



Star coral (*Montastraea annularis* spp. complex) population collapse: An unequivocal sign of climate change impacts in Caribbean coral reefs

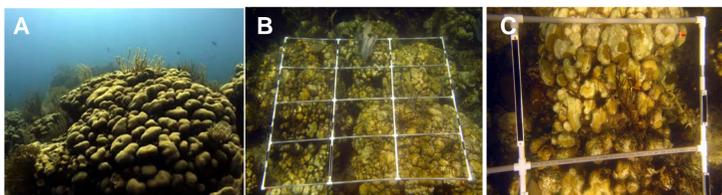
Abstract

A catastrophic warming event occurred during 2005 throughout the northeastern Caribbean Sea that caused a mass coral bleaching event in Puerto Rico that was followed by an unprecedented mass mortality of the *Montastraea annularis* species complex, the most significant reef-building coral in the Atlantic. It resulted in a severe net physiological fragmentation of large coral colonies. Permanent photo-stations were established in 4-6 m deep reef terraces dominated by *M. annularis*. at four sites in Culebra Island, Puerto Rico. Digital photography was used to document changes in benthic community structure before (2005) and after (2007-2009) this event.

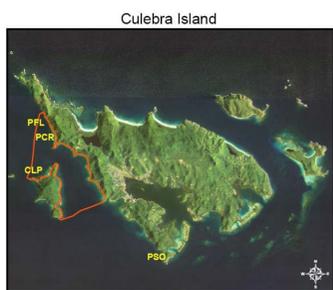
Mass coral mortality caused a 70 to 99% decline in % living tissue cover. There was a significant difference in % living tissue cover loss through time, among sites, particularly at a control site outside a no-take MPA. Abundant physiological tissue fragments were formed in each colony, typically ranging from just below 1 to 105 cm², but mostly in mean sizes below 10 cm², which showed higher mortality trends. There was no significant difference in mean fragment size distribution among sites. Fragment density was significantly higher ($p < 0.0001$) at Cayo Luis Peña (97/m²) in comparison to other sites (24-67/m²). Fragment density declined from 15 to 31% between 2007 and 2009.

There are not known precedents through the Caribbean of catastrophic events of this magnitude. The synergistic consequences of climate change and variable local anthropogenic impacts in major reef engineer taxa still remain largely unknown. However, a single warming event was unequivocally capable of causing an acute coral mortality event that resulted in a major ecological collapse.

Methods



Data collection and analysis: From left to right: (A) *M. annularis*; (B) A 2.5 x 2 m permanent photo-station quadrat grid established in triplicate locations within each study site; (C) Detail of partial colony mortality in *M. annularis* within one subquadrat.



Study sites:

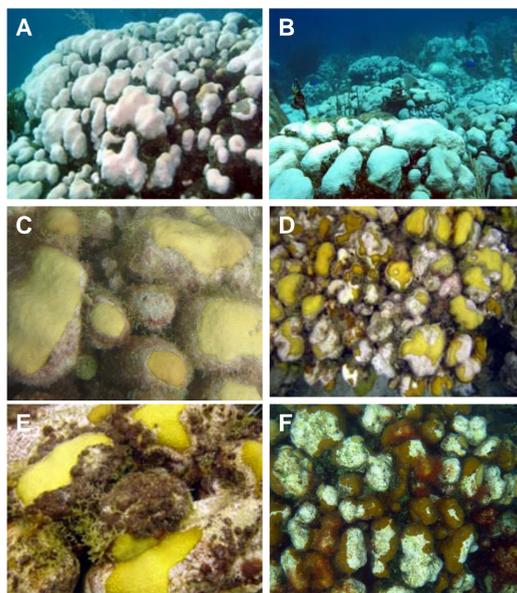
Luis Peña Channel No-Take Natural Reserve

PFL= Peninsula Flamenco
PCR= Playa Carlos Rosario
CLP= Cayo Luis Peña

Control site

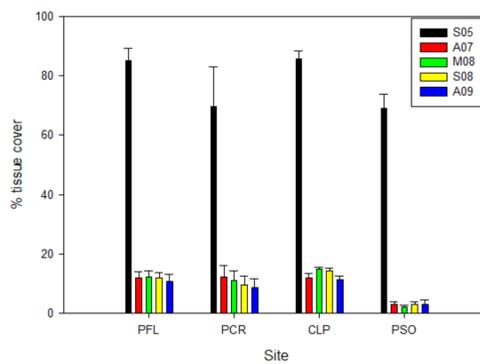
PSO= Punta Soldado

Results



Progressive conditions of *M. annularis* colonies between 2005 and 2009.

