

## Repercussions of embarkation wharves in Lakshadweep Islands on coral communities and their ecology

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Present study infers that the construction of embarkation wharves in four of the Lakshadweep islands (Agatti, Amini, Kavaratti and Minicoy) in the last 5 years was accompanied by a marked degradation of coral community structure and coral biodiversity. Reduction in live coral percent cover was significant, from 31% to 4.69% in Agatti, 24% to 5.92% in Minicoy, 22% to 3.49% in Amini and 30.5% to 4.4% in Kavaratti, with a simultaneous rise in the percent cover of other abiotic components. Species diversity of corals dominated by the massive reef-building corals was lost, affecting the structure and stability of the reef at these sites. Resilience potential of the reef became poor due to the monospecific colonization of corals belonging to very few genera like *Pocillopora* and *Montipora*. Reduction in coral cover and its diversity endangered the strength of the reef frame in the activity site and enhanced its vulnerability to the natural stress or calamities.

**[Keywords:** Corals, Lakshadweep, Development activities, Resilience, Monocolonization]

### Introduction

Coral reefs are the important and valuable economic assets for the countries hosting it. Coral reefs provide economic benefits worth 375\$ billion each year<sup>1,2</sup>. People live around the coral reef coasts benefit from the reef resources in terms of fisheries, storm surge and wave protection and tourist income. Despite their numerous benefits, coral reefs are degraded due to the natural and manmade disturbances. Development of coastal areas adjacent to the reefs becomes inevitable due to the continuous rise in the global coastal population. Various developmental activities has been promoted in the reef areas including construction of marine structures, recreational tourism and unsustainable exploitation of reef fishes all of which collectively leads to the deterioration of corals and severe economic losses<sup>3</sup>. An unplanned coastal development project not only affects the local economy but also damage the reef structure making it more vulnerable to the natural stresses.

Lakshadweep archipelago, the only atolls in the Indian sub continent comprises 11 inhabited and 25 uninhabited islands supporting wide variety of flora and fauna. The Islands are formed on the atolls

themselves, generally located on the eastern rim and separated from the reef on the west by shallow lagoon. Navigation is a major link for all islands. The normal practice for the ships is to anchor on the reef and have the passengers and cargo transported to the Islands by small mechanized boats and barges respectively. The anchoring of cargo and passenger vessels outside the reef and the movement of smaller vessels through the lagoon and the necessity of maintaining the navigational channels deep enough has contributed enough to the degradation of corals. In order to mitigate the impacts of vessel movement and anchoring on reefs, construction of embarkation facility has been proposed.

This study examines the impacts of construction of embarkation facility over corals and their diversity in four Lakshadweep islands (Agatti, Amini, Kavaratti and Minicoy). The reef building scleractinian corals which form large reef structures are highly vulnerable to the damage resulting from the introduction of marine structures like piers and piles. The biophysical status of the reef described by the percent cover of live corals and other reef communities were assessed before, during and post the construction of embarkation wharves. Records of abundance and

diversity of coral and other benthic cover in the intertidal and subtidal areas of the development sites were recorded every year. These were compared to detect changes on corals and their diversity as a result of development activities. In addition, the temporal pattern of chlorophyll a and turbidity were assessed around the study area.

## Materials and Methods

### Study area

The Lakshadweep archipelago was located 200-400 km of the southwest coast of India ( $8^{\circ}$ - $13^{\circ}$  N;  $71^{\circ}$ - $74^{\circ}$  E) and comprises 12 atolls, 3 reefs and 5 submerged banks distributed from the north to south. There are 36 islands covering an area of 32 sq.km and are geographically isolated. Of the 36 islands, 10 islands were inhabited. Lakshadweep archipelago is one of the significant tropical Island ecosystem encompassing fragile ecosystems including coral reefs, lagoons, sea grasses, seaweeds and Mangroves which in turn are inhabited by a wide variety of flora and fauna. Construction of embarkation facilities took place in the eastern side of 4 Lakshadweep Islands viz. Agatti, Amini, Kavaratti and Minicoy in order to divert the vessel traffic to east and relive pressure on the corals in the western side of Kavaratti and Agatti, southern side of Amini and northwestern side of Minicoy Islands (Fig. 1).

### Biophysical status of the reef

The developmental activities were started in 2005 and continued till 2011. A survey on the biophysical status of the reef was conducted in the study sites before the developmental activities begun. Later, the survey was conducted twice in a year during the progress of developmental activities. The survey in the developmental sites were carried out following the Line Intercept Transect Method and Belt transect method with slight modifications depending on the survey site and length of the transect.

### Intertidal Region

Three transects one on the alignment and close to the physical structure of the embarkation facility, one 50 m upstream to the north and another 50 m downstream to the south, were marked out in the intertidal region. The transects began at the supralittoral point (i.e. a point just above the highest water mark) and extended to the edge of the breaker zone i.e., where the reef begins to slope and

