Journal of the
Ocean Science Foundation

2016, Volume 21

Corallimorph and *Montipora* Reefs in Ulithi Atoll, Micronesia: documenting unusual reefs

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Abstract

Here we report the presence of two unusual reef types at Ulithi Atoll, Yap State, Federated States of Micronesia: 1. a corallimorph-dominated reef off the island of Mogmog is found within an otherwise coral-dominated area, and 2. a general spread of *Montipora* reefs that were found to dominate the reef landscapes near inhabited islands. The *Montipora* reefs primarily occur near villages and in disturbed areas such as near boat-launch ramps. Indigenous people in the area say these reefs are fairly recent (ca. late 1960s) and that *Montipora* has been spreading rapidly.

Key words: coral reefs, Yap, *Rhodactis*, ecology, Pacific Ocean.

Citation: Crane, N.L., Paddack, M.J., Nelson, P.A., Abelson, A., Rulmal, J. & Bernardi, G. (2016) Corallimorph and *Montipora* Reefs in Ulithi Atoll, Micronesia: documenting unusual reefs. *Journal of the Ocean Science Foundation*, 21, 10–17.
doi: 10.5281/zenodo.51289
Date of publication: 10 May, 2016

Introduction

Changes in reef assemblages have been documented worldwide, and may result in phase-shifts. The more common and best documented type of phase shift is from coral-dominated to macroalgal-dominated reef (e.g. Hughes 1994, Roff *et al*. 2015). Other types of shifts have also been documented, albeit less frequently, such as shifts towards sponge-dominated reefs (Pawlik *et al*. 2013) and corallimorph-dominated reefs (Work *et al*.2008). There have been very few accounts of diverse coral-dominated reefs becoming dominated by 'weedy' fast-growing monospecific scleractinian corals, which appear to be connected to disturbance events (Sapp 1999).

At Palmyra Atoll, such an unusual phase-shift from a coral to a corallimorph reef (*Rhodactis howesii*) was described and linked to the presence of a nearby metallic shipwreck (Work *et al*. 2008, Kelly *et al*. 2012). Here we report the presence of two unusual reef assemblages at Ulithi Atoll, Yap State, Federated States of Micronesia: one is a corallimorph reef and the other, more widespread, appears to be a phenomenon of reefs being overtaken by a fast-growing scleractinian coral of the genus *Montipora*.

Ulithi Atoll includes a complex of small (maximum area 0.88 km^2), low-lying (maximum elevation ca. 12 m), autonomously governed islands, and is one of several outer-island groups in Yap State, Federated States of Micronesia. The Ulithi lagoon encompasses approximately 320 km^2 making it one of the largest atolls on earth (Fig. 1). The atoll consists of ca. 40 islets and four inhabited islands, where the diversity of reef types (and associated biodiversity) is generally high (Houk & Starmer 2008). Permanent residents of Ulithi number about 1000, with approximately another 400 people from other outer islands living on the atoll during the school year. The four inhabited islands are Falalop (which lies just outside the main atoll), with a population of between 500–700 people; Mogmog, with a population of approximately 150; Asor, with a population of approximately 70; and Federai to the southeast, with a population of approximately 150. Populations of these islands have remained

