Marine Sciences,* 48(4): 416-422.

Saravanakumar, A., Rajkumar, M., Serebiah, S. and Thivakaran, G. A. 2007. Abundance and seasonal variations of zooplankton in the arid zone mangroves of Gulf of Kachchh-Gujarat, west coast of India. *Pakistan journal of biological sciences,* 10(20): 3525-3532.

Sarkar, S. D., Aparna, C., Geetanjali, D. and Babu, P. G. 2015. Assessment of genetic diversity among *Sargassum* species from selected locations along the north-west coast of India. *Indian Journal of Fisheries*, 62(3): 161-165.

Sarkis, S., van Beukering, P.J., McKenzie, E., Brander, L., Hess, S., Bervoets, T., Looijenstijn-van der Putten, L. and Roelfsema, M. 2013. Total economic value of Bermuda's coral reefs: a summary. In Coral Reefs of the United Kingdom Overseas Territories, *Springer,* pp. 201-211.

Saroj, J., Gautam, K. R., Joshi, A. and Tehseen, P. 2016. Review of Coral Reefs of India: Distribution, Status, Research and Management. *International Journal of Science*, *Environment,* 5(5): 3088-3098.

Sathianandan, T. V. 2013. Status of Marine Fisheries Resources in India–An Overview, CMFRI, pp. 11-22.

Satyanarayana, C. H. 2009. Handbook on hard corals of Gulf of Kachchh, Zoological Survey of India, Kolkata, 107 pp.

Saxena, A. 2015. Coral Reefs and Their Conservation, a Review. *Biological and Chemical Research*, pp.187-206.

Scheer, G. 1984. The distribution of reef-corals in the Indian Ocean with a historical review of its investigation. Deep Sea Research Part A. *Oceanographic Research Papers*, 31(6-8): 885-900.

Selig, E. R., Casey, K. S. and Bruno, J. F. 2012. Temperature-driven coral decline: the role of marine protected areas. *Global Change Biology*, 18(5): 1561-1570.

Sen Gupta, R. and Deshmukhe, G. 2000. Coastal and marine environments of Gujarat: Ecology and economics; Gujarat Ecological Commission, Vadodara, pp. 132-146.

Sen Gupta, R., Deshmukhe, G., Thivakaran, A., Ramamurthy, K., Chandra, R., Surahiah, S. and Bandhopadhay, S. 1999. Ecology of Gulf of Kachchh and threats to its biotic resources. In workshop on the Gulf of Kachchh, pp. 23-24.

Shah, P., Thakkar, N. J. and Mankodi, P. C. 2017. Comprehensive diversity study with few new records of sea anemones along the Saurashtra cost, Gujarat. *International Journal of Fauna and Biological Studies*. 4(4): 12-18.

Shannon-Wiener, C. E., Weaver, W. and Weater, W. J. 1949. The mathematical theory of communication. The Mathematical Theory of Communication. EUA: University of Illinois Press, Urbana, 96 pp.

Sharma, S., Bahuguna, A., Chaudhary, N. R., Nayak, S., Chavan, S. and Pandey, C. N. 2008. Status and monitoring the health of coral reef using Multi-temporal remote sensing-A case study of Pirotan Coral Reef Island, Marine National Park, Gulf of Kachchh, Gujarat, India. In Proceedings of 11th international coral reef symposium, pp. 647-651.

Shetty, V.R., Bhadalkar, A.A. and Umrania, V.V., 2016. Coral Reef Conservation and Management Strategy: Gulf of Kachchh. *Journal of Biological and Medical Sciences,* pp.169.

Shuchi, B., Joshi, D. and Kamboj, R. D. 2020. Diversity of marine Mollusca in Gulf of Kachchh, Gujarat. *Environment and Ecology*, 38(1): 17-23.

Simpson, E. H. 1949. Measurement of diversity. *Nature*, 163(4148): 688-688.

Singh, H. S. 2003. Marine Protected Areas in India. Singh, H. S., 2003. Marine protected areas in India. *Indian Journal of Geo-Marine Sciences*, 32(2): 226-233.

