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# Supplementary Materials for

## Spatial and temporal patterns of mass bleaching of corals in the Anthropocene

Terry P. Hughes,* Kristen D. Anderson, Sean R. Connolly, Scott F. Heron, James T. Kerry, Janice M. Lough, Andrew H. Baird, Julia K. Baum, Michael L. Berumen, Tom C. Bridge, Danielle C. Claar, C. Mark Eakin, James P. Gilmour, Nicholas A.J. Graham, Hugo Harrison, Jean-Paul A. Hobbs, Andrew S. Hoey, Mia Hoogenboom, Ryan J. Lowe, Malcolm T. McCulloch, John M. Pandolfi, Morgan Pratchett, Verena Schoepf, Gergely Torda, Shaun K. Wilson

*Corresponding author. Email: terry.hughes@jcu.edu.au

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**This PDF file includes:**

## Materials and Methods

Temperature Data, 1871-2016

We calculated the long-term amount of global warming throughout El Niño-Southern Oscillation (ENSO) phases (El Niño, La Niña and ENSO-neutral) for all 1,670 1-degree latitude by longitude boxes containing tropical coral reefs, between 31$^{o}$N to 31$^{o}$S. Monthly values of the Niño 3.4 SST index of ENSO were obtained from the HadISST data set (*25*) and the NOAA Climate Prediction Center (http://www.cpc.ncep.noaa.gov/data/indices/), from 1871-2016. The warming of the tropical oceans documented in the HadISST data set is also well-supported by tropical SST reconstructions (67% variance in common) developed from the skeletons of massive corals (*26*) which are not biased by data uncertainties in the instrumental SST records. We identified 23 El Niño periods when the index was more than one standard deviation above the mean; 24 La Niña episodes when the index was ≤ 1 SD below the mean; and 24 ENSO-neutral intervals when the index was ± 0.14 SD of the mean. For each of these three phases of ENSO cycles, thermal anomalies in maximum summer temperatures were compared to a 1961-1990 baseline (Fig. 1). Non-linear regressions of thermal anomalies versus year (Fig. 1) were produced in R (version 1.0.44), fitting generalized additive models (GAMs) to El Niño, ENSO-neutral and La Niña phases, using 3 splines (smoothing parameters).

To examine the relationship between the amount of global warming and the number of bleaching events per location, we also extracted monthly sea surface temperatures from the HadISST data set, for 1871-2016 (*25*), for a 1-degree latitude by longitude box centred on each of the 100 reef locations. The summer maximum temperature at each location was regressed against year to calculate the total amount of warming since the pre-industrial period. The level of warming at each location was then regressed against the number of severe (and total) bleaching events, separately for the locations in each of the four geographic regions (Fig. 4, Supplementary Tables S2 and S3). The results for severe and total bleaching events were virtually identical. Similarly, omitting high latitude reefs (sixteen locations north or south of 23.5° that have warmed more than average) did not affect the regression results.

Global analysis of coral bleaching, 1980-2016

We gathered information on coral bleaching for 100 well-studied locations, for each year between 1980 and September 2016. Because the number of locations in our analysis is fixed at 100, we avoided the potential bias in open access databases arising from the continuous addition through time of new sites, and of oversampling at well-studied or more accessible locations. Furthermore, the spatial scale of the locations we examined is fixed through time, allowing us to test for scale-dependency in the number of observed bleaching events. To constrain the size of more extensive reef systems, such as continental coastlines and large countries (e.g. Australia, Indonesia), we recorded bleaching at multiple locations (e.g. the northern, central and southern Great Barrier Reef, and separately for four major reef systems along the 3000 km coast of tropical and subtropical Western Australia). The size of each location is recorded in Supplementary Table S1 which presents the raw, binary data on bleaching records necessary to duplicate our results in Figures 2-4.

Each record was assessed using three sources: 349 publications that document bleaching events, our own observations at 70 of the locations, and communications with 43 colleagues who have expert knowledge of the history of specific locations (see sources cited for each location in Supplementary Table S1). The possibility of a type 2 error (a false negative) always exists in any analysis of this sort. Unlike any earlier compilation of bleaching records, we have sought to minimize this possibility by fixing the number of locations and compiling all of the available information for them. By making the Supplemental Table of 700 records available, we hope it will encourage any corrections and facilitate updates of future bleaching. We checked whether Reefbase (reference #258 in Supplemental Table S1) reports any additional bleaching events at our 100 study locations, up to 2010. This source accounts for 6 of our 613 bleaching records, of which 5 were minor. To compare locations, geographic regions and years, we standardized the severity of bleaching for each record into two categories, severe and more moderate, with roughly equal sample sizes. We defined bleaching as severe at each location if >30% of colonies bleached at replicate sites, at a scale of 10 to 100s of kilometres. We also recorded more moderate bleaching, defined as 1-30% of colonies affected at multiple sites. The thirty percent cut-off distinguished 300 severe versus 312 more moderate bleaching records at a global scale across the whole 1980-2016 period. We used the same 30% cut-off in our field studies of recurrent bleaching along the east and west coast of Australia, in the western Pacific and eastern Indian Ocean (*20*). Furthermore, mortality of corals increases steeply when more than 30% of corals are bleached (*11*).

To test for differences in the trajectory of bleaching events among geographic regions, we compared 22 locations in the Indian Ocean (including the Middle East), 32 in Australasia

(Australia, south-east Asia and the Coral Triangle), 24 in the Pacific, and 22 in the Western Atlantic. This classification also facilitated comparison with historical and projected changes in sea surface temperatures among major coral reef regions (*13,14,19*).

To test for scale-dependency in the frequency of bleaching, we plotted the number of bleaching records against the area of coral reefs at each of the 100 locations (*27*), as well as reef areas of regions that were larger, and individual reefs that were smaller in size than the 100 locations (Fig. SI). The larger regions were the Indian Ocean, Australasia, the Pacific, Western Atlantic, and the summed global total. The smaller individual reefs (n = 91) were all <10 sq km in size and located on the northern, central and southern Great Barrier Reef. Each of them bleached 0-3 times in three severe bleaching events from 1980-2016 (*20*). Across the full spectrum of reef areas, the number of severe bleaching records was strongly scale-dependent (Fig. S1, Adjusted R-squared = 0.610, $p < 0.0001$). However, there was no relationship between the number of bleaching events and the size of the 100 locations alone (severe bleaching events, $p = 0.952$; total number of bleaching events, $p = 0.415$)

<u>Statistical analyses</u>

We used a Generalized Linear Mixed Model (GLMM) with a binomial error structure to examine spatial and temporal trends in bleaching, treating the four geographic regions and year (1980-2016) as fixed effects, and location within region as a random effect. The error was modelled as binomial, for two analyses (based on unbleached versus bleached records, or severely bleached versus not severely bleached). For the unbleached versus bleached analysis, we fit the GLMM using maximum likelihood, as implemented by the function glmer() in the R library lme4 (*28*). For the severely bleached vs not severely bleached analysis, the maximum likelihood estimation failed to converge, so we used instead the penalized quasi-likelihood method implemented by the function glmmPQL() in the R library MASS (*29*). Time is measured as the number of years since 1980 (the start of the time series), and is an ordinal value. To facilitate ecological interpretation of the model's coefficients, the model has been parameterized such that the model's intercept, and the main effect of time, are fixed at zero. Thus, the fixed effect of region gives the log-odds of a location within that region bleaching in 1980, and the interaction between time and region gives the annual rate of change in the log-odds of bleaching for that region. A significant interaction between time and region indicates that the log-odds of bleaching changes significantly over time for that region.

