Is a Marine Heat Wave More Likely than a Cyclone to Trigger a Coral-to-Macroalgae Regime Shift on Coral Reefs?

How different material legacies from two major types of disturbance affect dynamics, state change & resilience

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1. The Rise of Marine Heat Waves (MHWs)

Changing the Material Legacy of Disturbances to Coral Reefs

While cyclones have been a major disturbance to coral throughout their history, episodes of mass coral bleaching from marine heat waves are increasing in severity and frequency as climate change warms the ocean.

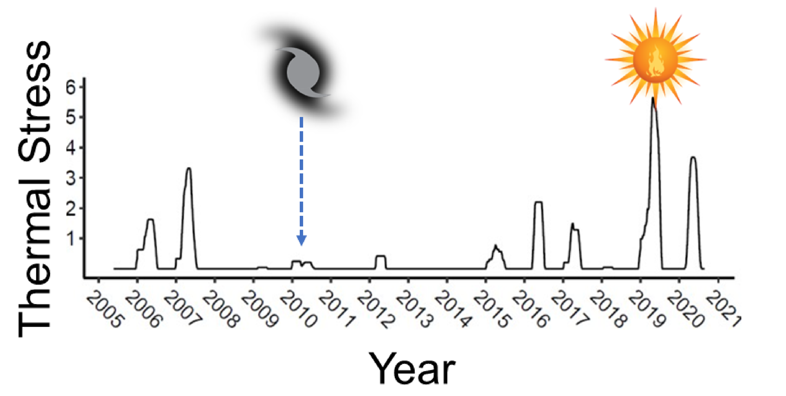
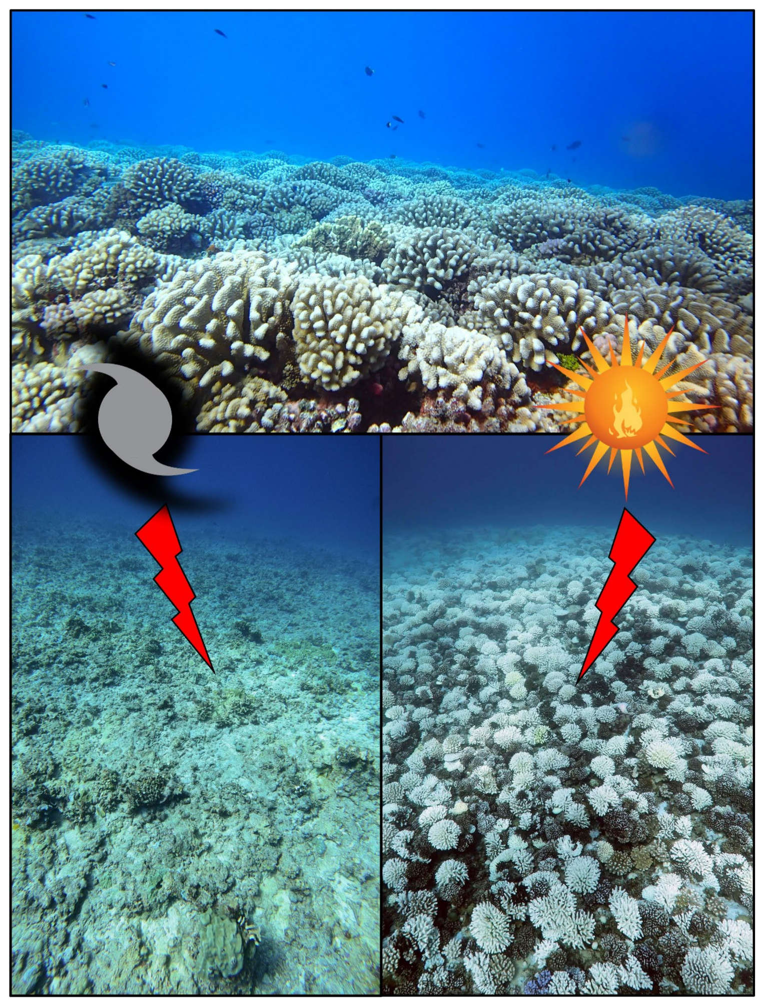


Fig. 1 Time Series of accumulated thermal stress that can cause corals to bleach and die.

The 2019 MHW was the strongest at Moorea in several decades, causing substantial bleaching death of corals.

After a powerful cyclone in 2010, coral recovered rapidly without a shift to macroalgae (Fig. 2).

