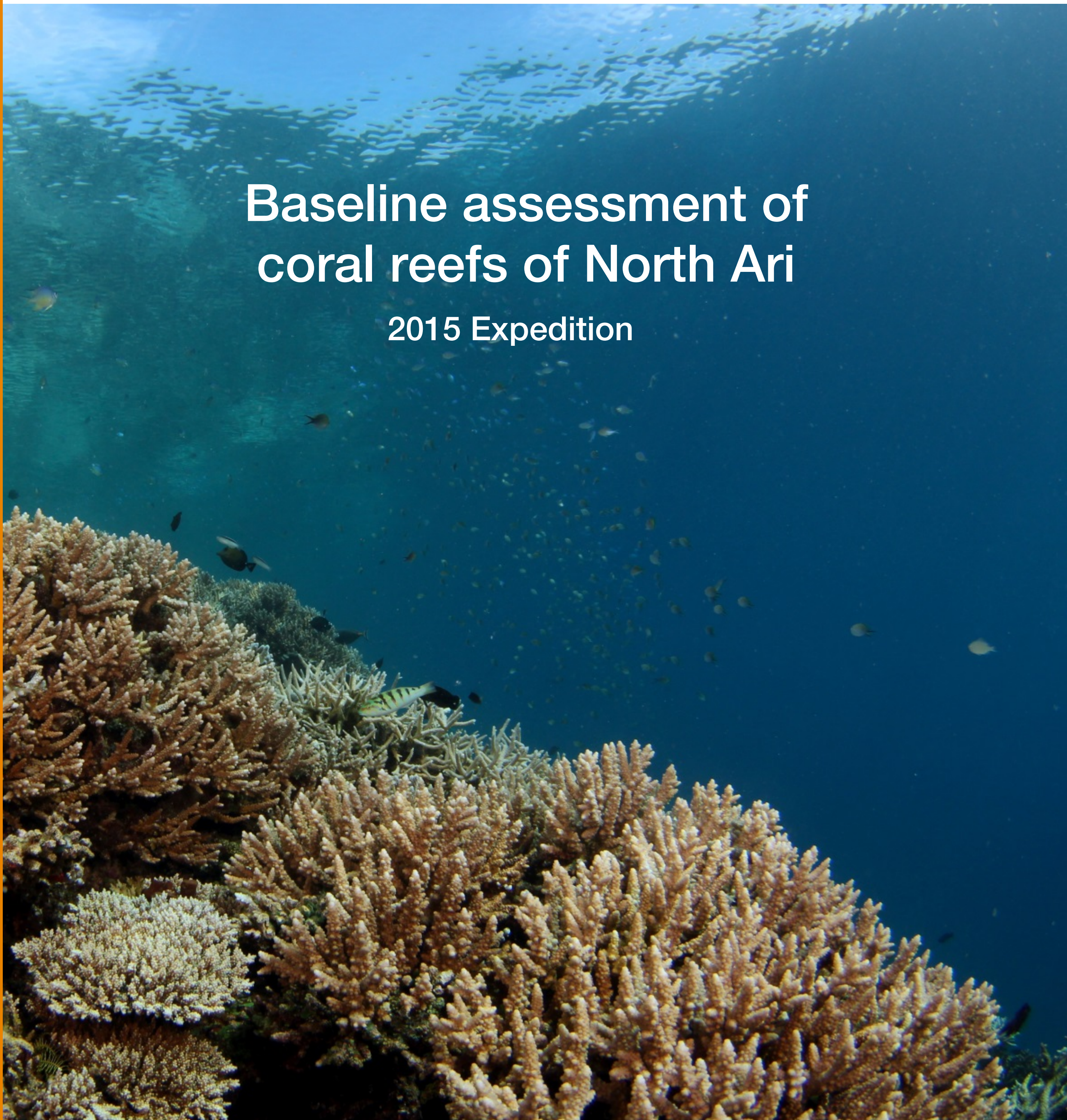
Baseline assessment of coral reefs of North Ari

2015 Expedition



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2015 Expedition

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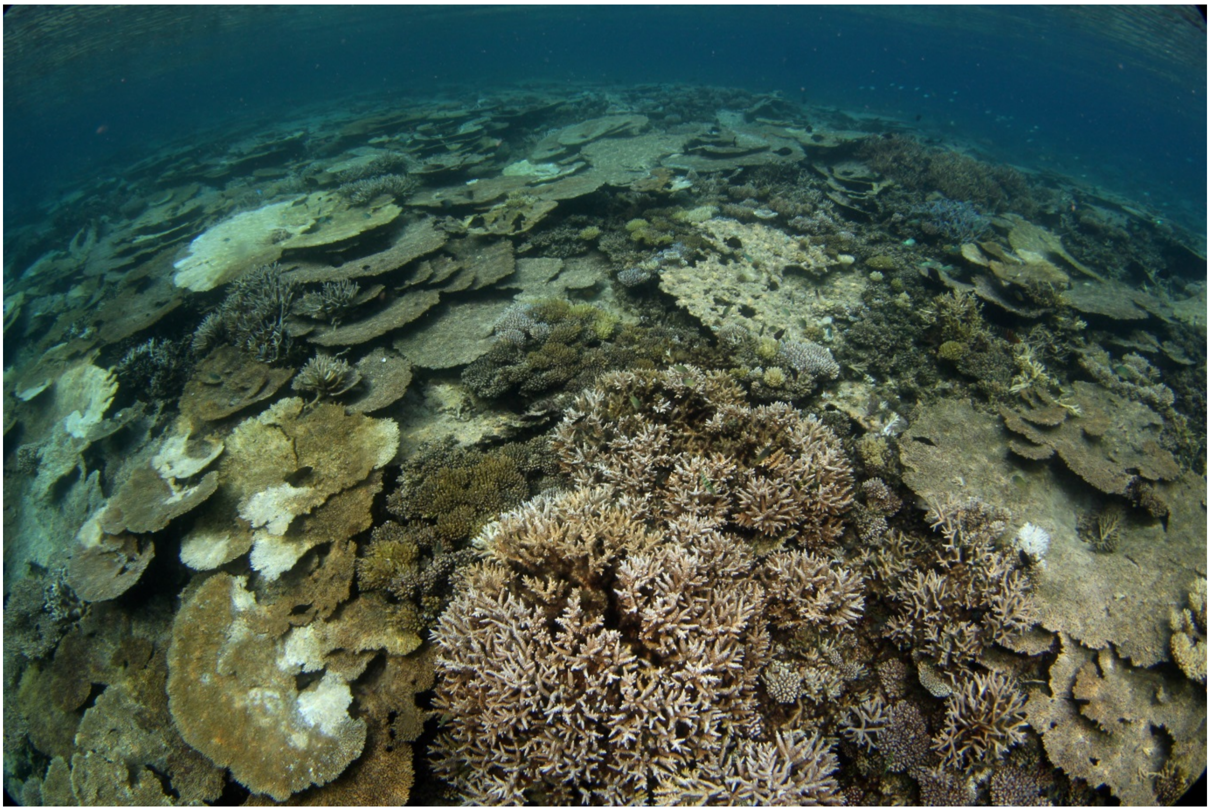
Introduction

Coral reef resilience

Coral reefs are highly dynamic ecosystems, naturally subject to a wide range of natural and anthropogenic disturbances. However, increasing effects of global climate change and other more direct anthropogenic disturbances appear to be increasing rates of coral mortality beyond those which can be sustained. The capacity of coral reefs to recover from successive disturbance events is potentially declining, due to continual declines in coral growth or reproductive output.

Coral reef recovery greatly depends upon disturbance regimes, reef characteristics, ecological characteristics, and anthropogenic influences (Sandin et al 2008; Graham et al 2011). Disturbance characteristics can affect condition and recovery capacity. Disturbances that kill the coral but do not affect the skeleton (e.g. coral bleaching) may be expected to maintain ecological processes and experience recovery more rapidly than disturbances that kill the coral and reduce habitat complexity, such as cyclones. Ecological characteristics, such as grazing and scraping by herbivorous fish and urchins and high levels of functional diversity, can promote functioning ecosystems that will recover more rapidly from disturbances (Bellwood et al 2004). Habitat conditions (often expressed as the percentage of living corals and habitat complexity) are also important because they underpin a series of ecosystem functions such as biodiversity and productivity of reef fish assemblages (Coker et al. 2014). Reefs exposed to high human pressure or in proximity to high human population centers may be expected to show slower recovery due to the likelihood of increased pollution, terrestrial run off and exploitation (Sandin et al 2008).

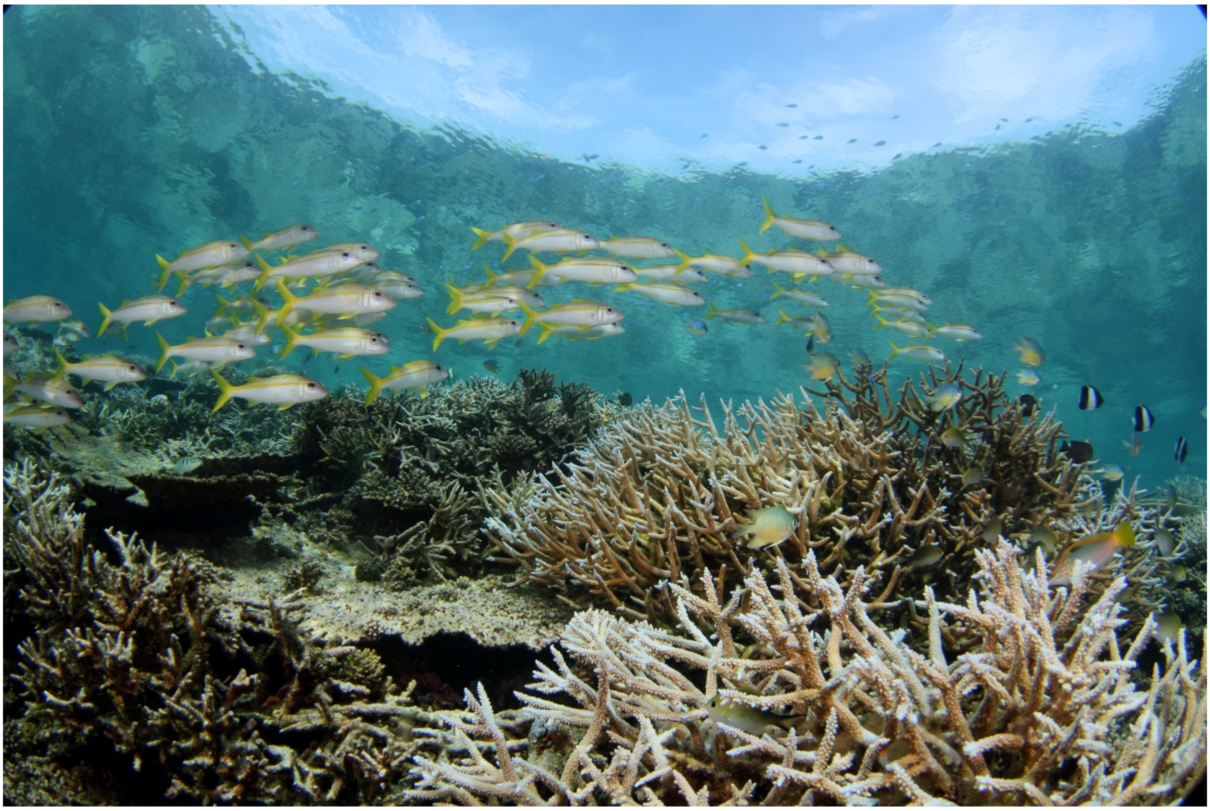


Coral reef scene © Brian Zgliczynski

Resilience in the Maldives

Much of our understanding of coral reefs and resilience comes from the Caribbean and Australia's Great Barrier Reef (Hughes 1994; Mumby et al. 2007; Sweatman et al. 2011; Death et al. 2012), while less is known about coral reef condition and resilience in the Maldives archipelago. The Maldives consists of 26 atolls with ca.1120 islands extending from the central part of the Chagos-Maldives-Laccadive ridge in the central Indian Ocean from about 7°07′ N to 0°40′ S in latitude and 72°33′ E to 73°45′ E in longitude. Maldivian coral reefs are some of the more diverse reefs of the Indian Ocean hosting more than 250 species of corals and 1200 species of fish (Naseer and Hatcher, 2004).