To calculate the predicted cumulative number of bleaching events in each of the four geographic regions, we estimated the number of bleached reefs each year by summing the probability of bleaching across all locations within that region. The predicted cumulative number of bleaching events globally was calculated in the same fashion, by summing the predicted number of bleaching events across all regions. To estimate the rate of increase in bleaching risk per annum, we used the equation:

$$B(t) = B(0)e^{rt}$$

where $B(t)$ is the estimated frequency of bleaching events per location in year $t$, and $r$ is the exponential rate of increase in bleaching frequency. After log-transformation, we have:

$$\ln(B(t)) = \ln\big(B(0)\big) + rt$$

We then used a linear model to fit the log bleaching frequencies (the left-hand side of the formula above) to the number of years since 1980 (i.e., $t$=0 in 1980).

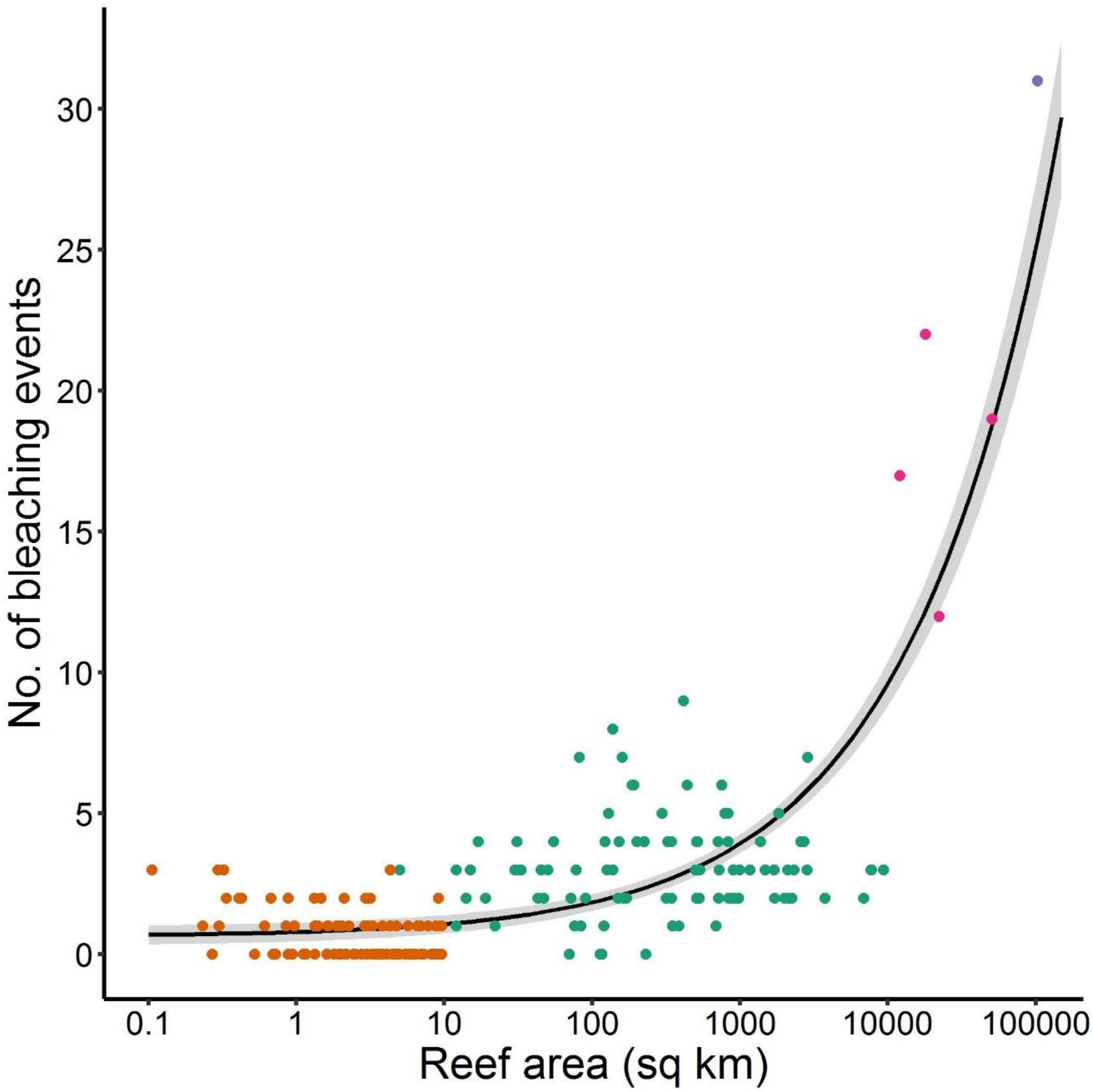


**Fig. S1.**

**A test for scale-dependency in bleaching frequency, across a spectrum of location sizes.** The orange symbols represent 91 individual reefs from the Great Barrier Reef, each smaller than 10 sq km in size. The green symbols are the 100 global locations (Fig. 3, Supplementary Table S1), the pink symbols are larger regions (the Indian Ocean, Australasia, the Pacific, and Western Atlantic) and the single purple symbol shows the global total area of coral reefs. The y-axis is the number of recorded severe bleaching events from 1980-2016. A linear regression for the 100 locations was not significant, either for severe or total number of bleaching events.