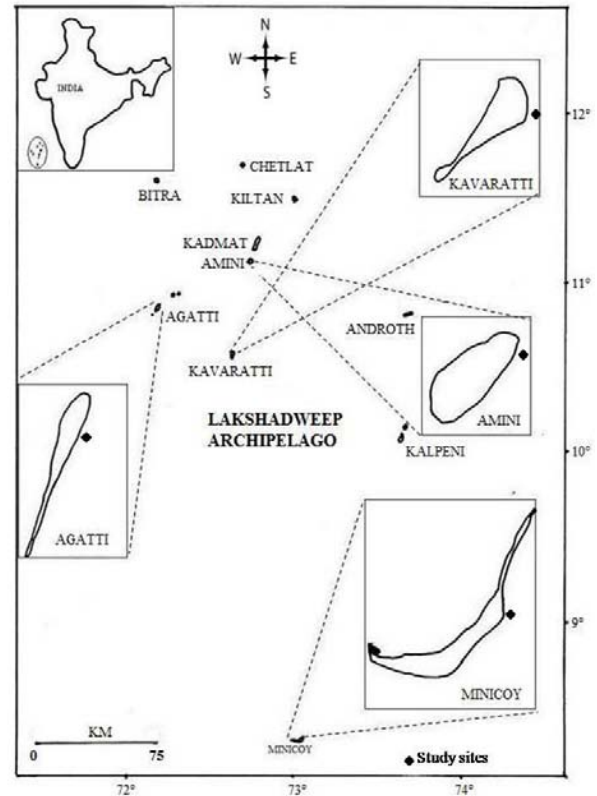


Fig. 1—Map showing the study sites in Lakshadweep Islands

constitutes the beginning of the subtidal zone. The lengths of the transects varied as a function of the expanse of the intertidal zone, from 30 m in Minicoy Island to 150 m in Amini Island. Observations in the intertidal areas were made on foot following the line transects. The belt transect survey design was adopted, with a distance of 2.5 m on either side of the line having been taken into consideration. The effective width of the transect is therefore 5 m. The line laid along the transect was marked at intervals of 5 m, thus enabling an observer to report data for every 25 m<sup>2</sup> areas of the transect. All the life forms within these squares were recorded and reported as percent cover of the area under consideration.

### Subtidal Region

In the subtidal region, the transects were extended from breaker zone down to a depth of 12 m-17 m, depending upon the projected extension of the wharf into the subtidal zone. The design of observations was the same as in the case of intertidal transects. i.e., belt transects of 5 m width and data records for every quadrat of 25 m<sup>2</sup>. However, considering that the density of corals is more and that the impacts could be

more widespread in subtidal region than in the intertidal region, two additional transects, each of 100 m length, perpendicular to the three transects, were also covered. The first of these two transects was as near to the breaker zone as possible (without the observer being smashed against the reef by the waves) and the other in the deeper waters, joining the outer extremities of the three transects. Unlike the intertidal transects, these subtidal transects were laid out in permanence, i.e. the ropes and markings locating the position of the transects were left in place so as to carry out observations at exactly the same points subsequently. The study sites were shown in the Fig. 1.

#### *Coral species diversity*

The corals present in the study site were identified to the maximum taxonomic resolution possible underwater. The corals were photographed using Olympus  $\mu$  tough 8000 camera in macro mode. High resolution photos that reveal the corallite details were used to identify the corals up to species level. The corals were identified using the taxonomic keys<sup>5</sup>.

#### *Chlorophyll a and Turbidity*

The concentration of chlorophyll a in sea water is an indirect measure of nutrient enrichment<sup>6</sup>. Nutrient enrichment in sea water leads to an increase in Phytoplankton biomass which is reflected in the concentration of Chlorophyll a pigment. A 4 km resolution remote sensing data from Moderate Resolution Imaging Spectroradiometer (MODIS) AQUA satellite were used to monitor the chlorophyll a and turbidity pattern around the study area in 4 Lakshadweep Islands during the progress of developmental activities. Both chlorophyll a and turbidity were closely connected with coral cover and influence the coral extent. The algorithm for surface chlorophyll-concentrations<sup>7</sup> was used. The algorithm form describes the polynomial best fit that relates the log-transformed geophysical variable to a log-transformed ratio of remote-sensing reflectance. Turbidity was measured as diffuse attenuation coefficient ( $kd_{490}$ ). Diffuse attenuation coefficient is a measure of downwelling spectral irradiance at a wavelength of 490 nm. It is directly related to the amount of scattering particles in the water column. The diffuse attenuation coefficients of downwelling irradiance at 490 nm were estimated using the algorithm<sup>8</sup>. The algorithm form describes the polynomial best fit that relates the log-transformed geophysical variable to a log-transformed ratio of

remote-sensing reflectances.

#### *Statistical analysis*

The data obtained from the Intertidal and subtidal areas were pooled to get an average percent cover of live corals and other benthic forms in the developmental sites. Multivariate analysis was performed to understand the present status of the reef environment in the developmental sites. Principal Component Analyses (PCA) was conducted for different life-form categories observed in order to determine the most important benthic composition that contributes to the community changes before and post the completion of developmental activities. Similarity between the community structures of the study sites was determined using correspondence analysis (CA). In addition, Bray-Curtis similarity analysis was performed to assess the similarity between islands based on the changes in community composition due to the developmental activities. All the statistical analysis was performed using the statistical software PAST, version 2.15.

