Long-term drivers of Caribbean coral reef degradation and their implications for management

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Curaçao reef, Mark Vermeij, 2012

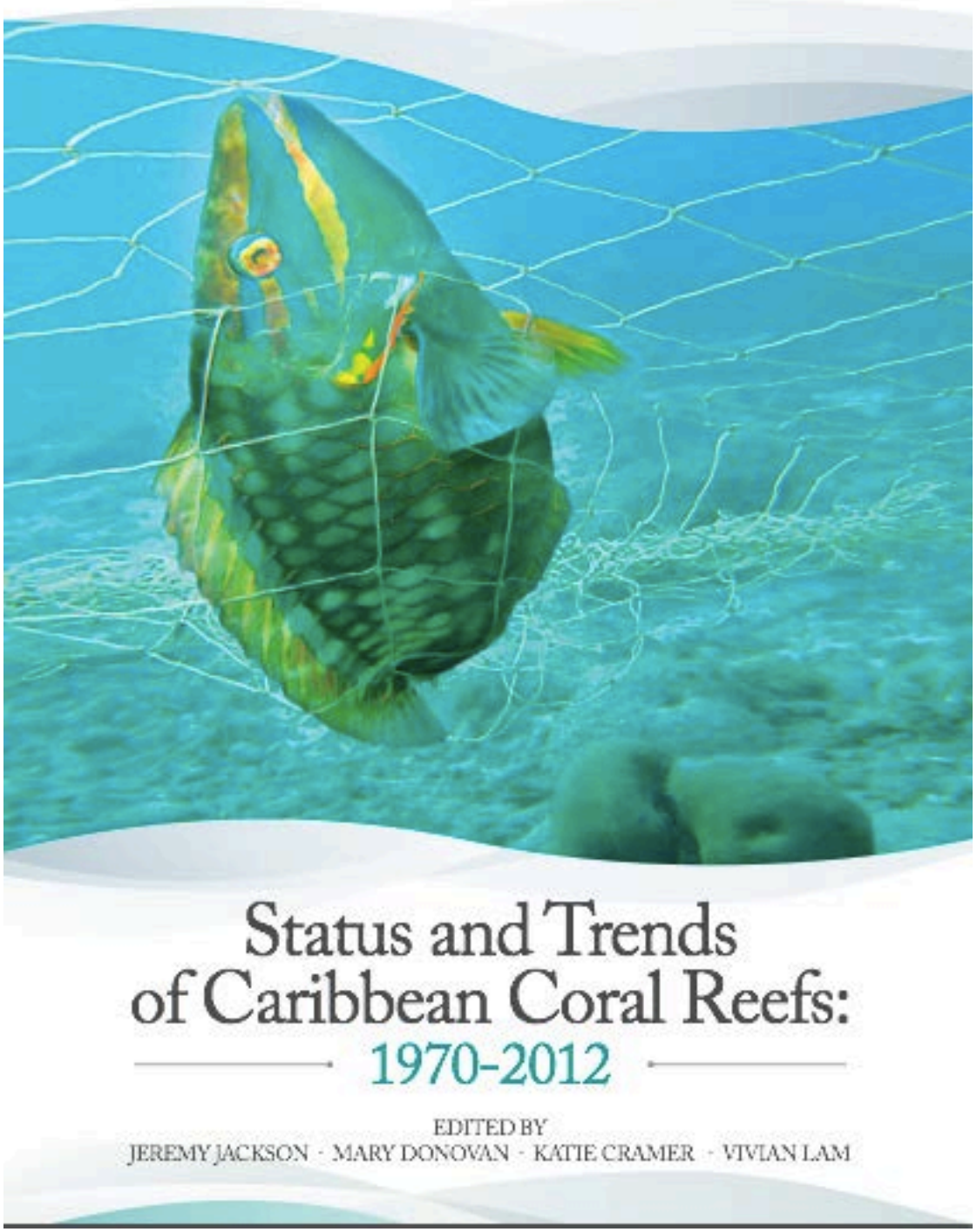
Coral reefs globally are severely degraded because of human impacts

To halt/reverse this decline and increase reef resilience we need to:

1. Understand what pristine reefs were like before people began to destroy them
2. Determine when, how, and why degradation occurred
3. Develop conservation and management strategies based upon these insights to stop degradation and restore reef ecosystem health

Outline of talk

1. Describe results of an exhaustive 3-year scientific analysis by the Global Coral Reef Monitoring Network on the extent of Caribbean reef decline since 1970 and the factors responsible.
2. Briefly discuss the relevance of the results from the Caribbean for reef systems elsewhere
3. Discuss the things that we can do now to significantly increase reef resilience against the future impacts of climate change
4. Put these insights into the context of the dire situation in the Florida Keys



