Cumulative effects of cyclones and bleaching on coral cover and species richness at Lizard Island

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Abstract: Coral reefs are being subjected to an increase in the frequency and intensity of disturbance, such as bleaching and cyclones, and it is important to document the effects of such disturbance on reef coral assemblages. Between March 2014 and May 2017, the reefs of Lizard Island in the northern section of the Great Barrier Reef were affected by four consecutive, disturbances: severe tropical cyclones Ita and Nathan in 2014 and 2015, and mass bleaching in 2016 and 2017. Loss of coral cover following the cyclones was patchy and dependent on the direction of the waves generated. In contrast, loss of cover following bleaching was much more uniform. Overall, coral cover declined five-fold from 36% pre-cyclone Ita to 7% post-bleaching in 2017, while mean species richness dropped from 10 to four species per transect. The spatial scale and magnitude of the loss of coral cover in the region suggests that it will be many years before these reefs recover.

Key words: community ecology, coral reefs, climate change, disturbance, diversity,

Introduction

Coral reefs are under threat, with the general consensus that these ecosystems are degrading globally (Hughes et al. 2003, Hughes et al. 2018a). Reef-building corals provide the habitat structure that allows associated coral reef fauna to thrive. Therefore, declines in coral cover lead to loss of fish abundance and species richness (e.g. Jones et al. 2004, Graham et al. 2006). In the context of global change, the intensity and frequency of climate-associated disturbances on coral reefs are increasing (Bender et al. 2010). To predict the fate of coral reefs, we need to document and understand the effects of different types of disturbance on reef coral abundance and diversity.

In the Indo-Pacific region, coral cover has declined on average by 0.7% per year since the late 1960s (Bruno & Selig 2007). Coral cover change is not monotonic: typically, declines are episodic and driven by disturbance events such as crown-of-thorn starfish outbreaks, cyclones and, more recently, mass bleaching events. Disturbance-led declines are typically interspersed with periods when, under the right conditions, coral cover increases (Gilmour et al. 2013). Coral reefs are naturally mosaics of communities at different successional stages of recovery from a myriad of disturbances. However, rapid sequences of intense disturbances can result in phase-shifts in coral ecosystems (Hughes 1994, Hughes & Connell 1999) from which recovery is much less likely. Some reefs can recover from large losses of cover, with the abundance of herbivores, topographic complexity, and depth being important predictors of the probability of recovery (Graham et al. 2015).

Sections of the northern Great Barrier Reef (GBR) centred around Lizard Island were recently affected by a sequence of extreme disturbances—the first disturbances on record to affect these reefs in 20 years (Wakeford et al. 2008, Pratchett 2010, Death et al. 2012). In April 2014, Severe Tropical Cyclone (STC) Ita (Category 4) crossed the island from the north. In March 2015, STC Nathan (Category 4) affected the island through waves generated from the south. The largest mass bleaching event on record affected the island in April 2016, with estimates of bleaching and loss of coral cover in the area of between 50-100% (Hughes et al. 2017), and close to 90% for Lizard Island (Hughes et al. 2018b). We documented a subsequent bleaching event in early 2017. This sequence of disturbance has drastically changed the assemblage structure of reefs around the island when compared to data from 2011 and the mid-1990s. Here, we quantified the cumulative effects of the two cyclones and two bleaching events on the cover, richness and composition of coral assemblages at 19 sites around Lizard Island.

Materials and methods

We used line intercept transects (Loya 1972) to estimate coral cover and species diversity at two to 19 sites around Lizard Island, in the northern Great Barrier Reef (14.6688° S, 145.4594° E) in 1995, 1996, 1997, 2011, 2014, 2015, 2016 and 2017 (see map in Fig. 3). North Reef and South Island were surveyed in 1995; Lizard Head and Washing Machine were added in 1996; North Reef, Lizard Head, Trimodal, Lagoon 1 and 2 and Horseshoe reef sites were sampled on every sampling occasion since 2011, the remaining 13 sites were sampled since 2015. At each site, five or six 10m transects were haphazardly deployed parallel to the reef margin at 1 to 2 m depth and no less than 10m apart. All colonies with a maximum diameter greater than 5 cm were identified to genus between 1995 and 1997 and to species between 2011 and 2017 following Veron (1986). We did not transform cover or richness data, and used Welch's t-tests for unequal variances for reporting comparisons with an alpha of 0.05. Analyses were run using the function "t.test" in the statistical software R (R Core Team 2018).