Disturbance regimes in Maldivian reefs have increased in recent years ranging from regular coral bleaching events due to increasing sea surface temperatures, destruction of coral reefs for land reclamation, increasing pressure on coral reef fisheries, increased sedimentation and eutrophication due to coastal construction, to crown-of-thorn starfish outbreaks (Morri et al 2010) resulting in spatial variation in the recovery potential and condition of reefs (McClanahan, 2000; Edwards et al 2001; McClanahan and Muthiga, 2014; Morri et al 2015). The extent to which recovery potential and current condition vary in space among Maldivian reefs is still poorly understood, especially in the context of differing anthropogenic pressures, because most studies have focused on investigating current condition and/or changes in coral cover, recruitment, colony size and species richness in Maldivian reefs following the 1998 and the 2004 bleaching and mass mortality events (McClanahan, 2000; Loch et al. 2004; Bianchi et al 2006a, 2006b; Lasagna et al 2008, Pichon and Benzoni 2007; Lasagna et al 2010; Morri et al 2015).



Coral reef scene © Brian Zgliczynski

Management regimes in Maldives

The management of different islands of the Maldives provides an appropriate setting in which to investigate how anthropogenic threats affect current condition of reefs because gradients can be observed in human settlement and fishing pressure, both of which have been demonstrated to influence community composition in other parts of the world (Sandin et al 2008; Rizzari et al 2014). Three main uses of islands can be observed. These are a) resorts where fishing and harvesting of any marine organisms is prohibited up to 1000 metres of the island (termed the resort 'house reef', and the size of which is determined by the lease agreement) but non-extractive activities (e.g., diving) are allowed; b) uninhabited islands, which are general-use areas permitting fishing and other non-extractive activities with no human settlement; and c) community islands, which are general-use areas permitting fishing and non-extractive activities exposed to human settlement with little waste management (Environmental Guidelines for Tourist Resort Development & Operation in the Maldives). Since management regulation plays a key role mediating between conservation of functional roles and fisheries objectives (Brown and Mumby 2014), it is critical to provide managers with baseline information on current condition of reefs in fished and un-fished areas.

Aims

This is the first study to investigate spatial variation in reef condition within the context of different human pressures in one atoll in the Maldives. Specifically, this study aimed to investigate whether and how coral reef condition (fish biomass, structural complexity, coral composition and live cover, and foraminiferal assemblages) vary spatially among reefs with different population levels and/or under different management regimes within North Ari atoll.

This study tested the hypothesis that fished community and uninhabited islands were more degraded than un-fished resort islands. We expected to find that coral cover, predator fish biomass and water quality would all be significantly lower in community islands than in resort islands, with uninhabited islands falling somewhere in between the two management regimes.

This study provides a detailed baseline of empirical data on coral reef benthic communities, habitat composition, coral reef fish biomass and ecological data for North Ari atoll in order to identify the role of anthropogenic and environmental stressors as drivers of the integrity of reef habitats (allowing classification of reefs into different levels of health and human disturbance). These data can also be useful for the evaluation and improvement of management actions such as the designation of and development of management plans for marine protected areas (MPAs) and marine managed areas (MMAs).

Material and Methods

Study site

This study focused on North Ari (Alifu Alifu) atoll, which was considered representative of Central Maldives as it contains all reef habitat classes and 12 resort islands, 8 community islands and 7 uninhabited islands. This study surveyed 12 islands (out of 27 islands in North Ari) exposed to different human impact and management regimes (four community islands: Rasdhoo, Bodufolhudhoo, Feridhoo and Maalhos, four uninhabited islands: Gaathafushi, Alikoirah, Vihamafaru and Madivaru, and four resorts: Velidhu, Kandholhudhoo, Maayaushi, and Madoogali) (Figure 1). At each island reef, three sites were randomly surveyed close to the island and at each site, three replicate transects of 50m each were laid lengthwise along the reef slope (10 meters depth), with a minimum of 3 m separating each transect.

This study provides a detailed baseline of empirical data on coral reef benthic communities, habitat composition, coral reef fish biomass and ecological data for North Ari atoll in order to identify the role of anthropogenic and environmental stressors as drivers of the integrity of reef habitats (allowing classification of reefs into different levels of health and human disturbance). These data can also be useful for the evaluation and improvement of management actions such as the designation of and development of management plans for marine protected areas (MPAs) and marine managed areas (MMAs).

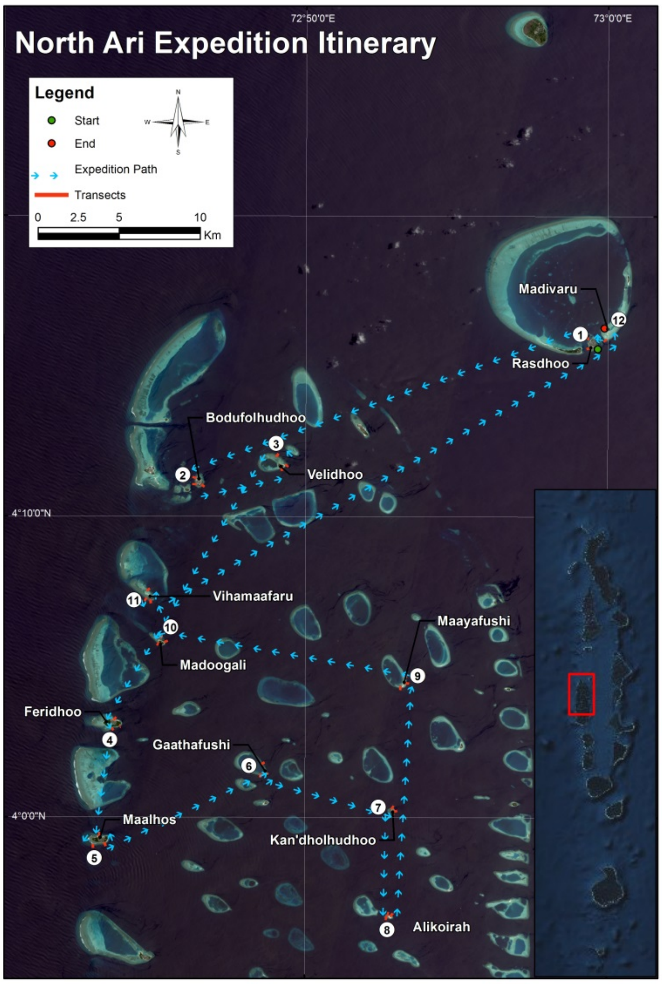


Figure 1. Map of the 12 islands exposed to different human impact and management regimes (4 resort islands, 4 community islands, 4 uninhabited islands) in North Ari (Alifu Alifu) Atoll, Maldives.

Assessment of benthic communities

Benthic composition was surveyed using the point-intercept method, where the substrate directly below the transect tape was surveyed every 50 cm along each transect. Benthic categories recorded included sand, consolidated rubble, turf, crustose coralline algae (CCA), fleshy macroalgae, hard and soft coral, and other benthic invertebrates (e.g. sponges). Hard corals were surveyed to the genus level and abundance (number of individual colonies) was recorded. For all the coral within the belt transect, colony size was also recorded using size classes (5 cm bins up to colonies >66 cm) and live area was then calculated. Similarly, soft corals and fleshy macroalgae were surveyed to genus level. The density of juvenile corals (colonies between 0.5 and 5 cm diameter) together with COTS abundance, sea cucumber, sea urchins abundance and diversity were quantified in a 10 m by 1 m belt transect at the start of each 50 m transect tape. Echinoderms along the 50m transect were also recorded.

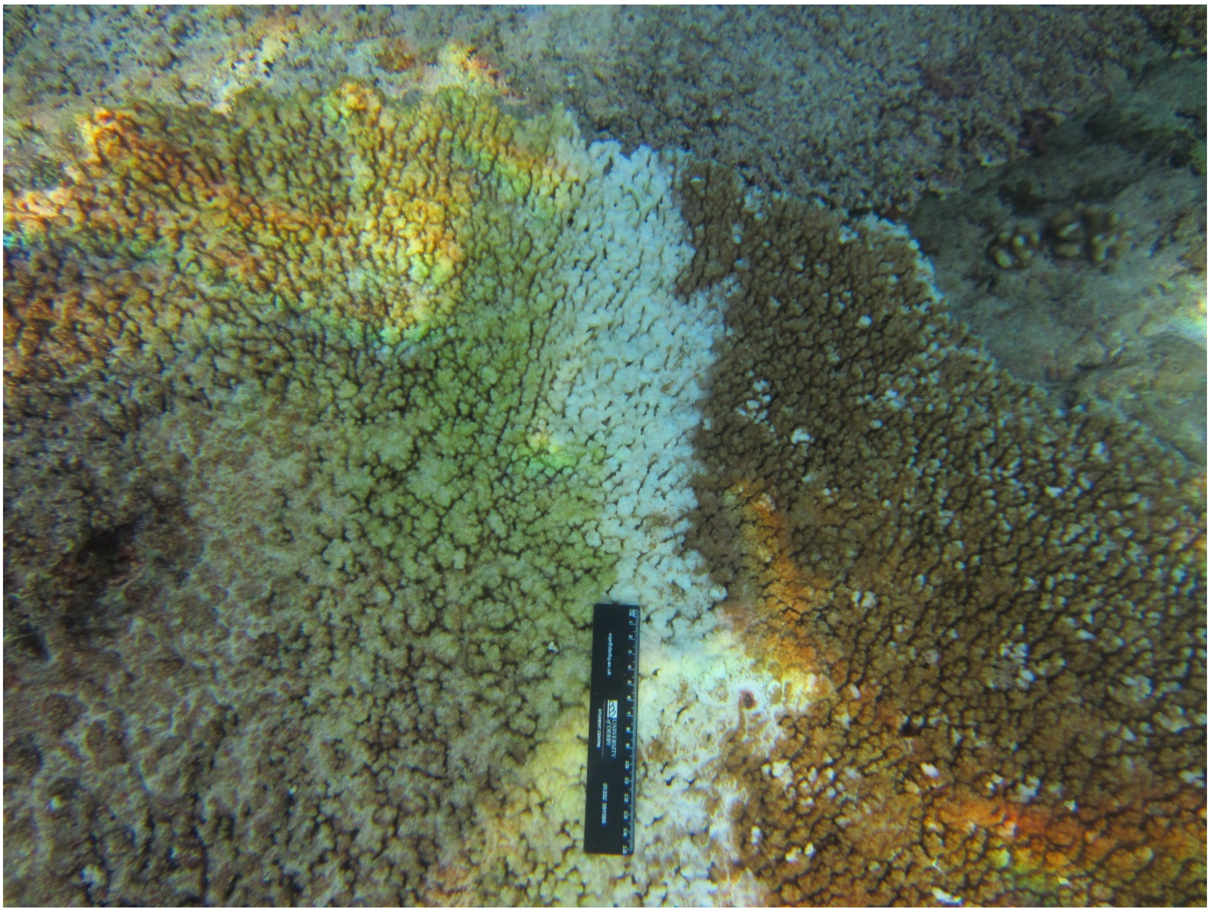
Rugosity

Rugosity is used as an indicator of substrate complexity and is an important ecological parameter. It is a measure of the amount of coral surface area compared to the linear area. Areas of high complexity are likely to provide more places of attachment for corals and algae. To measure rugosity, a 10 m chain was placed along the substrate contour, and the equivalent straight line horizontal distance encompassed by the 10 m of chain was measured. The chain was pushed into all crevices along the horizontal section of the reef. Rugosity (R) was calculated as the straight line horizontal distance along the reef divided by the total chain length, with values close to unity (close to 100%) indicating low structural complexity and lower values indicating high structural complexity (Verges et al. 2011).