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GCRMN
GLOBAL CORAL REEF MONITORING NETWORK

ICRI

UNEP

IUCN

Smithsonian

DEPARTMENT OF STATE
UNITED STATES OF AMERICA

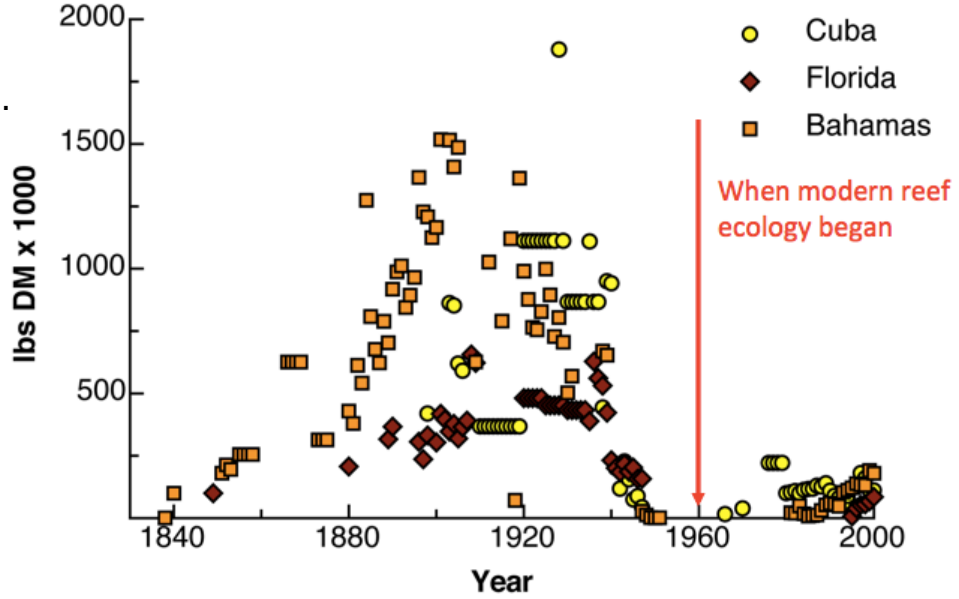
SCRIPPS INSTITUTION OF OCEANOGRAPHY

The Caribbean background

1. Most Caribbean reefs today are like burned out forests, overgrown by grasses and bushes, the large vertebrates gone, and overrun by smaller animals that bear little resemblance to the past.
2. There is an overwhelming sense of despair that reef destruction is inevitable due to climate change, and that reefs are doomed to extinction as oceans continue to warm and waters become more acidic.
3. This obsession with climate change dominates scientific and policy discussions to the virtual exclusion of everything else.
4. The purpose of our study was to evaluate the validity of that perspective.

Fishes decimated by the 1940s-1970s

McClenachan & Jackson, unpubl. Commercial fisheries data



McClenachan, L. 2009. *Conserv. Biol.* 23:636-643

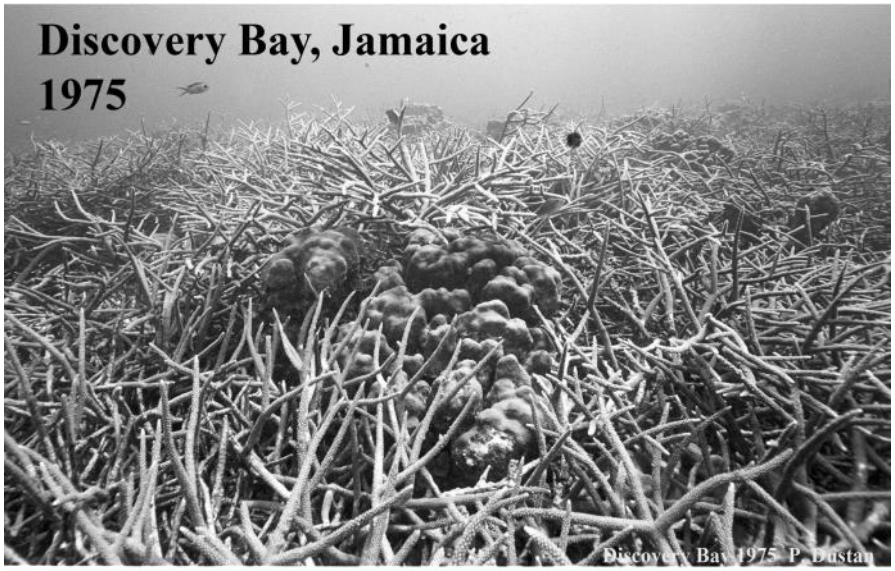
1956

2007

Corals decimated in the 1970s-1980s

Carysfort Reef Florida Keys

Discovery Bay, Jamaica



1975

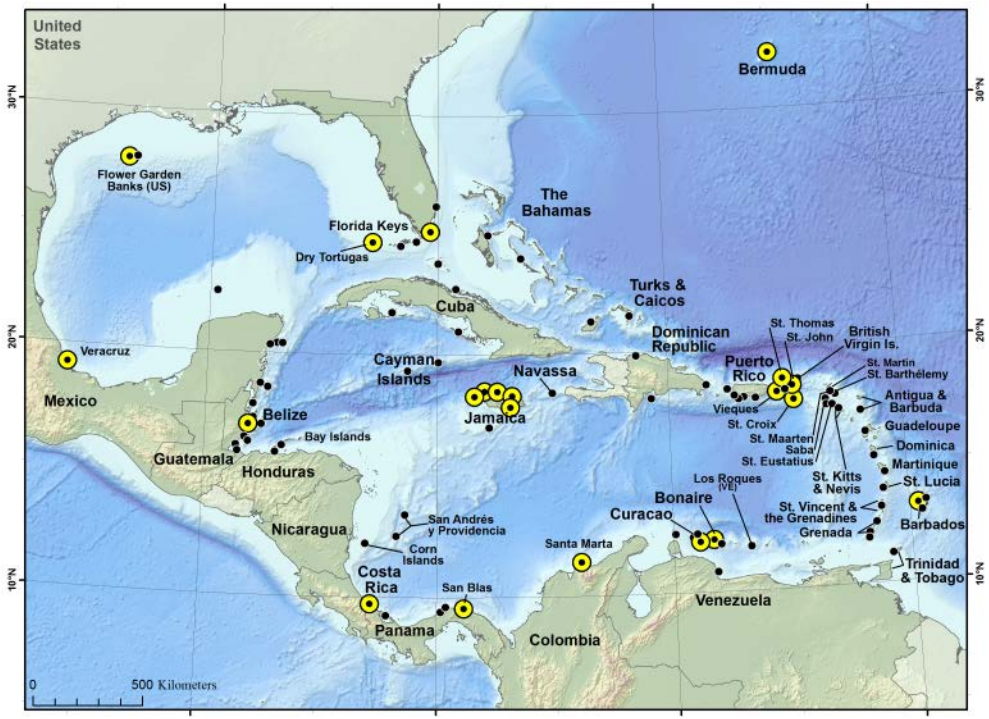
2000s

Scope of the GCRMN Caribbean Report:

>35,000 quant. surveys

90 reef locations

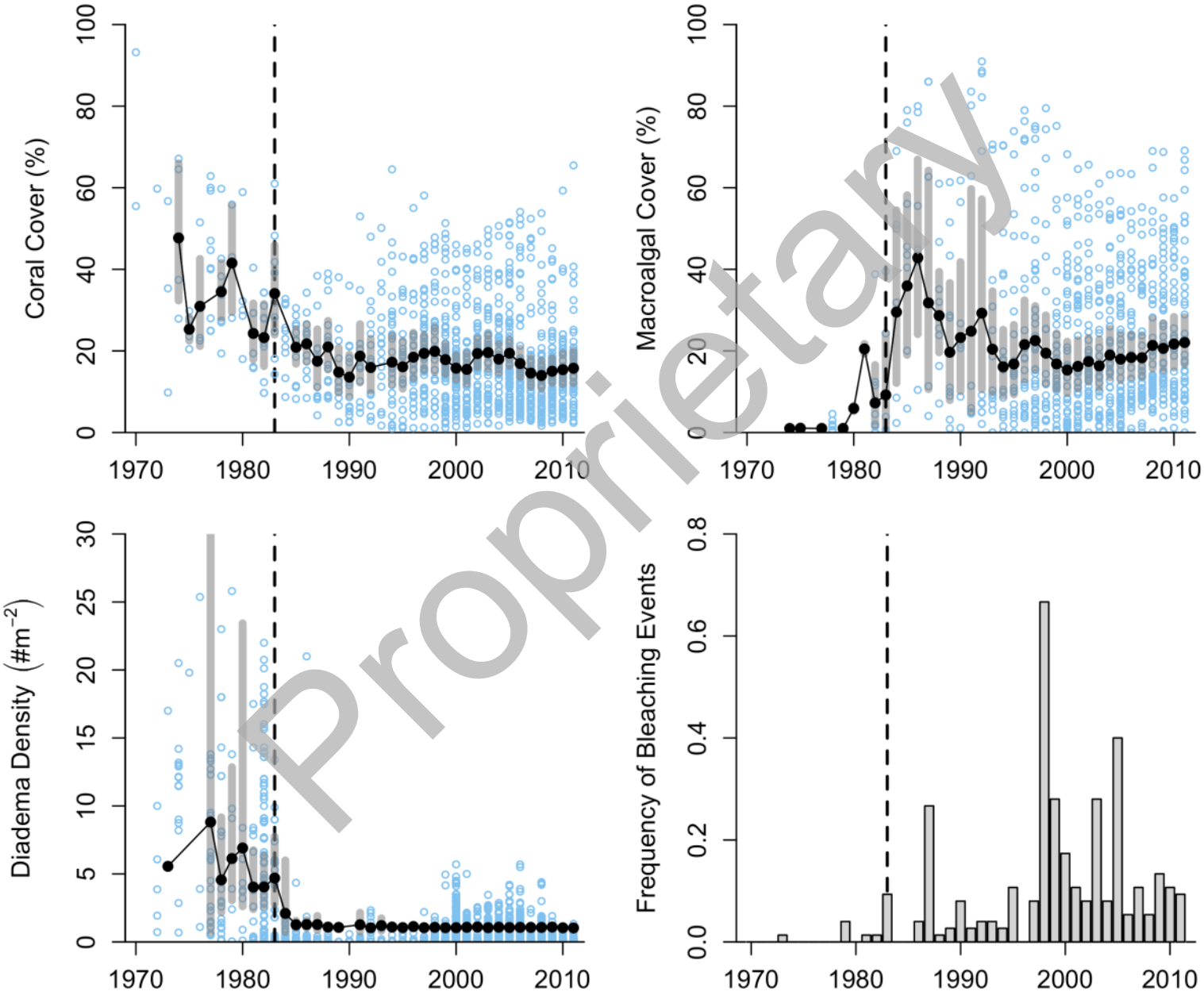
21 locations with data before 1984 to present



Number of:	Coral	Macroalgae	Urchin	Fishes	Overall
Countries/Territories	33	31	32	25	34
Locations	88	73	73	73	90
Datasets	193	129	107	68	287
Principal Investigators	65	55	19	20	78
Individual surveys	12,116	4,109	11,962	20,279	35,577
Datasets from papers	59	30	96	4	143
Start Year	1965	1970	1965	1988	1965
End Year	2012	2012	2012	2011	2012
Years surveyed	42	35	38	18	43

Raw time series for all locations throughout the wider Caribbean combined

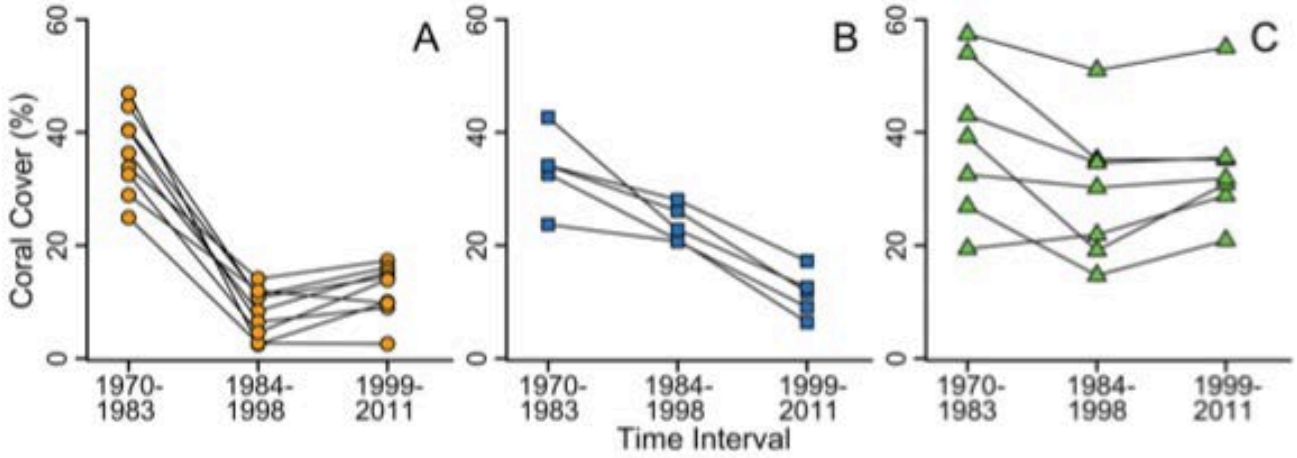
Time series of Caribbean reef degradation