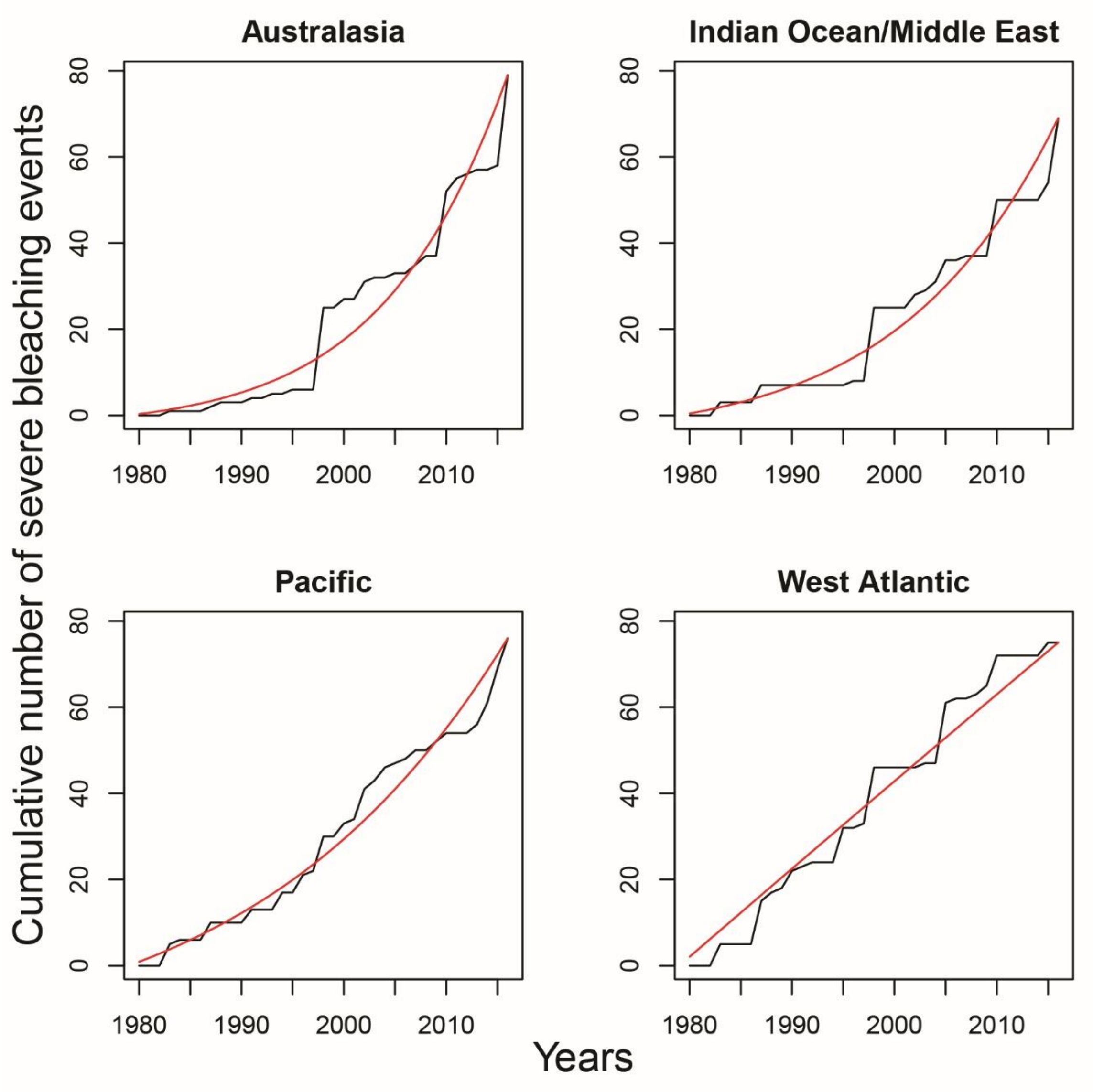
Australasia
Indian Ocean/Middle East
Pacific
West Atlantic
Cumulative number of severe bleaching events
Years
0
20
40
60
80
1980
1990
2000
2010

**Fig. S2A**

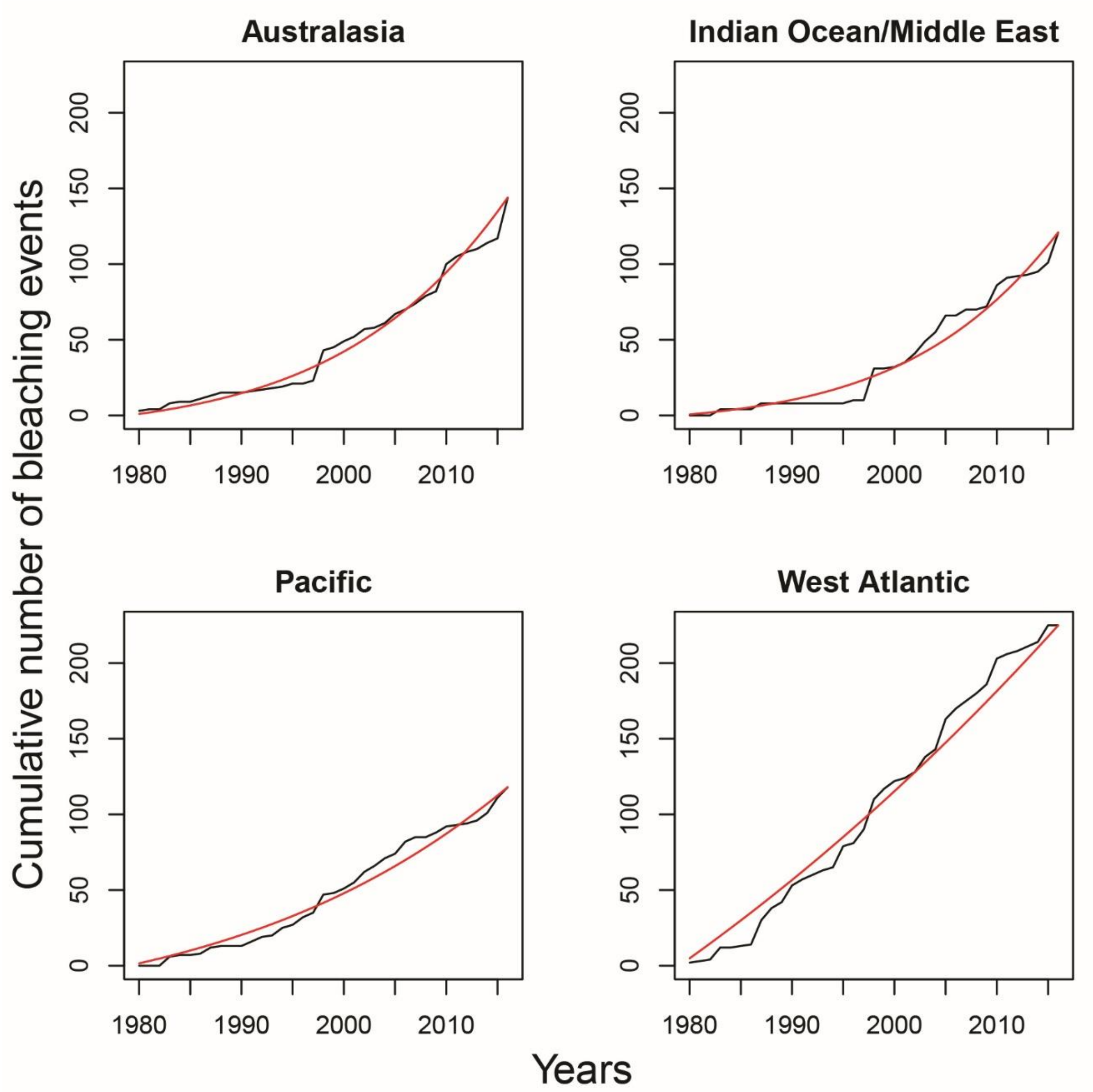


**Fig. S2B**

**Global patterns of coral bleaching.** The cumulative number of (A) severe and (B) total bleaching events for four geographic regions (Indian Ocean, Australasia, Pacific Ocean, and Western Atlantic). Each trajectory in black shows the total number of recorded events per region (n = 22-32 locations) and the fitted regression in red, calculated from the GLMM fits. See Fig. 2B for the global trajectory of severe and total bleaching events.

