Understanding drivers of coral reef resilience in the face of climate change in the Lakshadweep Archipelago

Rufford Interim report

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Interim Report

Introduction

The fate of tropical coral reefs is looking increasingly grim as global climate change and local anthropogenic factors interact, causing a rapid decline in what we can expect of the functioning of these system (Hughes et al. 2003; Pandolfi et al. 2003; Hoegh-Guldberg et al. 2007). Apart from being among the most biodiverse ecosystems in the world, reefs also support a large proportion of tropical fisheries, besides supplying dependent communities with a range of essential goods and services on which they rely (Moberg & Folke 1999; Kittinger et al. 2012). In this context, the ability of reefs to withstand multiple disturbances has consequences for the entire human-ecological system that depend on this buffer capacity. Understanding the underlying driving factors influencing resilience in a complex system is not easy, and there is an increasing effort across the tropics to determine what differentiates reefs with inherently high resilience from inherently susceptible reefs. It is clear for instance, that, in the relative absence of human influences, reefs often possess sufficient resilience to bounce back from even the most dramatic losses (Gilmour et al. 2013). Additionally, many studies have identified the important role that herbivores play in post-disturbance scenarios, promoting the settlement and survival of new coral recruits by mediating the growth and spread of algae (Hughes et al. 2007; Ledlie et al. 2007; Rasher et al. 2011). What appears to be emerging from this raft of research is that the resilience and recovery of reefs to climate and other disturbances is likely the result of an alignment of several environmental, ecological and anthropogenic drivers, acting at several spatial and temporal scales (Bellwood et al. 2004; Wooldridge et al. 2005; Maina et al. 2008; deyoung et al. 2008; Crabbe 2008; Obura & Grimsdith 2009; Mcclanahan et al. 2009; Côté & Darling 2010). The few attempts to derive a common global metric to assess the resilience potential of reefs are necessarily broad and may have little utility at the more regional levels at which ecosystem managers normally work.

At management-relevant scales, there is little that can replace direct observations of long-term trends, which are the most reliable metric of a systems' inherent response-potential to future events. These datasets are rare and often limited to a few locations, but they may still provide valuable insights on the specific drivers of resilience at the local level. Our ongoing project, supported by the Rufford Small Grants Foundation, uses a dataset from 10 reef sites at three atolls in the Lakshadweep Archipelago, Indian Ocean, where we have been tracking trends in reef condition since 1998. These reefs have been subject to two major bleaching mass mortality events, and our data shows that reef sites differ considerably in their ability to withstand and recover from these disturbances. We used this to identify factors that could help differentiate reefs according to their disturbance responses, and applied this to an archipelago-wide survey (>60 reef sites across 12 atolls, including two submerged banks) of reef condition. Our ongoing work identifies reefs along a putative gradient of resilience where we have established permanent locations to monitor trends within a predictive framework. At each of these sites, we are measuring a range of environmental, ecological and anthropogenic factors that together will help us determine the drivers of resilience or susceptibility at each site. This is a necessarily long-term programme, but in the medium-term we believe this will help in determining management priorities, identifying areas with inherent resilience, as well as the critical determinants of this resilience that need to be managed.

Progress to date:

Based on our archipelago-wide survey and an analysis of long-term benthic trends, we classified reefs in the Lakshadweep along a gradient of predicted resilience. We chose representative sites across this gradient to establish permanent monitoring locations. These include:

Low Resilience atolls: Kadmat Atoll and Agatti Atoll
Medium Resilience atoll: Bitra Atoll, Kalpeni Atoll
High Resilience atoll: Kavaratti Atoll and Minicoy Atoll

(note: permanent monitoring locations at Minicoy and Kalpeni atolls remain to be completed)

Our earlier research has also shown that there are significant differences in patterns of recovery and resilience based on aspect in relation to the monsoon, as well as depth (Arthur et al. 2006). To account for this, at each chosen atoll, we identified permanent monitoring sites at reef locations on the east (leeward) and west (windward) aspects of every atoll and at two depths, shallow reef flats (<10 m) and deeper reefs (>10 m). At each site, we established 5 x 5 m benthic plots (3 at each depth zone) which were permanently marked with plastic grids and cement blocks. For every location, we measured benthic and fish parameters and estimated anthropogenic influences. In addition, we developed assay techniques to determine relative rates of trophic processes at these sites.

