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## RESEARCH NOTE

# Rapid coral mortality following doldrums-like conditions on Iriomote, Japan [version 1; referees: awaiting peer review]

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## Abstract

Coral bleaching can be induced by many different stressors, however, the most common cause of mass bleaching in the field is high sea temperatures (SST). Here, we describe an unusual bleaching event that followed very calm sea conditions combined with higher than average sea surface temperatures (SST). Patterns of mortality differed from typical thermal bleaching in four ways: 1) mortality was very rapid; 2) the suite of species most affected was different; 3) tissue mortality in *Acropora* spp. was often restricted to the center of the colony; 4) the event occurred early in the summer. The two weeks prior to the event included 8 days where the average wind speed was less than 3 ms<sup>-1</sup>. In addition, SSTs in the weeks preceding this event were 1.0-1.5°C higher than the mean for the last 30 years. We hypothesize that the lack of water movement induced by low wind speeds combined with high SST to cause colonies anoxic stress resulting in this unusual bleaching event.

## Open Peer Review

**Referee Status:** Awaiting Peer

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## Introduction

Coral bleaching is a generalized response that can be induced by many different stressors<sup>1–3</sup>. Whilst the most common cause of large scale bleaching on coral reefs is unusually high sea surface temperatures (SSTs)<sup>4,5</sup>, prolonged periods of calm weather, known as the doldrums, have also been associated with mass bleaching events in the Caribbean<sup>6,7</sup> and the Indo-Pacific<sup>8–10</sup>. Experimental work has also confirmed that low water flow can exacerbate thermal bleaching<sup>11,12</sup>.

The ecology of thermal coral bleaching is reasonably well documented. For example, colonies affected by high temperatures typically take between two to six weeks to bleach and bleached tissue can take another two to twenty weeks to die<sup>13</sup>. In addition, species vary in their susceptibility to thermal bleaching<sup>14,15</sup>, resulting in a predictable hierarchy of response<sup>16,17</sup>. Temporal patterns are also apparent with most high temperature induced mass bleaching events generally occurring towards the end of the summer months<sup>18,19</sup>. Any change in this predictable bleaching ecology suggests an alternative cause (i.e., not thermal stress) for a given bleaching event.

Here, we describe an atypical bleaching event that we hypothesize was caused by an interaction of temperature with very calm sea conditions caused by an extended period of low winds. We identify a number of characteristic features of this doldrums bleaching that allow it to be distinguished from thermal bleaching in the field. Establishing the cause of specific bleaching events is vital in order to correctly attribute damage caused by climate change and other potential stressors.

## Methods

The study site was on the reef crest (1 m depth) at Nata Reef, Iriomote, Japan (24.4282°N, 123.7955°E). Initial observations at the site were made between 26 and 29 May, 2016 at which point in time no bleached corals were noted. Surveys to quantify bleaching and mortality were conducted on 12 June, 2016. Twenty replicate 1m<sup>2</sup> quadrats were placed haphazardly on the reef crest, and the condition and species identity of all hard coral colonies with a maximum diameter greater than 5cm were recorded. Species were identified in the field following<sup>20</sup> and the names updated to the currently accepted names following<sup>21</sup>. Colonies were placed in one of six bleaching categories following<sup>21</sup>: (1) unbleached, (2) the entire colony pale, (3) 1–50% of the colony white, (4) 51–99% of the colony white, (5) 100% of colony white or fluorescent, or (6) recently dead. The data from the quadrats was pooled as the

data was collected. The bleaching mortality index was calculated following<sup>16</sup>. Data on environmental conditions leading up to the bleaching episode were obtained from the Japan Meteorological Agency, which allows for these data to be used as long as due credit is given.

## Results

Bleaching and mortality was rapid. No colonies were bleached at the time of the first surveys (26 May, 2016) yet two weeks later (12 June, 2016), 5% of colonies were dead and a further 31% were bleached (Table 1).

Mortality was highest in *Montipora aequituberculata* and *Montipora efflorescens* (Figure 1A), and in an additional three species of the family Merulinidae, who were also badly affected (Table 1). Bleaching and tissue mortality were generally restricted to the center of colonies in the locally abundant species *Acropora digitifera* and *Acropora hyacinthus* (Figure 1B, C, D).