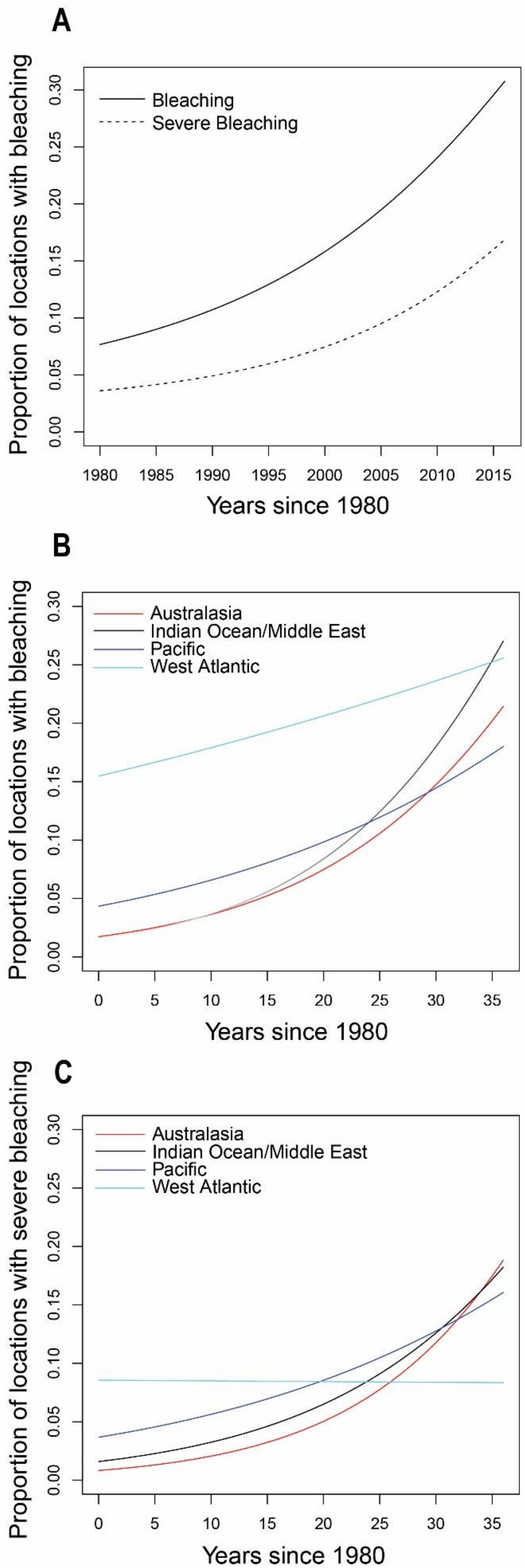
A
Proportion of locations with bleaching
Bleaching
Severe Bleaching
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1980
1985
1990
1995
2000
2005
2010
2015
Years since 1980
B
Proportion of locations with bleaching
Australasia
Indian Ocean/Middle East
Pacific
West Atlantic
0
5
10
15
20
25
30
35
Years since 1980
C
Proportion of locations with severe bleaching
Australasia
Indian Ocean/Middle East
Pacific
West Atlantic
Years since 1980

**Fig. S3**

**Escalating frequency of bleaching.** Proportion of locations that experienced bleaching each year since 1980. (A) total bleached and severely bleached for all locations, (B) bleached by region, and (C) severely bleached by region.

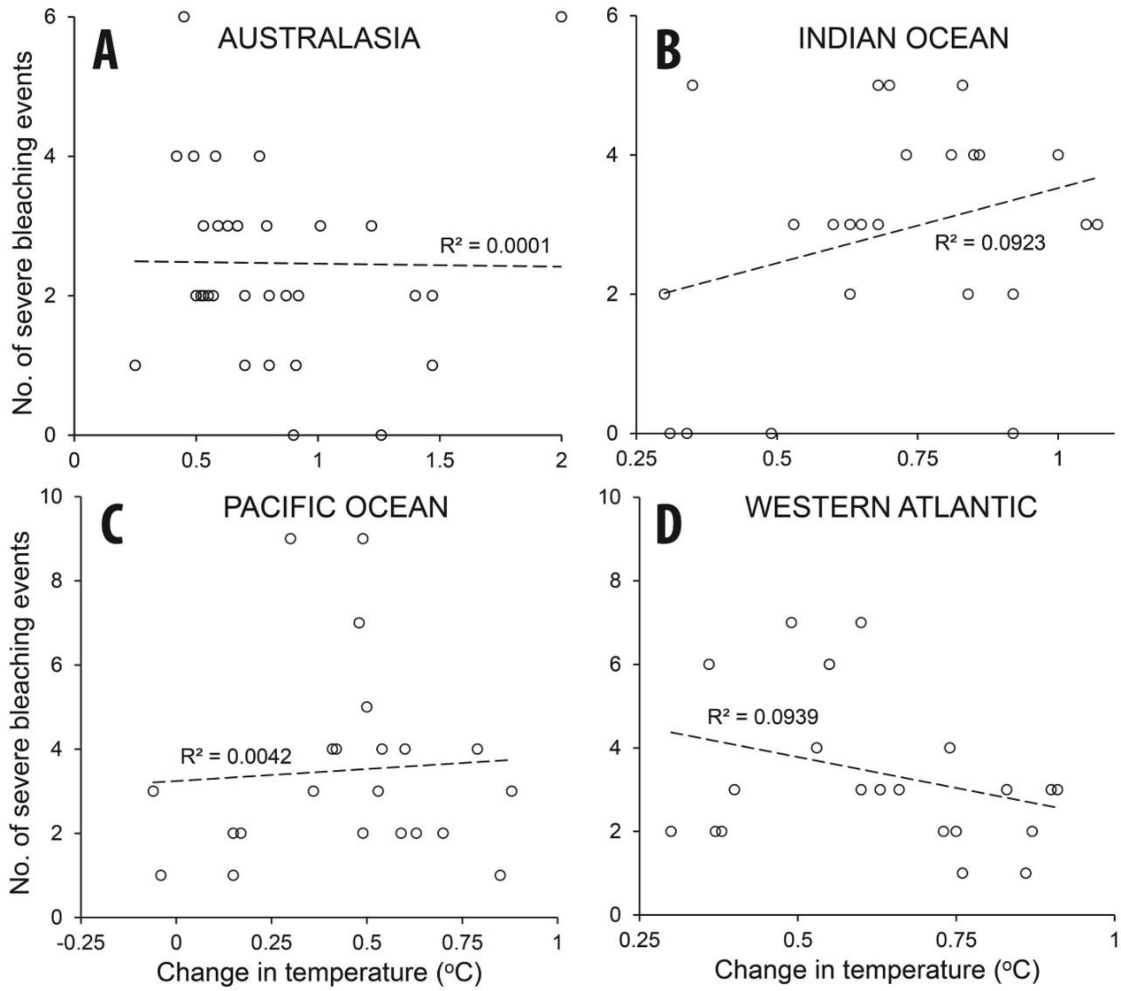


**Fig. S4**

**Frequency of bleaching versus global warming.** The relationship between the amount of global warming recorded since the pre-industrial period at each of 100 locations versus the number of observed bleaching events per location. Australasia (32 locations), the Indian Ocean (24 locations), the Pacific Ocean (22 locations), and the Western Atlantic (22 locations).