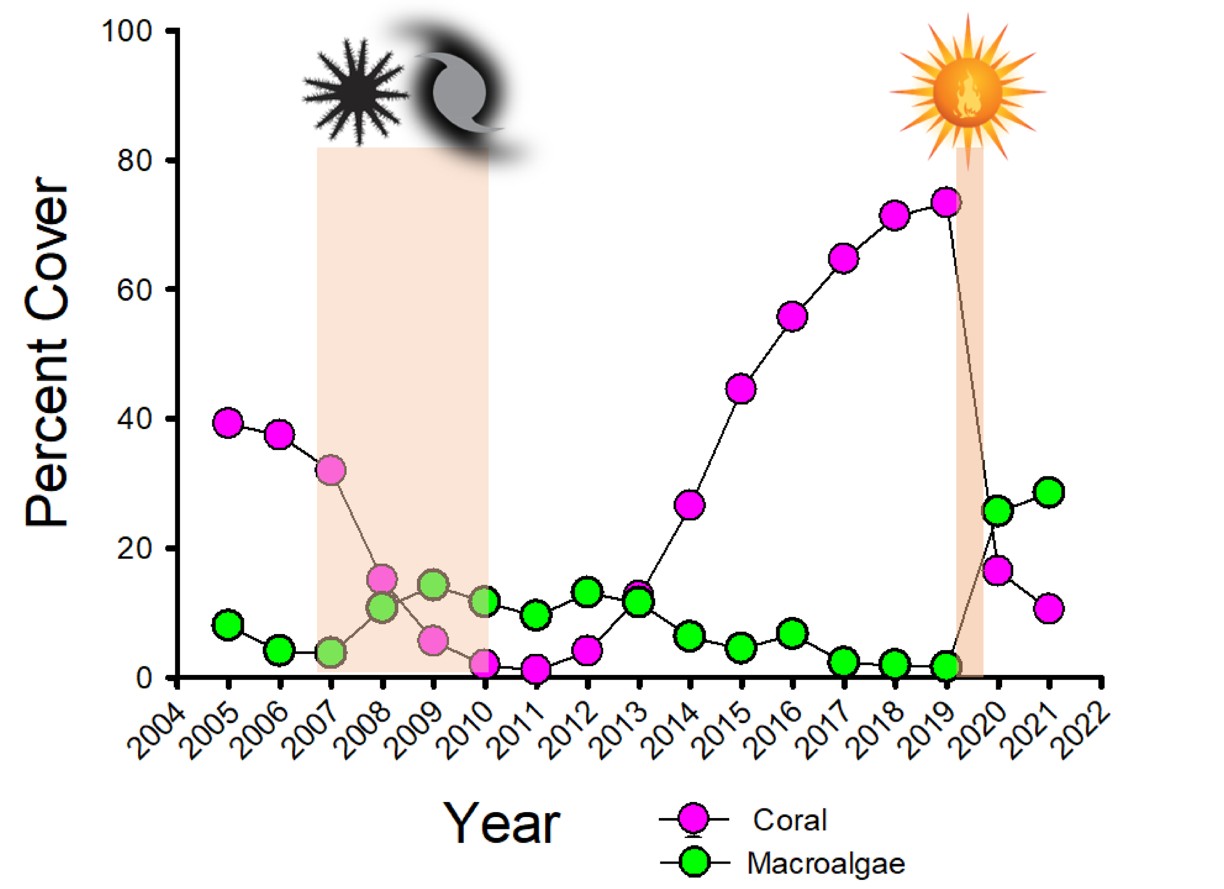


Cyclones and MHWs leave different material legacies. Powerful storms kill coral and remove their skeletons, leaving a low relief reef surface for recolonization (*bottom left*). A bleaching event (*bottom right*) leaves dead coral skeletons intact to gradually erode, which retains high structural complexity of the reef for early colonizers.

2. Post-Disturbance Trajectories

Coral on the fore reef was driven to low cover by an outbreak of a predatory sea star (✷) in 2007-09 followed by a powerful cyclone (🌀) in 2010 that removed coral structure; coral recovered in ~ 5 years without macroalgae becoming dominant. By contrast, after the 2019 MHW (☀), macroalgae are becoming a major space holder, a trajectory potentially facilitated by the presence of dead coral skeletons.

Fig. 2



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3. Dead Coral Skeletons Reduce Herbivory

Skeleton Legacy Inhibits Feeding by Herbivorous Fishes

Following a disturbance, recovery of coral requires herbivorous fishes to prevent the establishment of macroalgae, keeping denuded reef surfaces suitable for recolonization by coral propagules.