Figure: *Permanent sites were established on leeward (eastern) and windward (western) reefs at each chosen atoll (Aerial view of Agatti Atoll)*

Ecological parameters measured

1. *Benthic composition:* Evaluated in 1m^2 photographic quadrats within each plot. In each quadrat we estimated live and dead coral, algal cover and other benthic elements.
2. *Coral recruitment:* We counted all coral settlers and juveniles within the 5x5 m quadrat. Individuals were assigned to cm-wide size classes and identified to the genus where possible. Care was taken to count only individuals that were clearly new settlers or juveniles, avoiding all obvious coral fragments.
3. *Topographic Complexity:* The structural complexity of each location was estimated as the average total standing structure with each plot which we have earlier shown as a valid index of topographic complexity that scales well with contour distance and other standard measures of reef complexity.
4. *Fish Counts:* Fish were quantified in replicate 50 x 10 m belt transects laid at each site. All species within the belt were identified to the species, ignoring cryptic species below 5 cm. All individuals were assigned to size classes 5-10 cm, 10-20

cm, 20-30 cm, 30-50 cm and >50 cm. We then used standard species-specific volumetric conversions to calculate approximate biomasses using the midpoints of these size classes.

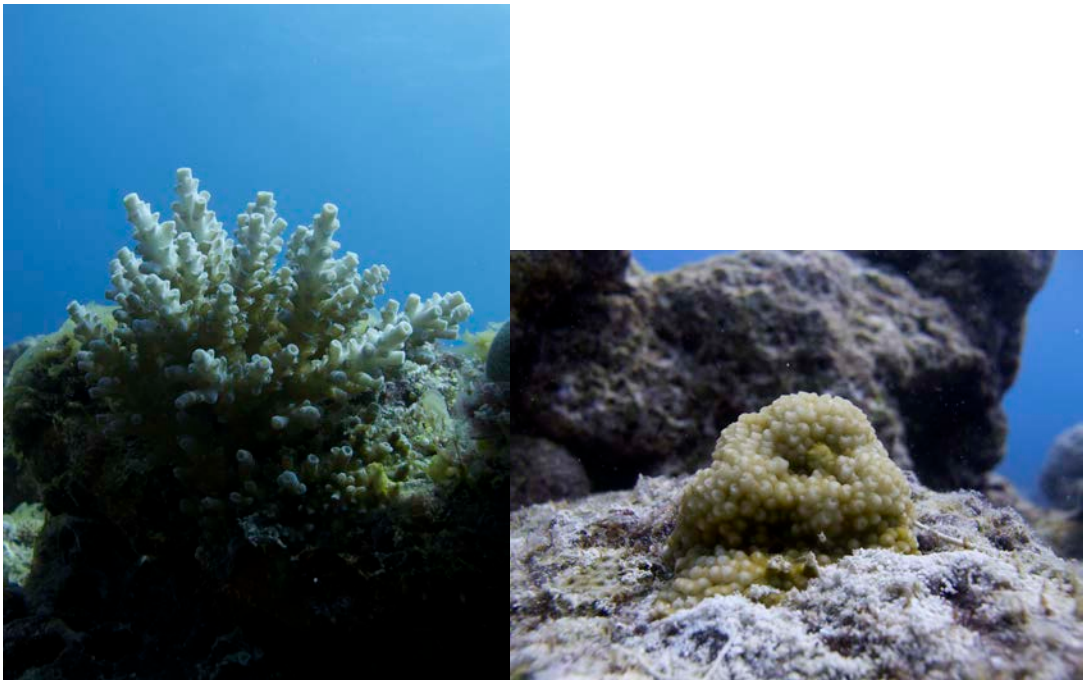

Figure: *Recruits of young settlers of the genus* *Acropora*

Figure: *Permanent quadrats were established across a gradient of predicted resilience*