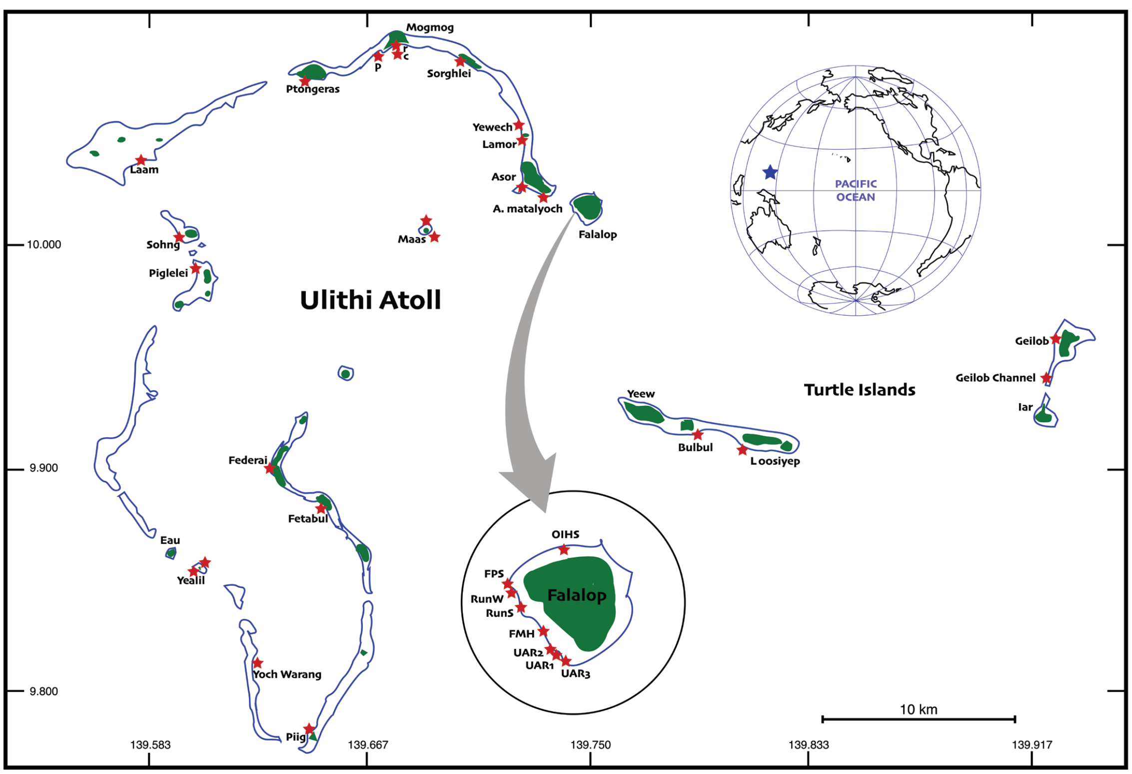

Figure 1. Study site locations (colored stars) at Ulithi Atoll and at neighboring Turtle Islands (outer islands of Yap State, Federated States of Micronesia).

relatively stable, with the exception of Falalop, which has increased by about 450 people since 1949 (this is largely due to the building of an airstrip during World War II, and the construction of the outer-islands high school in 1961)(Lessa 1966).

Community members alerted us to two reef types they were concerned about; the first being a large corallimorph patch in the northern part of the atoll near the island of Mogmog (Figs. 1 & 2), where fishing has been banned due to reports of toxicity. Chiefs told us that community members had become ill (including skin rashes and gastrointestinal problems) from eating fish and invertebrates from this reef, which is consistent with scientific reports about the toxicity of corallimorphs (Martin 1960). They believed the reef had become established post-World War II. Community members also reported an apparently 'invasive' or 'weedy' scleractinian coral growing over many reefs, reducing habitat for commonly fished invertebrates, such as octopus (Fig. 3). The latter phenomenon is described by local people as a fairly recent outbreak that may have started in the 1960s, coincident with Typhoon Ophelia, which passed over Ulithi Atoll on November 30, 1960. The goal of our study was to assess the reported descriptions by surveying the sites of these unusual reefs and identify the species involved via DNA barcoding.

Materials and Methods

Site selection.

For each of three consecutive years (2012–2014), we sampled benthic composition (twenty haphazardly placed 0.25 m^2 quadrats per site), coral morphology, and coral distribution at 32 sites throughout the atoll and associated nearby islands (Fig. 1). We selected sites across a broad spectrum of biotic and abiotic factors, including input from local people about fishing pressure, reef degradation, and historical and current use.