**Table S1**

**Global bleaching database 1980 – 2016.** Coral bleaching history from 1980 – 2016 at 100 fixed global locations. Latitude and longitude refer to centroids of locations. Bleaching events are recorded as either minor-moderate (M; 1-30% bleached) or severe (S; >30% bleached).

| # | Location | Lat | Long | Size ($km^2$) | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | References (and Pers. Comm.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Australasia** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Australia, Coral Sea Northern | 16.5ºS | 149.8ºE | 1165 | | | | | | | | | | | | | | | | | | | S | | | | S | | M | | | | | | | | | | | | S | 334, 236, 237, 216, 19, 58, 280, 156, (JR), TB, HH |
| 2 | Australia, Coral Sea Southern | 20.0ºS | 153.0ºE | 231 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | M | 236, 58, 248, 156, TB, HH, MP, AH, AB |
| 3 | Australia, GBR Central | 19.5ºS | 148.5ºE | 7735 | M | | | M | | | | M | | | | | M | | M | | | | S | | | | S | | | | | | | | | | | | | | S | 63, 232, 173, 151, 36, 205, 35, 216, 156, AB, MP, MH, GT |
| 4 | Australia, GBR Northern | 11.5ºS | 145.3ºE | 9319 | M | | | M | | | | | | | | | | | | | | | S | | | | S | | | | | | | | | | | | | | S | 63, 141, 35, 216, 156, AH, MP, AB, TH, GT |
| 5 | Australia, GBR Southern | 23.5ºS | 150.1ºE | 6872 | | | | | | | | | | | | | | | | | | | S | | | | S | | | | M | | | | | | | | | | M | 369, 63, 35, 216, 156, MH, TH, JK, KA, TB, MP |
| 6 | Australia, Kimberly Coast | 21.5ºS | 115.4ºE | 688 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | 221, 281, 238, 156, (DW), (AL), (DB), (DW), (JF), (CP), (JB), (AH), (AM), (DO), VS |
| 7 | Australia, Lord Howe Island | 31.5ºS | 159ºE | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | M | | | | | S | M | M | | M | | | 142, 84, 85, 156, AB, AH, MP, TH |
| 8 | Australia, Morton Bay | 27.4ºS | 153.5ºE | - | | | | | | | | | | | | | | | | | | | | | | | | | | | | M | | | M | | M | M | | | M | 156, (IB), (MB), JP |
| 9 | Australia, Ningaloo Reef | 22.5ºS | 113.7ºE | 120 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | | | | M | 58, 221, 87, 156, (DT), (GS), (PB), (TE), (RB), SW, RL |
| 10 | Australia, Pilbara (Dampier, Montebello, Onslow) | 19.5ºS | 119.9ºE | 316 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | S | M | | | 221, 189, 260, 156, (DT), (MM), (RM), (RE), (RB), SW |
| 11 | Australia, Solitary Island | 30.0ºS | 153.3ºE | - | | | | | | | | | | | | | | | | | | | S | | | M | M | | | M | M | M | | | | | | | | M | S | 339, 97, 58, 84, 76, 156, (MB), (WF), (SD), (HM), AB, JP |
| 12 | Australia, South West Rocks | 30.5ºS | 153.1ºE | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | S | 156, (WF), (SD), (HM), (MB) |
| 13 | Australia, Southwest (Shark Bay, Abrohlos, Rottnest) | 29.0ºS | 114.0ºE | 385 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | | | | | 313, 221, 1, 291, 156, (TF), SW, RL |
| 14 | Australia, Torres Strait | 9.0ºS | 142.0ºE | 3735 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | | | | | S | 28, 317, 156, (TS), AB, TH, JK |
| 15 | Indonesia, Aceh | 4.8ºN | 98.9ºE | 344 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | | | | | S | 322, 133, 158, 157, AB |
| 16 | Indonesia, Bali/Lombok | 8.5ºS | 115.4ºE | 152 | | | | | | | | | | | | | | S | | | | | S | | | | | | | | | | | M | S | | | | | | S | 305, 154, 61, 322, 158, 313, 157, 174, 164, AB |
| 17 | Indonesia, Central Sulawesi | 0.5ºS | 122.3ºE | 170 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | | M | 154, 61, 322, 157 |
| 18 | Indonesia, Java | 6.4ºS | 108.9ºE | 343 | | | | S | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | | S | 339, 44, 305, 61, 322, 158, 157 |
| 19 | Indonesia, Kalimantan | 2.9ºS | 110.6ºE | 14 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | M | | | | | | S | 313, 157, 246 |

| | Location | Lat | Long | Size ($km^2$) | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | References (and Pers. Comm.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | Indonesia, North Sulawesi/Manado | 1.5ºN | 124.8ºE | 325 | | | | | | | | | | | | | | | | | | | S | | S | | | | | | | | | | S | | | | | | S | 154, 61, 322, 190, 157, TH, DB |
| 21 | Indonesia, South Sulawesi | 5.6ºS | 120.0ºE | 90 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | | | | | S | 339, 322, 157, 138, 145 |
| 22 | Indonesia, South-East Sulawesi/Wakatobi | 5.7ºS | 123.5ºE | 715 | | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | | S | | | | | | S | 158, 157, 174 |
| 23 | Indonesia, West/South Sumatra | 1.8ºS | 100.8ºE | 899 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | | S | 61, 322, 158, 157, 174, 200, 225 |
| 24 | Japan, Kyushu | 32.5ºN | 130.5ºE | 43 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | M | | S | | | | | | | 179, 327, 180, 178, (JR) |
| 25 | Japan, Ryukyu Islands | 26.5ºN | 128.0ºE | 993 | M | | | M | M | | M | | M | | | | | | | | | | S | | | M | | | M | M | M | S | M | M | M | | | | | | S | 175, 319, 339, 197, 278, 327, 178, 82, 153, 258, 346, 316, 156, AB |
| 26 | Malacca Strait | 1.4ºN | 103.1ºE | 230 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | | S | 305, 60, 62, 133, 157, AB |
| 27 | Papua New Guinea, Kimbe Bay | 5.0ºS | 151.0ºE | 72 | | | | | | | | | | | | | | | | | | M | S | M | M | M | | | M | | | | S | | | | | | | | | 339, 170, 41, 57, (MB), (GJ), TH, AB |
| 28 | Philippines, Central/Southern | 9.4ºN | 120.0ºE | 7690 | | M | | | | | | | | | | | | | | M | | M | S | M | M | | | | | M | | | M | | S | | | | M | M | S | 59, 21, 8, 322, 99, 258, 312, 252 |
| 29 | Solomon Islands | 9.7ºS | 160.6ºE | 2835 | | | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | M | S | | | S | M | 195, 9, 57, 94, 256, 258, TH, AB |
| 30 | Taiwan, Southern | 23.7ºN | 121.0ºE | 191 | | | | | | | M | S | S | | | | | | | | | | S | | | | | | | | | S | S | M | | | | | M | | S | 339, 297, 179, 180, 83, 188, 310, 64, 56 |
| 31 | Thailand, Gulf of Thailand | 10.0 ºN | 99.8ºE | 186 | | | | | | | | | | | | S | | | | S | | | S | | | | | S | | | | | | | S | | | | | | S | 43, 340, 322, 313, 241, 347, 307, 219, 311 |
| 32 | Vietnam, Con Dao Archipelago | 14.3ºN | 109.3ºE | 17 | | | | | | | | | | | | | | | | | | | S | | | | | | | S | | | | | S | | | | | | S | 320, 129, 61, 124, 296, 321, 86 |
| | **Indian Ocean/ Middle East** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 33 | Australia, Ashmore Reef | 12.3ºS | 123.0ºE | 70 | | | | | | | | | | | | | | | | | | | M | | | | | M | | | | | | | M | | | | | | M | 216, 149, 54, 156, JG |
| 34 | Australia, Christmas Island | 10.5ºS | 105.6ºE | 5 | | | | S | | | | | | | | | | | | | | | S | | | | | | | M | | | | | | M | | | | | S | 37, 130, 301, 156, J-PH |
| 35 | Australia, Cocos Island | 12.2ºS | 96.8ºE | 518 | | | | | | | | | | | | | | | | | M | | M | | | | | | | | | | | | | | | | M | | M | 216, 25, 156, (SE), (DM), J-PH |
| 36 | Australia, Rowley Shoals | 17.4ºS | 119.2ºE | 113 | | | | | | | | | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | M | 308, 156, (LS), (AH), JG |
| 37 | Australia, Scott Reef & Seringapatam Reef | 14.0ºS | 121.5ºE | 150 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | | M | | M | | | S | 340, 292, 111, 156, JG |
| 38 | Chagos Archipelago (UK) | 6.0ºS | 72.ºE | 1822 | | | | | | | | | | | | | | | | | | | S | | | | | S | S | M | | | | | | | | | | S | S | 288, 286, 255, 309, 17, 94 |
| 39 | Comoros | 11.5ºS | 43.3ºE | 518 | | | | S | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | | S | 7, 251, 73, 245, 74 |
| 40 | Egypt, Red Sea, Hurghada | 27.3ºN | 33.8ºE | 2240 | | | | | | | | | | | | | | | | | | | | | | | | | S | S | | M | | | | | | | | | | 182, 218, 183, (MK), MB |
| 41 | India, Lakshadweep | 8.3ºN | 73.1ºE | 827 | | | | | | | | | | | | | | | | | | | S | | | | S | | | | | S | | | S | | | | | | S | 340, 23, 24, 255, 309, 231, 333, 187, 16, 219, 222 |