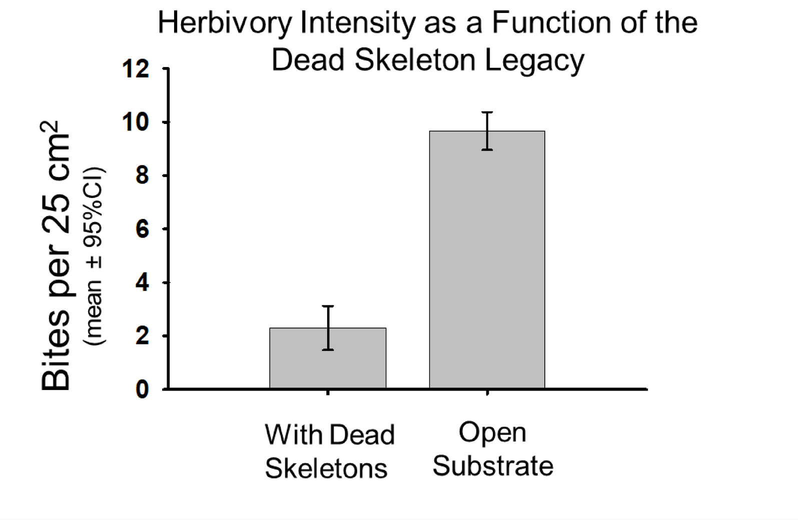


Fig. 3 Intensity of feeding by herbivorous fishes on reef surfaces with and without dead coral skeletons.

Fig. 4 (*below*) Herbivorous parrotfish feeding on algae from an open reef surface, a critical process that keeps macroalgae under control.

Following a MHW bleaching event, the dead skeleton legacy greatly reduces the ability of herbivorous fishes to keep algae cropped (Figs. 3 & 5).

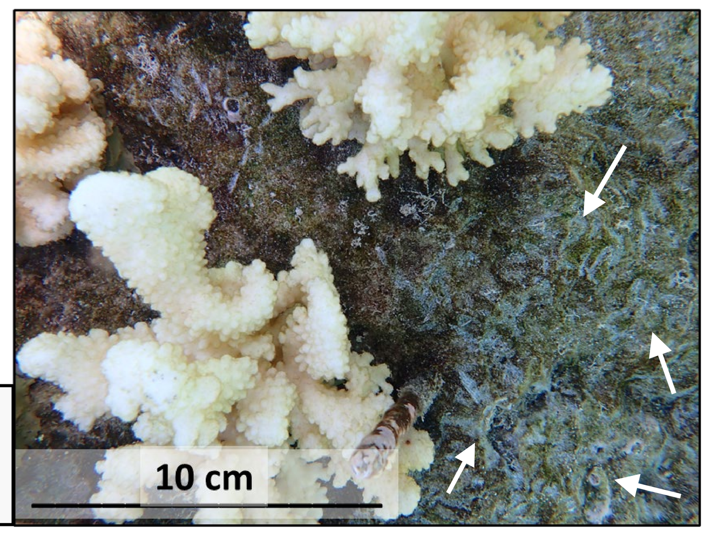
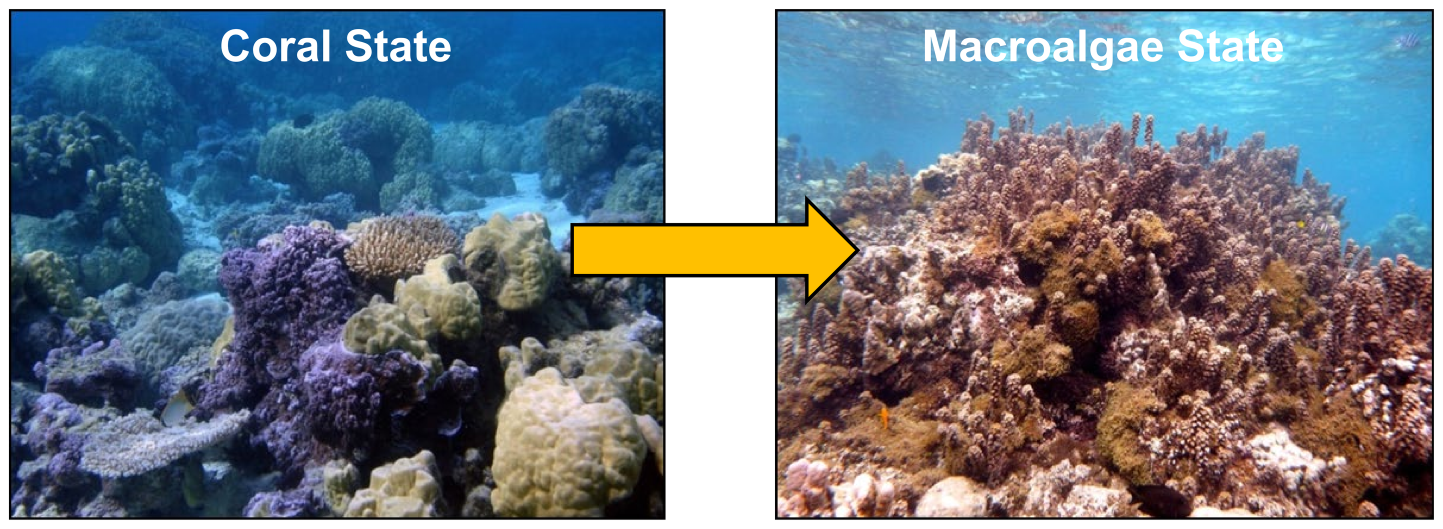