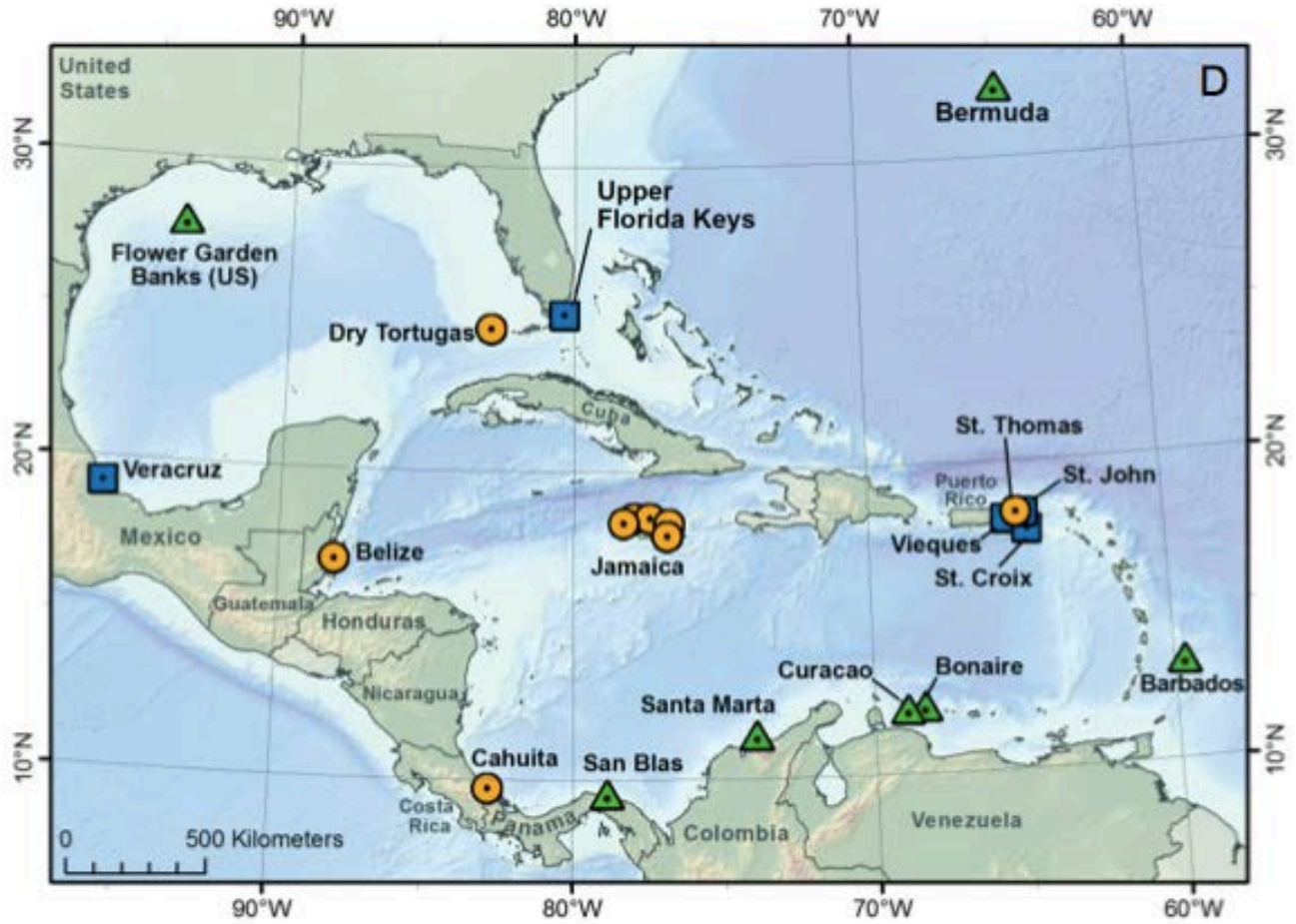


Initial inferences from the time series

1. The overall decline in coral cover began in the 1970s and stabilized by 1990
2. The massive phase shift in coral and macroalgal abundance closely followed the >95% die-off of the grazing sea urchin *Diadema* due to disease
3. However corals were already declining at least a decade before the loss of *Diadema* due to coral disease
4. These major changes in reef composition long preceded any known impacts of climate change

***BUT**, combining all the data obscures striking differences among locations that provide important clues to the causes of reef degradation*





21 locations with long-term data

No obvious geographic or oceanographic pattern

→ ***Local differences*** *in human impacts are somehow responsible*

Which were the primary anthropogenic drivers of reef degradation?

Fundamental importance of distinguishing between drivers and their effects

Drivers versus effects

Anthropogenic drivers

- Overfishing
- Introduced species
- Greenhouse gas emissions, warming and acidification
- Coastal development and runoff
- Human population increase and tourism

Biological effects

- Coral bleaching
- Outbreaks of disease
- Rise of macroalgae
- Decline in coral recruitment and growth
- Failure to recover after hurricanes
- Collapse of 3-D reef framework

Potential anthropogenic drivers of Caribbean reef decline?