Results and Discussion

Coral cover, taxonomic richness and assemblage structure at the start of surveys in 2011, and prior to the sequence of severe disturbances, were very similar to those in the historical surveys in the

1990s (Figs. 1 and 2). The series of disturbances corresponded with in a five-fold loss of coral cover between 2011 and 2017 at the six sites that were surveyed consistently during this time (from 36% to 7% average cover; Fig. 1). At the island scale, the decline in cover was particularly high following cyclone Nathan in 2015, after which cover approximately halved, followed by the 2016 bleaching, after which cover halved again. However, the spatial pattern of loss varied among the different disturbances (Fig. 3). Following cyclones, coral loss was greatest at sites facing the direction from which the cyclone approached. For example, following STC Ita, cover declined proportionally by 85% at North Reef (t=5.33, df=7.47, p<0.001), whereas there was no statistically significant change in cover at sites on the south side of the island (e.g., Trimodal, Lagoon 1 and 2, Lizard Head and Horseshoe). Similarly, south-facing sites suffered major declines following cyclone Nathan. Coral cover declined proportionally by 90% and 66% at Trimodal and Lagoon 2, respectively (t=9.7, df=8.57, p<0.001; t=2.98, df=6.62, p=0.02), whereas there was no further change in cover at North Reef (t=0.40, df=2.82, p=0.72). In contrast, loss of cover following bleaching was more uniform across the six main sites following both bleaching events, with all sites with greater than 10% cover remaining showing significant declines in cover. Nonetheless, coral cover at some of the 19 sites surveyed since 2014 has remained relatively constant or even increased, particularly Resort, Cooks Path and Turtle Beach (Fig. 3), which were dominated by taxa such as *Montipora* and *Porites* that are less susceptible to bleaching. Overall, these patterns are consistent with previous research suggesting that cyclone-driven declines in cover are patchy and mediated by exposure to prevailing winds (Connell et al. 2004, Wakeford et al. 2008, Fabricius et al. 2008), whereas bleaching-driven declines tend to be more uniform and contingent on the structure of the coral assemblage at the time of bleaching (Marshall & Baird 2000, McClanahan et al. 2005).

The cumulative results of these four major disturbances are drastically altered coral assemblages. Loss of cover was accompanied by declines in genus and species richness (Fig. 4). The total number of species across the six consistently surveyed sites decreased from 76 in 2011 to

49 in 2017. Furthermore, only 28 of the species recorded in 2011 were recorded again in 2017. Many of the additional 21 species recorded in 2017 were likely hidden within the living structure of the reef, such as underneath tabular-*Acropora* spp. colonies (Baird & Hughes 2000). Therefore, the loss of species richness is likely to be more extensive than the observed net difference before and after the disturbances (i.e., 76 vs. 28 species). The spatial patterns across sites for average species richness per transect (and genus richness, which could be included for 1995-97) were consistent with the patterns of change in cover, but far less pronounced (Fig. 1 and 3).

In the historical surveys, and prior to STC Ita, most reefs around Lizard Island were dominated by *Acropora* spp. (Fig. 2). For instance, on Trimodal Reef in 2005 there were 43 *Acropora* spp, including the third and fourth most abundant species at the site (Dornelas & Connolly 2008). Only one of these species, *A. hyacinthus*, occurred on the transects in 2017 and was represented by only a few, very small colonies. *Acropora* cover declined by over 95% (Fig. 2, dark blue), more than any other genus. Currently, the dominant benthic taxa at Lizard Island are soft corals and members of the hard coral genus *Porites*, and family *Faviidae*. Here, *Porites*, *Pocillopora*, *Faviidae* and *Stylophora* were the only common taxa that lost less than half their cover across the sequence of disturbances (Fig. 2).

The two cyclones and two bleaching events have changed Lizard Island coral assemblages profoundly. The high mortalities resulting from these events have reduced coral cover to below 4% at ten out of the 19 sites. Only two sites have cover above 40% in 2017, which was the norm for Lizard Island's reefs prior to these disturbances (Fig. 1; Wakeford et al. 2008, Pratchett et al. 2010). Moreover, the species most affected were those that created much of the structural complexity of these reefs. The current most common taxa have much simpler morphologies (e.g., massive *Porites* and *Faviidae*) and account for very little coral over on the reef of Lizard Island. These changes are likely to have severe knock-on effects on the abundance and diversity of fishes that rely on structural complexity for habitat (Pratchett et al. 2006, Wilson et al. 2006).