| # | Location | Lat | Long | Size ($km^2$) | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | References (and Pers. Comm.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | Kenya | 3.5ºS | 40.0ºE | 510 | | | | | | | | S | | | | | | | | | | | S | | | | | M | | S | | M | | | S | | | | | | M | 339, 230, 124, 208, 223, 73, 207, 74 |
| 43 | La Reunion (France) | 21.1ºS | 55.5ºE | 12 | | | | M | | | | S | | | | | | | | | | | S | | | M | | | M | M | | | | M | | M | | | | | S | 339, 340, 67, 324, 68, 7, 208, 284, 346, (PC), (LB) |
| 44 | Madagascar, Southwest | 20.5ºS | 46.5ºE | 1374 | | | | | | | | | | | | | | | | | | | S | | | M | M | M | | S | | | | | S | | | | | | S | 340, 124, 231, 73, 74 |
| 45 | Maldives | 1.9ºN | 73.5ºE | 2714 | | | | | | | | S | | | | | | | | | | | S | | | | | M | M | | | M | | | S | | | | | M | S | 90, 340, 129, 255, 124, 283, 317, 42, 228, 335, 94, 346, (CP), MP |
| 46 | Mauritius (France) | 20.3ºS | 57.6ºE | 720 | | | | | | | | | | | | | | | | | | | M | | | | M | M | M | S | | | | M | S | | | | | | S | 340, 322, 7, 209, 206, 38, 94 |
| 47 | Mayotte (France) | 12.5ºS | 45.5ºE | 296 | | | | S | | | | S | | | | | | | | | | | S | | | | | | | | | | | | S | M | | | | | S | 339, 251, 6, 245, 207, 74, 75 |
| 48 | Mozambique | 21.9ºS | 35.6ºE | 2103 | | | | | | | | | | | | | | | | | | | S | | | | | | | S | | | | | | | | | | | S | 230, 231, 285, 73, 74 |
| 49 | Saudi Arabia, Red Sea, Al Lith | 19.8ºN | 39.9ºE | 975 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | S | | | | | S | | 88, 182, 106, 198, MB |
| 50 | Saudi Arabia, Red Sea, Thuwal | 22.3ºN | 39.1ºE | 1705 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | S | | 88, 182, 106, 198, 94, MB |
| 51 | Seychelles | 4.7ºS | 55.5ºE | 1482 | | | | | | | | | | | | | | | | | | | S | | | | M | M | | | | | | | S | | | | | | S | 340, 298, 7, 192, 132, 131, 242, (CM-P), (UE), NG |
| 52 | Seychelles, Aldabra | 9.5ºS | 46.3ºE | 78 | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | S | | | | | | S | 7, 90, 287, 302, (KC-S), NG |
| 53 | South Africa, St Lucia | 28.4ºS | 32.4ºE | 2 | | | | | | | | | | | | | | | | | | | M | | M | M | | | | M | | | | | | | | | | | | 73, 55, 262, 101, 282, 285, 74 |
| 54 | Sri Lanka | 7.3ºN | 80ºS | 122 | | | | | | | | | | | | | | | | | | | S | | | | S | | M | M | | | | | S | | | | | M | S | 163, 254, 255, 124, 72, 93, 92, (NP), (CM) |
| 55 | Tanzania | 7.9ºS | 39.5ºE | 2126 | | | | | | | | | | | | | | | | | | | S | | | | | M | | | | | | | | | | | | | S | 230, 124, 73, 207, 74 |
| 56 | United Arab Emirates, Arabian Gulf | 24.5ºN | 54.4ºE | 129 | | | | | | | | | | | | | | | | | S | | S | | | | S | | | | | | | | S | M | M | | M | S | M | 110, 261, 262, 259, 199, 263, 66, 289, (JB), MB |
| | **Pacific** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 57 | American Samoa | 14.3ºS | 170.7ºW | 45 | | | | | | | | | | | | | | | S | | | | M | | | M | S | M | M | M | M | | | | | | | | | S | | 128, 129, 2, 80, 123, 39, 57, 346, (DB), TH |
| 58 | Colombia (Pacific) | 5.1ºN | 77.4ºW | 19 | | | | S | | | | | | | | | | | | | | | S | | | | | | | | | | | | | | | | | M | | 117, 115, 339, 328, 243, (FZ) |
| 59 | Commonwealth of the Northern Mariana Islands | 15.2ºN | 145.8ºE | 82 | | | | | | | | | | | | | | | M | M | | M | S | | | M | | S | | | M | | | | S | | | S | S | S | S | 2, 123, 57, 194, 94, 70 |
| 60 | Cook Island | 21.3º | 159.8ºW | 255 | | | | | | | | | | | | S | | | S | | | | M | | S | | | | | | M | | | M | | | | | | | S | 128, 81, 152, 57, 273, 98 |
| 61 | Costa Rica (Pacific) | 8.7ºN | 83.9ºW | 55 | | | | S | | | | S | | | | S | M | | | | | | S | | | | | | | | | | | | | | | | | | | 135, 115, 134, 108, 161, 162, (JC) |
| 62 | Ecuador (mainland) | 0.5ºN | 80.4ºW | - | | | | | | | | | | | | | | | | | | | S | | | | | | | | | | | | | | | | | | | 116, 243, (FR) |
| 63 | Fiji, Southeast & Southwest | 17.7ºS | 178.ºE | 2325 | | | | | | | | | | | | | | | | | | | | | S | | S | | | | M | | | | | | | | | | S | 306, 81, 152, 195, 196, 57, 346, 94 |