The bleaching event occurred early in June, the first month of the northern summer, following a period of low wind and higher than average sea surface temperature (SST). Eight days in the previous two weeks had average wind speeds of under 3 ms<sup>-1</sup> (Table 2). Winds were also mostly from the south, which is offshore at the study site and therefore likely to further reduce wave size and water motion (Table 2). Mean daily SSTs in the month preceding the second survey were 1.0–1.5°C higher than the mean for the previous 30 years (Table 3).

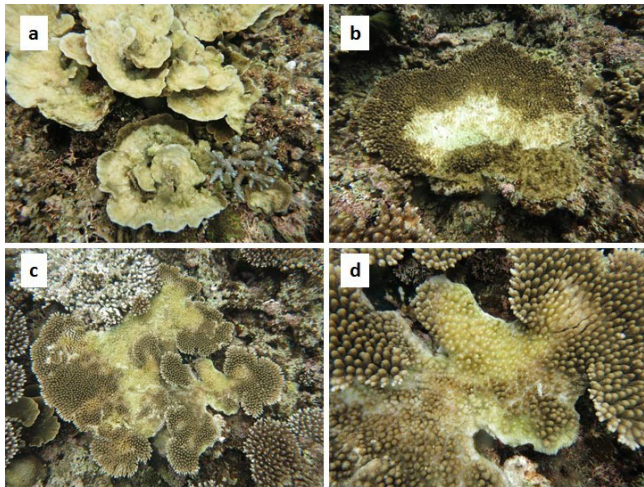
## Discussion

This bleaching event was different to typical thermal bleaching in a number of important ways. In particular, rapid bleaching and tissue mortality restricted to the center of *Acropora* colonies, an atypical hierarchy of susceptibility, and the occurrence of the event in early summer, all distinguish this event from typical thermal bleaching. We hypothesize that unusually high SST combined with a lack of water flow due to low winds speeds resulted in anoxic stress to these colonies. This hypothesis is supported by doldrums like conditions (Table 2) combined with higher than average mean daily surface ocean temperatures (Table 3) in the weeks prior to the event.

In contrast to the typical thermal response, bleaching and mortality were very rapid, with a high proportion of colonies bleached and some dying within the two week period between the surveys (Table 1). Bleaching and, in particular, mortality typically take between 4–6 weeks to present in corals following thermal stress<sup>13</sup>.

**Table 1. Bleaching categories of hard corals at Nata Reef on 12 June 2016.** BMI = Bleaching Mortality Index.

taxa	unbleached	moderate	severe	dead	BMI	n
<i>Acropora aspera</i>	100	0	0	0	0	1
<i>Acropora digitifera</i>	81	19	0	0	6	32
<i>Acropora gemmifera</i>	100	0	0	0	0	1
<i>Acropora hyacinthus</i>	71	29	0	0	10	7
<i>Acropora nasuta</i>	50	50	0	0	17	2
<i>Acropora selago</i>	0	0	0	100	100	1
<i>Astrea annuligera</i>	100	0	0	0	0	1
<i>Cyphastrea serailia</i>	100	0	0	0	0	3
<i>Dipsastraea rotumana</i>	0	100	0	0	33	1
<i>Dipsastrea pallida</i>	30	50	20	0	30	10
<i>Favites abdita</i>	100	0	0	0	0	3
<i>Favites halicora</i>	86	14	0	0	5	7
<i>Favites magnistellata</i>	100	0	0	0	0	2
<i>Galaxea fascicularis</i>	82	18	0	0	6	11
<i>Goniastrea pectinata</i>	0	50	50	0	50	2
<i>Goniastrea retiformis</i>	86	14	0	0	5	14
<i>Milleporidae</i>	17	33	50	0	44	6
<i>Montipora aequituberculata</i>	0	0	0	100	100	3
<i>Montipora crassituberculata</i>	46	32	18	4	26	28
<i>Montipora digitata</i>	71	0	29	0	19	7
<i>Montipora efflorescens</i>	0	27	27	45	73	11
<i>Montipora monasteriata</i>	100	0	0	0	0	4
<i>Montipora turgescens</i>	0	100	0	0	33	1
<i>Pavona decussata</i>	100	0	0	0	0	2
<i>Pavona venosa</i>	57	43	0	0	14	7
<i>Platygyra pini</i>	75	25	0	0	8	4
<i>Platygyra ryukyuensis</i>	25	50	25	0	33	4
<i>Platygyra verweyi</i>	67	0	0	33	33	3
<i>Pocillopora damicornis</i>	67	22	11	0	15	9
<i>Porites annae</i>	60	40	0	0	13	5
<i>Porites cylindrica</i>	77	23	0	0	8	13
<i>Porites lichen</i>	100	0	0	0	0	3
<i>Porites lutea</i>	100	0	0	0	0	1
<i>Porites rus</i>	100	0	0	0	0	6
<i>Psammocora contigua</i>	100	0	0	0	0	1
total	64	23	8	5	216	18



**Figure 1.** (a) Dead and dying *Montipora aequituberculata* colonies (b) *Acropora hyacinthus* colony with bleached and dying tissue in the middle of the colony (c) a second *A. hyacinthus* colony (d) close up of the colony in (c).

