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Commentary: Reconstructing Four Centuries of Temperature-Induced Coral Bleaching on the Great Barrier Reef

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A Commentary on

Reconstructing Four Centuries of Temperature-Induced Coral Bleaching on the Great Barrier Reef
by Kamenos, N. A. and Hennige, S. J. (2018). Front. Mar. Sci. 5:283. doi: 10.3389/fmars.2018.00283

Coral reefs are spectacular ecosystems found along tropical coastlines where they provide goods and services to hundreds of millions of people. While under threat from local factors, coral reefs are increasingly susceptible to ocean warming from anthropogenic climate change. One of the signature disturbances is the large-scale, and often deadly, breakdown of the symbiosis between corals and dinoflagellates. This is referred to as mass coral bleaching and often causes mass mortality. The first scientific records of mass bleaching date to the early 1980s (Hoegh-Guldberg et al., 2017).

Kamenos and Hennige (2018, hereafter KH18), however, claim to show that mass coral bleaching is not a recent phenomenon, and has occurred regularly over the past four centuries (1572–2001) on the Great Barrier Reef (GBR), Australia. They support their claim by developing a putative proxy for coral bleaching that uses the suggested relationship between elevated sea surface temperatures (SSTs) and reduced linear extension rates of 44 *Porites* spp. coral cores from 28 GBR reefs. If their results are correct, then mass coral bleaching events have been a frequent feature for hundreds of years in sharp contrast to the vast majority of scientific evidence.

There are, however, major flaws in the KH18 methodology. Their use of the Extended Reconstructed Sea Surface Temperature (ERSST) dataset (based on ship and buoy observations) for reef temperatures from 1854 to 2001, ignores the increasing unreliability of these data which become sparse, less rigorous, and more interpolated going back in time. To demonstrate how the quality of these data degrades, we plot the average number of SST observations per month that contribute to each 200 x 200 km ERSST pixel (**Figure 1A**, black line). Note that from 1854 to 1900 the four ERSST pixels used by KH18 averaged only 0.85 observations per month, and 82% of these months had no observations at all. Given the heterogeneous nature of SST at local and regional levels, using such broad-scale data as ERSST, is likely to produce substantial errors at reef scales (**Figure 1A**, red line prior to 1900).