| # | Location | Lat | Long | Size (km$^2$) | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | References (and Pers. Comm.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | French Polynesia, Society Islands | 17.7ºS | 149.4ºW | 416 ||||S|||S||||S|||S|||M|M|||M|S|S||||S||S|||||||S| 63, 339, 275, 128, 113, 276, 129, 124, 331, 240, 4, 57, 249, 318, 94, TH, MP |
| 65 | Galapagos | 0.5ºS | 90.8ºW | 126 |||S||||S|||||||||||S|||||||||||||||||| 115, 63, 116, 201, 203, 118, (FR) |
| 66 | Guam | 13.4ºN | 144.5ºE | 138 ||||||||||||||S||S||||||||||S|S|||M|M|M|S|S|S|S| 239, 2, 247, 48, 57, 194, 94, 70, 144 |
| 67 | Hawaii (main islands) | 19.5ºN | 155.5ºW | 788 ||||||M|S|M||||||||S||||||||S||||||M||||S|S|| 169, 104, 168, 103, 57, 304, 194, 346, 94, 26, 264 |
| 68 | Hawaii (North West Islands) | 25.5ºN | 171.4ºW | 2567 ||||||||||||||||||||||S||S||M||||||||S|S|| 5, 104, 105, 168, 177, 194, 94 |
| 69 | Johnston Atoll (USA) | 16.3ºN | 169.5ºE | 76 ||||||||||||||||S|||||||||||||||||||| 65, 168, (BV-A) |
| 70 | Kiribati, Gilbert Islands | 1.5ºS | 176.5ºE | 1718 ||||||||||||||||||||||||S|||||S||||||| 89, 51, (SD) |
| 71 | Kiribati, Kiritimati (Christmas Island) | 1.9ºN | 157.5ºE | 164 |||||||||||||||||S||||||||||||||||||S|| 129, 276, 94, JB, DC |
| 72 | New Caledonia, Southwest | 21.5ºS | 165.6ºE | 833 |||M|||||||||||||S||M||||||||||||||||||S| 339, 337, 57, 120, 50, 346, 94 |
| 73 | Palau | 7.5ºN | 134.5ºE | 510 ||||||||||||||||M||S|M|||||||||||S||||||| 40, 46, 2, 122, 123, 121, 57, 326, (YG) |
| 74 | Panama (Gulf of Chiriqui) | 8.1ºN | 82.0ºW | 50 |||S|||||||||||||||S||||||||||||||||||S|| 115, 116, 337, 243, 213, 94, 211 |
| 75 | Panama (Gulf of Panama) | 8.5ºN | 79.1ºE | 84 |||S|||||||||M|||M|||||||||||||||||||||| 115, 116, 243, 211 |
| 76 | Republic of the Marshall Islands | 11.5ºN | 166.8ºE | 2005 ||||||||||||M|M|||||||||S|M|M|M|M||||||||S|M|| 239, 2, 32, 57, 215, 94, 147 |
| 77 | Samoa (Western) | 13.6ºS | 172.4ºW | 201 ||||||||||||||||||S||S||S|||||||||||||S|| 339, 2, 94 |
| 78 | Vanuatu | 15.2ºS | 167.2ºE | 711 |||||||||||||||||||||S|S|||S|M|M|||||||||S| 256, 57, 257, 127 |
| | **West Atlantic** | | | |||||||||||||||||||||||||||||||||||||| |
| 79 | Bahamas | 24.5ºN | 77.8ºW | 2236 |||M||||S|||M|M|M|M|M|M|||S|||||||M||M|||M|||||M|| 339, 191, 20, 333, 212, 202, 341, 95, 45, 159, 229 |
| 80 | Barbados | 13.2ºN | 59.5ºW | 31 |||||||S|||||||||||S||||||S|M||||S||||M||| 233, 234, 95, 159, 226, 235, (NH) |
| 81 | Belize | 17.5ºN | 88.1ºW | 877 |||||||||||||||S|M|M|S|M|M|||M||M||M|M||M|||||M|| 113, 303, 224, 210, 186, 22, 49, 341, 52, 95, 172, 159, 33, 185 |
| 82 | Bermuda | 32.2ºN | 64.7ºW | 530 |||M|||||S||M|S|M|||M||M|M||M|||M||M||||||||M||M|| 69, 339, 220, 113, 339, 343, 171, 341, 95, 293, 345, 34, 159, 167 |
| 83 | Bonaire | 12.2ºN | 68.3ºW | 22 |||||||M|||||||||S|||M|||||||M|||||M|||||M|| 339, 341, 299, 45, 159, 229 |