Trophic Assays

Invertebrate predation and herbivory: We standardised an assay using pieces of broken branches of dead coral from within farming damselfish territories (*Stegastes* sps.) that were covered with macroalgal growth, turf algae and several species of invertebrates. Replicate branches (~5 cm in length) were attached with cable ties at several locations in the reef and monitored with an underwater video camera for 15 minutes each. From the videos, we are able to determine bite rates by herbivores and invertivores, which we will use as comparative indices of herbivory and invertivory respectively to compare trophic rates between reefs. In addition, to standardise this method for invertebrates, we collected these 'experimental' branches as well as 'control' branches from within damsel territories. Invertebrates were extracted from control and experimental braches using a standard protocol (placing the branch in a plastic bag of sea water and shaking the bag 30 times). All invertebrates that were dislodged were enumerated to compare branches exposed to invertivory with controls, protected within damsel territories.

To measure rates of piscivory, we captured small planktivore damselfish (*Chromis viridis*) using a baited hand net. Individual damselfish were placed in water-filled plastic bags attached to lead weights and suspended close to the benthos at different reef sites. We monitored each assay for 15 minutes using an underwater video. We enumerated all species that approached the damsel and calculated approach rates and attack rates to compare piscivory between locations. After the assays, all damsels were released back from the reef they were extracted from.

We completed most data collection only recently and are presently analysing benthic photographs and video footage for trophic assays.

Key findings and next steps

Much of this season was spent establishing permanent plots at sites along the gradient – a mammoth task in itself. We also dedicated a significant proportion of time designing and standardising assays to estimate trophic rates that we will use to compare between locations. We are using the remaining months to analyse benthic quadrats, fish transects, and assay videos. Data collation is nearing completion and we will finalise results before the end of the monsoon.

From our on-going long-term monitoring of the Lakshadweep, it is apparent that the 1998 mass bleaching and mortality event has been the dominant structuring agent across the archipelago (Arthur 2005; Arthur et al. 2006; Arthur 2008). The overall response of reefs to this and subsequent bleaching events (for instance, 2010) is dependent on two distinct phases – the response to the immediate disturbance and the recovery phase, both driven by very different factors (see Table).

Deconstructing reef responses in the Lakshadweep Archipelago: Bleaching and Recovery processes			
Phase	Bleaching Disturbance	Post-Bleaching Recovery	
Process	Bleaching mortality	Settlement Success	Post-settlement survival
Drivers	Temperature Anomaly (temperature and exposure time)	Recruit Availability	Coral Growth
	Reef Depth	Suitability of Settlement Substrate	Substrate Stability
	Species-specific bleaching susceptibility	Herbivory (reducing macroalgal growth)	Herbivory (reducing macroalgal growth)
		Negative Coralivory	Negative Coralivory
			Nutrients/Macroalgal growth

This framework supports trends observed over the last 14 years, which are showing that the reefs of the archipelago respond to repeated disturbances in three qualitatively different ways which we have classified as:

1. **Stable Reefs:** Reefs that are not heavily impacted by disturbance events including coral bleaching.
2. **Dynamic Reefs:** Reefs that may be very heavily impacted by coral mortality events like bleaching but show very rapid rates of recovery post-mortality
3. **Susceptible Reefs:** Reefs that may be very heavily impacted by disturbances like bleaching but do not apparently have the ability to recover from these disturbances.

Our predictive monitoring framework has been set up with an eye to determining the specific drivers that differentiate these responses over the next few years. This will allow us to map these responses across the entire archipelago to help in conservation planning to ensure that the inherent resilience potential of this unique group of atolls is maintained and enhanced.

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