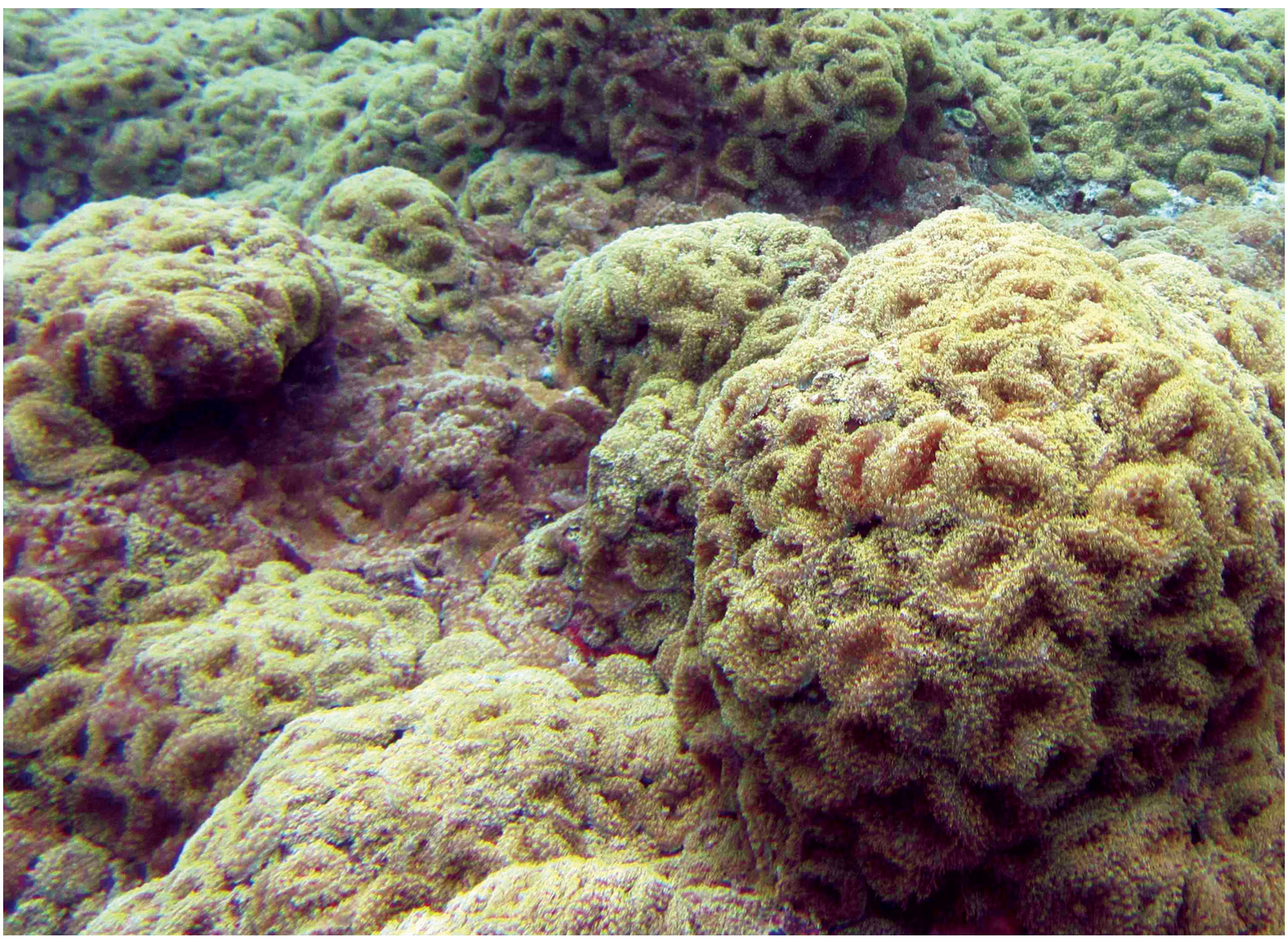

Figure 2. Corallimorph reef off Mogmog, Ulithi Atoll, Federated States of Micronesia.

Figure 3. *Montipora* reef, Asor Island, Ulithi Atoll, Federated States of Micronesia.

Surveys were conducted using snorkel on the reef crest and the reef table, in shallow sites at depths from 1.5–5 m depth. In general, the reefs dropped off quickly below this depth, as the atoll is surrounded by very deep water. Even the lagoon sites dropped off rapidly to sand or deeper reefs.

Benthic characterization.

Benthic community structure was evaluated using twenty 0.25 m^2 quadrats placed randomly on the reef crest area at each site. Quadrat locations were selected by using a random-number generator to set the distance between quadrats and direction of swim within the reef-crest corridor. Percent cover of key organisms was determined within each quadrat (counts were used for larger mobile invertebrates). Each quadrat was documented by photography. A total of 10 functional-group categories were used to assess benthic cover: stony coral, octocorals, hydrocorals, macroalgae, algal turfs, encrusting algae, cyanobacteria, bare substrate, and non-coral, sessile, and mobile invertebrates. In addition, we used 12 morphological categories for stony coral and hydrocoral. Instances of disease, paling, and bleaching were noted for all corals. In addition to quadrat data, coral-colony sizes were measured by recording maximum length, width, height, and coral functional group for each coral that intersected the 50 m fish-transect line.