Whether the reefs around Lizard will recover from this degraded state remains to be seen. Estimates of recovery time following major disturbances range from 5-20 years (Done et al. 2010, Johns et al. 2014). While the effects of the cyclones were dramatic, the spatially clustered nature of their effects mean that multiple source populations remained in the region to potentially supply recruits for recovery. However, the cumulative effects of the cyclones and mass bleaching means that far fewer reproductively active adults remain in the region. In fact, recruitment rates in the area have dropped by two orders of magnitude following the mass bleaching (Woods et al. in prep) and are likely to increase the expected recovery period. In contrast, the abundance of juveniles (i.e., colonies < 5 cm maximum diameter) has been much more stable, and the juveniles of most taxa were less affected by bleaching than the adults (Alvarez-Noriega et al. 2018) offering some promise of a recovery, but only if the region does not experience another severe disturbance event in the next decade.

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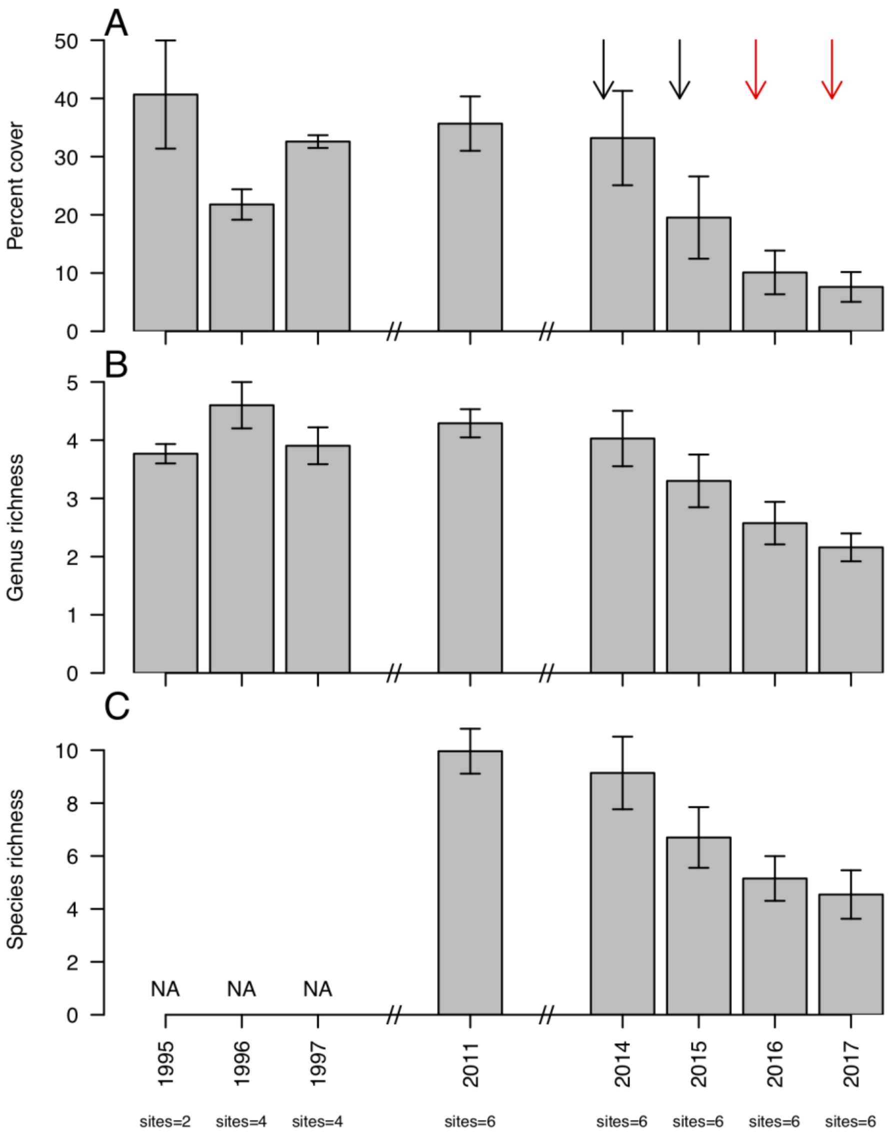
Figure captions

