Marine ecology: Forecasting global coral bleaching

Predicting coral bleaching is critical to better manage and preserve coral reefs from global warming. An impressive coordination of surveys across oceans now offers new metrics to help predict coral bleaching events on a global scale.

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Visible from space, coral reefs are hotspots of marine diversity that provide significant socio-economic benefits to humankind[1]. Yet, “mass bleaching events”, driven by exposure to extreme temperature stress caused by ocean warming, have resulted in alarming degradation of coral reefs[2]. This accelerating ecological crisis requires tools to predict imminent bleaching events spatially and temporally to prioritise management of vulnerable reef systems. Existing models, which work well for some locations, but not others across the vast mosaic of reef systems[3] that spans over 280,000 km^2 worldwide, do not have these capabilities. Writing in *Nature Climate Change*, Tim McClanahan and co-authors[4] coordinated an impressive large-scale coral survey in response to record temperatures triggered by the 2014-2016 El Nino event. This survey has unveiled a multivariate approach that captures nuances in local environmental conditions to predict mass coral bleaching with greater accuracy at a global scale.

Corals are highly sensitive to ocean warming due to their symbiotic partnership with photosynthetic algae that provide energy (and colour) to the coral, yet are expelled under heat stress, leaving the coral “bleached” and without energy[5]. Strong links between rising ocean temperatures measured by satellite, and mass bleaching events witnessed on the ground were established during late-1990s. This prompted the National Oceanic and Atmospheric Administration (NOAA) to develop the degree heating weeks (DHW) index of thermal stress. This metric describes accumulation of temperature anomalies ≥1°C over a three month window, and has become the most widely-used early-warning system to identify impending bleaching events in real-time around the globe.

Although routinely-used, the DHW metric has faced scrutiny over its variable accuracy between locations[6]. Until now, however, no systematic, wide-scale validation of its predictive power has been performed. McClanahan et al.[4] did precisely this by coordinating a large-range survey of reefs to test different metrics as putative predictors for bleaching in response to the elevated temperature tied to the 2014-2016 El Niño event, which resulted in the most severe global mass bleaching event to date[6].

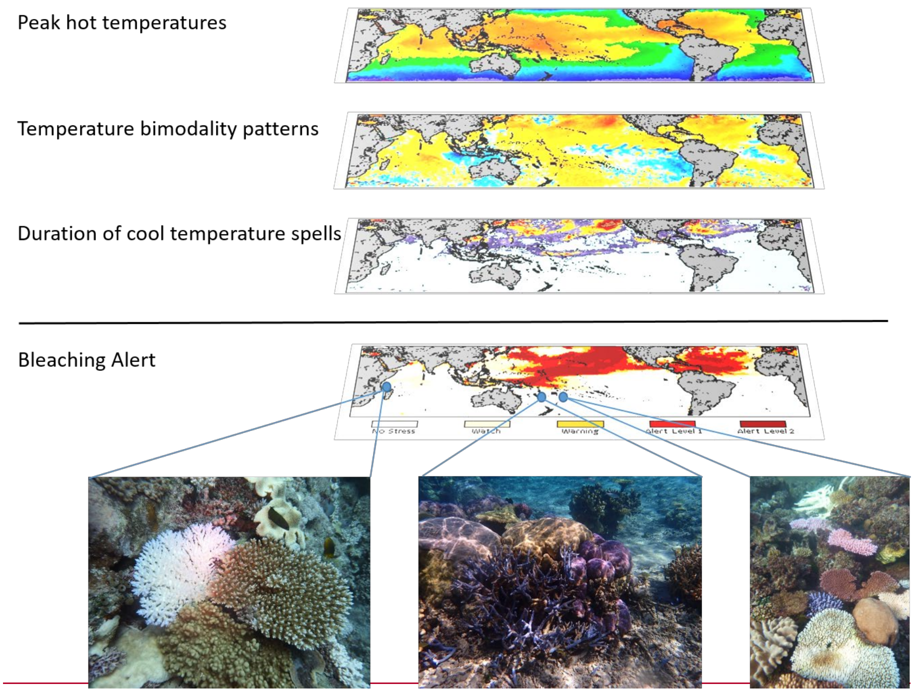
In doing so, their study provides important evidence that, even though DHW may be an accurate predictor of coral bleaching in some regions, its overall predictive power is limited at the global level, explaining less than 10% of variability in global bleaching patterns.

McClanahan et al.[4] suggest that conventional DHW models underperform because they do not adequately account for the environmental history experienced by coral reefs at a given location. This is critical because thermal history is a key shaper of a coral's tolerance or sensitivity to extreme temperature stress[7]. Exposure to fluctuating temperatures, for example, raises thermal tolerance limits of individual corals[8], while previous exposure to warm thermal anomalies can favour more thermally-tolerant symbionts that play an important role in coral health[9]. At the ecosystem level, marine heatwave events can even select for communities of heatresistant, “weedy” corals over more sensitive species, boosting resilience at the reef scale[10]. The story is not always straightforward, however, as certain corals may expend valuable energy reserves to survive transient thermal stress events, which actually increases their sensitivity to future temperature perturbations[11]. A range of other environmental factors may interact with temperature to exacerbate or mitigate coral bleaching and geographic context is often important. For example, late summer cooling and increased cloud cover tied to ex-cyclones Winston and Tatiana spared southern parts of the Great Barrier Reefs from the extensive bleaching that devastated northern reefs in 2016[12].