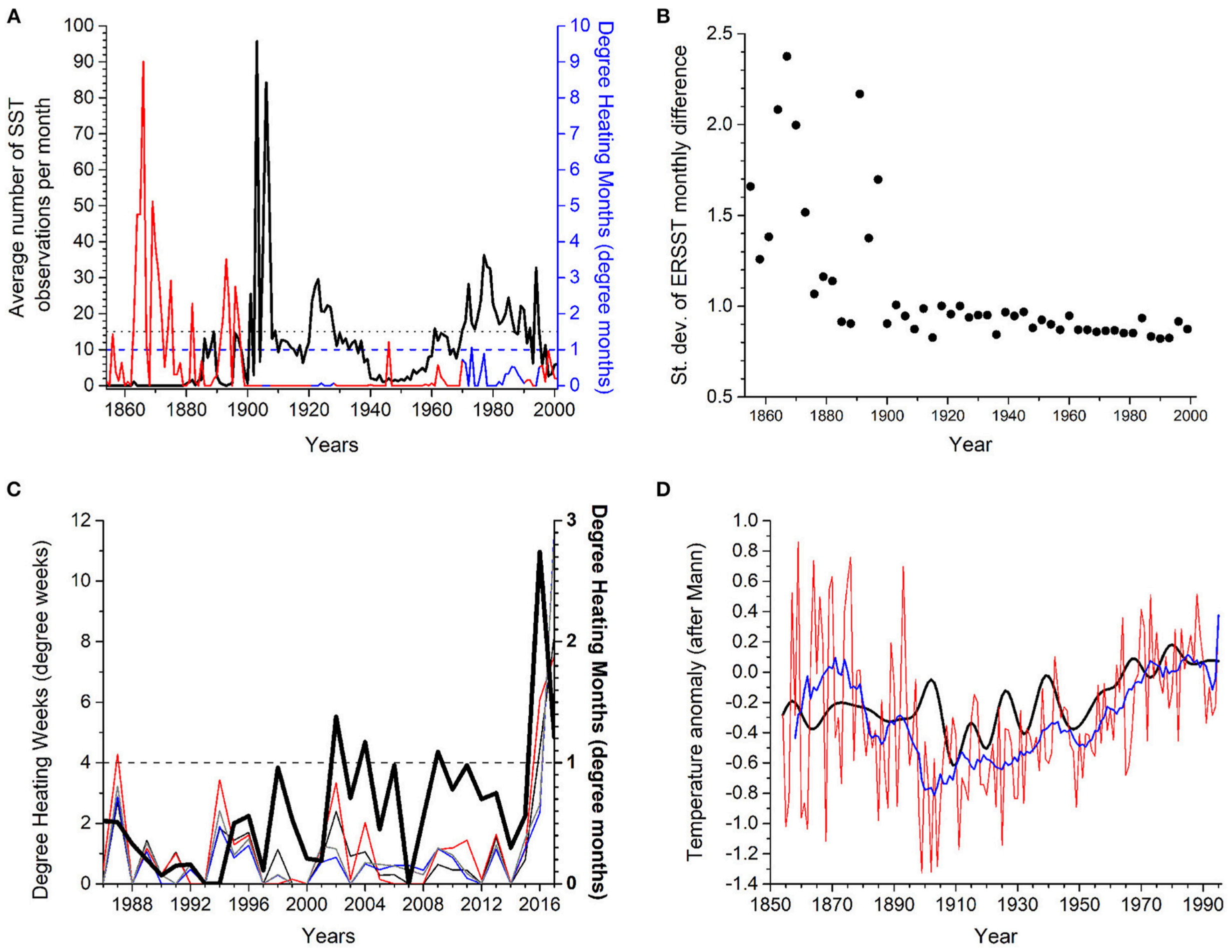

FIGURE 1 | Variation in precision and accuracy of sea surface temperature (SST) over time for the northern most ERSST pixel of the Great Barrier Reef (other pixels are similar). **(A)** Average number of observations per month (Black line) versus thermal stress (Degree Heating Months; DHM) calculated from more than 15 observations per month (black dotted line) within ERSST pixel (blue DHM trace), or less than 15 observations per month (red DHM trace). Blue dashed line indicates a DHM of 1.0, which is considered to be the thermal stress required to trigger mass coral bleaching. **(B)** Standard deviation of temperature difference from 1 month to the next for three-year intervals from the same ERSST pixel. Standard deviation, and hence variability, decreases dramatically after 1900. **(C)** Ability of ERSST pixel (i.e., 200 x 200 km^2, thick black line) to accurately estimate thermal stress using ground truthed satellite measurements in four 5 x 5 km^2 reef pixels, covered by the single larger ERSST pixel. The four satellite pixels shown are co-located with Conical Rocks (dark gray), Agincourt Reef (Red), Snapper reef (Blue), and Low Isles (light gray). Notably, measurements for the ERSST pixel predict bleaching in 2002, 2004, 2006, 2009, and 2011 when there was none and does not predict bleaching stress in 1987 when there was. **(D)** SST (red line, annual; blue line, averaged over 11 years) from of the single ERSST pixel vs. the annual blended surface temperature for the entire Southern Hemisphere (black line after Mann et al., 2008).

To further explore these issues, we also plotted the average mean heat stress (as Degree Heating Months, DHM) since 1854 for the four ERSST pixels (containing the 28 reefs of KH18) alongside the mean number of monthly observations for each year. The KH18 analysis suggested that the putative heat stress "extremes" were very frequent prior to 1900 (**Figure 1A**, red line). These values were, however, drawn from very low numbers of observations that increase the month-to-month variability for periods prior to 1900 (**Figure 1B**) demonstrating that the higher DMH values are artifacts of the data scarcity within ERSST going back in time. The effect of pixel size is demonstrated by comparing the modern record (regular satellite measurements of Degree Heating Weeks (DHW) across 5 x 5 km^2 pixels) with that of the ERSST data (infrequent samples across 200 x 200 km^2 pixels) for the period 1986–2017. The results show a degradation of signals at the reef level by the infrequent ERSST measurements (**Figure 1C**), resulting in incorrect predictions of the heat stress required to trigger mass bleaching and mortality.

Secondly, the study combines putative heat stress with *Porites* growth rates, using the assumption that low linear extension during periods of high SST might be a proxy for coral bleaching. Although reduced linear extension has been observed in association with recorded bleaching events (Cantin and Lough, 2014), it is neither an unequivocal nor a unique signature of bleaching. There are other potential environmental causes for such declines, which KH18 acknowledge but ignore the implications of, as well as some sources of variability that can be simply attributed to measurement technique; coral growth going off-axis in the core slice and random variations in growth rates typical of massive coral records such as these. KH18 also failed to acknowledge that 14 of the 44 core records represent two cores each from seven coral colonies. This should have provided an opportunity for demonstrating the robustness of the approach as these seven pairs of records should provide the same bleaching histories. Similarly, the "bleaching proxy" could also be tested using the multiple cores available for 10 of the 28 reefs. Finally, the coral extension records should have been validated against the original X-ray images of cores to verify that minimal growth years are not actually sub-annual bands.