#### **Results**

The developmental activities in the reef areas of Lakshadweep Islands have drastically reduced the live coral cover with simultaneous increase in other abiotic components in all the four islands. Mechanical damage and suspended particles arising from the developmental activities were the prime factors that lead to the death of majority of the reef building corals. Changes in the percent cover of different benthic forms in the developmental sites between 2005 and 2011 were presented in the Fig. 2. Preliminary survey on the study sites before the initiation of development activities revealed the presence of healthy coral cover ranging a maximum of 33.5% in Agatti to a minimum of 17% in Kavaratti. However, dead corals were the dominant forms in the study sites of all the islands ranging from 79.6% in Kavaratti to 51.8% in Agatti. The developmental activities begun in 2005 and proceeds at different phases and at different time intervals. The development activities were highly active in between 2006 and 2009 and impart maximum damage to the live coral colonies. This was evident from the decrease in live coral cover from 35% to 15% in Agatti; 19% to 8% in Amini; 20.3% to 4.4% in Minicoy. The scenario was however, different in Kavaratti as there was no perceptible change in the live coral cover. The loss of corals out of

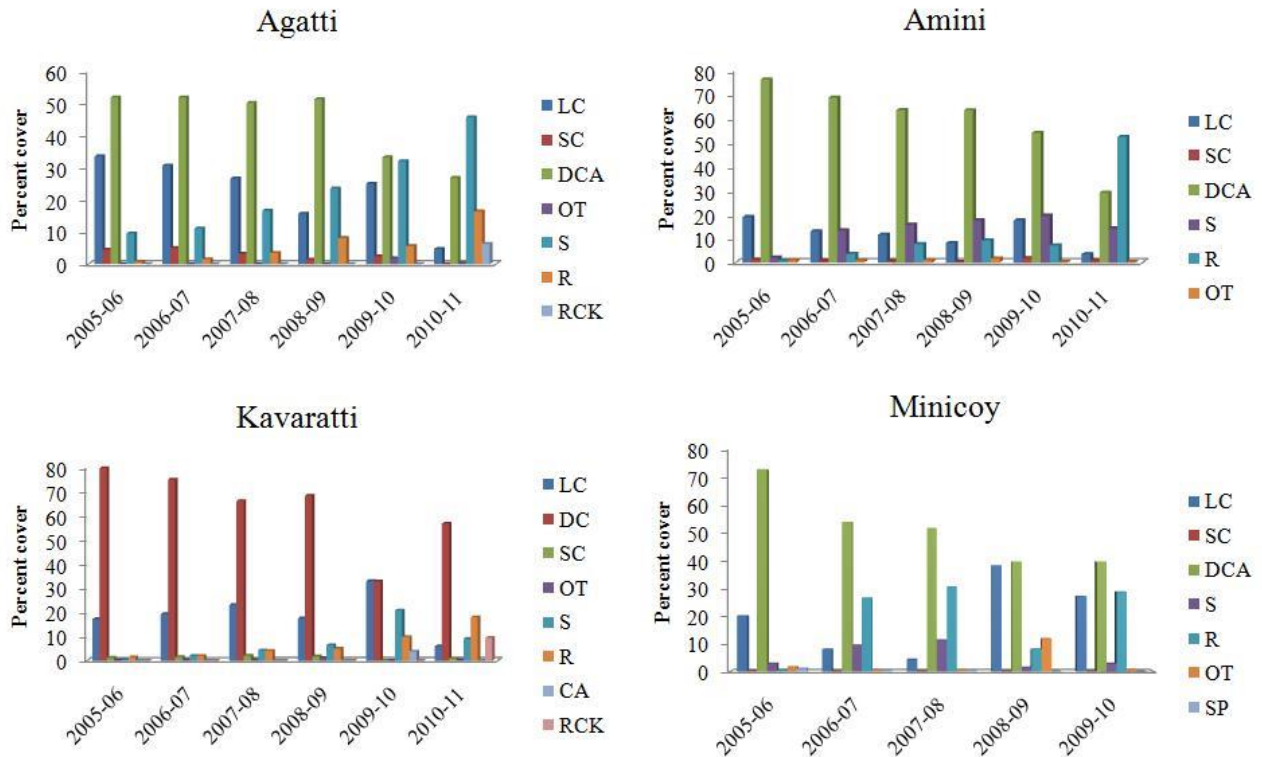


Fig. 2—Percent cover of benthic forms during the study period. The live coral cover was significantly reduced between the Initial and Final Observations

developmental activities was compensated by the recruitment of new coral colonies.

Towards the final phase of developmental activities, there was a gradual increase in the percent cover of live corals. The live coral cover has increased to a maximum of 38.6% in Minicoy to a minimum of 17% in Amini. Similarly the live coral cover has increased up to 25% and 33% in Agatti and Kavaratti respectively. The hike in the live coral cover was mainly due to the recruitment of new coral colonies. However, the live coral cover has decreased during the final observations in 2011. The loss of live coral colonies supersede the recruitment of new coral colonies as the developmental activities advance to the subtidal area. Moreover, the survival rate of new coral recruits was poor in Agatti, Amini and Kavaratti Islands. Majority of the new recruits were smothered by sediment and dead. The live coral cover decreased to a minimum of 4.69% in Agatti; 3.49% in Amini; 5.92% in Kavaratti and 27.41% in Minicoy. Corals of *Acropora* sp were the major victims to the developmental activities, as they were totally absent during the final observation (Fig. 3).

List of coral species recorded in the study

sites during the preliminary and final observations were presented in the Table 1. Species diversity of corals has been severely reduced due to the developmental activities in the reef areas of Lakshadweep islands. The species diversity of corals decline by 75% in Agatti and 76% in Amini Island. Similarly, the species diversity of corals decline by 80% and 66% in Kavaratti and Minicoy islands respectively (Fig. 4). The percent cover of branching form of corals belonging to *Acropora* was largely turned to rubbles. The massive corals belonging to the genus *Porites*, *Symphilia*, *Platygyra*, *Favia* and *Favites* shows partial mortality due to the smothering effect of sediments. The reef shows a good resilient potential as evident from the presence of new recruits and this contributed to the rise in percent cover of live corals in the later phase of developmental activities. However, the recruitment of new coral colonies was monospecific belonging to very few species of *Pocillopora* and *Montipora*. The survival rate of new coral recruits was poor as most of the new recruits of *Pocillopora* sp were dead within a year due to the smothering effect of sediment particles.