| # | Location | Lat | Long | Size ($km^2$) | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | References (and Pers. Comm.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 84 | British Virgin Islands | 18.4ºN | 64.6ºW | 138 | | | | | | | |S| | | | | | | | | | |S| | | | | | |S| | | | | | | | | | | |181, 339, 155, 341, 95, 159 |
| 85 | Cayman Islands | 19.3ºN | 81.3ºW | 188 | | | | | | | |S|M| | | | | | |S| | |S|M|M| |M|M|M|S| |M| |S|M| | | | |S| |146, 339, 340, 129, 343, 62, 341, 95, 325, 45, 323, 159, 229 |
| 86 | Columbia (Caribbean) | 9.6ºN | 75.9ºW | 922 | | | |S| | | |M|M| |M| | | | |M| |M|M|M| | | |M|M|S| | | |M|M| | | | |M| |114, 348, 339, 294, 295, 339, 108, 328, 268, 269, 95, 329, 31, 159, (VP) |
| 87 | Costa Rica (Caribbean) | 10.2ºN | 83.1ºW | 15 | | | |S| | | | | | | | |S| | |S| | |M| | | | | | | | | | | |M| | | | | | |78, 114, 108, 160, 77, 159, (AR S) |
| 88 | Cuba | 22.ºN | 78.8ºW | 2854 | | | |S| | | | | |M|M| | |M|M|S| |M|S| | |M| | | |S| | | |S|S|M|M|M|M|S| |343, 10, 341, 95, 12, 13, 159, 11, 14 |
| 89 | Curacao | 12.2ºN | 69.0ºW | 47 | | | | | | | |S| | |S| | | | | |M| |M| | | | | | | | | | | |M| | | | | | |214, 339, 27, 341, 330, 159, (MJAV) |
| 90 | Dominican Republic | 18.9ºN | 69.6ºW | 518 | | | | | | | |S| | |M| | | | | | | | | | | | |M|M|S|S| | |M|M| | | | |M| |339, 340, 341, 95, 159, 229 |
| 91 | Florida Keys | 24.8ºN | 80.9ºW | 750 |M| | |S| |M| |S| |M|S| | | | | | |S|S|M|M| | |M|M|M|M|M| | | |M| | |M|S| |100, 53, 143, 91, 279, 202, 341, 95, 333, 159, 204, 29, 229, 112, 339 |
| 92 | Gulf of Mexico (Texas Flower Gardens) | 27.9ºN | 93.8ºW | 3 | | | | | | | |M| |M|M|M| | | | | |M|M| | | |M|M| |S|M| |S| |M| | | | | | |339, 137, 53, 18, 150, 341, 95, 166, 159, 165 |
| 93 | Honduras | 16.1ºN | 86.8ºW | 831 | | | | | | | |S| | | | | | | |S| |M|S| | | | | | |S| | | |M|M| | | | | | |136, 339, 184, 184, 139, 124, 274, 52, 102, 159, 185, 265 |
| 94 | Jamaica | 18.0ºN | 77.3ºW | 439 | | | | | | |M|S|M|S|S|M| | | |M| | |S|M|M| | |M| |S| | |M| |S| | | | | | |125, 109, 126, 113, 343, 171, 341, 95, 79, 159, TH |
| 95 | Mexico (Yucatan) | 19.8ºN | 87.4ºW | 532 | | | | | | | | |M| | | | | | |S| |M|S| | | | |M|M|S|M|M|M|M| |M| | | | | |339, 184, 300, 341, 95, 159, 148, 176, 185 (AR-S) |
| 96 | Panama (Caribbean) | 9.3ºN | 82.0ºW | 501 | | | |S| | | | |S| | | | | | |M| |M| | | | |M| | |S| | | | | | | | | |M| |114, 339, 108, 95, 159, 227, 193, 213 |
| 97 | Puerto Rico | 18.3ºN | 66.5ºW | 159 |M|M|M|M| | | |S|M| |S| | | | |S| | |S|M| |M| |S| |S| | | | |S| | | | |M| |339, 119, 191, 342, 53, 107, 341, 95, 45, 159, 229 |
| 98 | St Croix & US Virgin Islands | 17.7ºN | 64.8ºW | 33 | | | | | | | |M|M| |M| | |M| | | | |S|M| | | | | |S|M| | | |S| | | | | | |339, 181, 250, 53, 270, 18, 202, 341, 217, 271, 95, 272, 96, 159 |
| 99 | Tobago | 11.2ºN | 60.7ºW | 32 | | | | | | | |M| | | | | | | | | | |S| | | |M| | |S| | |M| |S| |M|M| | | |339, 290, 140, 201, 95, 159, 15, 47 |
| 100 | Venezuela | 11.2ºN | 66.9ºW | 349 | | | | | | | |M| | | | | | | |M| | |M| | | | | | |M|M| | | |S| | | | | | |191, 267, 266, 30, 159 |

Personal Communications List: Aldabra: KC-S=K. Chong-Seng; Arabian Gulf: JB=J. Burt; Barbados: NH=N. Hassell; Cocos Island: SE= S. Evans, DM= D. McKinney; Columbia Pacific: FZ= F. Zapata; Columbia Caribbean: VP=V. Pizarro, Coral Sea North: JR= J. Rumney; Costa Rica (Caribbean): AR-S= A. Rivera-Sosa; Costa Rica Pacific: JC= J. Cortés; Curacao: MJAV=M.J.A Vermeij; Ecuador (Mainland) and Galapagos: FR=F. Rivera; Gilbert Islands: SD=Simon Donner; Japan Northern: JR= J. Reimer; Johnston Atoll: BV-A=B. Vargas-Angel; Kimberly Coast WA: DW=D. Williams, AL=A. Lewis, DB=D. Barrow, DW=D. Woods, JF=J. French, CP=C. Piggot, JB=J Brown, AH=A. Halford, AM=A. McCarthy, DO=D. Oades; La Reunion: PC=P. Chabanet , LB=L. Bigot; Ningaloo: DT=D. Thomson, GS=G. Shedrawi, PB=P. Barnes, TE=T. Edgecombe; Palau: PICRC= Palau International Coral Reef Centre; Papua New Guinea: MB= M. Bonin, GJ=G. Jones; Pilbara: DT= D. Thomson, MM=M. Morhing, RM=R. Marshall, RE=R. Evans; Red Sea (Hurghada Egypt):MK=M. Khalil; Rowley Shoals, WA: LS= L. Smith, AH=A. Halford; Seychelles: CM-P= C. Mason-Parker, UE= U. Engelhardt; Sri Lanka: NP= N. Perera, CM=C. Manfrino; SW Western Australia: TF=T. Foster

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**Table S2.**

**Bleaching probability since 1980.** Results of a generalized linear mixed model fit by maximum likelihood (Laplace Approximation) showing the bleaching probability (bleached or not bleached) for different regions, and for years since 1980.

| Region and years | **Estimate** | **Std. Error** | **z value** | **Pr(>\|z\|)** |
|---|---|---|---|---|
| **Australasia** | -3.675661 | 0.26823 | -13.703 | **2.00e-16** |
| **Indian Ocean/Middle East** | -3.776389 | 0.309041 | -12.220 | **2.00e-16** |
| **Pacific** | -2.728397 | 0.259412 | -10.518 | **2.00e-16** |
| **West Atlantic** | -1.335086 | 0.194862 | -6.851 | **7.31e-12** |
| **Years since 1980 (Australasia)** | 0.076119 | 0.009823 | 7.749 | **9.26e-15** |
| **Years since 1980 (Indian Ocean/Middle East)** | 0.087404 | 0.011227 | 7.785 | **6.96e-15** |
| **Years since 1980 (Pacific)** | 0.043760 | 0.009936 | 4.404 | **1.06e-05** |
| **Years since 1980 (West Atlantic)** | 0.017479 | 0.007540 | 2.318 | **0.0204** |

**Table S3**

**Bleaching severity probability since 1980.** Results of a generalized linear model fit by maximum likelihood with simple random effects structure via Breslow and Clayton's PQL algorithm, showing probability of bleaching status (severe or not severe) for different regions, and for years since 1980.

| Region and years | **Estimate** | **Std. Error** | **t-value** | **p-value** |
|---|---|---|---|---|
| **Australasia** | -4.685643 | 0.3691068 | -12.694545 | **0.0000** |
| **Indian Ocean/Middle East** | -4.025899 | 0.3511802 | -11.463911 | **0.0000** |
| **Pacific** | -3.172498 | 0.2872635 | -11.043858 | **0.0000** |
| **West Atlantic** | -2.276737 | 0.2360508 | -9.645112 | **0.0000** |
| **Years since 1980 (Australasia)** | 0.092086 | 0.0134598 | 6.841573 | **0.0000** |
| **Years since 1980 (Indian Ocean/Middle East)** | 0.072645 | 0.0133423 | 5.444755 | **0.0000** |
| **Years since 1980 (Pacific)** | 0.044698 | 0.0116927 | 3.822747 | **0.0001** |
| **Years since 1980 (West Atlantic)** | -0.000773 | 0.0110730 | -0.069850 | 0.9443 |

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