



RESEARCH NOTE

REVISED Rapid coral mortality following unusually calm and hot conditions on Iriomote, Japan [version 2; referees: 2 approved]

Previously titled: Rapid coral mortality following doldrums-like conditions on Iriomote, Japan

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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 higher than average sea surface temperatures (SST). Here, we describe an unusual bleaching event that followed very calm sea conditions combined with higher than average SST. Patterns of mortality differed from typical bleaching in four ways: 1) mortality was very rapid; 2) a different suite of species were most affected; 3) tissue mortality in *Acropora* spp. was often restricted to the center of the colony; 4) the event occurred early in summer. The two weeks prior to the event included 8 days where the average wind speed was less than 3 ms⁻¹. In addition, SSTs in the weeks preceding and during the event were 1.0-1.5°C higher than the mean for the last 30 years. We hypothesize that this unusual bleaching event was caused by anoxia resulting from a lack of water movement induced by low wind speeds combined with high SST.

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REVISED Amendments from Version 1

In response to the comments of Robert van Woessik we have removed all reference to the doldrums, the table has been rearranged so the species are ranked from most to least impacted, we have specified the aspect of the site and addressed all the grammatical and typographical errors identified. In response to the comments of Misha Matz we now included sea surface temperatures and wind speeds for the year preceding the bleaching event. These data suggest it was both hotter and calmer in the week prior to the bleaching than at the same time of year in 2015. However, as Misha points out, it is not possible to *prove* that this bleaching was a result of hypoxia driven by calm or hot conditions. To do this we would need to have placed oxygen electrodes in the centre of colonies during the event. We have, however, added comments to the effect that wind speeds less than 3 m/s are generally regarded as the cut-off below which calm weather bleaching can occur and cited the NOAA website in support of this statement. Absolute values of wind speed are the correct metric to present – this is what affects wave and water movement. Unfortunately, we can find no literature in support of the statement that “Tissue mortality beginning in the center of the colony typically indicates anoxia..”. Therefore, we have reworded the sentence to make it clear that this statement is based on personal observation alone. We have kept the BMI index in [Table 1](#) because this is now used to rank the taxa as requested by Robert van Woessik.

See referee reports

Introduction

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

The ecology of thermal coral bleaching in response to high SSTs 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 die¹³. In addition, species vary in their susceptibility to thermal bleaching^{14,15}, resulting in a predictable hierarchy of response^{16,17}. Temporal patterns are also apparent with most high temperature induced mass bleaching events generally occurring towards the end of the summer months^{18,19}. 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 calm weather 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 1m² 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 following²⁰ and the names updated to the currently accepted names following²¹. Colonies were placed in one of six bleaching categories following²²: (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 following¹⁶. Data on environmental conditions leading up to the bleaching episode and for a similar time frame in 2015 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 *M. efflorescens* ([Figure 1A](#)), and in an additional three species of the family Merulinidae, that 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 *A. 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⁻¹ ([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 0.0–1.5°C higher than the mean for the previous 30 years ([Table 3](#)). Wind speeds were higher and SST lower during the same time interval in 2015 ([Table 2 & Table 3](#)).

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

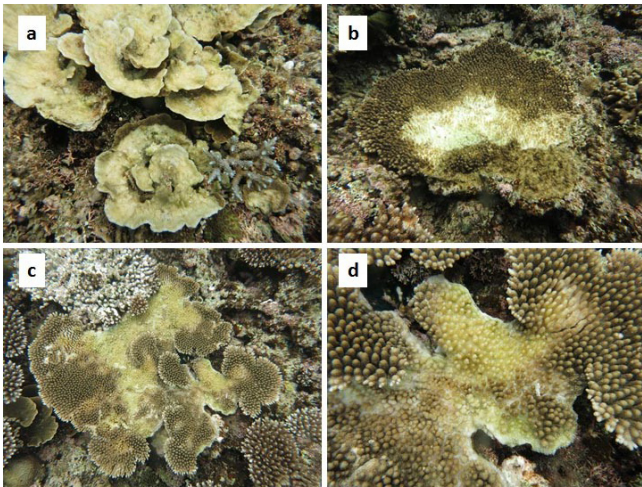


Figure 1. (a) Dead and dying *Montipora aequituberculata* colonies (b) *Acropora hyacinthus* colony with bleached and dying tissue in the middle of the colony (c) a second *A. hyacinthus* colony (d) close up of the colony in (c). Images were captured using a Canon S100 digital camera in waterproof housing.

Table 2. Mean daily wind speeds in the 12 days prior to the first observations of bleaching on 12 June 2016 and for the same dates in 2015. Data from Japan Meteorological Agency.

Date	2015 wind speed (m/s)	2015 wind direction	2016 wind speed (m/s)	2016 wind direction
30 May	2.2	SSE	2.1	ENE
31 May	3.1	ENE	1.8	SE
1 June	2.6	NE	3.4	W
2 June	4.8	SSW	3	NE
3 June	4.6	SSW	2.1	SW
4 June	2.3	S	2.1	ENE
5 June	5.5	SSW	3.2	NE
6 June	3.8	S	2.5	NE
7 June	4.2	SSW	1.6	SE
8 June	3.3	SW	1.9	ESE
9 June	3	SSW	2	ENE
10 June	4.2	SSW	3	SSW
11 June	5.3	S	6.4	SSW
12 June	4	S	8.2	SSW

Table 3. Sea surface temperature anomalies in the weeks preceding the bleaching event on Nata Reef and a similar time interval in 2015. Values are the degrees in centigrade above the 30 year average for this site in each time interval. Data from the Japan Meteorological Agency.