1. Introductions of exotic pathogens
2. Ocean warming and acidification
3. Population density (tourism and residents)
4. Coastal pollution
5. Overfishing of grazers

Strongly conflicting views about which factors are "most important"

Virtually all studies focus on single factors in isolation precluding systematic analysis of the relative contribution of different factors

Climate change, coral bleaching and the future of the world's coral reefs

Historical Overfishing and the Recent Collapse of Coastal Ecosystems

The Impact of Climate Change on the World's Marine Ecosystems

Are U.S. Coral Reefs on the Slippery Slope to Slime?

Nutrient Thresholds for Bottom-Up Control of Macroalgal Blooms on Coral Reefs in Jamaica and Southeast Florida

White-band disease and the changing face of Caribbean coral reefs

Shifting Baselines, Local Impacts, and Global Change on Coral Reefs

Coral Reefs Under Rapid Climate Change and Ocean Acidification

Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis

The Impact of Climate Change on the World's Marine Ecosystems

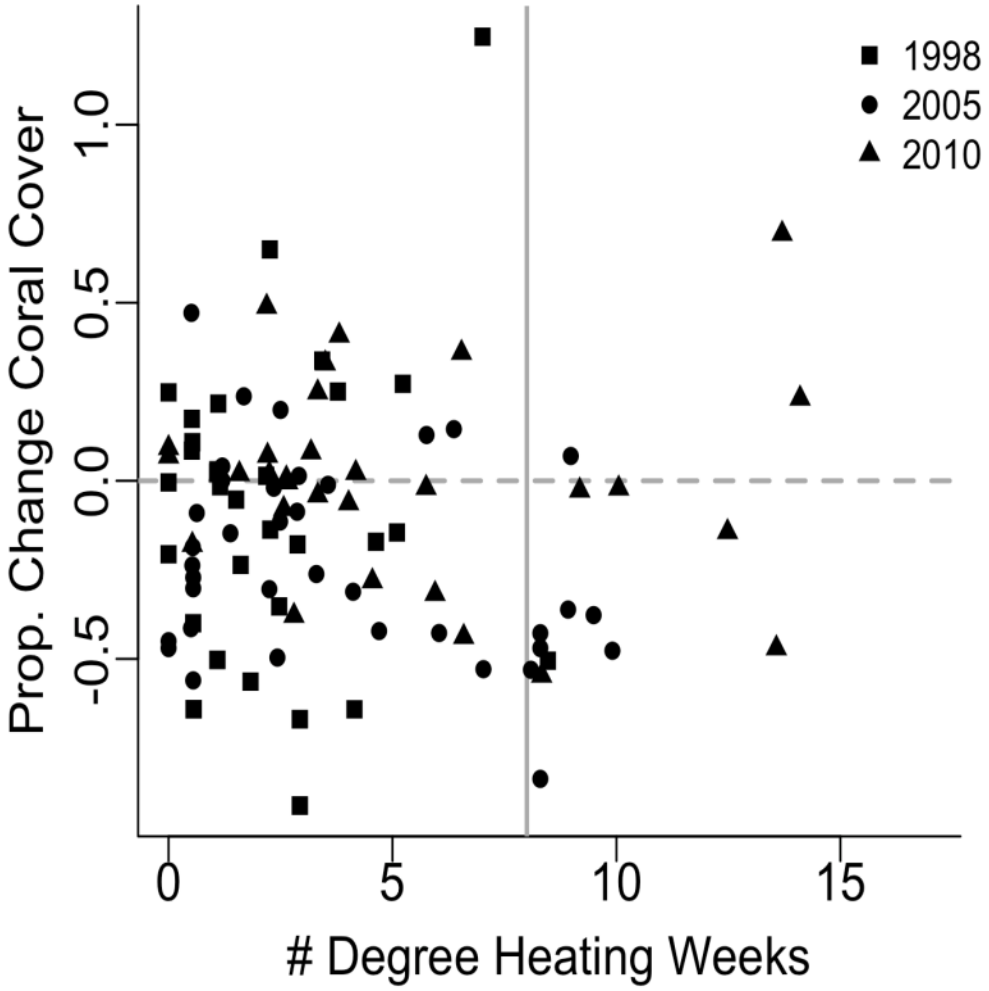
1. Were reef pathogens introduced?

- The Caribbean has been globally isolated from other reef regions for 3-5 million years
- Outbreaks of disease first occurred during the explosion of international shipping and dumping of ballast water beginning in the 1960s
- *Diadema* disease was first observed near the entry to the Panama Canal
- Nothing like the epidemic mortality and ecological extinction of acroporid corals and *Diadema* has been observed in the Indo-West Pacific

→ that Caribbean reef biota suffered a fate comparable to the genocide of native Americans after 1492

The explosions of introduced Pacific lionfish in the Caribbean and introduced groupers and snappers in Hawaii are consistent with this evolutionary vulnerability hypothesis