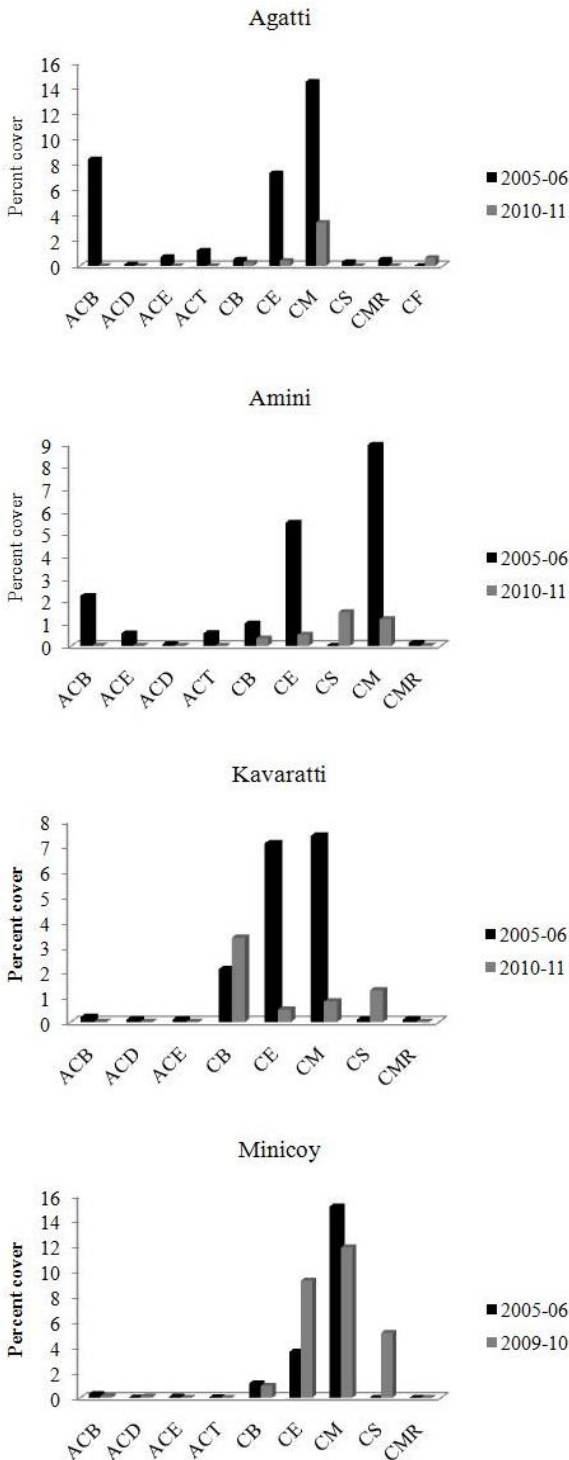


Fig. 3—Percent cover of different forms of reef building corals before and after the developmental activities in Lakshadweep Islands

The annual average concentration of chlorophyll a pigment was low ranging between a minimum of 0.16 mg/m<sup>3</sup> in Amini to a maximum of 0.19 mg/m<sup>3</sup> in Minicoy during the initial phase of developmental

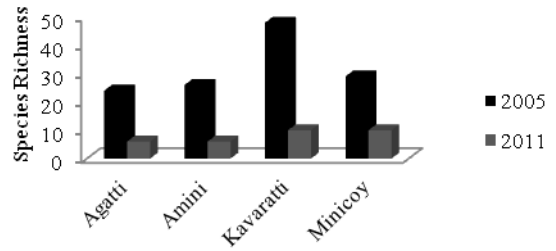


Fig. 4—Coral species richness between the Initial and Final Observation

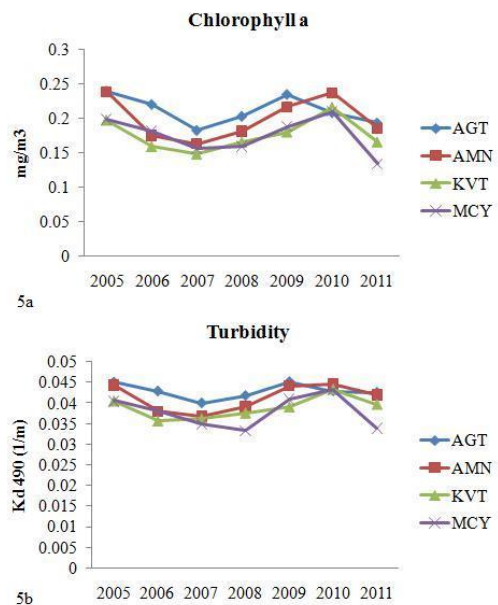


Fig. 5—5a- Chlorophyll a pattern in the study sites of Lakshadweep Islands, 5b- Turbidity pattern in the study sites of Lakshadweep Islands

activities in the intertidal region till 2007. The chlorophyll a concentration, increased to maximum of 0.24 mg/m<sup>3</sup> in Amini and Agatti and 0.21 mg/m<sup>3</sup> in Kavaratti and Minicoy as the developmental activities progressed towards the reef crest (Fig. 5a). The chlorophyll a concentration around the study site however, decreased post the developmental activities. Similar trend was observed with annual average of Kd490 values as it increased during the progress of developmental activities in the subtidal area and decreased post the termination of developmental activities (Fig. 5b).