DNA barcoding and molecular identification.

Two samples of corallimorph were taken at the Mogmog corallimorph reef site (Figs. 1 & 2). Samples of *Montipora* were collected at Mogmog (two samples) and at Falalop, Asor, and Yewech (one sample each)(Fig. 1). Using published primers (Folmer *et al*. 1994), we amplified a fragment of the mitochondrial cytochrome oxidase subunit 1. Reactions were carried out in 50 µl, with 5 µl of 10X PCR Buffer, 5 µl of 2 mM dNTPs, 5 µl of 25 mM $MgCl_2$, 2.5 µl of each primer (10 mM each), 0.4 µl of *Taq* polymerase, and 2 µl of template. PCR conditions used were: a denaturation first step of 95°C for 1 min, followed by 35 cycles of 30 s at 95°C, 30 s at 46°C, and 90 s at 72°C, followed by 10 min at 72°C. Neighbor-Joining distance trees were used to visualize relationships between our sequences and closely related sequences available in GenBank as described in Bariche *et al*. (2015).

Results

Reef surveys resulted in the identification of a corallimorph reef off the inhabited island of Mogmog and the widespread presence of *Montipora* reefs, which were predominantly associated with sites near villages (Fig. 4).

Corallimorph reef.

The ca. 4,000 m^2 reef is approximately one km off the island of Mogmog, within the extensive lagoon of Ulithi Atoll. Local people are discouraged from fishing in this area because organisms there are reputed to be toxic.

DNA extracted from two colonies and barcoded for the CO1 marker (GenBank accession number KF164283) revealed that the sequences were identical to an undescribed species of *Rhodactis* previously collected in Okinawa, Japan (GenBank accession number AB441265; Fukami *et al*. 2008)(Fig. 5A).

Reports from local residents and our own observations are consistent with a potential phase shift from a coral to a corallimorph-dominated reef. The genetic results suggest that this is either a widespread species that is genetically identical (at the CO1 level) from Japan to Ulithi, or it is an invasive species, potentially introduced from Japan.

Montipora reefs.

DNA barcoding confirmed the identity of the 'weedy' scleractinian coral as an unidentified species in the genus *Montipora* (GenBank accession number KU736951-6)(Fig. 5B). Sites with high cover of *Montipora* were associated with villages and boat landings (villages ranging in populations size from 70 [Asor] to 600 [Falalop]). *Montipora* cover at these sites ranged from 38% (Mogmog) to 59% (Asor), with other stony corals at very low cover levels (0–19%)(Fig. 4), resulting in low coral morphological diversity (<5% cover of branching, mounding, columnar, and encrusting corals). Turf algae were abundant at these sites (26–46% cover), whereas cover of macroalgae and crustose coralline algae (CCA) was relatively low (<1–10% and 5–11% respectively, with the exception of Sorghlei which had 23% CCA)(Fig. 4).

