## Coral Reef Resilience by Jim Steele

In the Friends' last newsletter, coral reefs' ability to recover from disruptions as discussed in my presentation was misinterpreted. As an aside, I mentioned that 18,000 years ago during the worst of the last Ice Age, sea levels had dropped 400 feet killing all the shallow reefs that existed before. Yet as temperatures warmed and sea level rose, coral rebounded to the magnificence that we see today. Unfortunately, that dynamic response was incorrectly reported to mean it takes reefs 1000 years to recover.

Indeed there is great concern today because coral cover has been reduced over the past 3 decades due to many factors. As illustrated by the pie graph below from a 2011 expert assessment, the Great Barrier Reef has suffered from an explosion of the coral-eating Crown of Thorns starfish and tropical storms, causing 70.5% of the lost coral cover. Bleaching was a minor contributor to overall loss of coral causing just 5.6%, but that percentage increased in 2016-17.

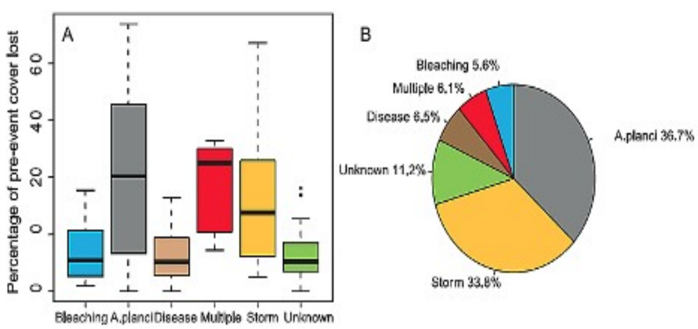


**Figure 4. Prevalence and severity of disturbance events.** *A.planci*, storms and multiple disturbances were associated with the greatest coral decline and the largest distribution of coral loss. Despite bleaching being widespread in 1998 and 2002, coral mortality was relatively low. (A) the loss in live coral cover as a percentage of the pre-event cover. (B) Relative magnitude of loss of pre-event cover summed for all reefs and years. doi:10.1371/journal.pone.0017516.g004

To survive the constant onslaught of predators and tropical storms, or to survive deadly drops in sea level and warmer temperatures caused by El Niños, coral reefs evolved to recover in ways analogous to how forests recover after a forest fire. For example, during the 1998 El Nino, the upper 3 meters of Australia's Scott Reef lost 80 to 90% of its living coral and the disappearance of half of the coral genera. Largely due to recruitment from unscathed coral below 3 meters, within 12 years coral cover, generic diversity, and community structure were again similar to the pre-bleaching years. Such a recovery time is typical for most reefs.

That clarified, the emphasis of my talk focused on the adaptive benefits of symbioses that promote resilience and rapid recovery unfortunately not reported.

Most coral depend on photosynthesizing algal "symbionts" that provide over 90% of the coral's energy. To compete with seaweeds for substrate, coral symbionts must efficiently photosynthesize during the lower light and cooler temperatures of tropical winters. However, because increased photosynthesis can also increase harmful oxygen radicals, coral will gradually reduce their number of symbionts each year as sunlight increases and temperatures warm. However too much sun and warmth forces some coral to eject all their colorful symbionts, so the coral look bleached.

But bleaching doesn't mean death. Although severe bleaching can cause death, many bleached coral recover within weeks to months by re-acquiring new symbionts. Sometimes coral acquire the same symbionts they had just ejected. But we now know, due to advances in genetic techniques, that coral also acquire different "species" of symbionts with different genes allowing them to quickly adapt to a changing environment.

Darwinian adaptation requires mutations and natural selection of beneficial mutations. But that process can take thousands of years. In contrast, when coral expel their old symbionts, they can then acquire new and more beneficial ones. Unlike Darwinian adaptation, by shuffling and shifting their symbionts, coral can adapt within just a couple of years. Research shows coral species that bleached one year can rapidly evolve resilience, and not bleach in the following years, despite the same warm conditions.

Ocean acidification is not likely to be a concern, as it benefits photosynthesis. Coral actively lower their internal pH to 4.5, because by doing so it converts abundant bicarbonate ions into more scarce CO2 that the algal symbionts must have in order to photosynthesize. Measurements of daytime pH show photosynthesis can raise pH to about 8.5. If lower nighttime pH causes dissolution of calcium carbonate, the release of carbonate ions serves as a negative feedback that neutralizes the increased H+ ions.

Thus in combination with their ability to shuffle and shift their symbionts, coral have quickly adapted to millions of years of extreme rising or falling sea levels and dramatic temperature changes inflicted by alternating ice ages. Thus there is good reason to hope that we will not just read about bleaching coral, but also rapid coral recoveries similar to observed at Scott Reef.