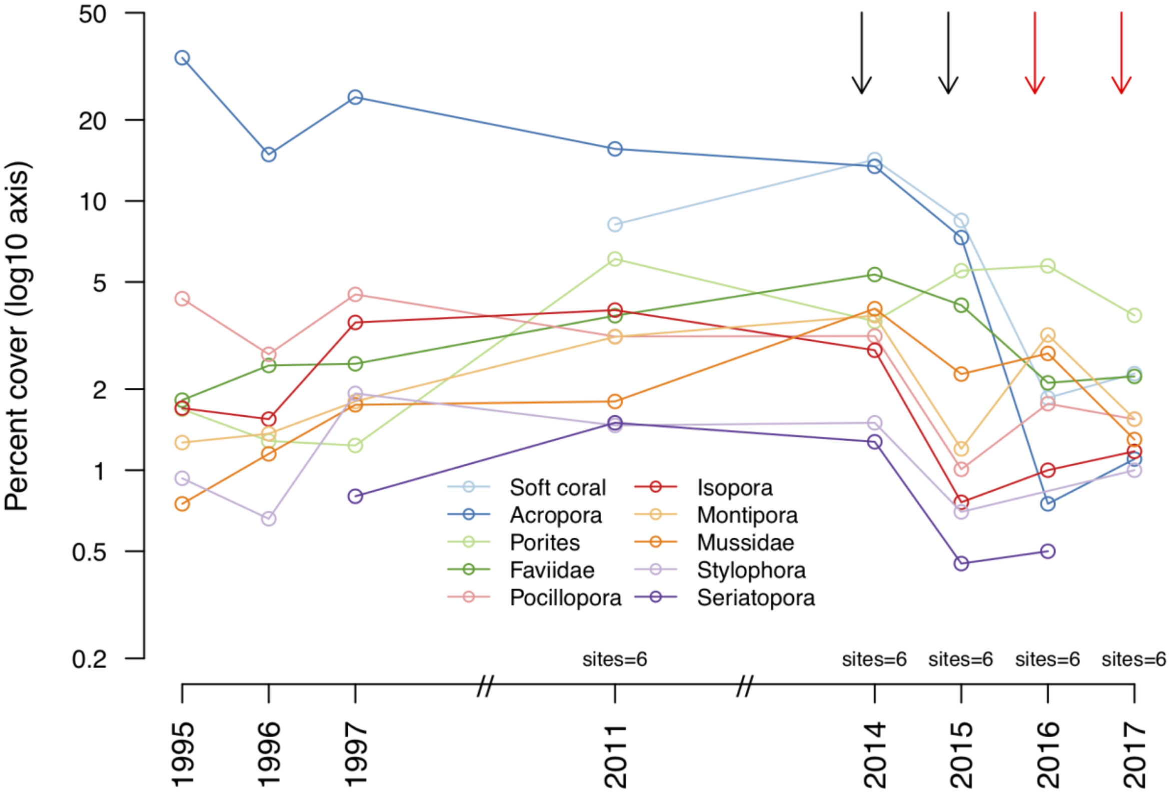
Figure 1. Change in average (A) coral cover, (B) genus richness and (C) species richness per transect (±SE) for the six consistently surveyed reefs at Lizard Island. Black arrows: tropical cyclones; red arrows: bleaching events.