Diver measuring Rugosity. © Brian Zgliczynski

Disease surveys

Diseases were visually estimated in each colony within the 10 m by 1 m belt transect. Health status of these corals was also monitored, noting those, which were diseased, bleached and had predatory damage. This was conducted in the first 10 m by 1 m belt transect as for benthic communities. As we were unable to measure if the lesions were progressing, diseases were identified based on their visual signs only (e.g. Porites White Patch Syndrome, [PWPS], White Syndrome [WS], etc.) and thus our analysis may include corals with non-active lesions. Any scleractinian corals displaying such evidence of disease was identified to the genus level and counted within each transect. The prevalence of diseased, bleached and predated corals were estimated as (number of diseased/bleached/predated colonies)/(total number of coral colonies >2 cm) × 100.



Acropora colony affected by pathogens in the community island of Maalhos. © Michael Sweet

Fish assemblages

All fish species were counted by observers on three 50 m x 5 m belt transects. Large and mobile fish species including scarids, serranids, lethrinids, lutjanids, carangids, and a subset of reef-associated scombrids were counted by one observer as transect tapes were laid on the reef and in a 5 m wide belt. Smaller territorial and more cryptic species (including pomacentrids, labrids, planktivorous serranids, cirrhitids, gobiids, balistids, pomacanthids, monacanthids, holocentrids) were surveyed simultaneously by an additional 2 surveyers on a 2 m wide belt who were following the team counting the larger fishes. Individual fish were identified to species, their abundance counted and their size estimated in 5 cm size classes. Species were assigned to feeding groups (apex predator, benthic invertivore, corallivores, herbivores, omnivores, piscivores, planktivores) based on the literature and dietary information

(Froese and Pauly 2015). Total length for individual fish was converted to biomass using the following formula: W= a * TLb, where W is weight in grams, TL is total length and parameters a and b are constants obtained from the literature and other expert knowledge/databases (Froese and Pauly 2015).

Transect on the reef slope. © Chiara Pisapia

Photoquadrats

On each 50 m transect, at every 2 m a 1sq-m photoquadrat was taken at alternate sides of the tape. A PVC stick was used to ensure that the camera was kept at the right distance from the substrate. Reef-building coral genera, and benthic life forms were then identified in the photos using the program coralnet (http://coralnet.ucsd.edu/). Coralnet uses a specified number of spatially random points (in this study 25 points), which were distributed on a photoquadrat image and the features underlying the points were identified.

Diver taking photoquadrats on the slope. © Brian Zgliczynski

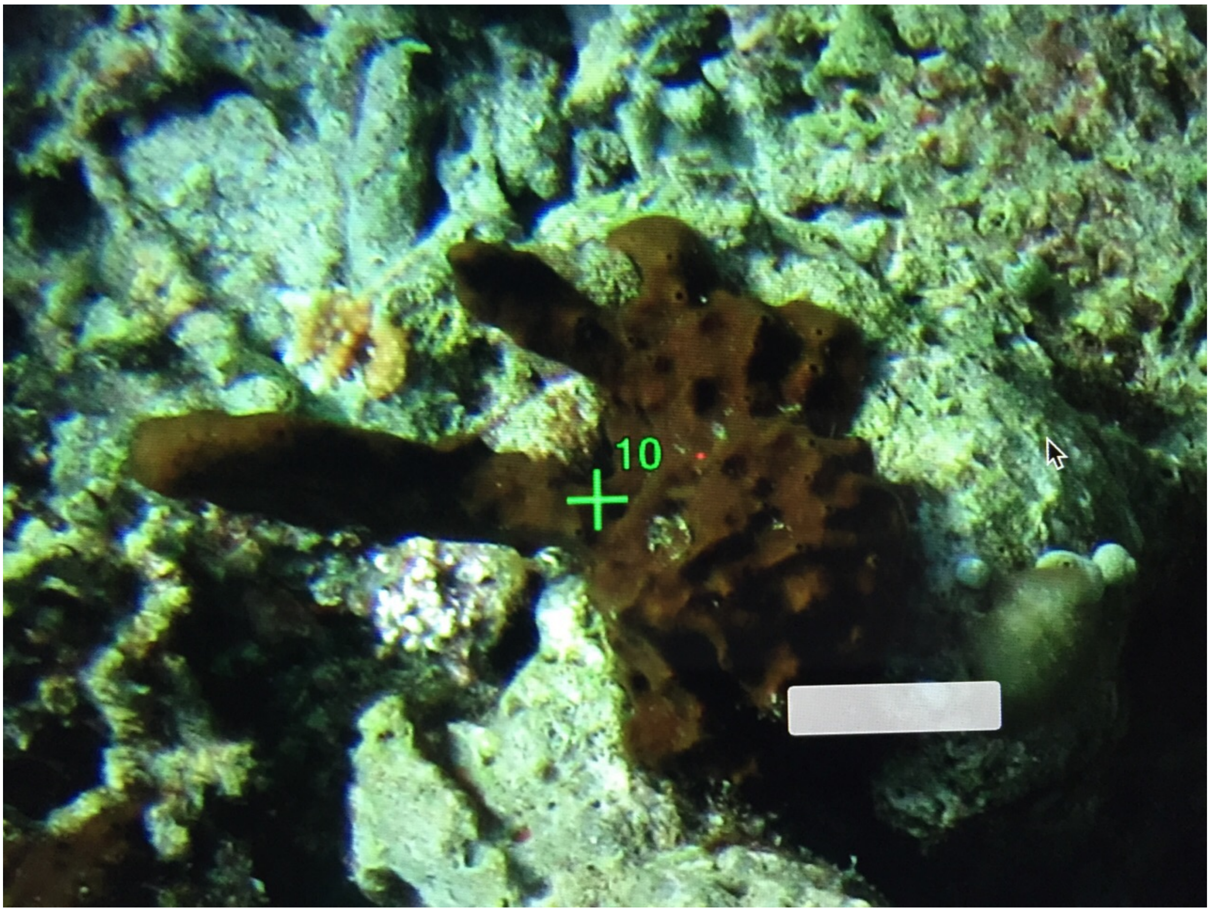


Image from coralnet showing a random point on the photoquadrat. © Kate Furby

Foraminiferal assemblages

Foraminifera were used as bioindicators to validate differences in ecological health between islands under different management regimes. One resort island (Velidhoo), one community (Rasdhoo) and one uninhabited (Gaathafushi) islands were chosen to investigate foramniferal assemblages, and in each site 3 replicate samples were collected at 10 meters depth. A falcon tube of 15 ml was used to collect sediments samples from the 0-1 cm interval in areas with no coral cover. An amount of approximately 6-7 grams of the 15 ml was stored in a solution of ethanol (<70%) and Rose Bengal (2 gr of stain for 1 liter of ethanol). The ethanol was removed after 5-7 days and the sediments dried at open air. The samples were stained to highlight living specimens in case of future biodiversity investigations and to check if the species included in the FI were present with living specimens, i.e. they are still thriving in this region. The remaining part of each subsample was dried at open air for grain size and geochemical analyses. The Foram Index (FI) was calculated based on functional groups according to Hallock et al. (2003) and following the suggestion of Hallock (2012). For each sample, a subsample of 1 gr was used to pick 150-200 specimens. Dix (2001) and Hallock et al. (2003) demonstrated that this amount provides a useful compromise between the precision of larger samples and processing cost.

Water quality

Water samples were taken at the sea floor from the same locations where foramniferal samples were collected. These were immediately taken on board the diving boat for the water quality parameters measurement. PH, temperature and conductivity were measured with a multiparameter meter Orion^{tm} Star A325. The model sensor for the pH was the Orion^{tm} Ross Ultra^{tm} 8107UWMMD and the sensor for the conductivity was the Orion^{tm} DuraProbe^{tm} 013010MD. Dissolved oxygen was measured with DO600 Waterproof ExStik® II Dissolved Oxygen Meter. The measures were repeated also at the sea-surface to record any potential difference between the sea floor (10 m depth) and the surface. The atmospheric temperature from Rasdhoo at 12h00 for each day was compared to the water temperature measured at 10 m depth and averaged per day. Differences in water quality were analysed with a PCA comparing Temperature (°C), dissolved oxygen (ppm), conductivity (mS/cm), salinity and pH between resort, community and uninhabited islands.

Diver collecting water quality samples. © Brian Zgliczynski

Results

Benthic communities

Structural complexity was low (close to 100%) indicating a relatively flat substratum in all islands ranging from 64.9% ± 1.7 SE in the fished community island of Rasdhoo to 78.8% ± 1.2 SE in the community island of Feridhoo (Figure 2). Spatial variation in structural complexity among islands under different management regimes was very low (12.7%) as most of the variation occurred within the same reef habitat.

Coral cover was lowest in the community island Feridhoo 9.2% ±3.6 SE and highest in the uninhabited island Alikoirah 34.6% ± 3.9 SE, while it was consistent among sites with limited variation between islands (around 26% ± 4.8 SE) (Figure 2). Juvenile coral density varied with management regime, being significantly higher in uninhabited islands compared to resorts and community islands (Figure 4). Juvenile density was higher in uninhabited islands, while abundance of adult corals was higher in resort islands (Figure 4).

Crustose coralline algae (CCA) and macroalgal cover were consistently low in all the sites (averaging 5.3 %± 2.3 SE and 2.1%± 0.3 SE respectively). The greatest spatial variation in macroalgal cover was at the very small spatial scale (within the same reef habitat). Turf cover varied with management regimes (variance 19.9%) (Figure 3) as it was significantly lower in unfished resorts (17.3% ± 2.6 SE) and highest in community islands (29.8% ± 4.3 SE) (Figure 2).