McClanahan et al.[4] extend existing modelling efforts by incorporating a total of 26 metrics containing information about patterns in thermal stress and exposure, habitat, depth and geography to far better capture location-specific environmental history. For example, sea surface temperature data over a 90 day period was used to extract empirical descriptors of peak hot temperature, duration of cool temperature spells, and temperature bimodality patterns, among others. Predicted bleaching patterns generated from the new multivariate models were then “ground-tested” during a vast ~~coordinated~~ survey of coral bleaching of reef systems across 50 sites ranging from East Africa to Fiji.

The results of this effort are impressive, with their top models predicting ~~≈~~about 50% of variance in the global bleaching patterns triggered by the 2014-2016 El Niño event.

Not only do such models provide a solution for identifying imminent coral bleaching in regions where the DHW metric historically under-performs, they also highlight the value in identifying additional empirical descriptors that further capture nuances in local environmental conditions. Ultimately, time-series of daily temperatures from satellites could be used to derive similar metrics, opening the door for possible integration into user-friendly platforms such as NOAA’s widely-accessible Coral Reef Watch. Identification of such new metrics as putative bleaching predictors potentially paves the way to improved global forecasting of coral bleaching, empowering cross-disciplinary stakeholders to better manage the world’s coral reefs in a time of unprecedented, rapid environmental change.



~~**Figure 1**~~

~~**Conceptual view of new multivariate models to predict global coral bleaching.**~~ ~~Incorporation of multiple metrics describing geographic context and localised thermal history predicts bleaching patterns across the world's reefs with improved accuracy over conventional degree heating week (DHW) models.~~

~~Photos illustrating differences in coral bleaching intensity observed *in situ* across different locations.~~

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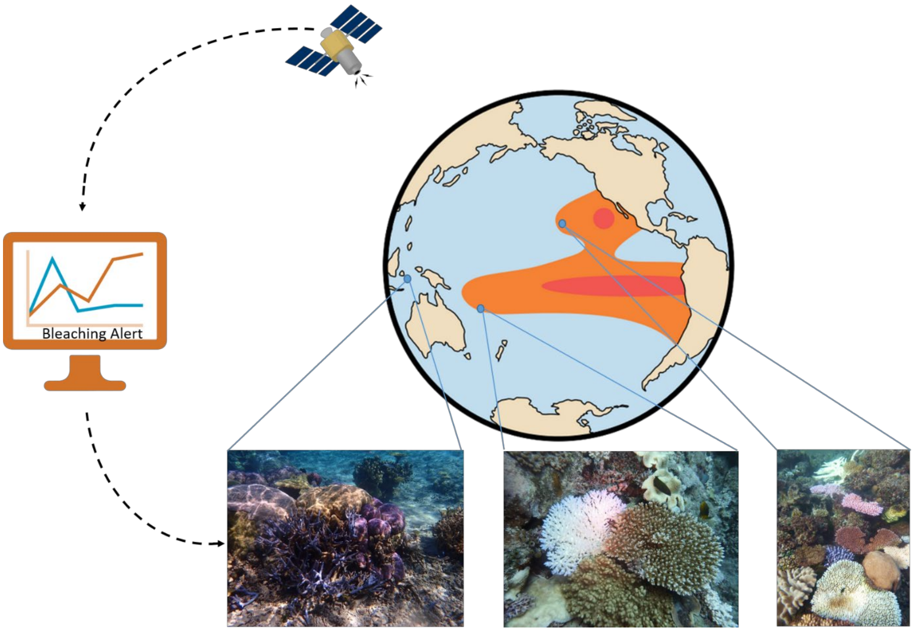

Figure 1

Conceptual view of forecasting global coral bleaching.

Metrics derived from time-series of temperatures obtained by satellites are integrated into models to predict coral bleaching in different locations worldwide. By identifying new metrics capturing nuances in local environmental conditions, the work of McClanahan et al holds potential to improve global forecasting of coral bleaching.

Photos illustrating differences in coral bleaching intensity (indicated by the presence of white corals) observed *in situ* across different locations. Credit: Icons courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

References

1. Costanza, R. *et al.* Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **26**, 152–158 (2014).
2. Hughes, T. P. *et al.* Coral reefs in the Anthropocene. *Nature* **546**, 82–90 (2017).
3. van Hooidonk, R. & Huber, M. Quantifying the quality of coral bleaching predictions. *Coral Reefs* **28**, 579–587 (2009).
4. Mclanahan, T. R. *et al.* Evaluating temperature patterns and mechanisms influencing coral bleaching during the 2016 El Nino.
5. Hoegh-Guldberg, O. Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshw. Res.* **50**, 839 (1999).
6. Hughes, T. P. *et al.* Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science (80-.).* **359**, 80–83 (2018).
7. Ainsworth, T. D. *et al.* Climate change disables coral bleaching protection on the Great Barrier Reef. *Science* **352**, 338–42 (2016).
8. Oliver, T. A. & Palumbi, S. R. Do fluctuating temperature environments elevate coral thermal tolerance? *Coral Reefs* **30**, 429–440 (2011).
9. Howells, E. J. *et al.* Coral thermal tolerance shaped by local adaptation of photosymbionts. *Nat. Clim. Chang.* **2**, 116–120 (2012).
10. McClanahan, T. *et al.* Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. *Mar. Ecol. Prog. Ser.* **337**, 1–13 (2007).
11. Grottoli, A. G. *et al.* The cumulative impact of annual coral bleaching can turn some coral species winners into losers. *Glob. Chang. Biol.* **20**, 3823–3833 (2014).

12. Hughes, T. P. *et al.* Global warming and recurrent mass bleaching of corals. *Nature* **543**, 373–377 (2017).