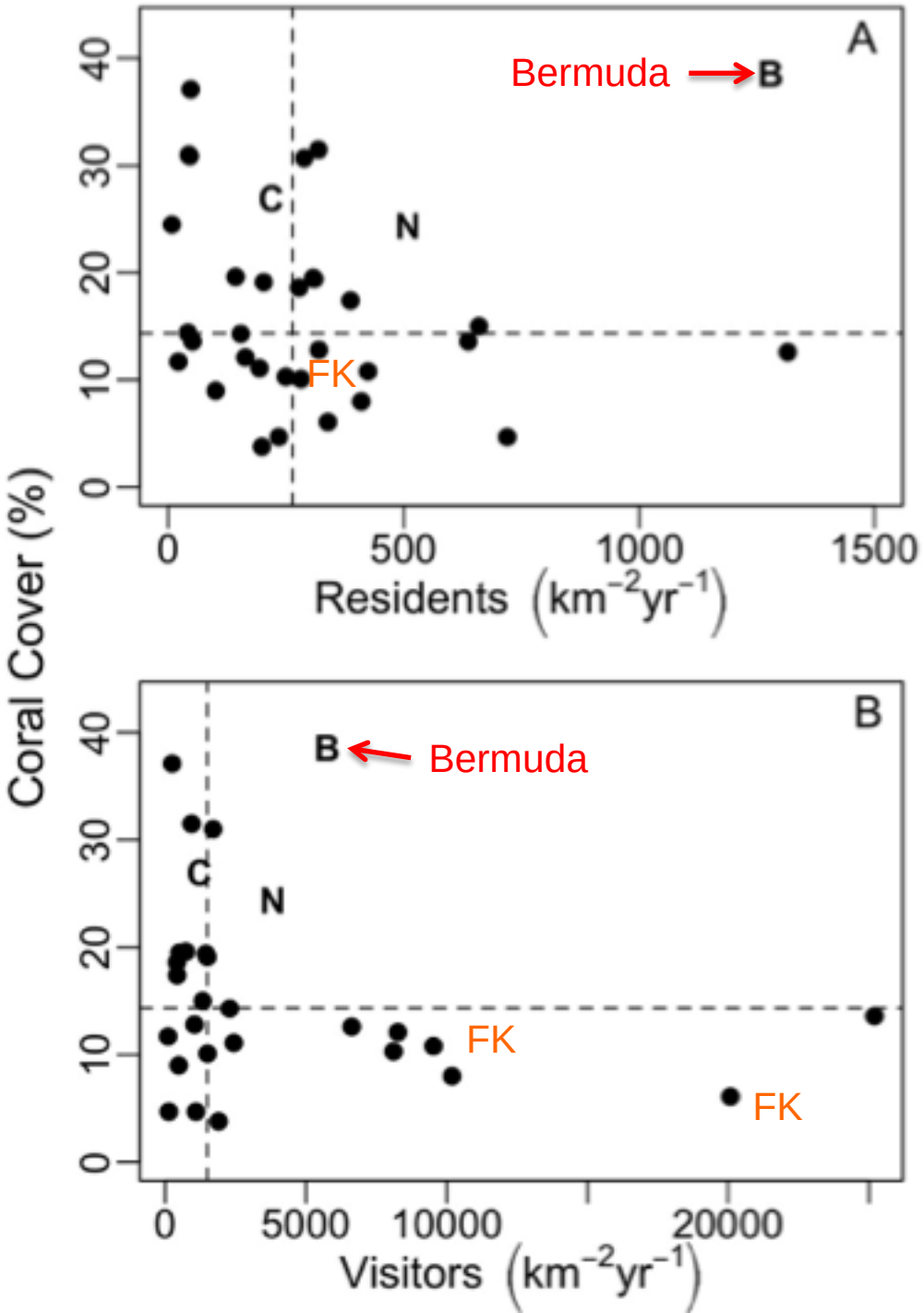
2. Changes in coral cover are not correlated with #s of DHWs during extreme heating events



All data: r_s= -0.10, *p*=0.34

>8 DHW: r_s= +0.66, *p*=0.01

Huge surprise given the focus on climate but unsurprising given time series of bleaching frequency



3. Locations with greater than average population density have lower than average coral cover.

Except for Bermuda, which enacted strong regulations of fishing and pollution

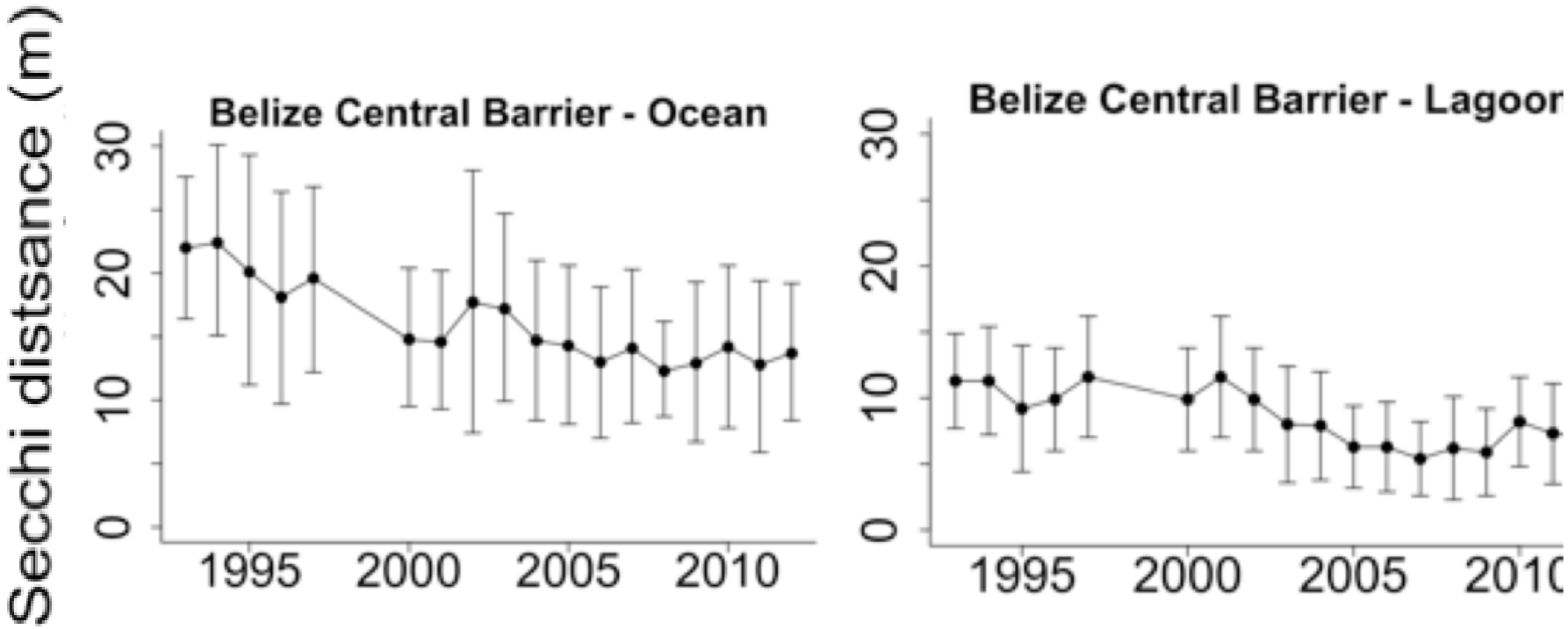
X^2 tests, $p<0.01$ in both cases

4. Coastal pollution

Declining water clarity on the Belize Barrier Reef

Similar pattern at La Parguera Puerto Rico

Inadequate comparative data on water quality is the most glaring gap in virtually all Caribbean monitoring programs