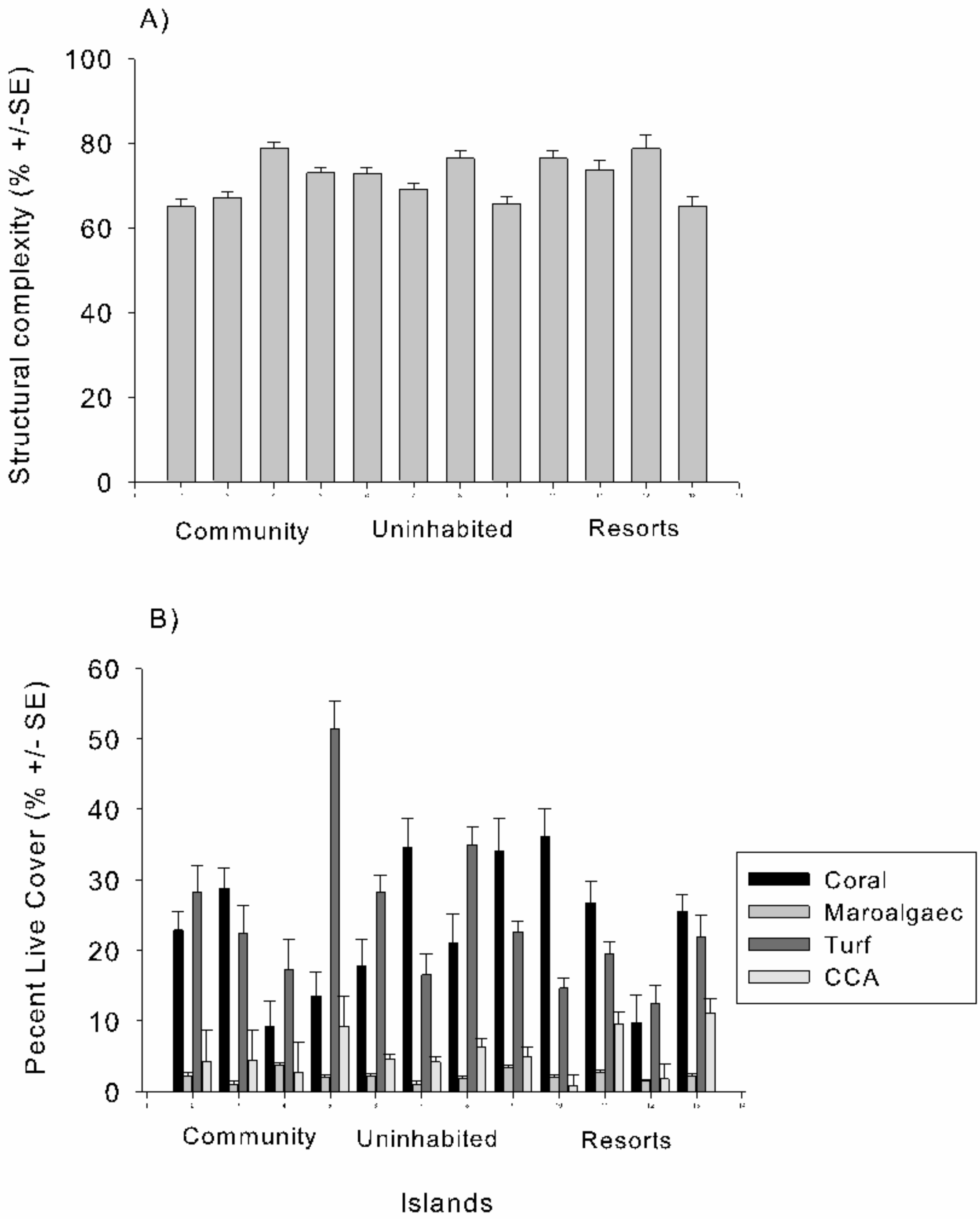


Figure 2. A) Structural complexity (% ± SE) in the 12 different islands under different management regimes and B) percent cover of coral, macroalgae, turf and crustose coralline algae (CCA) in the 12 islands exposed to different management regimes. These data represent the average (± SE) of the three sites per island. The four community islands are in order Rasdhoo, Bodufolhudhoo, Feridhoo and Maalhos, the four uninhabited are Gaathafushi, Alikoirah, Vihamaafaru and Madivaru, and the four resorts are Velidhu, Kandholhudhoo, Maayafushi, and Madoogali.

When compared between management regime, community islands showed lowest total coral cover but highest turf cover (Figure 3).

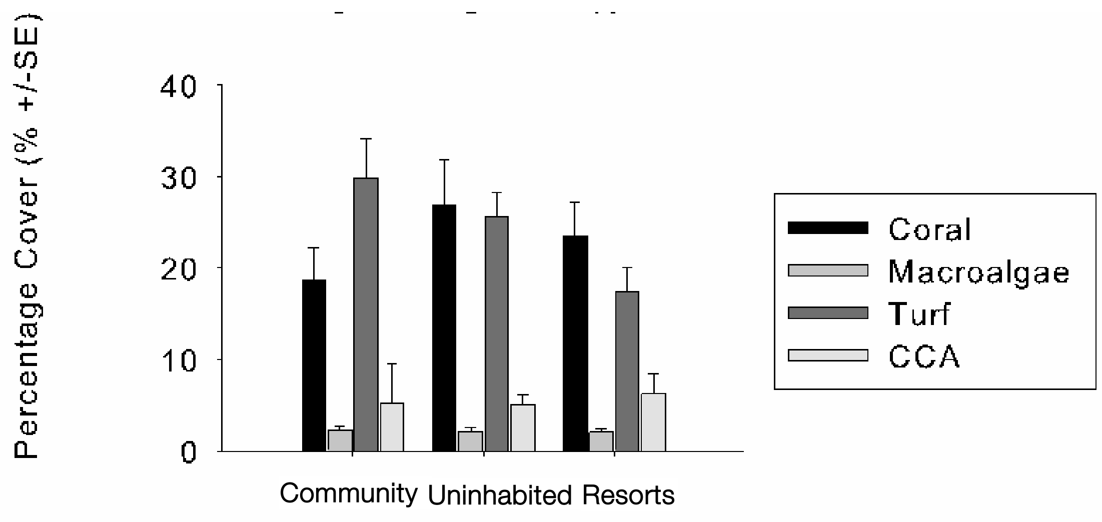


Figure 3. Percent cover of coral, macroalgae, turf and crustose coralline algae (CCA) with different management regimes. These data represent the average (± SE) of the four islands per management regime. Data are from Point Intercept Transects.

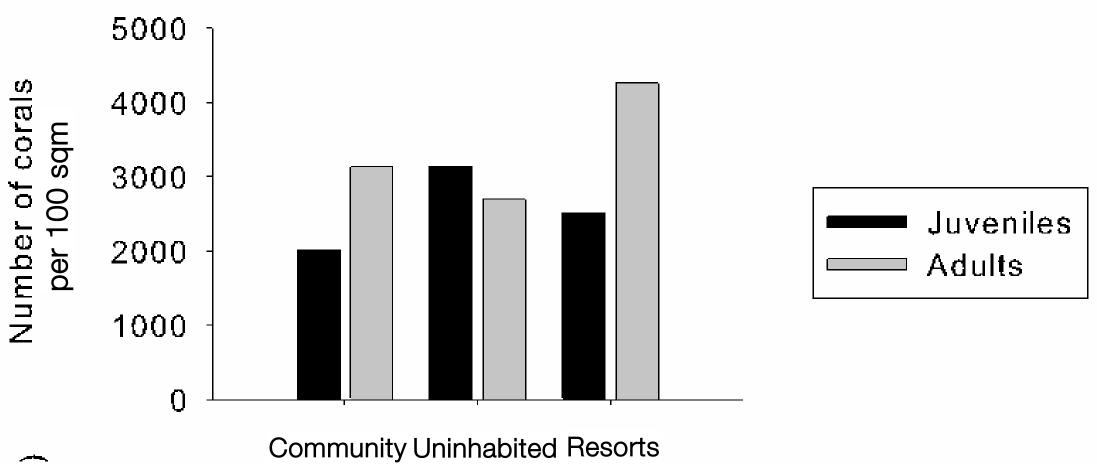


Figure 4. Total number of juvenile and adult corals in the four community islands (C), four uninhabited (U) and four resorts islands (R) in North Ari, Maldives.

Background prevalence of disease (proportion of diseased colonies versus non-diseased colonies) was extremely low and constant among islands (0.02 +/- 0.004 SE). However, it varied significantly among sites (ANOVA $F_{11/24}$=10.9 $p<0.0001$) with 9.5% of colonies in the community island Maalhos showing signs of disease (Tukey test<0.05; Figure 5).

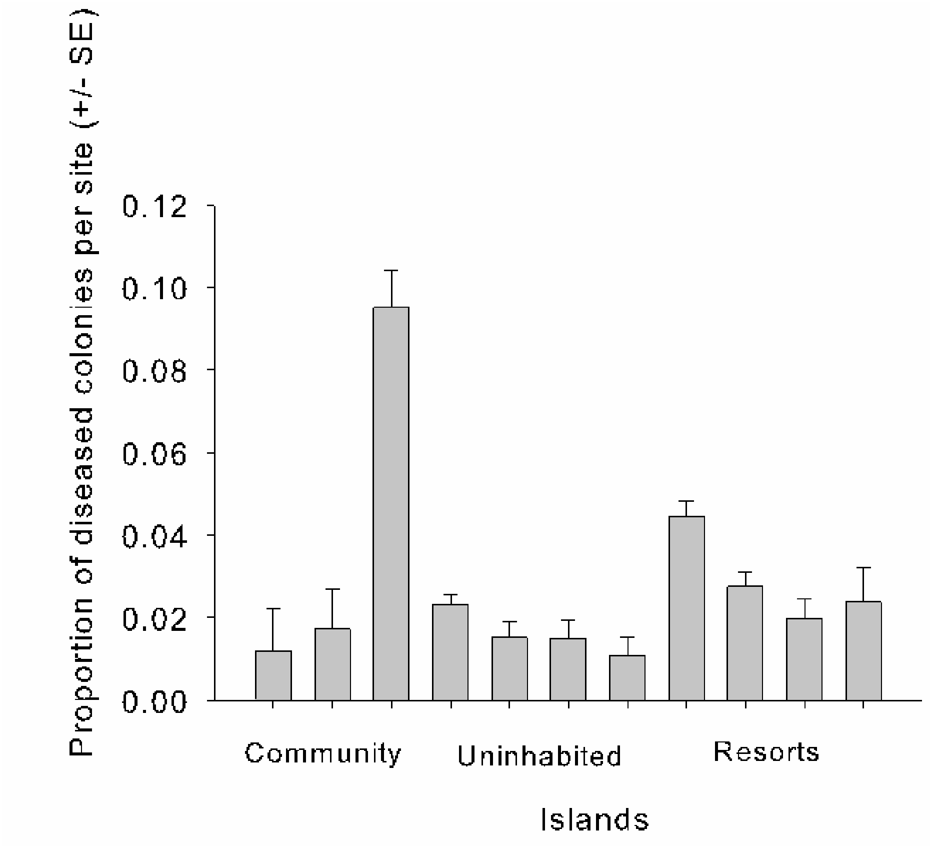


Figure 5. Prevalence of disease (proportion of diseased versus non-diseased colonies) in all genera among 11 islands. The three community islands are in order Rasdhoo, Feridhoo and Maalhos, the four uninhabited are Gaathafushi, Alikoirah, Vihamaafaru and Madivaru, and the four resorts are Velidhu, Kandholhudhoo, Maayafushi, and Madoogali. The community island Bodufolhudhoo was not sampled for disease survey. The black lines separate the islands according to the management regime.

Bleaching

During the expedition the onset of a coral bleaching event was observed, however bleaching prevalence was very low and did not vary significantly between islands. Spatial variation in prevalence of bleaching was very low so all the sites were pulled together. Proportion of bleached colonies versus unbleached among all coral genera was below 0.02 (Figure 6). *Porites* and *Fungia* showed the highest prevalence of bleaching (Figure 6).