Principal component analysis showed the contribution of DCA and Rubbles as major drivers of change in the community composition of Kavaratti and Minicoy respectively (Fig. 6). Similarly the

Table 1—List of corals recorded in the study sites of Lakshadweep Islands

S. No	Coral sp	Agatti		Amini		Kavaratti		Minicoy	
		2005	2011	2005	2011	2005	2011	2005	2011
1	<i>Acanthastrea echinata</i>	-	-	-	-	-	-	+	-
2	<i>Acanthastrea hiliae</i>	-	-	-	-	+	-	-	-
3	<i>Acropora aspera</i>	+	-	+	-	-	-	+	-
4	<i>Acropora carduus</i>	-	-	-	-	+	-	-	-
5	<i>Acropora digitifera</i>	-	-	-	-	+	-	-	-
6	<i>Acropora formosa</i>	-	-	-	-	-	-	+	-
7	<i>Acropora humilis</i>	-	-	-	-	-	-	+	+
8	<i>Acropora hyacinthus</i>	+	-	-	-	-	-	-	-
9	<i>Acropora indica</i>	-	-	-	-	-	-	+	-
10	<i>Acropora palifera</i>	-	-	+	-	-	-	-	-
11	<i>Acropora robusta</i>	-	-	-	-	+	-	+	-
12	<i>Acropora subulata</i>	-	-	-	-	+	-	-	-
13	<i>Acropora terus</i>	-	-	-	-	-	-	+	-
14	<i>Astreopora myriophthalma</i>	-	-	-	-	+	-	-	-
15	<i>Coscinarea columna</i>	-	-	-	-	+	-	-	-
16	<i>Cycloseris costulata</i>	-	-	-	-	+	-	-	-
17	<i>Diplostrea heliopora</i>	+	-	-	-	+	-	+	-
18	<i>Echinopora lamellosa</i>	-	-	+	-	+	-	-	-
19	<i>Euphyllia glabrescens</i>	-	-	+	-	-	-	-	-
20	<i>Favia mathoi</i>	-	-	-	-	+	-	-	-
21	<i>Favia pallida</i>	+	-	+	-	+	-	+	+
22	<i>Favia speciosa</i>	+	-	+	-	+	+	+	+
23	<i>Favia stelligera</i>	-	-	-	-	+	-	-	-
24	<i>Favites abdita</i>	-	-	-	-	+	-	-	-
25	<i>Favites complanata</i>	-	-	-	-	+	-	+	-
26	<i>Favites melicerum</i>	-	-	+	-	-	-	-	-
27	<i>Favites virens</i>	+	-	+	-	-	-	-	-
20	<i>Fungia fungites</i>	+	-	+	-	+	+	+	-
21	<i>Fungia fungites</i>	-	-	-	-	-	-	-	-
22	<i>Fungia horrida</i>	-	-	-	-	+	-	-	-
23	<i>Fungia repanda</i>	-	-	-	-	+	-	-	-
24	<i>Fungia scutaria</i>	+	-	+	-	+	+	-	-
25	<i>Galaxea fascicularis</i>	+	-	+	-	+	-	+	+
26	<i>Galaxea ostreata</i>	-	-	-	-	+	-	-	-
27	<i>Gardinerosis planulata</i>	-	-	+	-	+	-	+	-
28	<i>Goniastrea aspera</i>	-	-	-	-	+	-	-	-
29	<i>Goniastrea retiformis</i>	-	-	+	-	+	+	+	-
30	<i>Goniopora columna</i>	+	-	-	-	-	-	-	-
31	<i>Goniopora minor</i>	+	-	+	-	-	-	-	-
32	<i>Goniopora stokesi</i>	+	+	-	-	-	-	-	-
33	<i>Hydnophora microconos</i>	+	-	+	-	+	-	+	-
34	<i>Hydnophora pilosa</i>	-	-	-	-	+	-	-	-
35	<i>Leptastrea transversa</i>	-	-	+	-	-	-	+	-
36	<i>Leptoria phrygia</i>	-	-	-	-	+	-	+	-
37	<i>Leptostrea inaequalis</i>	-	-	-	-	+	-	-	-
38	<i>Lobophyllia corymbosa</i>	-	-	-	-	-	-	+	-
39	<i>Lobophyllia hemprichi</i>	-	-	-	-	+	-	-	-
40	<i>Merulina ampliata</i>	-	-	+	-	-	-	-	-
41	<i>Montastrea annuligera</i>	-	-	-	-	+	-	-	-
42	<i>Montipora divaricata</i>	-	-	+	-	-	-	-	-
43	<i>Montipora aequituberculata</i>	-	-	-	-	+	+	-	-
44	<i>Montipora fovelota</i>	-	-	-	-	+	-	-	-
45	<i>Montipora hoffmeisteri</i>	-	-	-	-	+	-	-	-
46	<i>Montipora monasteria</i>	-	-	-	-	+	-	-	-
47	<i>Montipora tuberculata</i>	-	-	-	-	-	-	+	+
48	<i>Montipora turgescens</i>	-	-	+	+	+	+	-	-
49	<i>Pachyseris rugosa</i>	-	-	+	-	+	-	-	-