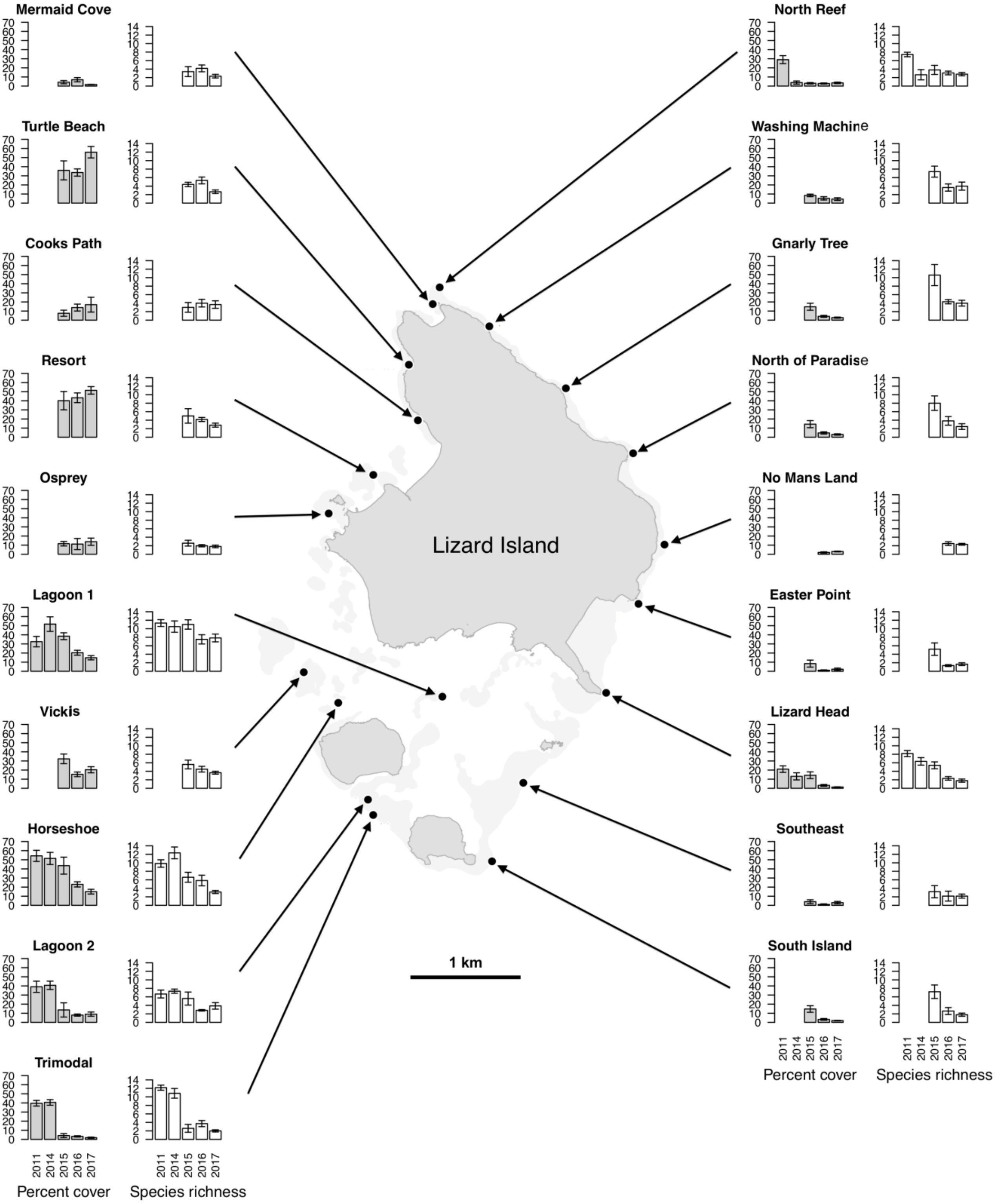
Figure 2. Compositional change in cover of the ten most dominant taxa: nine coral genera and a single category for soft corals. Arrows correspond with tropical cyclones (black) and bleaching events (red). Soft coral was not surveyed in the 1990s. Due to low densities, *Seriatopora* was not recorded in some years. Sample sizes reported refer to number of sites surveyed (see Methods for details of within-site replication).