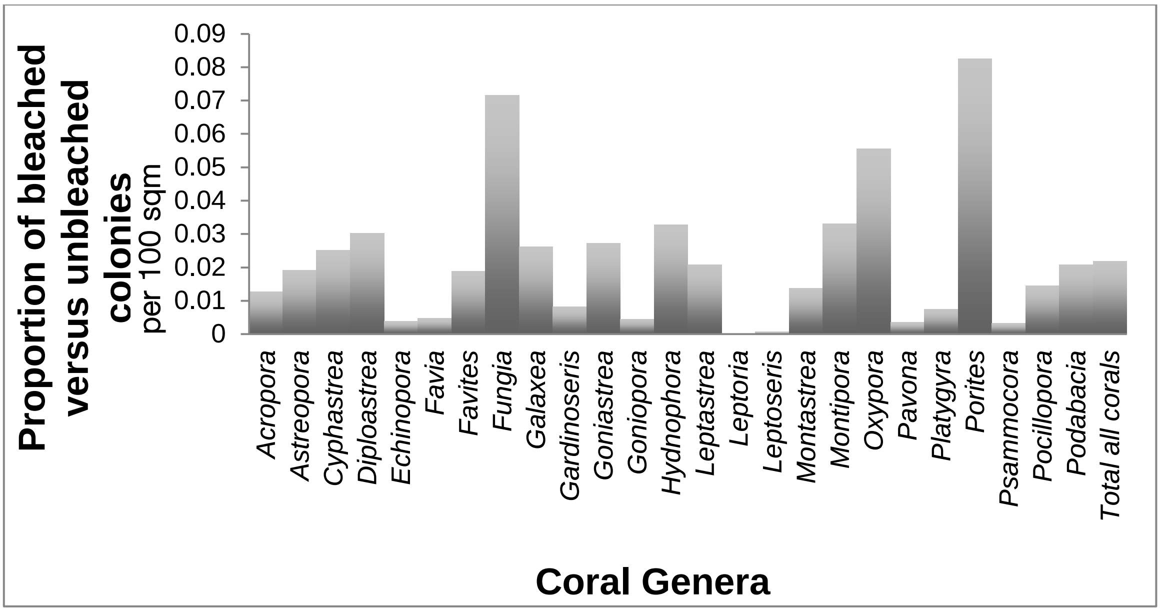
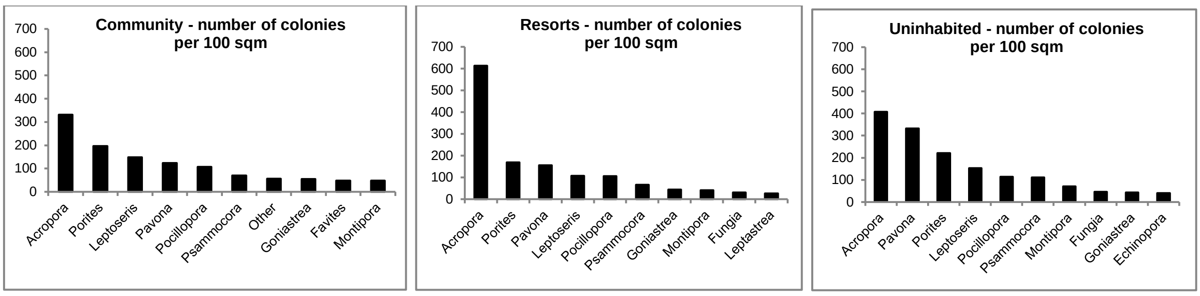


Figure 6. Bleaching prevalence among different coral genera. Proportion was calculated as number of bleached colonies/total number of colonies.

Coral size classes and genera

The total number of colonies and live surface area were significantly different in islands with different management regime. On average, all the management regimes were dominated by *Acropora* both in the total number of colonies recorded as well as the total area covered. However in both resorts and uninhabited islands, the average number of *Acropora* colonies per 100 m^2 (614 colonies in resorts, 407 colonies in uninhabited islands) and the average *Acropora* cover (21.4 m^2 per 100m^2 in resorts and 18.3 m^2 in uninhabited islands) were significantly higher than in community islands (332 *Acropora* colonies per 100 m^2 covering 7.1m^2) (Figure 7). *Acropora* corals thus appear to find more favourable habitats to grow in both resorts and uninhabited islands compared to community islands, with resort islands being the most favourable. Massive *Porites* colonies accounted for the second largest areas of coral cover in all management regimes, and did not vary significantly between them. Some coral genera that were abundant often had low area cover. For instance *Pavona* sp (especially in uninhabited islands) and *Leptoseris* sp were highly abundant while live area was low meaning that their populations were dominated by large numbers of small colonies but very few larger sized colonies. Importantly, the area of the reef covered by larger coral size classes (Figure 7), that is corals larger than 66 cm in diameter, was significantly lower in community islands (1.8m^2 per 100m^2) compared to resorts (7.6m^2 per 100m^2) and uninhabited islands (10.6m^2 per 100m^2) (Figure 7).

A)



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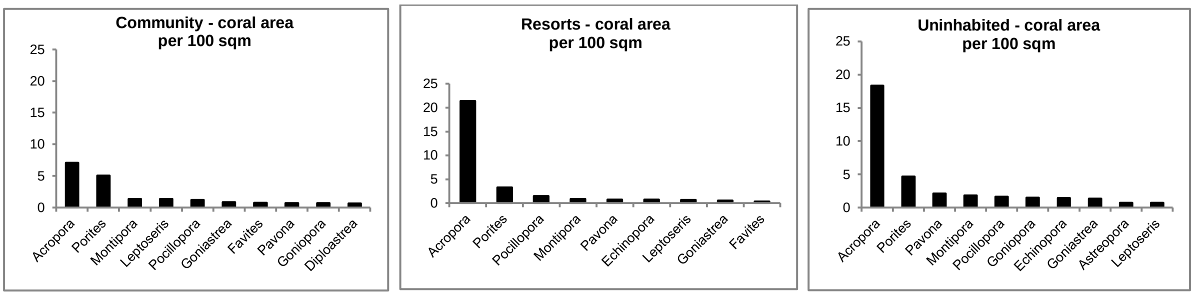


C)

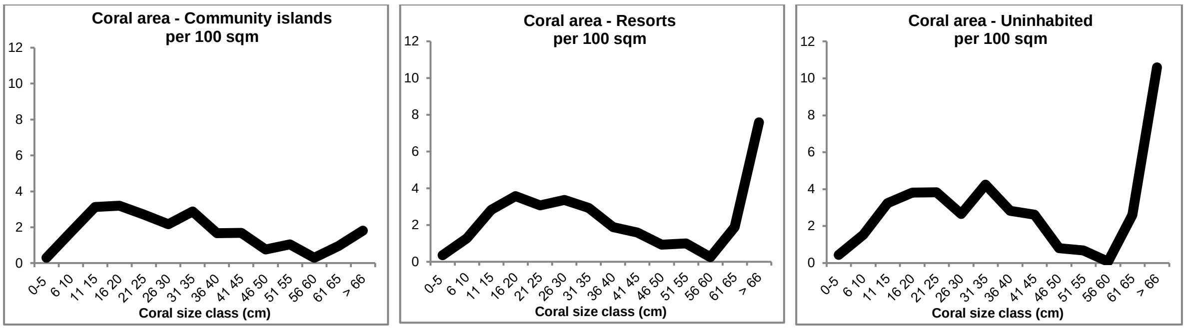
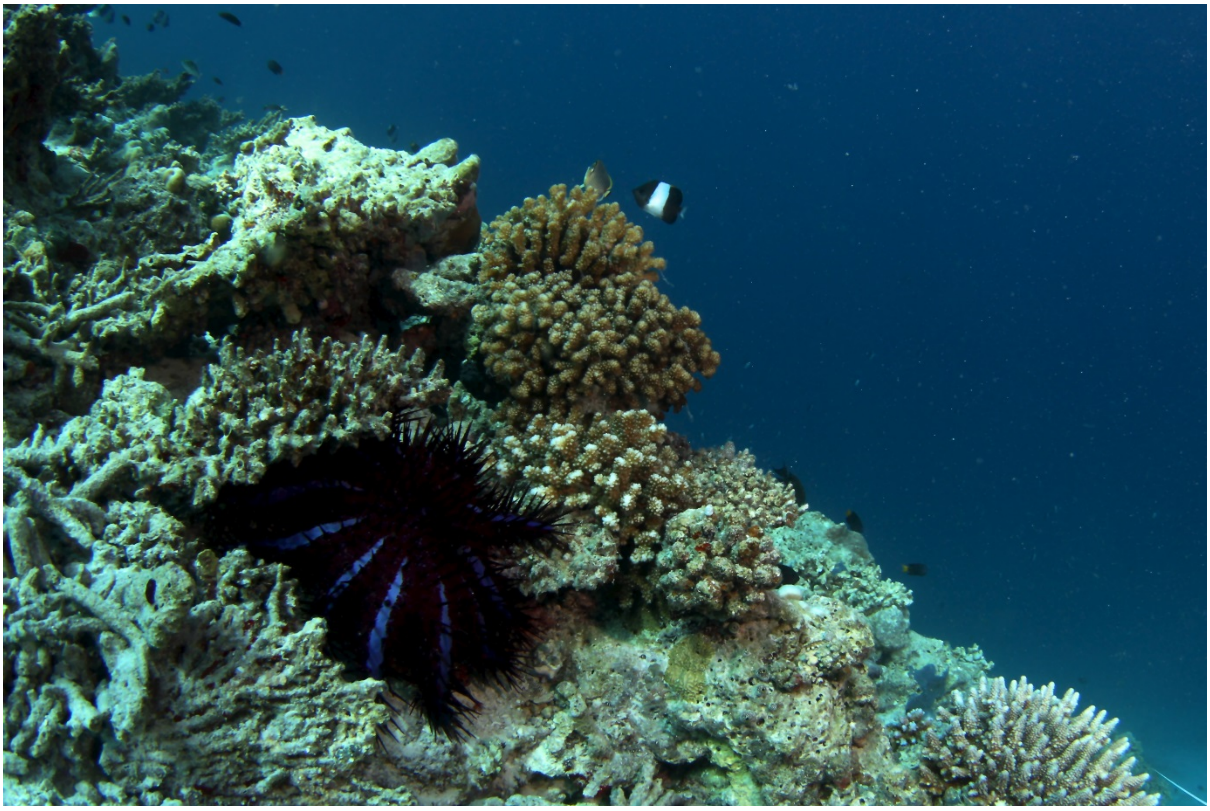


Figure 7. A) Total number of colonies of each genera. B) Colony area per genera based on size class $1m^2$ per $100m^2$. C) Total colony area in each size class per $1m^2$ per $100m^2$.

Echinoderms

The corallivorous sea star *Acanthaster planci* was only found in the uninhabited island Gaathafushi with a total of 19 individuals and only one individual in Maayafushi. Outbreaks of *A. planci* are sporadically and anecdotally reported around the Maldives, and these outbreaks cause mass coral mortality events.



Acanthaster planci on the reef slope. © Brian Zgliczynski

Sea urchins from the genus *Diadema* were not observed during the study, probably due to the morphology of the reef, low level of macroalgae and high abundance of predators. Only scarce and very small juveniles were observed at night at the top of the reef crest during extra night surveys. Commercially important sea cucumbers were more abundant and diverse in un-fished resort islands compared to fished community and uninhabited islands (Figure 8).