R^2=0.80, ***p*<0.001**

R^2=0.63, ***p*<0.001**

Data courtesy of K. Koltes

5. Overfishing of herbivores

- Lack of historical data on fish biomass before the 1990s hindered previous studies
- So we used well documented historical abundance of the sea urchin *Diadema* before the die-off of the urchin in 1983 as a proxy for herbivorous fish abundance
- The justification for using *Diadema* abundance as a proxy for historical fishing pressure is based on the strong inverse correlation between *Diadema* and parrotfish before 1984 as demonstrated in numerous field surveys and experiments

Overfishing of herbivores, cont.

17 locations with long-term data classified as overfished or less fished based on *Diadema* density/m^2 before 1984.

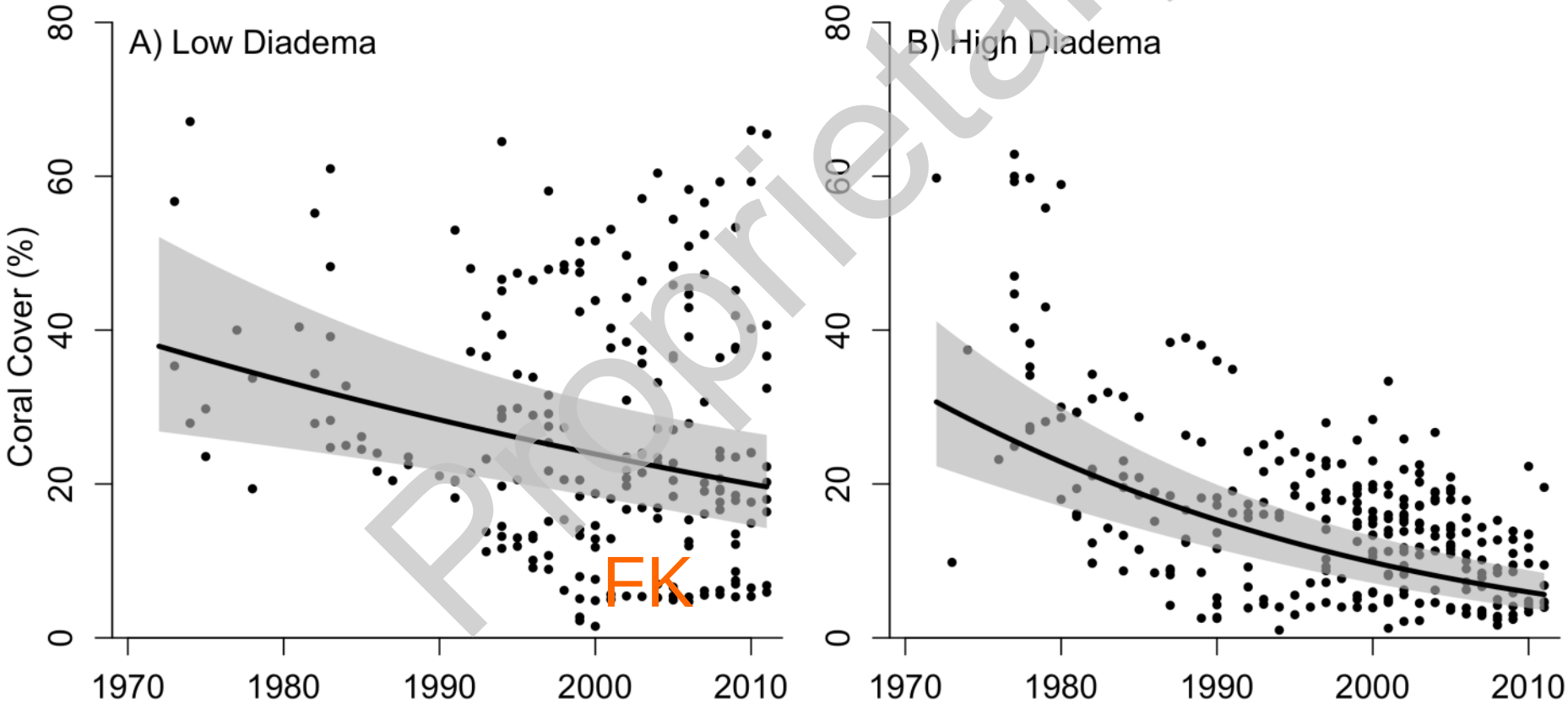
<u>Less fished (range 0.5-3.8 *Diadema*/$m^{2,}$)</u>:

Panama San Blas (0.5), Bermuda (0.6), Flower Garden Banks (1.0), Florida Upper Keys (1.2), Bonaire Leeward (1.5), Belize Central Barrier (1.7), , Curacao SW (3.0), Costa Rica Cahuita (3.8)

<u>Overfished (range 6.9-12.4 *Diadema*/m^2)</u>:

Jamaica north central (6.9), USVI St. Croix 7.0), Jamaica Montego Bay (7.1), Jamaica NE (7.9), USVI St. John (9.1), Jamaica west (9.2), USVI St. Thomas (9.8), Barbados leeward (11.2), Jamaica Port Royal Cays (12.4)

Long-term & persistent differences in coral cover in relation to historic fishing pressure (high versus low Diadema density) at the 17 locations



Overfishing herbivores kills corals due to the harmful effects of macroalgae (MA)

1. MA were rare on Caribbean reefs before 1984 due to grazing by parrotfish and/or *Diadema*
2. MA abundance increased by 300-500% after the *Diadema* die-off in 1983/84, especially on reefs that had been overfished of parrotfish.
3. Experiments show that abundant MA decrease recruitment of juvenile corals by up to 80% and strongly inhibit coral growth.
4. Experiments also show that MA cause coral disease and death. There are no counter examples.