10 day period ending	2015 SST anomaly °C	2016 SST anomaly °C
10 April	0	0
20 April	-0.5	1
30 April	0	1.5
10 May	0.5	1.5
20 May	0.5	1
30 May	0.5	1
10 June	0.5	1

Discussion

This bleaching event was different to typical thermal bleaching in a number of important ways. In particular, rapid tissue mortality, 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 very low wind speeds (Table 2) combined with higher than average mean daily SST (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 stress¹³. 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^{5,15,22}.

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 bleach¹³. 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 is suggestive of 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.²³ and a naïve observer might well have attributed this mortality to either of these corallivores²⁴. 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., February¹⁸. Similarly, the 1998 mass bleaching event in Japan was first noticed in the latter part of the summer i.e., late July²⁵. In contrast, this calm weather 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⁻¹) have previously been linked to mass bleaching events^{6–9}. However, the capacity of calm weather 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 laboratory²⁶, 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 events²⁷ 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://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php?prec_no=91&block_no=47917&year=2015&month=05&day=30&view=a3

http://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php?prec_no=91&block_no=47917&year=2015&month=06&day=30&view=a3

http://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php?prec_no=91&block_no=47917&year=2016&month=05&day=30&view=a3

http://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php?prec_no=91&block_no=47917&year=2016&month=06&day=30&view=a3

Source data to generate the values in [Table 3](#) are available from the Japan Meteorological Agency, at: <http://bit.ly/2y8qlBw>.

Competing interests

No competing interests were disclosed.

Grant information

This work was funded by the Australian Research Council Centre of Excellence for Coral Reef Studies (CE140100020) and VILLUM FONDEN (10114).

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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[PubMed Abstract](#) | [Publisher Full Text](#)

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Mikhail V. Matz 

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I'm generally satisfied with the authors' response, although I really hoped to see more previous-years data than just one year before the event - in my opinion the case for the "doldrums effect" becomes progressively more convincing the better you can show that these conditions were indeed really unusual. Also, next time, please consider using some form of graphs rather than tables to illustrate this type of data (perhaps a scatterplot of wind speed vs temperature, points colored by month?... Or, overlaid temperature and wind speed line graphs for the event time vs previous years?)

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Referee Report 04 December 2017

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Robert van Woesik 

Department of Biological Sciences, Florida Institute of Technology, Melbourne, FL, USA

The manuscript by Baird and colleagues is a useful contribution to the literature. There are however a few minor edits that are necessary to make this short contribution publishable.

Firstly, the title is inaccurate, or at least misleading. Doldrums is a maritime term that refers to the low-pressure area affected by the Intertropical Convergence Zone, where the prevailing winds are generally calm. The doldrums are considered to lie between 10°N and 10°S. Using the term doldrum-like conditions, instead of calm conditions, for a reef that is located at latitude 24 north confuses the terminology. I understand that NOAA, the US agency, has been using the term to refer to atypically calm periods irrespective of latitude, but again that doesn't make it correct because they are also misusing the term. Change the title to reflect a short, atypically calm period.

Table 1 should not simply have the corals in alphabetical order, but instead sort the table from most to least impacted.

Introduction

Again, revise the use of the term doldrums.

Methods

Several periods are missing at the ends of sentences in the Methods section.

Specify the aspect of the site. Which direction is the site facing?

Data were pooled and were collected, not data was.

Results

Delete the word “who” in the sentence “who were also badly affected (Table 1)”

Discussion

“was different from...”, not different to

Revise doldrums-like conditions in several places.

Again, different from, not different to.

Periods are missing from the ends of sentences in several places of the Discussion.

Split infinitive: change to : has not been previously...

Data availability

Data are provided, not, data is provided

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

doi:10.5256/f1000research.13707.r26307



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This is a compact report of an unusual bleaching episode, presenting an interesting hypothesis that it could have been caused by anoxia during atypical doldrums conditions. Both are valuable for improving our understanding of factors affecting coral survival in times of changing climate.

While there is no way to rigorously prove that the doldrums hypothesis is true, it certainly seems reasonable (and the wording throughout the paper is appropriate – there is never a claim that doldrums actually caused the observed bleaching).

That said, the paper would greatly benefit from expanded characterization of the doldrums episode, beyond tables 1 and 2. Is it possible to make wind speed and temperature graphs for broader range of dates (start in April) and compare that to conditions in the same time in previous years? This might show what was actually the most unusual – early temperature anomaly, low wind anomaly (by the way absolute values in Table 2 are not very informative without knowing how much below typical they are), or a combination of the two? Come to think of it, wave height could be a better proxy of water movement on the reef than wind speed, if it is possible to get that data (from satellite?).

Minor things:

“Tissue mortality beginning in the center of the colony typically indicates anoxia, which often occurs in aquaria with inadequate flow or oxygenation (pers obs)” – I am not quite happy with the word “typically” used in a statement supported by nothing but personal observation... Can you please try once more to look up literature on this? (this is why my answer in “partly” to the literature citing question). This would also strengthen the doldrums case.

“The bleaching mortality index was calculated following [16]” – as far as I can see, this index is not actually used for anything in the paper, so maybe it is not necessary? If keeping it, please expand a little: “The bleaching mortality index was calculated by [doing this and that], following [16].”

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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