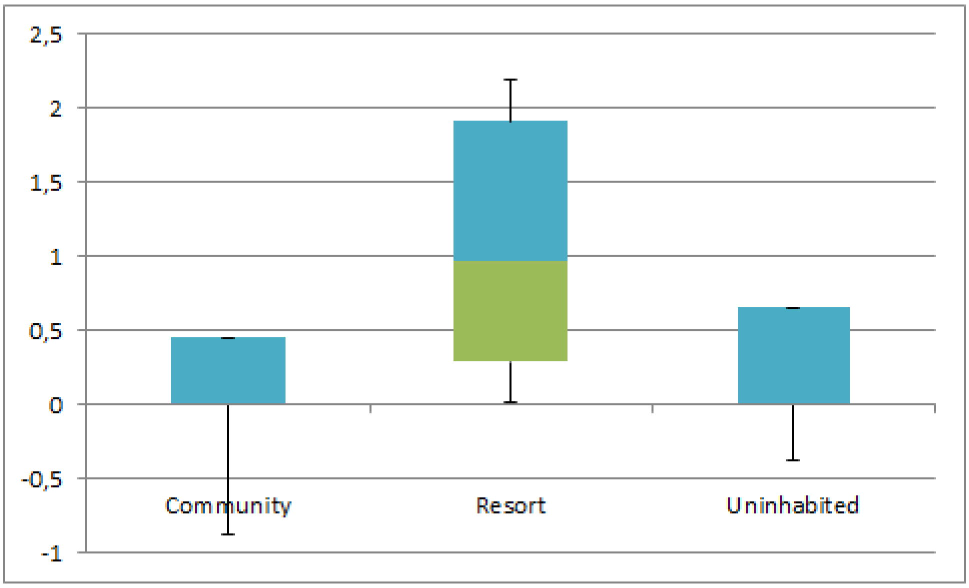


Figure 8. Boxplot comparing diversity and abundance of sea cucumber (through a Shannon Index) in reefs under different management regime. The shift between the 2 colors indicates the median value, which is invisible in the boxplots for community and uninhabited. On the Y axis is the Shannon index including both diversity and abundance of sea cucumber, while the X axis represents the islands exposed to different management regimes.

Rubbish and fishing lines

The number of fishing lines found on a reef is widely used as a metric of fishing pressure. We counted the number of fishing lines in each transect and we found that they were significantly higher in community islands compared to uninhabited and un-fished resort islands. Both resort and uninhabited island had less than 10 fishing lines per island, while this number increased to just under 40 in fished community islands (Figure 9). We observed a similar pattern for total number of pieces of rubbish on the reef. The great discrepancies between community and resort islands is possibly due to waste management and regular "reef clean ups" of resort house reefs.

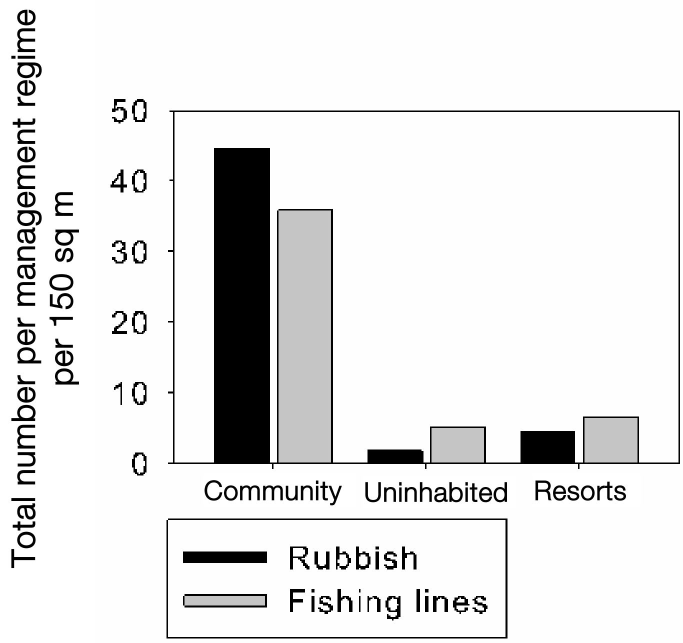


Figure 9. Total number of fishing lines and rubbish pieces counted per island in the four community (C), uninhabited (U) and resort (R) islands.

Reef fish

Total fish biomass was similar among sites, islands and management regimes, and it varied at the very small spatial scale with the greatest variation not explained by the management regime. However, when the total fish biomass was broken down into different trophic groups, then differences could be observed between islands with different management regimes. Planktivore biomass was significantly higher in community and uninhabited islands, where it accounted for 86% and 74% of the total biomass respectively, but declined to 17.8% in resort islands (Figure 10). Parrotfish biomass was higher in resort islands where it accounted for 26.4% of the total biomass, while it declined to 6.5% in community islands (Figure 10). Resort islands were dominated by apex predator (43% of total biomass), which declined significantly to 1% and 2.3% in community and uninhabited islands respectively (ANOVA $F_{51/81}$ 1.6, $p< 0.02$; Tukey test < 0.05; Figure 10). Abundance had a similar pattern to biomass with few large apex predators in unfished resort islands and many much smaller, lower trophic level consumers such as planktivores in fished community and uninhabited islands (Figure 10, 11).

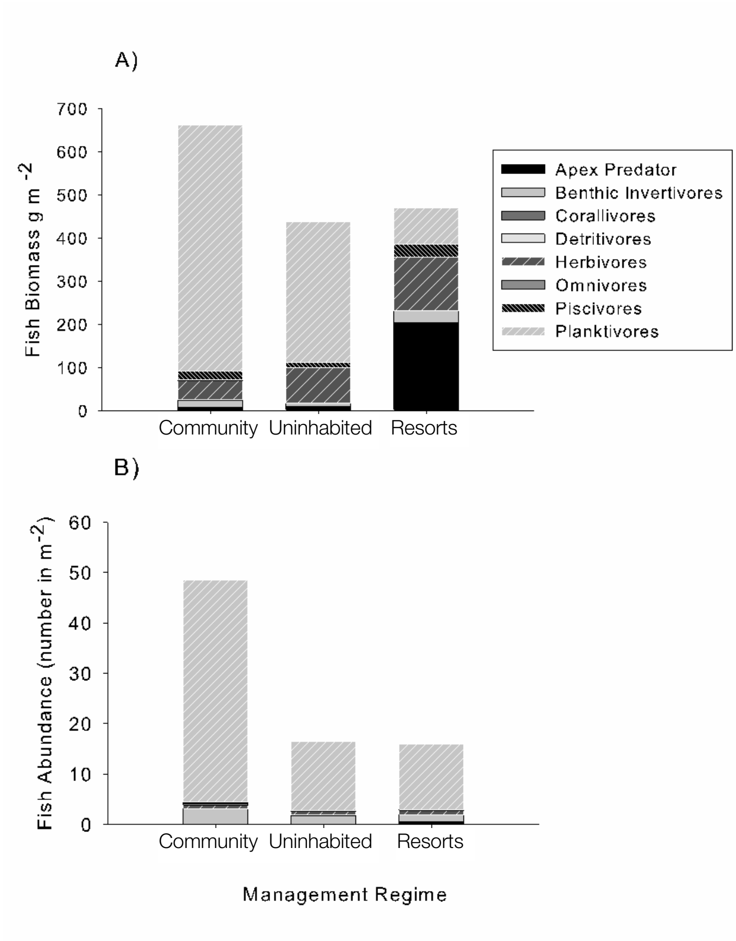


Figure 10. Fish A) biomass and B) abundance among the 12 islands under different management regime in North Ari.

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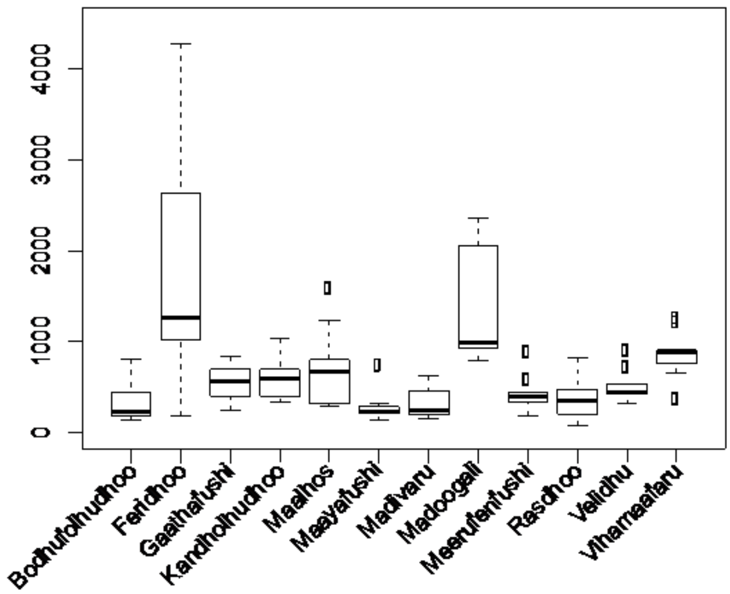

Figure 11. Boxplot for total fish abundance in the 12 islands. Each box is 3transects x 3 sites, the dark line indicates the mean over the 9 transects.

Benthic Foraminifera and the Foram Index

The Foram Index (FI) calculated for the transects sampled along the reefs of the community island of Rasdhoo (Figure 12) give values fluctuating between 3.84 and 6. Those from the resort island of Velidhoo range from 4.54 to 5.76 and those form the uninhabited island of Gaathafushi varied from 4.98 and 6.99. The weighed sediment φ categories indicate that the most representative grain size fractions are generally ranging from 1-2 mm to 63µm. The larger fraction (>2mm) is slightly more abundant for the samples from Gaathafushi, and shows the lower values for Rasdhoo. The size fractions 40-63 µm are generally very scarce and never exceeding the 0.03, 0.16 and the 0.12 for the resort, community and uninhabited settings, respectively. The smaller size fraction <40 µm is overall very scarce or absent, although is more continuously present in the samples from Gaathafushi.