Singh, H. S., Yennawar, P., Asari, R. J., Tatu, K. and Raval, B. R. 2006. An Ecological and Socioeconomic Study in Marine National Park and

Sanctuary in the Gulf of Katch: A Comprehensive Study on Biodiversity and Management Issues, GEER Foundation, Gandhinagar, pp. 152-160.

Smith, S. V. 1978. Coral-reef area and the contributions of reefs to processes and resources of the world's oceans. *Nature,* 273(18): 225-226.

Sorokin, Y. I. 1995. Ecological Studies, Coral Reef Ecology Vol. 102, Berlin: Springer- Verlag, 468 pp.

Souter, D. W. and Linden, O. 2000. The health and future of coral reef systems. *Ocean & Coastal Management*, 43(8-9): 657-688.

Spalding, M. D. and Grenfell, A. M. 1997. New estimates of global and regional coral reef areas. *Coral reefs*, 16(4): 225-230.

Spalding, M., Burke, L., Wood, S. A., Ashpole, J., Hutchison, J. and Zu Ermgassen, P. 2017. Mapping the global value and distribution of coral reef tourism. *Marine Policy*, 82: 104-113.

Spalding, M., Spalding, M. D., Ravilious, C. and Green, E. P. 2001. World atlas of coral reefs, Univ of California Press, 520 pp.

Sreenath K R, Ecological studies of Gulf of Kutch coral reefs with special emphasis on scleractinian diversity, 2015. Ph.D. thesis, ICAR- Central Institute of Fisheries Education, Mumbai, India.

Sreenath, K. R., Jasmine, S., George, R. M., Ranjith, L., Koya, M. and Kingsly, H. J. 2015. Community structure and spatial patterns in hard coral diversity of Agatti Island, Lakshadweep, India. *Indian Journal of Fisheries*, 62(3): 35-44.

Sridhar, A., Menon, M., Rodriguez, S. S. and Shenoy, S. 2008. Coastal Management Zone Notification 08 – The Last Nail in the Coffin. ATREE, Bangalore, 81 pp.

Subba Rao, N. V. and Sastry, D. R. K. 2005. Fauna of Marine National Park, Gulf of Kachchh (Gujarat). Zoological Survey of India, 79 pp.

Subha, G. 2013. Environmental and Ecological Importance of Coral Reefs, A Review. *International Research Journal of Environment Sciences*, 2(7): 85-86.

Sukumaran, S., George, R. M. and Kasinathan, C. 2008. Community structure and spatial patterns of hard coral biodiversity in Kilakarai group of islands in Gulf of Mannar, India. *Journal of the Marine Biological Association of India*, 50(1): 79-86.

Teh, L.S., Teh, L.C. and Sumaila, U.R., 2013. A global estimate of the number of coral reef fishers. *PLoS One*, *8*(6): 65397.

Thakur, M. C. and Rao, M. U. 2009. Seaweeds of India: the diversity and distribution of seaweeds of Gujarat coast (Vol. 3). Springer Science & Business Media. 215 pp.

Thivakaran, G. A. and Kundu, S. 2011. Ecology of macro benthos in the coastal waters of Gulf of Kachchh, West coast of India. Marine Biodiversity: Present status and Prospects, pp. 207-225.

Thomas, P. A., Pillai, C. G. & Rajagopalan, M. S. 1996. Demospongae of the Gulf of Kutch. *Journal of Marine Biological Association of India*, 38:124-132.

Tkachenko, K. S., Hoang, D. T. and Dang, H. N. 2020. Ecological status of coral reefs in the Spratly Islands, South China Sea (East Sea) and its relation to thermal anomalies. *Estuarine, Coastal and Shelf Science*, 238:106722.

Toda, T., Okashita, T., Maekawa, T., Alfian, B. A. A. K., Rajuddin, M. K. M., Nakajima, R., Chen, W., Takahashi, K. T., Othman, B. H. R. and Terazaki, M. 2007. Community structures of coral reefs around Peninsular Malaysia, *Journal of Oceanography*, 63(1): 113-123.

Trivedi, J. N., Gadhavi, M. K. and Vachhrajani, K. D. 2012. Diversity and habitat preference of brachyuran crabs in Gulf of Kutch, Gujarat, India. *Arthropods*, 1(1): 13-23.