50	<i>Pavona maldivensis</i>	-	-	-	-	+	-	-	-
51	<i>Pavona varians</i>	-	-	-	-	+	-	+	-
52	<i>Physogyra lichtensteini</i>	+	-	-	-	-	-	-	-
53	<i>Platygyra daedelia</i>	+	-	-	-	-	-	+	+
54	<i>Platygyra lamellina</i>	+	+	-	-	+	+	+	-
55	<i>Platygyra pini</i>	-	-	-	-	+	-	-	-
56	<i>Platygyra sinensis</i>	-	-	+	+	-	-	-	-
57	<i>Pocillopora eydouxi</i>	-	-	-	-	-	-	+	-
58	<i>Pocillopora meandrina</i>	+	+	-	+	-	+	-	-
59	<i>Pocillopora verrucosa</i>	+	+	+	+	+	+	-	+
60	<i>Porites lichen</i>	-	-	-	-	-	-	+	+
61	<i>Porites lutea</i>	+	+	+	+	+	+	+	+
62	<i>Porites solida</i>	+	+	+	+	+	-	-	-
63	<i>Psammacora contigua</i>	+	-	-	-	+	-	+	-
64	<i>Siderastrea sp</i>	+	-	-	-	-	-	-	-
65	<i>Symphyllia radians</i>	+	-	+	-	+	-	+	+
66	<i>Symphyllia recta</i>	+	-	+	-	+	-	-	-
67	<i>Turbinaria mesenterina</i>	-	-	-	-	+	-	+	-

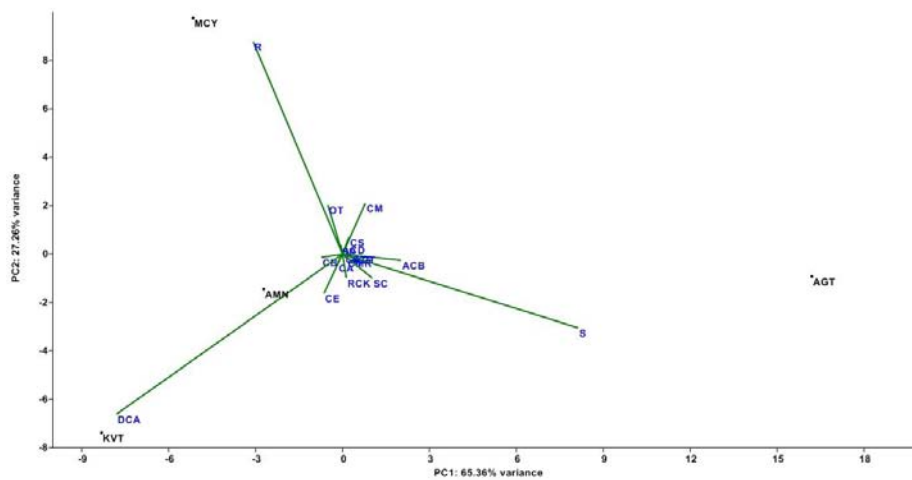


Fig. 6—Principal Component Analyses (PCA) of life-form categories at study sites. (AGT – Agatti, AMN – Amini, KVT- Kavaratti, MCY- Minicoy, DCA – Dead coral with algae, S- Sand, CE- Coral encrusting, CB- Coral branching, RCK- Rock, SC- Soft coral, CM- Coral Massive, CS- Coral Submassive, CA- Coralline algae, ACB- Acropora branching, ACD- Acropora digitate, R- Rubbles, OT- Others including Ascidians, Zoanthids etc.)

contribution of sand towards changes in the community composition of Agatti was also confirmed by this analysis. The first axis (Principal component 1) explains 65.36% of variance and the second axis (Principal component 2) explains 27.26% of variance. Bray-Curtis cluster analysis under paired linkage yielded two groups with more than 75% similarity based on the community composition in the study sites (Fig. 7). The southernmost island of Lakshadweep archipelago, Minicoy was merged with the Kavaratti Island due to their similar community composition especially due to high live coral cover in 2009-10. Similarly the Amini Island was merged with Agatti Island in to a separate group.

### Discussion

From the foregoing account, it is clear that the incidence of live coral cover decreased drastically due to the developmental activities. Unplanned developmental activities like construction of marine structures have profound impact over the ecosystem structure and function ([www.coral.org](http://www.coral.org)). Construction activities that include drilling, dredging, pile erection etc can kill the corals directly in variety of ways and cause habitat degradation. The impact of loss of live corals will be felt in the entire reef ecosystem which could affect the reef services. Numerous studies had reported the adverse impacts of activities associated with coastal development<sup>9,10</sup> and recreational tourism<sup>11,12</sup> over corals.