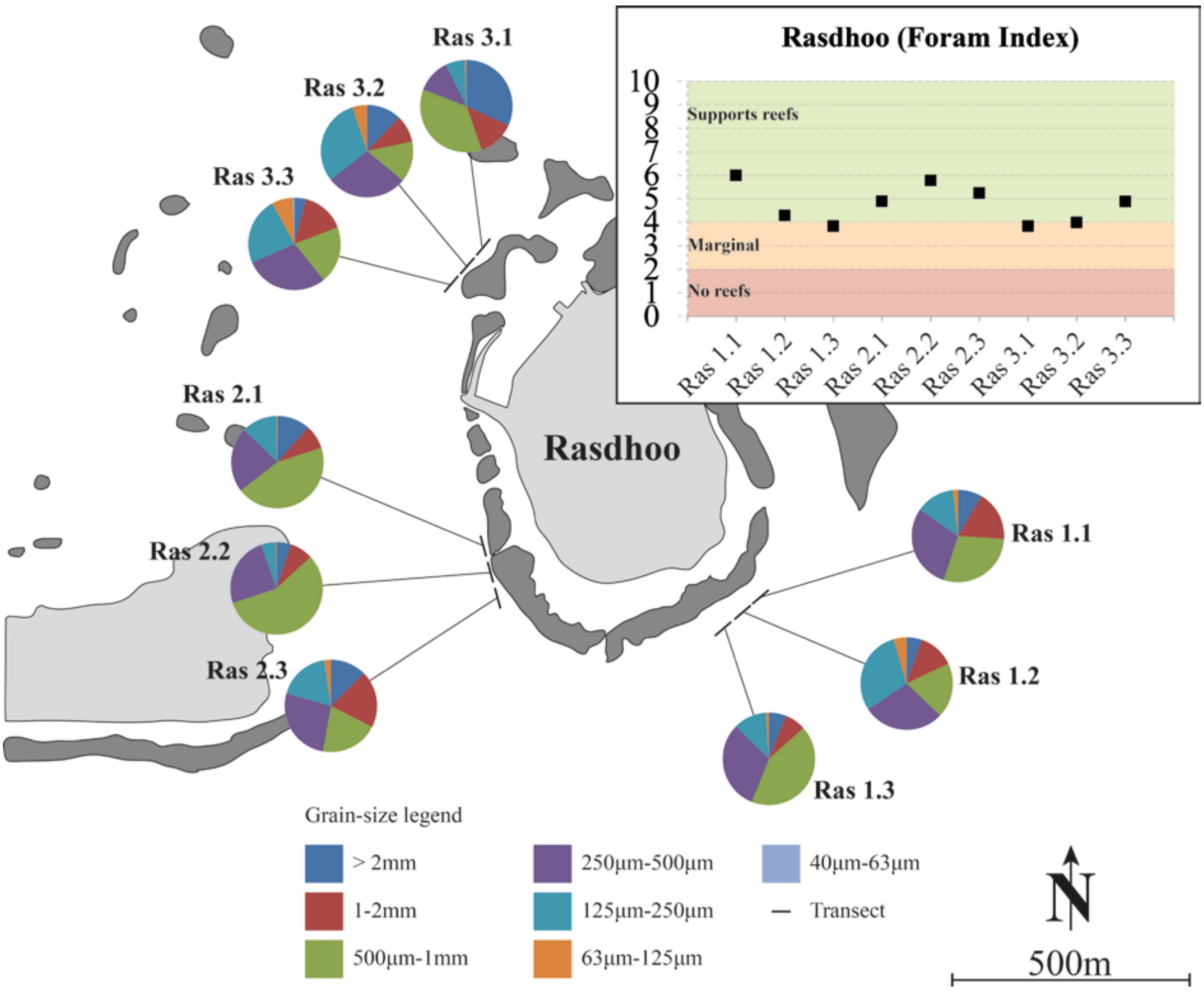

Figure 12. The Foram Index calculated for the transects sampled along the reefs of the community island of Rasdhoo.

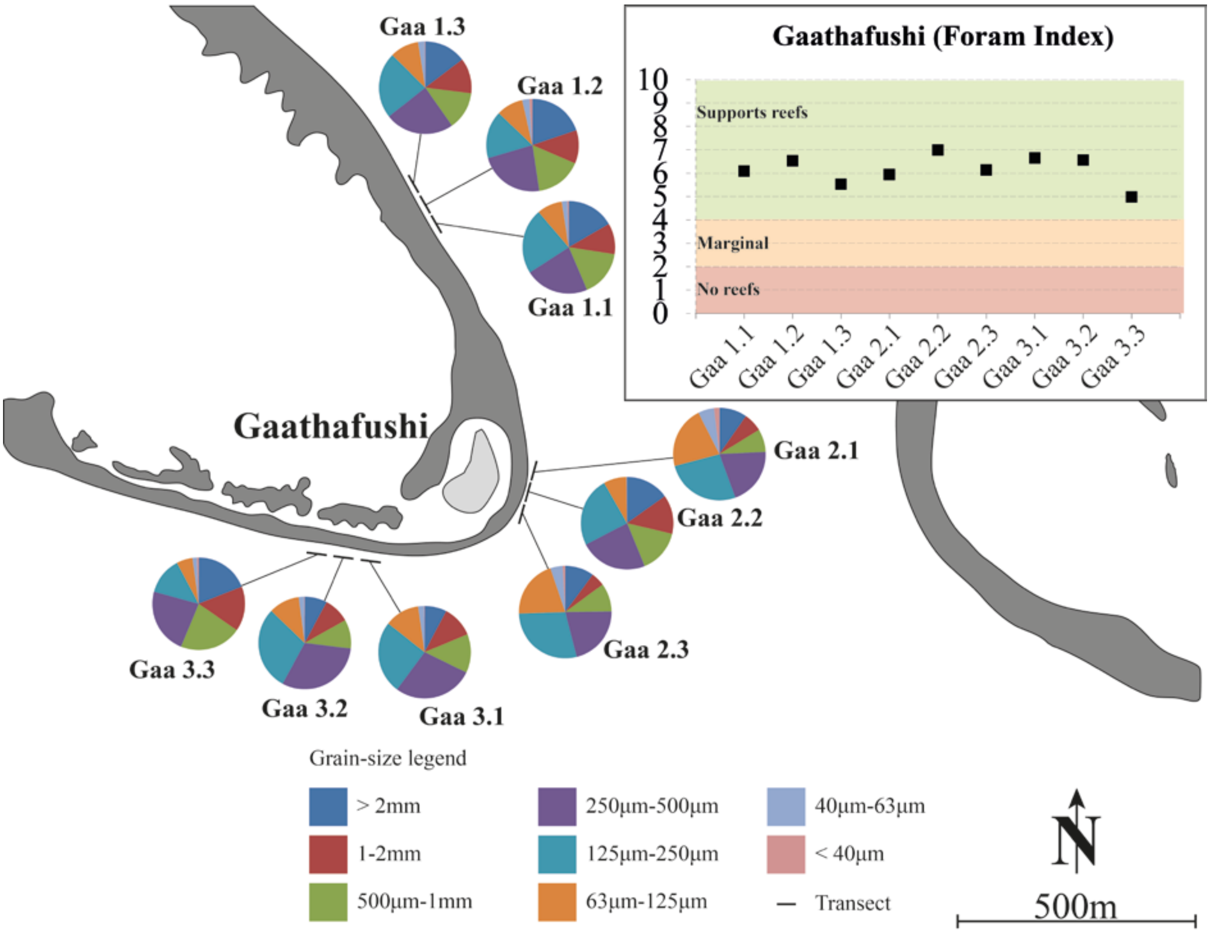

Figure 13. The Foram Index calculated for the transects sampled along the reefs of the fished uninhabited island Gaathafushi.

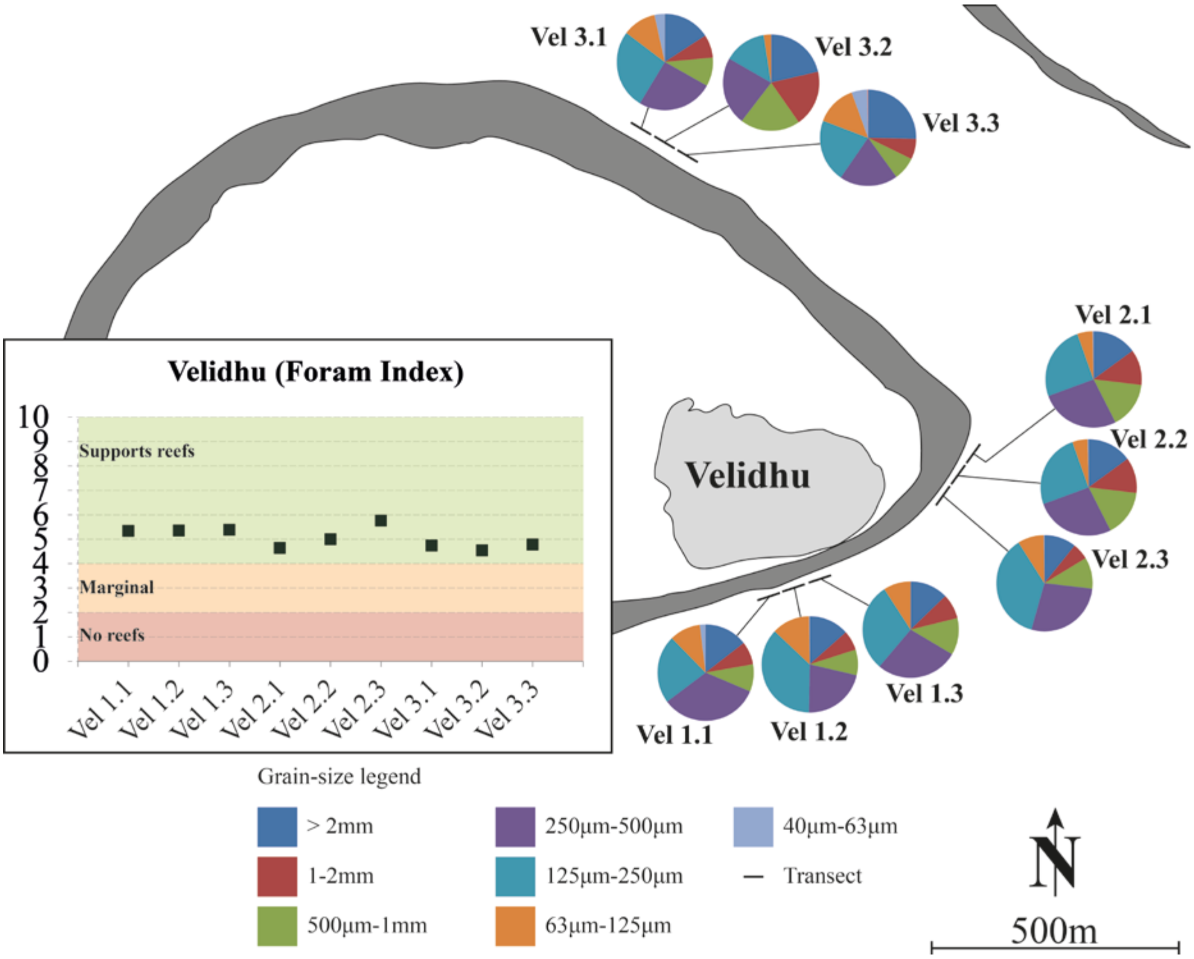

Figure 14. The Foram Index calculated for the transects sampled along the reefs of the un-fished island Velidhoo.

Water quality

Water quality parameters indicated a significant trend with management regimes. Resorts and community formed a different cluster from the uninhabited islands (Figure 15). Differences in conductivity between the two clusters were limited (Figure 15). Temperature (C°), dissolved oxygen (ppm), conductivity (mS/cm) and pH were significantly different between uninhabited islands and community and resorts (Figure 15). However the resort island Kandholudhoo formed a separate cluster due to the higher temperature of the seawater comparing to the other sites and islands.