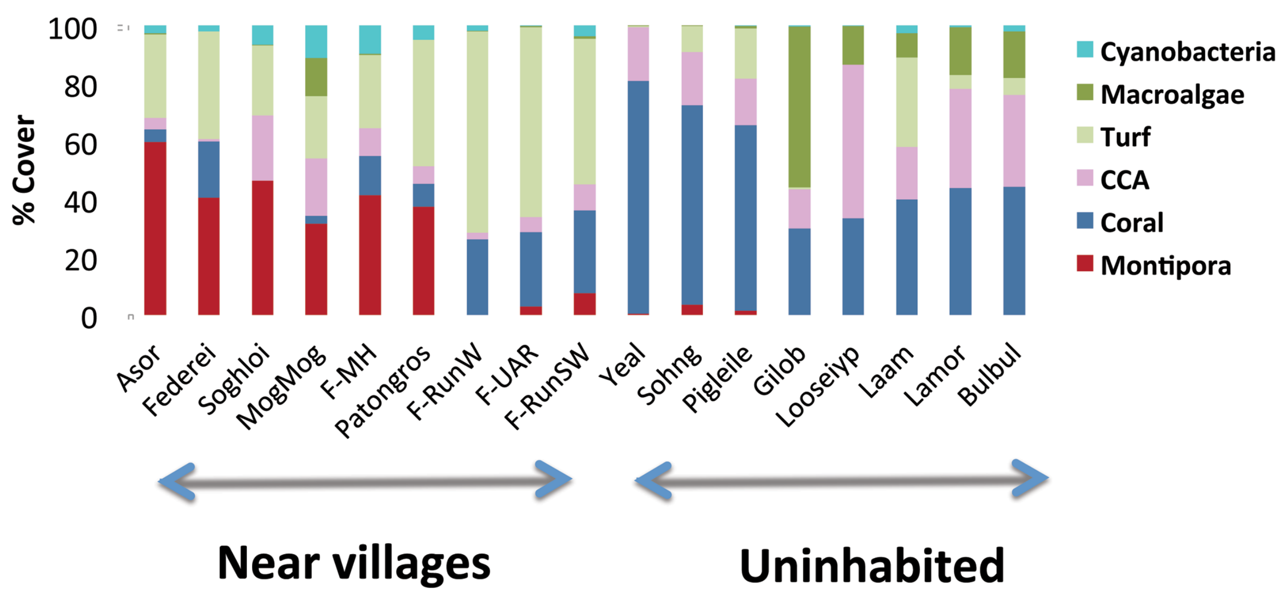

Figure 4. Reef benthic habitats at 17 sites on Ulithi Atoll, divided into sites near villages and sites not associated with villages (no people living within 10 km).

Montipora accounted for only 0.75% of the benthic cover (1.5% of the stony corals) in sites that were uninhabited and not near villages. In general, sites that were dominated by *Montipora* reefs were facing the lagoon; the only site that was not lagoon-facing which had high *Montipora* cover (38%) was Falalop Men's House near the boat landing, a zone of heavy boat traffic and disturbance (FMH in Fig. 1).

Discussion

The traditional alternate states of coral reefs are either reefs composed of stony reef-building corals, or disturbed reefs dominated by macroalgal assemblages (Hughes 1994, Roff *et al*. 2015). Recently, additional states have been described, where coral reefs shifted into sponge (Bell *et al*. 2013, Pawlik *et al*. 2013), microbial mat (Kelly *et al*. 2012), or corallimorph (Work *et al*. 2008) reefs. Here we describe another example of a phase shift to a corallimorph reef, and also a potential phase shift into a monospecific 'weedy' coral. In the past few decades, two unusual cnidarian outbreaks at Ulithi Atoll have resulted in overgrowth of diverse coral assemblages by these two cnidarians. Local people are concerned by these "new reefs" for different reasons. Corallimorph reefs are deemed "poisonous", while *Montipora* reefs reduce diversity and size of fish and reduce habitat availability (e.g. octopus shelters) (Crane *et al*., unpub. data). In both cases, natural disturbance events (such as Typhoon Ophelia) and anthropogenic influence may have contributed to the changes in these reefs.

Corallimorph reef.

Phase shifts to corallimorph reefs have been linked to both natural and anthropogenic disturbance – possibly beginning with a large-scale natural disturbance and exacerbated by anthropogenic factors (Norström *et al*. 2009). The phase shift that has been observed in Palmyra has been associated with the presence of a metallic shipwreck (Kelly *et al*. 2012). During World War II, Ulithi lagoon was used as a staging area for hundreds of US Navy vessels (Mair 2008). The Japanese Navy was also present on the atoll during both World Wars. Several shipwrecks are present in the lagoon in close vicinity but not in contact with the corallimorph reef.