Fig. 5 Parrotfish feeding scrapes (4 indicated by arrows) are abundant on the open reef surface (right portion of image), but are uncommon in gaps between dead skeletons.

4. How Skeleton-retaining Disturbances May Increase the Chance of a Regime Shift



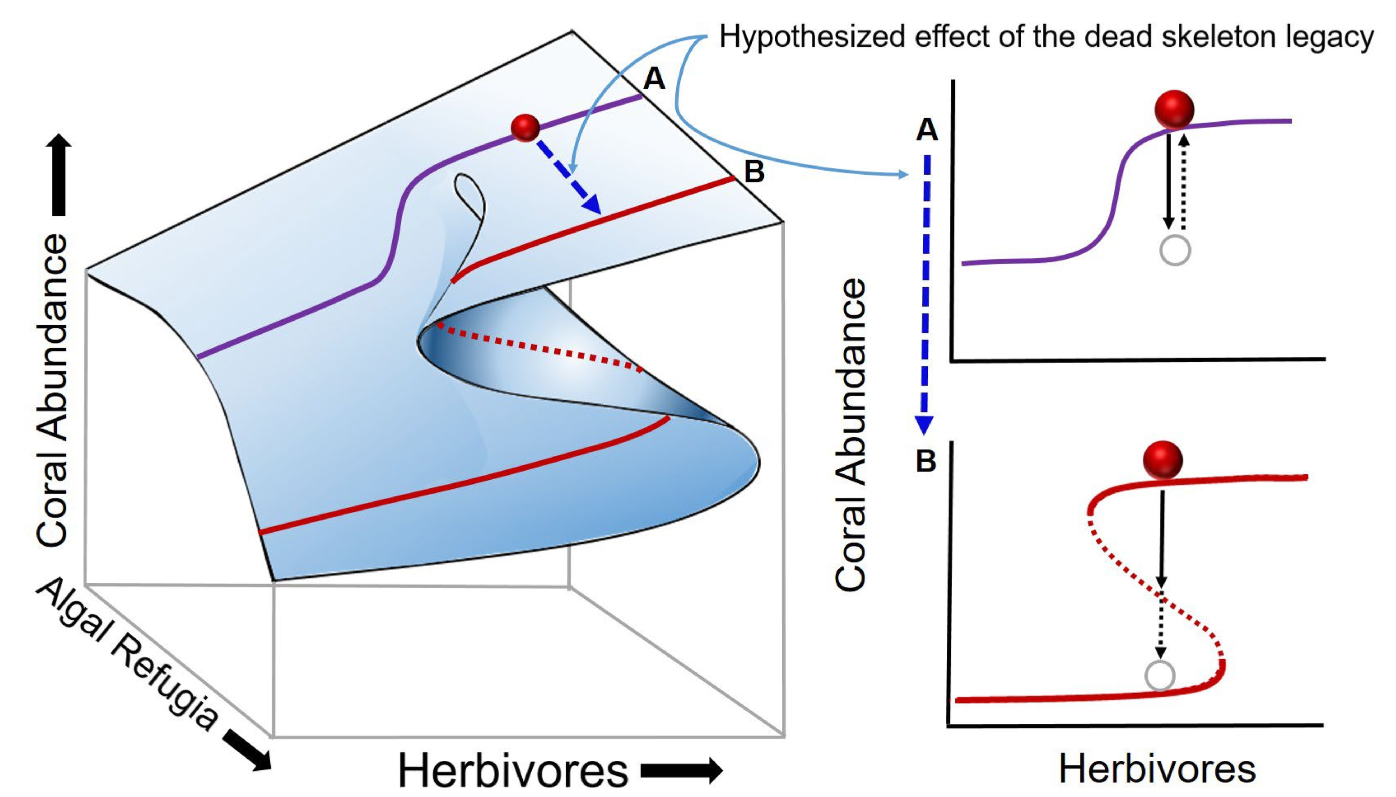


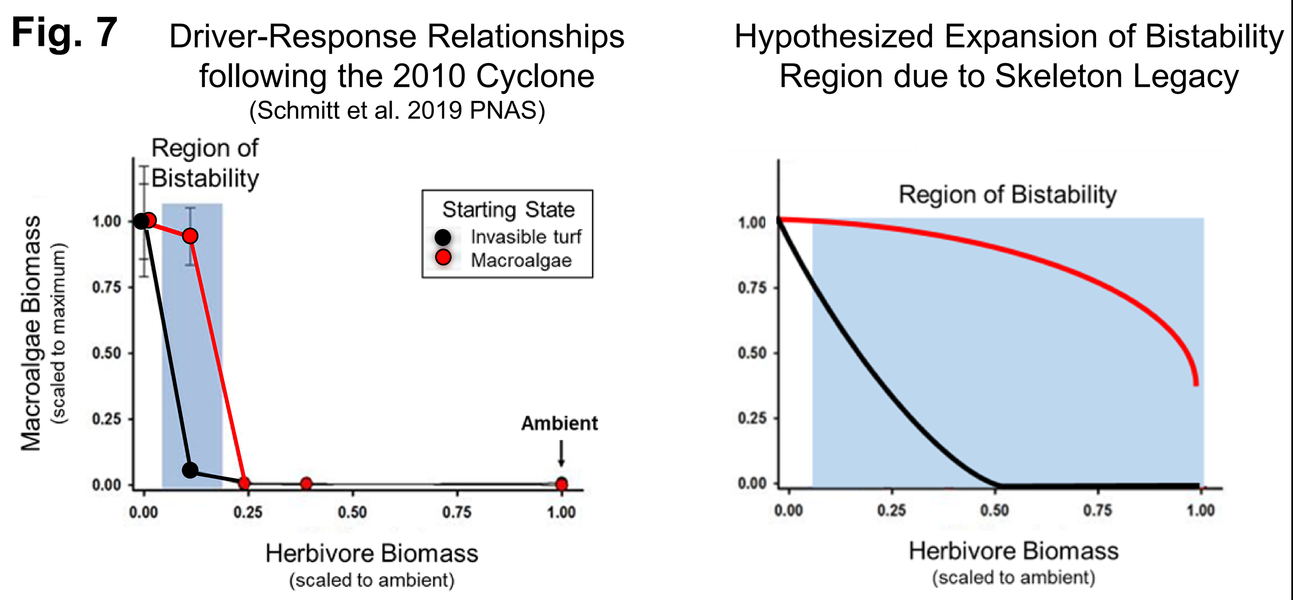
Fig. 6 *Left* A hypothetical response surface showing how the equilibrium abundance of coral might vary as a function of herbivore biomass and amount of physical refugia that facilitates the proliferation of macroalgae. Dead coral skeletons provide vulnerable stages of algae protection from herbivores, shifting the system into a region of state space where coral and macroalgae can be bistable. This reduces the resilience of the coral state (*right graphs*) and increases the likelihood of a regime shift to macroalgae.

5. Tests of Effects of Dead Skeletons on Bistabilty & Regime Shifts

__Question 1__: Do skeleton-retaining disturbances increase the region of coral and macroalgal bistability?

__Prediction__: Dead skeletons expand the region of bistability, potentially to the ambient biomass of herbivores (Fig. 7).

Fig. 7



__Experimental Test__: A multi-year Hysteresis Experiment is quantifying the relationship between herbivore biomass and macroalgae as a function of disturbance type (presence vs. absence of dead skeletons) and initial community state (coral-invasible substrate vs. non-invasible macroalgae).

__Question 2__: Is a coral-to-macroalgae regime shift more likely after a MHW than a cyclone?

__Prediction__: Reefs subjected to coral bleaching have a higher probability of shifting to a persistent macroalgae state.

__Experimental Test__: Results after a year from an ongoing Disturbance Type – Resilience Experiment on 45 patch reefs suggest that most experimentally disturbed reefs with dead skeletons are transitioning to macroalgae (top images below), whereas those without skeletons are not (bottom images).

Simulated Coral Bleaching Disturbance

Simulated Cyclone Disturbance