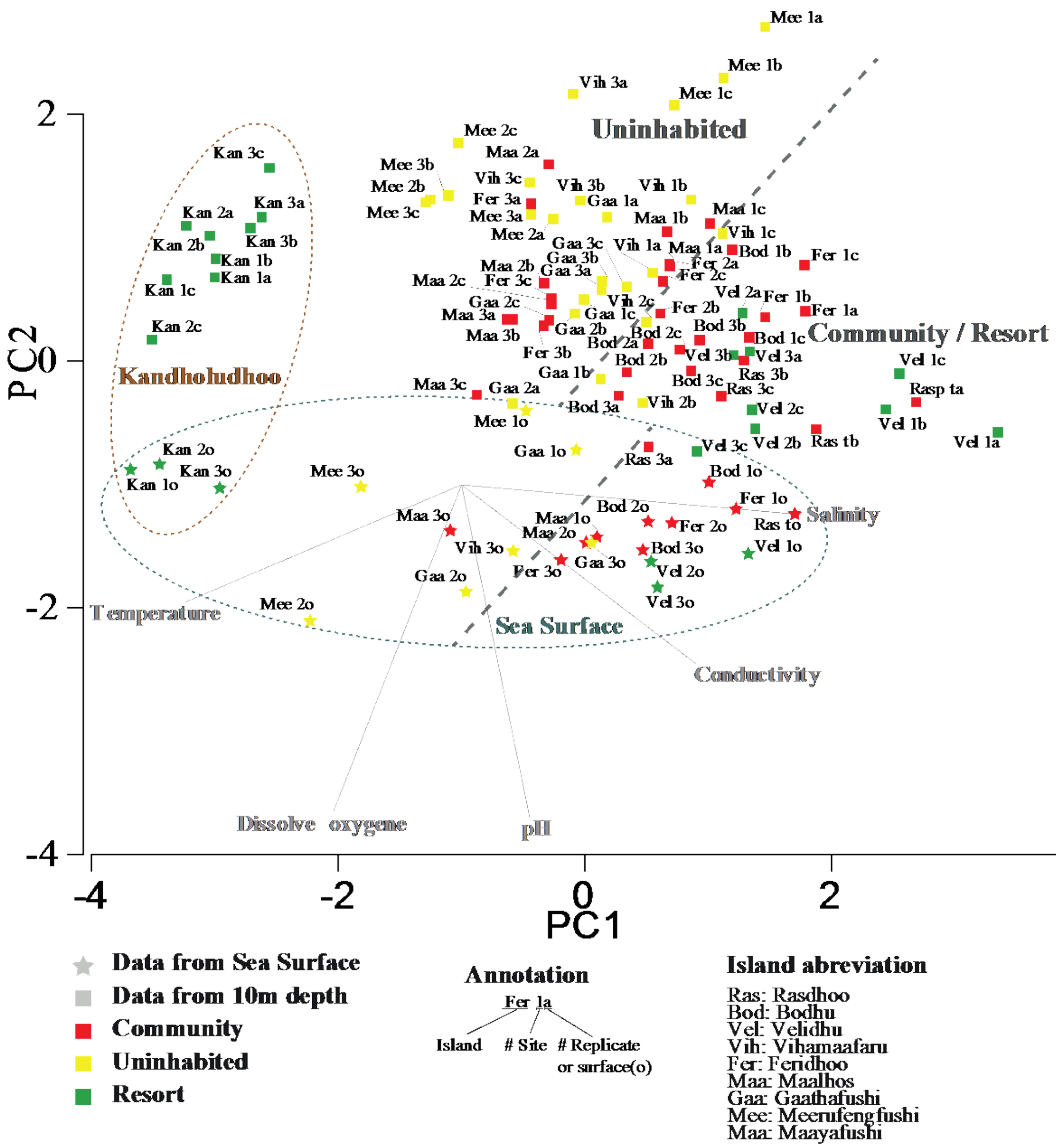

Figure 15. PCA showing differences in water quality in islands with different management regimes. The 12 sites in community islands were indicated in red, the 12 sites in resorts islands in green and in yellow for the 12 sites on uninhabited islands.

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Principal Components Analysis

To set management and conservation priorities for supporting the natural reef resilience it is critical to select sites with the best set of positive characteristics. When we correlated all the measured variables to select the sites, we did not find a clear distinctive pattern with management regime and/or island geo-position within the atoll (Figure 16). The variation explained by the PCA component was only 35% (Figure 16). Planktivores and omnivores biomass was higher in community islands, but parrotfish biomass and juvenile coral number were lower.

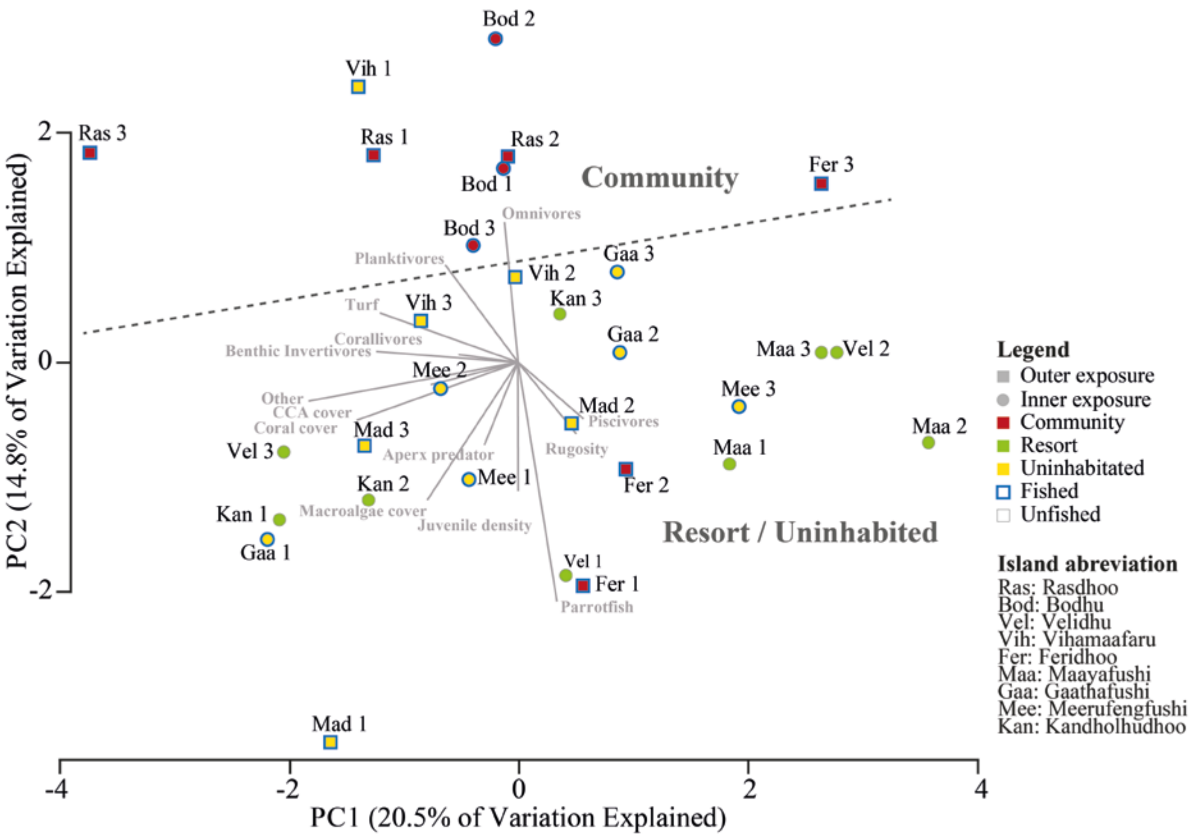

Figure 16. PCA showing correlation between variables measured in islands with different management regimes and different geoposition within the atoll (inner and outer).

Discussion and management recommendations

Under the threat of climate change and ongoing degradation worldwide (Gardner et al. 2003; Bellwood et al. 2004), it is critical to provide managers with information that will allow them to make decisions that can increase local resilience and enhance recovery of coral reefs following disturbances. This report suggests that reefs in community islands were more degraded than reefs in uninhabited and resort islands because they exhibited lower biomass of parrotfish, lower numbers of juvenile corals, and a lower number of larger-sized corals.

The changes in reef fish assemblages structure and sea cucumber abundance documented in this study are likely a response to different fishing pressure among the islands. The higher biomass of apex predator and parrotfish and the higher abundance and diversity of sea cucumber in un-fished resort islands suggest that resort may act as de facto 'no-take' marine protected areas. Resort islands are closed to fishing, while community and uninhabited islands are open to fishing. Fishing pressure tends to reduce densities of larger-bodied individuals (Jennings and Kaiser 1998). Apex predator and parrotfish biomass were higher in un-fished sites but they were not necessarily closely associated with higher coral cover, structural complexity or density of juvenile corals.

Commercially valuable sea cucumbers were only observed in no-take resorts reefs. Lack of these organisms in reefs open to fishing suggests an overharvesting with potential consequences in reef functioning. Echinoderms are a useful indicator of fishing pressure in different reefs, because contrary to many fish they do not migrate and their population is more reef-dependent.

Live coral cover did not differ significantly between fished and un-fished reefs. Similarly, low live cover of calcifying algae and low limited complexity may suggest declining reef accretion regardless of management regimes (Bellwood et al. 2004; Mumby et al. 2007).

Importantly, larger coral colonies (bigger than 66cm in diameter) were mostly found in resort and uninhabited islands, but were less abundant in community islands. Larger coral size classes are important as they represent corals that have survived previous mortality events as well as a reservoir of fecundity for reseeding coral reefs after mortality events. Healthy numbers of larger coral size classes, along with healthy numbers of recruits and juveniles, can give some indication of coral reef resilience. The low numbers of larger coral size classes in community islands could indicate unfavourable conditions for coral survival during past mortality events, and reduced resilience to future events.

This study potentially recorded for the first time *Porites* White Patch Syndrome in the Maldives, the majority of which were found in the fish-processing site in the community island of Maalhos. Further research needs to be conducted at this site to attempt to link proposed pathogens of PWPS, *Vibrio tubiashii* (Sere et al. 2015) to the outflow of the plant. The disease has also been linked to increases in sea surface water temperature and as the majority of bleached corals were of *Porites* genus throughout the expedition, again it would not be unexpected to see an outbreak of PWPS during the survey.

Foraminifera assemblages indicate that conditions for reef growth were overall healthy in North Ari Atoll. However, lower values that may eventually evolve to chronic stress were calculated for sites around the community island of Rasdhoo hosting a permanent human settlement. These lower values may be related to the scarcity or lacking of means of final disposal of domestic wastes, and their consequent accumulation close to the island (Boblme 2010). The slightly higher foraminifera index for sites around resort islands of Velidhoo showed a better

environmental status. The best ecological conditions according to foraminifera were recorded in the uninhabited island of Gaathafushi.
Findings from this study showed that the community island of Maalhos was very degraded, with high incidence of coral disease and low coral cover, and this is confirmed also by a study on the sediment budget of the island. In North Ari atoll the western rim islands showed a limited growth in the sediment budget and Maalhos, which is one of the largest island on the western rim together with Mathiveri and Himandhoo, showed a net loss of -3% of island area since 1969 (Shaig in preparation). Maalhos was exhibiting erosion in both the lagoon and the ocean side. The observed negative budget may be due to reef size, types of coral species and bioeroding fish species as they play a role in sediment production rate.

From these results it is clear that community islands need improved management of their coral reefs and marine resources – they generally exhibit the lowest water quality, the lowest biomass of apex predators and parrotfish (crucial for resilience), the lowest number of larger coral size classes and highest number of pieces of rubbish.

A potential management strategy for community islands to take greater ownership of the management of their coral reefs is the development of a network of Managed Marine Areas (MMAs). A MMA can be defined as *'an area of nearshore waters and coastal resources that is largely or wholly managed at a local level by the coastal communities, land-owning groups, partner organizations, and/or collaborative government representatives who reside or are based in the immediate area'* (Govan & Tawake, 2009). MMAs can be useful for defining regulations that control fishing pressure on the reef, mitigate land-based sources of pollution as well as tourism activities that may damage the reef, in order to promote the resilience of coral reefs in the face of bleaching or other mortality events. MMAs empower local communities, resorts and local island councils to develop management strategies for their coral reefs and marine resources. MMAs can be designed in collaboration with central government research, administrative and enforcement agencies such as the Marine Research Centre (MRC), the Ministry of Environment and Energy (MEE), and the Environmental Protection Agency (EPA).

As next steps in defining MMAs for North Ari, we would recommend the following steps:
- Mapping and characterizing of the coral reefs of community islands in order to identify biodiversity hotspots, vulnerable areas and important areas to protect and conserve;
- Engagement of the local communities, resorts and local government to ascertain the willingness and capacity of community islands and resorts to develop MMAs;
- Capacity-building exercises with local government, resorts and local community groups in development of MMAs

All these steps would be taken in close collaboration with central government bodies such as MRC, MEE and EPA.

The data and results presented in this report can provide important baseline information for developing these management strategies and developing a network of MMAs and MPAs in North Ari Atoll.

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