Turner, J. R. 2009. Coral reef ecosystem of Andaman Islands, Zoologycal Survey of India, Kolkata, 132 pp.

Vadher, P., Gadhvi, I. R., Parekh, H. and Dabhi, J. 2014. Occurrence of marine molluscan along the Chorwad Coast, Gujarat-India. *Advances in Applied Science Research*, 5(5): 24-28.

Vala, R. B., Vadher, K. H., Parmar, A. M., Pampaniya, N. A., Pushp, A. and Joshi, A. 2016. Diversity and status of corals along the Okhamandal coast, western coast of India. *Journal of Experimental Zoology, India*, 19(2): 851-855.

Vala, R., Vadher, K., Patel, M., Parmar, A., Pampaniya, N. and Pushp, A. 2016. Diversity and Distribution of Seaweed at Port "Okha" in Winter Season. *Advances in Life Sciences,* 5(6): 2220-2227.

Vaughan, T. W. 1914. Reef corals of the Bahamas and of southern Florida. *Carnegie Inst Wash Year Book*, 13: 222-226.

Venkataraman, K. 2006. Coral reefs in India, National Biodiversity Authority, Chennai, 16 pp.

Venkataraman, K. and Raghuram, K.P., 2006. Status of Gulf of Mannar coral reefs, India. In *National Research and Monitoring Moderation Workshop* (p. 29).

Venkataraman, K. and Satyanarayana, C. 2012. Coral Identification manual: Published by the Director, 2001. Zoological Survey of India, Kolkata, 136 pp.

Venkataraman, K., Jeyabaskaram, R., Raghuram, K. P. and Alfred, J. R. B. 2004. Bibliography and Checklist of Coral and Coral Reef Associated Organisms of India, Records of Zoological Survey of India. 1-468.

Venkataraman, K., Satyanarayana, C., Alfred, J. R. B. and Wolstenhome, J. 2003. Handbook on Hard corals of India, Zoological Survey of India, Kolkata, pp 1-266.

Venkataraman, K., Srinivasan, M., Satyanarayana, C. H. and Prabakar, D. 2002. Faunal diversity of Gulf of Mannar Biosphere Reserve. Zoological Survey of India, Kolkata, 77 pp.

Veron, J. E. N., and Stafford-Smith, M. G. 2000. Corals of the World, Townsville M.C. Australian Institute of Marine Science, Australia, Mitochondrial DNA part B. 913 pp.

Veron, J. E. N., Stafford-Smith, M. G., Turak, E. and DeVantier, L. M. 2019. *Corals of the World*, 8/19. http://www.coralsoftheworld.org/page/home/

Veron, J. J. 1985, January. Aspects of the biogeography of hermatypic corals. In Proceedings of the 5th International Coral Reef Congress, Tahiti, pp 83-88.

Vivekanandan, E., Hussain Ali, M., Jasper, B. and Rajagopalan, M. 2008. Thermal thresholds for coral bleaching in the Indian seas. *Journal of the Marine Biological Association of India*, 50(2): 209-214.

Wafar, M. V. M. 1999. Status Report India. In: CORDIO Status Report, Linden, O and N. Sprong, eds., pp 25-26.

Wagner, D., Friedlander, A.M., Pyle, R.L., Brooks, C.M., Gjerde, K.M. and Wilhelm, T.A., 2020. Coral reefs of the high seas: hidden biodiversity hotspots in need of protection. *Frontiers in Marine Science*, 776 pp.

Westmacott, S., Cesar, H. S., Pet-Soede, L. and Lindén, O. 2000. Coral bleaching in the Indian Ocean: Socio-economic assessment of effects. Essays on the Economics of Coral Reefs. HSJ Cesar (ed.), pp. 94-106.

Wilkinson, C. 2008. Status of coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia, 296 pp.

Wilkinson, C. R. 1996. Global change and coral reefs: impacts on reefs, economies and human cultures. *Global Change Biology*, 2(6): 547-558.

Wilkinson, C. R., Linden, O., Cesar, H., Hodgson, G., Rubens, J. and Strong, A. E. 1999 “Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change?” *Ambio*, 28(2): 188–196.