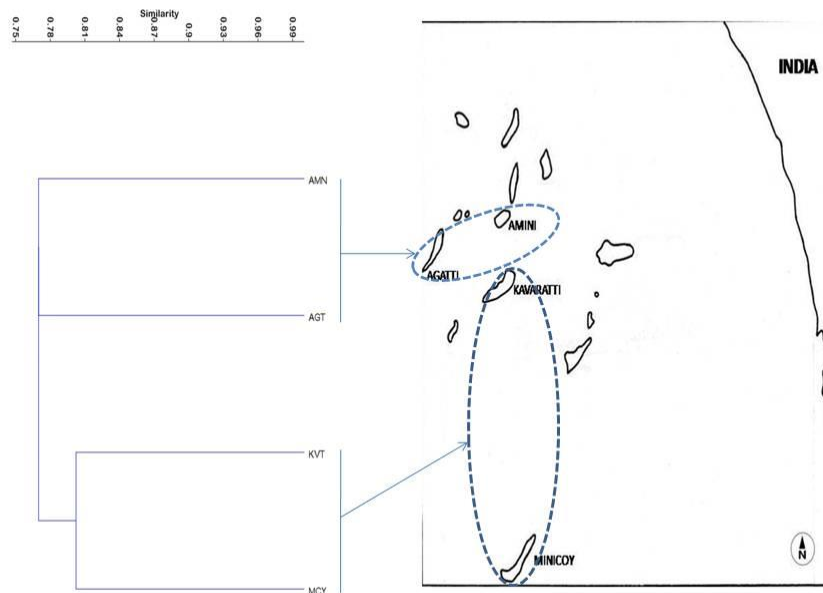


Fig. 7—Bray-Curtis Cluster analysis of study sites under paired linkage. Islands were grouped together based on the similarity in their community composition

Mechanical damage and Physical elimination were the predominant factors associated with developmental activities that take toll on corals. Other stressors resulting from the development activities include sedimentation, bleaching, reduction in the available light and habitat degradation.

Construction of piles includes drilling activities and it results in the suspension of the sand particles from the substrate and their deposition over live coral colonies. In Agatti Island, increase in the percentage of sand resulted in the burial of many coral colonies and the resulting sandy substratum could not support the recruitment of new corals. Massive coral colonies that lie parallel to the jetty alignment in all the islands were completely destroyed which in turn could weaken the reef frame in this part of the island. The construction activity created a corridor of destroyed reef starting from the intertidal and sub tidal regions up to the reef crest.

The suspended sediment particles smothered the live coral colonies and our observation suggested that it was the dominant stressor compared to the other factors taking toll on corals. Even the massive corals that are resistant to sedimentation<sup>13</sup> also were affected and the dead portions of the corals were encrusted with algae. Release of the dugout materials while erecting the piles reduced the available light to the

corals. This has resulted in bleaching in some of the corals belonging to *Porites* and *Platygyra* sp in Kavaratti and Amini Islands. Bleaching is the whitening of corals due to the expulsion of its symbiotic partner zooxanthellae upon stress<sup>14,15</sup>. Corals can recover from bleaching if the conditions become favourable within short period of time<sup>16</sup>. It is the time that determines the bleached colonies to survive or perish and it depends upon the duration of the time that would have taken to complete the construction after the colonies were bleached.

Loss of species diversity of corals was another impact due to the construction activity. The coral diversity reported prior to construction as in the pre-assessment was lost to a greater extent post construction. This is of much concern, because the fallout of the biodiversity loss will be felt in the entire ecosystem<sup>17,18</sup>. The rate and diversity of the recruitment of the new coral colonies was not sufficient to compensate the loss of coral species. They were mostly monospecific belonging to the species like *Pocillopora*, *Symphillia* and *Montipora* compared to the wide range of species reported in the pre-assessment report. There were no signs of recovery of massive coral colonies except that it served as a substrate for new coral recruits. Continued stress conditions could result in the changes in the



cover of massive corals and leads to the dominance of mono species<sup>19</sup>. Elimination of massive forms in the reefs will weaken the reefs and thereby eliminate the important microhabitats available for fishes<sup>20</sup>.

Being small oceanic islands surrounded by vast open ocean, the islands of Lakshadweep were highly vulnerable to natural factors like storms and surge, waves, cyclones. Moreover, the Lakshadweep islands were low lying and suffer from the risk of sea level rise. The fragility of Lakshadweep islands and ecosystems has been reviewed by James<sup>21</sup>. In addition to the natural calamities, the coral reefs of Lakshadweep were also highly sensitive to the global phenomena like ENSO. The bleaching event in 1998 has killed nearly 26% of the live corals and almost 82% of the corals were bleached<sup>22</sup>. The recovery of corals after the bleaching event was relatively slow and it is influenced by the local processes<sup>23</sup>. Though the recovery of corals largely depends on the return of optimal conditions of temperature and light, the secondary stress factors like macro algal dominance, sedimentation and developmental activities could hinder the recovery of corals. Despite the fact that, islands of Lakshadweep were formed on the coral reefs, various developmental activities were in progress that could damage the reef and endanger the very existence of the Islands.

It is evident from earlier studies that corals possess the potential to recover from any disturbance and continue its service<sup>24, 25</sup>. The coral ecosystems that are usually affected by construction of marine structures create a large space of rocks and dead corals that can profoundly support the recruitment of new coral colonies. In this study, the increments in the percent cover of live corals during the later phase of developmental activities were solely due to the recruitment of new coral colonies. However they fail to survive due to continued disturbances. Recruitment of new coral colonies and less disturbances though proper management has been the key to the reef resilience potential.

The impacts of coastal development activities over coral reefs can be mitigated through proper management practice. Integrated coastal zone management practice has been put forward globally to ensure minimal disturbance to the reefs ([www.coral.org](http://www.coral.org); [www.reefresilience.org](http://www.reefresilience.org)). This involves set of regulations, laws and guidelines to regulate all sort of developmental activities like tourism, marine construction and pollution. The coral reef areas of Lakshadweep

were categorized as Coastal Regulation Zone – I (<http://lakshadweep.nic.in/depts/forest/crz.htm>) which has its own set of regulations for its conservation<sup>26</sup>. Strict adherence to the regulations under CRZ-I will ensure minimal disturbances to the coral reefs and its speedy recovery.