**Table 2.** Mean daily wind speeds in the 12 days prior to the first observations of bleaching on 12 June 2016. Data from Japan Meteorological Agency.

date	Mean wind speed (m/s)	Mean wind speed (knots)	wind direction
30/05/2016	2.1	4.1	ENE
31/05/2016	1.8	3.5	SE
1/06/2016	3.4	6.6	W
2/06/2016	3	5.8	NE
3/06/2016	2.1	4.1	SW
4/06/2016	2.1	4.1	ENE
5/06/2016	3.2	6.2	NE
6/06/2016	2.5	4.9	NE
7/06/2016	1.6	3.1	SE
8/06/2016	1.9	3.7	ESE
9/06/2016	2	3.9	ENE
10/06/2016	3	5.8	SSW
11/06/2016	6.4	12.4	SSW
12/06/2016	8.2	15.9	SSW

**Table 3.** Sea surface temperature anomalies in the weeks preceding the bleaching event on Nata Reef. Values are the degrees in centigrade above the 30 year average for this site in each time interval. Data from the Japan Meteorological Agency.

Week ending	Sea surface temperature anomaly (°C)
27 April 2016	+1.5
9 May 2016	+1.5
19 May 2016	+1.0
30 May 2016	+1.5
9 June 2016	+1.5

In addition, the hierarchy of susceptibility was very different to that following thermal bleaching. Here, the worst affected species included two *Montipora* spp. and a number of merulinids (Table 1), when typically *Acropora* spp. and *Pocillopora* spp. are the most severely affected following thermal bleaching<sup>5,15,22</sup>.

The pattern of tissue bleaching and mortality was also unusual. In *Acropora* colonies the typical pattern following thermal stress is for the whole colony to bleach<sup>13</sup>. In contrast, mortality was restricted to the center of most *Acropora* colonies in this event (Figure 1a, b, c). Tissue mortality beginning in the center of the colony typically indicates anoxia, which often occurs in aquaria with inadequate flow or oxygenation (pers obs). This pattern of mortality is also superficially similar to feeding scars caused by *Acanthaster planci* or *Drupella* spp.<sup>23</sup> and a naïve observer might well have attributed this mortality to either of these corallivores<sup>24</sup>. A thorough search of the site, including underneath these and adjacent colonies, indicated that neither of these corallivores were present.

The timing of the bleaching event in early summer is also unusual. Thermal bleaching typically occurs much later in the summer. For example, recurrent seasonal bleaching on Magnetic Island, Australia, occurs in the last month of the austral summer i.e., February<sup>18</sup>. Similarly, the 1998 mass bleaching event in Japan was first noticed in the latter part of the summer i.e., late July<sup>25</sup>. In contrast, this doldrums event occurred early in June, the first month of the northern summer.

Doldrums-like conditions (defined by NOAA as days with average wind speeds of less than 3 ms<sup>-1</sup>) have previously been linked to mass bleaching events<sup>6–9</sup>. However, the capacity of the doldrums to cause more localized damage outside of the typical thermal bleaching window in late summer has not previously been recognized. In addition, the potential link to anoxia, while tested in the laboratory<sup>26</sup>, has not been made in the field. This observation is especially important in the context of the continuing increase in the scale and frequency of mass bleaching events<sup>27</sup> because it would generally be assumed that this small-scale phenomenon might presage a larger mass bleaching event. Determining the cause of specific bleaching events is vital in order to accurately distinguish the effects of climate change versus other causes of degradation on coral reefs.

### Data availability

The pooled raw bleaching data is provided in Table 1.

Source data for Table 2 are available from the Japan Meteorological Agency, at: <http://bit.ly/2hck2G6>, <http://bit.ly/2wAVhcg>.

Source data to generate the values in Table 3 are available from the Japan Meteorological Agency, at: <http://bit.ly/2y8qIBw>.

### Competing interests

No competing interests were disclosed.

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