Zacharia, P. U., Krishnakumar, P. K., Dineshbabu, A. P., Vijayakumaran, K., Rohit, P., Thomas, S., Sasikumar, G., Kaladharan, P., Durgekar, N. R. and Mohamed, K. S. 2008. Species assemblage in the coral reef ecosystem of Netrani Island off Karnataka along the southwest coast of India. *Journal of the Marine Biological Association of India*, 50(1): 87-97.

Zainee, N. F. A., Ismail, A., Taip, M. E., Ibrahim, N. and Ismail, A. 2019. Habitat preference of seaweeds at a tropical island of southern Malaysia. *Songklanakarin Journal of Science & Technology*, 41(5): 1171-1177.

ACRONYMS

$	US Dollar
%	Percent
°	Degree
°C	Degree Celsius
ANI	Andaman and Nicobar Island
BOD	Biological Oxygen demand
CBR	Cost-Benefit Ratio
CCA	Canonical Correspondence Analysis
CIO	Central Indian Ocean
cm	Centimeter
cm^2	Centimeter Square
CMFRI	Central Marine Fisheries Research Institute
CMI	Coral Mortality Index
CO_2	Carbon Dioxide
Do	Dissolved Oxygen
DO_2	Dissolved Oxygen
EEZs	Exclusive Economic Zones
ENSO	El-Nino Southern Oscillation
g	Gram
g C/m^2/Day	Gram Calories per Meter Square per Day
GDP	Gross Domestic Product
GEER	Gujarat Environment and Education Foundation
GOI	Government of India
GoK	Gulf of Kachchh
GoMBR	Gulf of Mannar Biosphere Reserve
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
km^2	Kilometer Square
LI	Lakshadweep island
LIT	Line Intercept Transect
m^2	Meter Square

mg/lit	Milligram per Liter
MNP	Marine National Park
MPAs	Marine Protected Areas
MS	Marine Sanctuary
NOAA	National Oceanic Atmospheric Administration
NASA	National Aeronautic and Space Administration
PCA	Principal Component Analysis
POS	Public Opinion Scaling
ppm	Parts per Million
ppt	Parts per Thousand
RA	Relative Abundance
RA	Relative Abundance
ROS	Rank Order scaling
sp.	Species
SST	Sea Surface Temperature
TCL	TATA Chemicals Limited
TEV	Total Economic Value
TOC	Total Organic carbon
WoRMS	World Register of Marine Species
WPA	Wildlife Protection Act
ZSI	Zoological Survey of India

APPENDICES

A. Questionnaire- I

ECONOMIC EVALUATION OF CORAL REEF DIVERSITY-A CASE STUDY IN OUTER GULF OF KACHCHH REGION

SCHEDULE-A

I. SOCIO ECONOMIC BACKGROUND

1. Name :
2. Sex :
3. Age :
4. Educational Status :
5. Occupation :

II. GENERAL INFORMATION :

1. Suppose that the Indian Government is going to invest money for the development of the coral reef distributed area and its inhabitants. Which of these measures masers do you consider to be important by ranking them (I to VIII) in order of your preference?

Measures	Ranking
Enhancing eco-tourism	
Increasing fisheries and sea food resources	
Protecting natural habitat and the diversity	
Creating more employment opportunities as alternative livelihood options for the villagers and stakeholders	
Improving educational status	
Others	

2. What problems concerning the natural environment are you most worried about by ranking them (I to VIII) in order of your preference?

Problem	Ranking
Global warming & climate change	
Water pollution	
Habitat destruction	
Overexploitation of reef ecosystem	
Declining fish catches	
Low fish price	
Poor conservation efforts	
Exclusion of stakeholders in coral reef conservation and management	
Others	

3. Are you a member of any social or environmental organizations? …………………………………………………………………..…………………
   If yes, please specify the name (s): ………………………………………………………………………………………
   ………………………………………………………………………………………
4. Which of the following are the most important uses of the coral reef ecosystem?