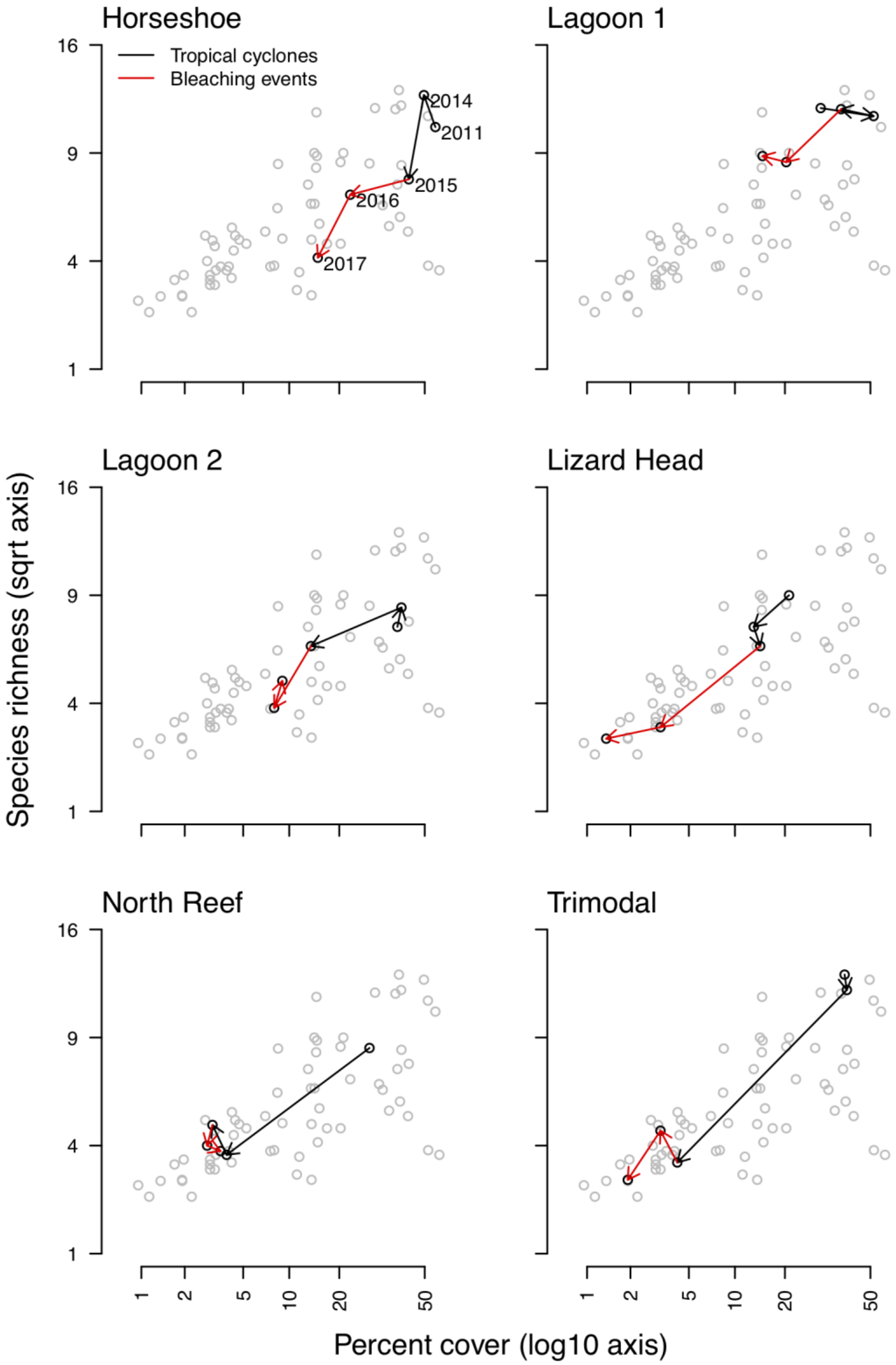
Figure 3. Change in coral cover (grey bars ±SE) and per transect species richness (white bars ±SE) across the 19 Lizard Island sites (6 surveyed since 2011, 13 since 2015). Grey shading land and light grey shading is coral reef.

Figure 4. Temporal trajectories of changes in coral cover and species richness per transect for the six consistently surveyed sites. Grey background points show data for all sites and years.


A
Percent cover
0
10
20
30
40
50
B
Genus richness
0
1
2
3
4
5
C
Species richness
0
2
4
6
8
10
NA
NA
NA
1995
1996
1997
2011
2014
2015
2016
2017
sites=2
sites=4
sites=4
sites=6
sites=6
sites=6
sites=6
sites=6


50
20
10
5
2
1
0.5
0.2
Percent cover (log10 axis)
Soft coral
Acropora
Porites
Faviidae
Pocillopora
Isopora
Montipora
Mussidae
Stylophora
Seriatopora
sites=6
sites=6
sites=6
sites=6
sites=6
1995
1996
1997
2011
2014
2015
2016
2017


Mermaid Cove
North Reef
Turtle Beach
Washing Machine
Cooks Path
Gnarly Tree
Resort
North of Paradise
Osprey
No Mans Land
Lizard Island
Lagoon 1
Easter Point
Vickis
Lizard Head
Horseshoe
Southeast
Lagoon 2
South Island
1 km
Trimodal
0 10 20 30 40 50 60 70
0 2 4 6 8 10 12 14
2011 2014 2015 2016 2017
Percent cover
Species richness


Horseshoe
Lagoon 1
Lagoon 2
Lizard Head
North Reef
Trimodal
Tropical cyclones
Bleaching events
2014
2011
2015
2016
2017
16
9
4
1
1
2
5
10
20
50
Species richness (sqrt axis)
Percent cover (log10 axis)