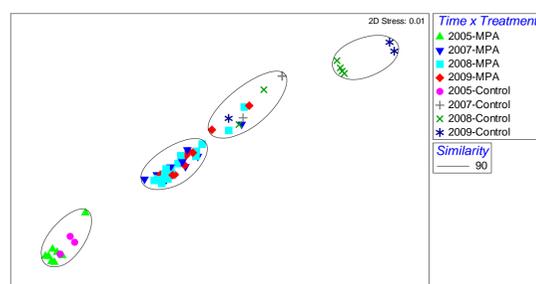
From top left to right: (A-B) Bleached colonies of *M. annularis* (2005); (C) Partial colony mortality in partially bleached colonies (2006); (D) Post-bleaching fragmentation of colonies (2007); (E) Development of algal turfs on partially killed colonies; (F) Mortality of colony fragments (2009).



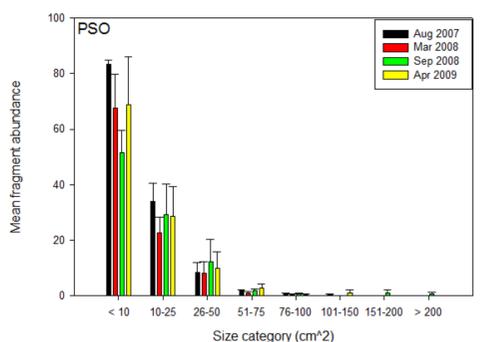
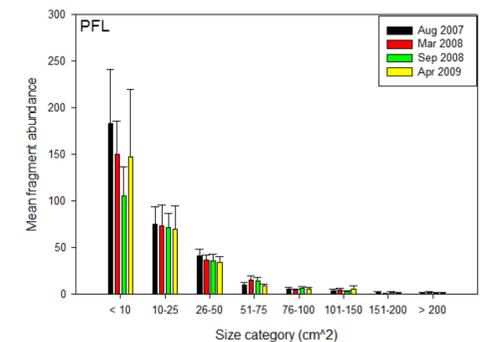
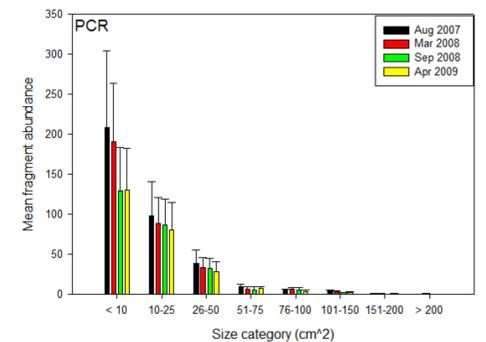
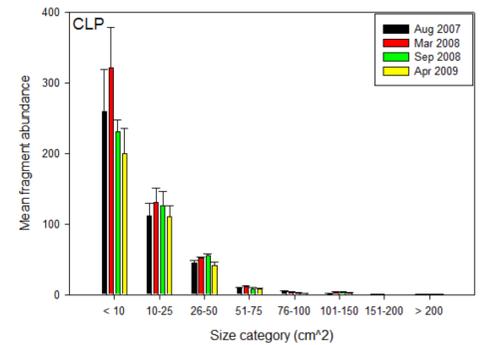
Percent tissue cover of *M. annularis* among four different sites

PERMANOVA % tissue loss

Parameter	D.F.	Pseudo-F	P
Time	3,56	22.06	0.0001
Treatment	1,58	20.08	0.0001
Site	3,56	7.04	0.0002
Grid	2,57	0.16	0.9129
Time x Site	6,53	1.86	0.1849
Site x Grid	4,55	22.84	0.0006
Time x Site x Grid	12,47	4.19	0.0211



Multi-dimensional scaling plot based on percent tissue cover loss of *M. annularis*.



Mean fragment abundance per size category.

Conclusions

There was a dramatic coral mortality event after prolonged massive coral bleaching following unprecedented sea surface warming (31.8°C, 14.3 Degree Heating Weeks). There are not known precedents through the Caribbean of events of this magnitude. This will have deleterious long-term ecological implications for coral reef construction and resilience under increasing sea surface warming and ocean acidification trends. Coupled with major recurrent failures in sexual reproduction in the near future, this may permanently compromise coral reef ecosystem resilience at least at a regional scale.

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