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### References

- 1 Brander, L.M., P. Van Beukering, and H.S. Cesar, The recreational value of coral reefs: a meta-analysis. *Ecological Economics*, 2007. **63**(1): p. 209-218.
- 2 Cesar, H.S.J. and P. Van Beukering, Economic valuation of the coral reefs of Hawai'i. *Pacific Science*, 2004. **58**(2): p. 231-242.
- 3 Cesar, H., L. Burke, and L. Pet-Soede, The economics of worldwide coral reef degradation. 2003, Cesar Environmental Economics Consulting, the Netherlands.
- 4 English, S., V. Baker, and C. Wilkinson, *Survey manual for tropical marine resources*, 1997, Australian Institute of Marine Science, Townsville, Australia.
- 5 Veron, J., Corals of the World, vol. 3. *Australian Institute of Marine Science. Townsville, Australia*, 2000.
- 6 Novoa, S., G. Chust, Y. Sagarminaga, M. Revilla, A. Borja, and J. Franco, Water quality assessment using satellite-derived chlorophyll-*a* within the European directives, in the southeastern Bay of Biscay. *Marine Pollution Bulletin*, 2012. **64**(4): p. 739-750.
- 7 O'Reilly, J.E., S. Maritorena, D.A. Siegel, M.C. O'Brien, D. Toole, B.G. Mitchell, M. Kahru, F.P. Chavez, P. Strutton, and G.F. Cota, Ocean color chlorophyll *a* algorithms for SeaWiFS, OC2, and OC4: Version 4. *SeaWiFS postlaunch calibration and validation analyses, part*, 2000. **3**: p. 9-23.
- 8 Mueller, J.L., SeaWiFS algorithm for the diffuse attenuation coefficient, *K* (490), using water-leaving radiances at 490 and 555 nm. *SeaWiFS postlaunch calibration and validation analyses, part*, 2000. **3**(11): p. 24-27.
- 9 Hawkins, J.P. and C.M. Roberts, The growth of coastal tourism in the Red Sea: present and future effects on coral reefs. *Ambio*, 1994. **23**(8): p. 503-508.
- 10 Bozec, Y.-M., G. Acosta-González, E. Núñez-Lara, and J. Arias-González. *Impacts of coastal development on ecosystem structure and function of Yucatan coral reefs, Mexico*. in *Proceedings of the 11th International Coral Reef Symposium*. 2008.
- 11 Allison, W., Snorkeler damage to reef corals in the Maldives Islands. *Coral Reefs*, 1996. **15**(4): p. 215-218.
- 12 Tratalos, J.A. and T.J. Austin, Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, 2001. **102**(1): p. 67-75.

- 13 Stafford-Smith, M. and R. Ormond, Sediment-rejection mechanisms of 42 species of Australian scleractinian corals. *Marine and Freshwater Research*, 1992. **43**(4): p. 683-705.
- 14 Brown, B., Coral bleaching: causes and consequences. *Coral Reefs*, 1997. **16**(1): p. S129-S138.
- 15 Buchheim, J., Coral reef bleaching. *Odyssey Expeditions*, 1998.
- 16 Glynn, P.W., Coral reef bleaching: facts, hypotheses and implications. *Global Change Biology*, 1996. **2**(6): p. 495-509.
- 17 Worm, B., E.B. Barbier, N. Beaumont, J.E. Duffy, C. Folke, B.S. Halpern, J.B. Jackson, H.K. Lotze, F. Micheli, and S.R. Palumbi, Impacts of biodiversity loss on ocean ecosystem services. *Science*, 2006. **314** (5800): p. 787-790.
- 18 Naeem, S., L.J. Thompson, S.P. Lawler, and J.H. Lawton, Declining biodiversity can. *Nature*, 1994. **368**: p. 21.
- 19 Morelock, J., K. Boulon, and G. Galler. *Sediment Stress Coral Reefs*, in: *Proceedings, Energy Industry and the Marine Environment in Guayanilla Bay. Center for Energy and Environmental Research, University of Puerto Rico*. 1979.
- 20 Glynn, P.W., Bioerosion and coral-reef growth: a dynamic balance. *Life and death of coral reefs*, 1997: p. 68-95.
- 21 James, P., Lakshadweep: Islands of Ecological Fragility, Environmental Sensitivity and Anthropogenic Vulnerability. *Journal of Coastal Environment*, 2011. **2**(1): p. 9-25.
- 22 Arthur, R., Coral bleaching and mortality in three Indian reef regions during an El Niño southern oscillation event. *Current Science*, 2000. **79**(12): p. 1723-1729.
- 23 Arthur, R., T.J. Done, H. Marsh, and V. Harriott, Local processes strongly influence post-bleaching benthic recovery in the Lakshadweep Islands. *Coral Reefs*, 2006. **25**(3): p. 427-440.
- 24 Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. Jackson, and J. Kleypas, Climate change, human impacts, and the resilience of coral reefs. *Science*, 2003. **301**(5635): p. 929-933.
- 25 Graham, N., K. Nash, and J. Kool, Coral reef recovery dynamics in a changing world. *Coral Reefs*, 2011. **30**(2): p. 283-294.
- 26 Coastal Regulation Zone Notification., F.a.W.L. Department of Environment, Ministry of Environment and Forests, Editor 2011, Government of India.