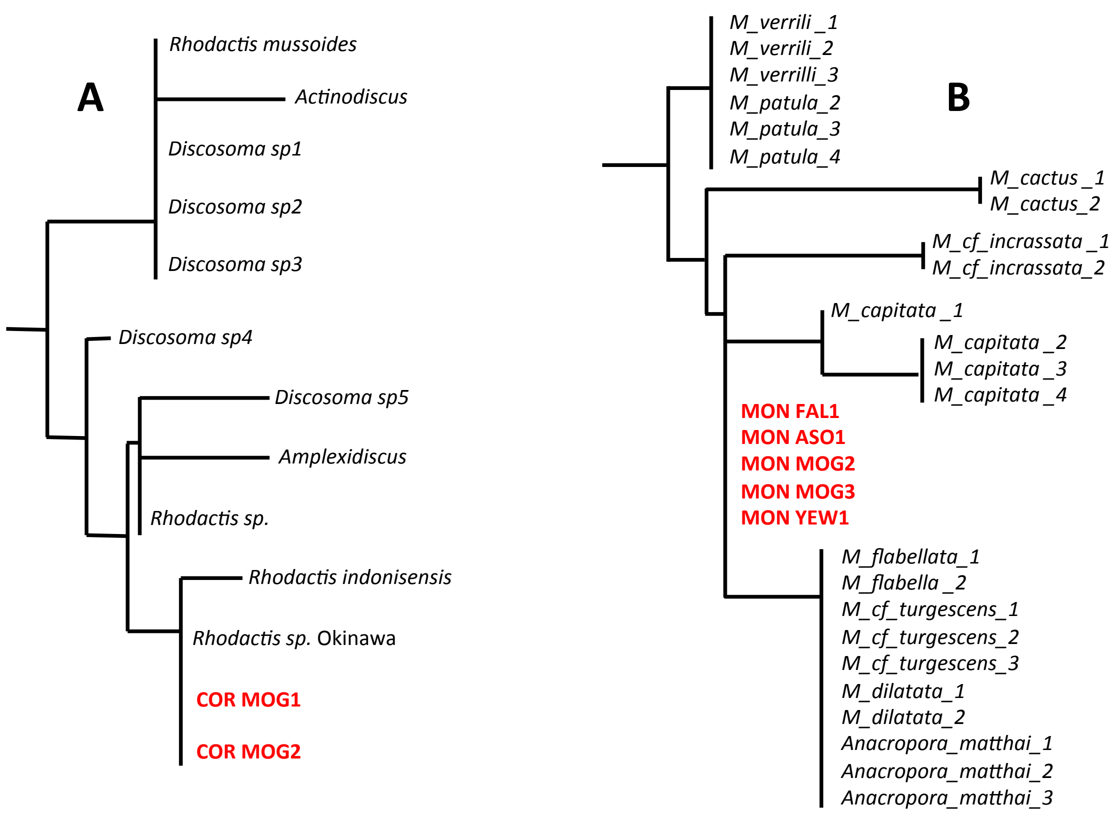

Figure 5. Phylogenetic relationships of corallimorphs and *Montipora*: Neighbor-Joining trees based on the cytochrome c oxidase 1 (CO1) mitochondrial marker. A- samples from the corallimorph reef, B- samples from *Montipora* reefs. Sequences from samples collected in Ulithi in red, all other sequences are from Genbank.

Our genetic results indicate that the corallimorph species may have been introduced via ship traffic from Japan during World War II. We cannot yet determine whether this outbreak is related to metal debris, as it was in the Palmyra outbreak (Work *et al*. 2008, Kelly *et al*. 2012). In Ulithi, there are no shipwrecks adjacent to the reef. However, the adjacent island, Mogmog, was the only site on the atoll where bombs were dropped during the war and had a large metal pier. In addition, a target-practice area was used in the vicinity of the corallimorph reef (Mair 2008). Therefore, there are several potential sources of enhanced iron levels in the area.

Montipora reefs.

While local people consider *Montipora* to be an alien invader, there is no evidence to indicate an exogenous origin. It is possible that the right ecological conditions (such as post-typhoon disturbance) contributed to the establishment and success of this 'weedy' species, enabling it to be competitively dominant over other species of corals. Some *Montipora* species have been shown to be superior competitors when in stressful environments (Evensen *et al*. 2015). The presence of *Montipora*-dominated reefs in the vicinity of disturbed areas near villages suggest that human activities may play a role in the spread of this species.

Conclusions

Documentation of the spatial and temporal distribution of these 'weedy' species, along with investigations of local sources of disturbance, will help provide insight into how reefs are responding to global and local stressors and how these factors interact synergistically (Coté *et al*. 2016). We are conducting further field-work and detailed analyses to provide a mechanistic understanding of these outbreaks. It is likely that more events and types of phase-shifts will be described in the future (Norström *et al*. 2009), and the documentation and analysis of these trends is important to our understanding of reef dynamics and management.

Acknowledgments

We would like to thank the people of Ulithi Atoll with whom we work closely, and who keep welcoming our research team. We would also like to thank Kristin Precoda for help in the field and for extensive data analysis, and Sarah Cannon for help with data collection. This work was funded by the UC Pacific Rim Program, the US Office of Insular Affairs, and the David and Lucile Packard Foundation. Two anonymous reviewers supplied valuable comments.

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