The third major problem is the use of two long-term, large-scale temperature reconstructions (Mann et al., 2008; Tierney et al., 2015) to "verify" the bleaching reconstruction for the centuries prior to 1854. KH18 used decadal-smoothed annual reconstructed temperatures for the Southern Hemisphere and Western Pacific (both hemispheres) to detect temperature anomalies for the GBR from 1570 to 1995. To understand how unreliable this approach is, we examined the relationship between average annual temperature anomalies for the Southern Hemisphere (Mann et al., 2008) and the average annual SST anomaly for the northern most ERSST pixel (**Figure 1D**, red = annual, blue = 11 year moving average). Not surprisingly, the ERSST are uncorrelated with long-term proxy data at a hemispheric scale, and since ERSST are not correlated with reef-scale thermal stress (**Figure 1C**), then neither data set is representative of coral stress on the GBR. Correlation with the Western Pacific reconstruction is likely to be at least as poor.

KH18 try to demonstrate the accuracy of their bleaching reconstruction (KH18, Figure 3) by exploring a total of 10 years in which bleaching was reported on the GBR. The annual patterns are similar to Oliver et al. (2009) although we have been unable to trace their data source due to an incorrect citation. Only 1998, however, can be considered a mass bleaching event, since all other bleaching observations involved less than 1% of the GBR (KH18, Figure 3Bi). Their reconstruction yielded 11 bleaching years (defined by them as being $\geq$20% of colonies bleached), although only five of these matched years are reported in their figure (see Figure 3Bi vs. Figure 3Bii, KH18). KH18 also used DHMs derived from ERSST to determine their "threshold extension attainable during a bleaching year". It is interesting that this analysis predicted bleaching (DHM $\geq$ 1) only once in 1998 for the period 1979 to 2001, and yet KH18 state that extension rates for DHM $\geq$ 1 were less than those during years with DHM $<$ 1, and claim that this validated their extension thresholds. If this is correct, use of these extension rates for the reconstruction of bleaching years should have predicted only one bleaching event greater than 20% in this period instead of 11 claimed by the authors (KH18, Figure 3Bii). This reduces the comparison to a single point. The only way we could envisage this outcome is for the DMHs calculated by KH18 to be incorrect.

In conclusion, the many serious flaws in KH18 severely destroy its value as a contribution to understanding climate change impacts on coral reefs. Many of us have reviewed this paper repeatedly over the past 5 years (over 14 instances that we know of). The lack of response to reviewers' concerns, repeated submission to other journals without change, and highly questionable use of datasets that many of us have developed, is extremely regrettable and misleading. Given these major problems, we respectfully call for KH18 to be withdrawn.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

Cantin, N. E., and Lough, J. M. (2014). Surviving coral bleaching events: *Porites* growth anomalies on the great barrier reef. *PLoS ONE* 9:e88720. doi: 10.1371/journal.pone.0088720

Hoegh-Guldberg, O., Poloczanska, E. S., Skirving, W., and Dove, S. (2017). Coral reef ecosystems under climate change and ocean acidification. *Front. Mar. Sci.* 4:158. doi: 10.3389/fmars.2017.00158

Mann, M. E., Zhang, Z., Hughes, M. K., Bradley, R. S., Miller, S. K., Rutherford, S., et al. (2008). Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proc. Natl. Acad. Sci. U.S.A.* 105, 13252–13257. doi: 10.1073/pnas.0805721105

Oliver, J. K., Berkelmans, R., and Eakin, C. M. (2009). "Coral Bleaching in Space and Time," in *Coral Bleaching: Patterns, Processes, Causes and Consequences*, eds M. Van Oppen, and J. Lough (Berlin: Springer-Verlag), 21–39.

Tierney, J. E., Abram, N. J., Anchukaitis, K. J., Evans, M. N., Giry, C., Kilbourne, K. H., et al. (2015). Tropical sea surface temperatures for the past four centuries reconstructed from coral archives. *Paleoceanog. Paleoclim.* 30, 226–252. doi: 10.1002/2014PA002717

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