Uses	Rank
Fish/Shell fish catch	
Medicine	
Breeding and nursery ground to fish	
Ecological functions (Shore stabilization, shield against natural hazards like tsunami)	
Other	

5. Please indicate your opinion on a scale of 'Strongly agree' to 'strongly disagree'.

	Strongly agree	Agree	No opinion	Disagree	Strongly disagree
We have a duty to protect coral reef ecosystem from anthropogenic development regardless of the cost					
We should reduce exploitation of the coral reef ecosystem so that our future generation may benefit from it					
Because rare species of fishes, animals depend on coral reef, they should be protected regardless of the costs					
I should pay for the conservation of the coral reef ecosystem even if I do not visit or do not directly depend on them					
Even if I don't use coral reef now, I am prepared to pay now to protect productivity of the coral reef ecosystem					
It is worth spending money to protect the coral reef ecosystem because they help to protect productivity in the					

area					
We should not disturb coral reef because they provide protective barrier against tsunami & other natural disasters					
We have more important things to think about than the loss of coral reef					

6. Do you think there is a necessity to conserve coral reef ecosystems? …………………… If yes, Why? ………………………………………………..
7. Are you aware of economic evaluation projects of coral reef ecosystems? ....….
8. Do you think there would be any direct or indirect benefit to you or commercially or fisheries resources from this evaluation study? ………………………………………………………………………………………
   If yes,
   Direct Benefits ……………………………………………………………………....
   Indirect Benefits ………………………………………………………………….

CONTINGENT VALUATION SCENARIO

USE OF CORAL REEF ECOSYSTEM

1. Have you heard of the coral reef availabilities at your shore? ………………………………………………………………………………………....
2. (i). have you ever visited the reef ecosystem at your shore?..
   (ii). If yes, how many times?..
   (iii). With how many members?...
3. Are you likely to visit the coral reef ecosystem in the next 5 years? ………………………………………………………………………………………
4. Do you think you are able to get any direct or indirect benefits from the shore?..
   If yes, please list out the direct and/or indirect benefits:
   Direct benefits:…………………………………………………………………
   Indirect benefits:………………………………………………………………..

II. CORAL REEF ECOSYSTEM USE SCENARIO

1. Of the following, which are the most important uses of the coral reef ecosystem? Please according to preference :

Uses	Rank
(a) Medicine	
(b) Finfishes	
(c) Shellfish	
(d) Shoreline protection	
(e) Protection against tsunami, floods etc.	
(f) Tourism	
(g) Others	

2. When in a year do you harvest the coral reef ecosystem?

Resources	Seasons or times in the year

3. How much quality of the resources do you get in a single harvest or time?

Resources	Seasons or times in the year

4. Please classify the resources according to the way you use them.

Resource	Commercial use	Own use

5. What earning (if any) do you get from the coral reef recourses you use?

Resources	Amount

6. Do you feel the necessity of conversing the coral reef ecosystem? ……………………………………………………………………………………….
   If yes, why? ……………………………………………………………………..
   ………………………………………………………………………………………..

7. What do you feel about the actual management rules implemented by the Government protection and exploitation of coral reef?

i. Very strict
ii. Somewhat strict
iii. Moderate
iv. Liberal
v. Other

8. Would you like to start any economic activity if the government allowed you?..

If yes, what?...

9. Are you aware of the ecological importance of the coral reef ecosystem?...
If yes, in what ways ? …………………………………………………………………

10. Are you aware of economic valuation project of coral reef? ……………………………………………………………………………………….....

11. What in general do you think are the most important problems relating to coral reef ecosystem?
(a) Fishing activities
(b) Ghost fishing
(c) Low fish price
(d) Tourism
(e) Increasing fishing pressure
(f) Shore pollution
(g) Loss of biodiversity
(h) Coral reef death

B. Questionnaire-II

ECONOMIC EVALUATION OF CORAL REEF DIVERSITY- A CASE STUDY IN OUTER GULF OF KACHCHH REGION

SCHEDULE-B

SURVEY BY CONTINGENT VALUATION METHOD OF THE RESPONDENTS IN THE STUDY AREA

SOCIO ECONOMIC BACKGROUND

1. Name and address :
2. Sex :
3. Age :
4. Educational status :

Illiterate	Primary	Secondary	H.S.C	Diploma	Degree

5. Occupation :
6. Type of family :

Joint	Nuclear

7. Other household members:

Age	Occupation

8. Are you a member of any social organization? ………………………………………………………………………………………

   If yes, specify name: ………………………………………………………………