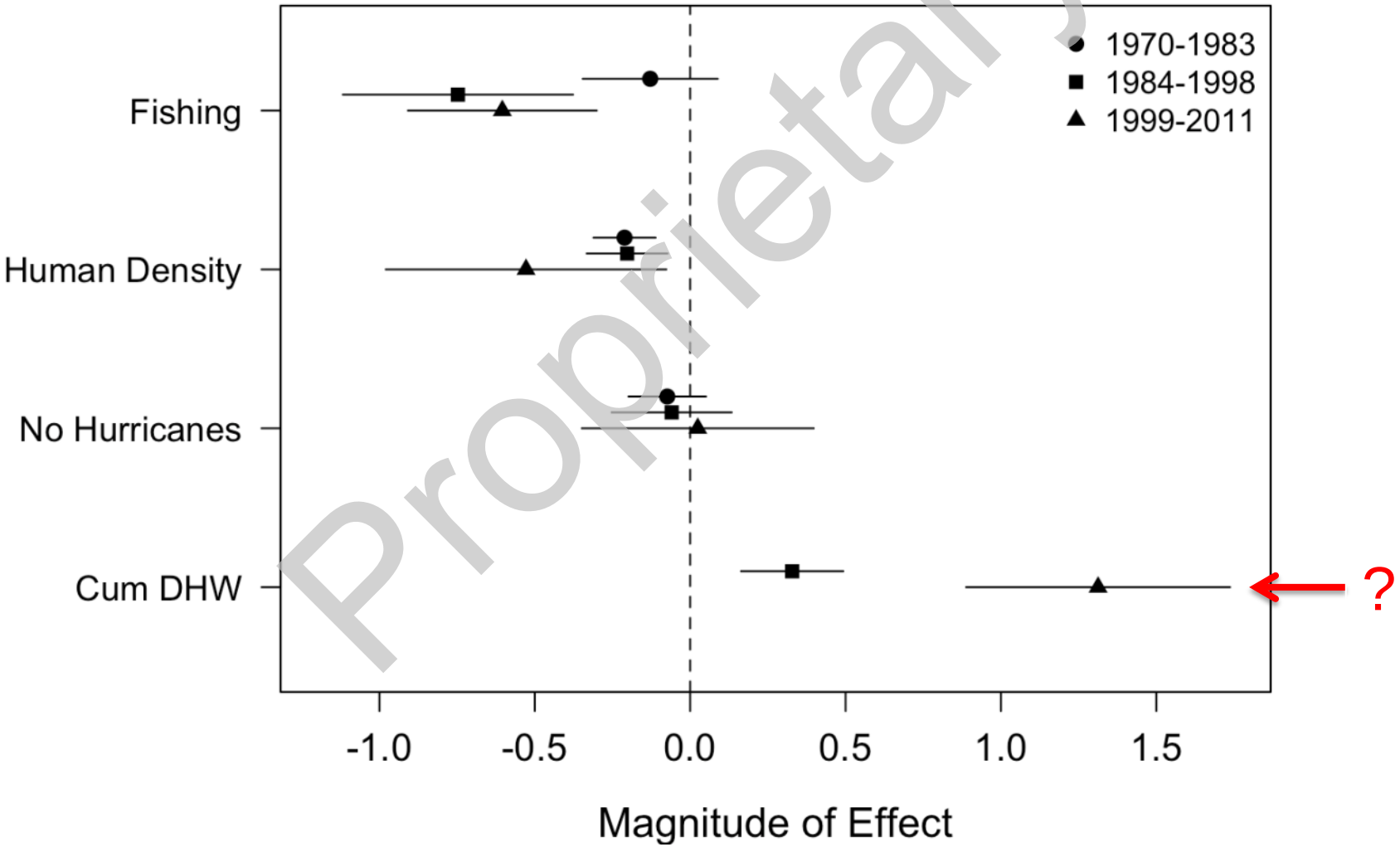
Multivariate analysis of factors

Generalized linear mixed effect model of coral cover for 3 time intervals at 17 locations

Models fit with beta error and random effects of Dataset and Location.

- Fishing is 2-level factor based on low vs high *Diadema* densities before 1984
- Number hurricanes is sum for each time bin individually
- Cumulative degree heating weeks (DHWs) is the sum of DHWs within each time bin for years with $\geq$ 4 DHWs
- Human population density is for time interval 3 applied throughout

Comparative magnitude of effects with standard errors



Why does warming come out positive?

Bermuda and the Flower Gardens experienced double the DHWs of anywhere else

- but corals survived
- fishing and development are strictly regulated

The USVI experienced the next highest DHWs

- more than half the corals died
- reefs are overfished and tourism and development are uncontrolled

Bonaire experienced nearly as many DHWs as USVI

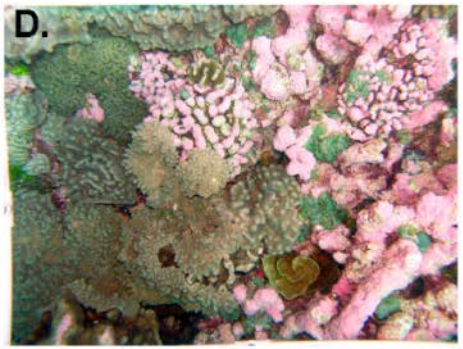
- coral cover increased
- fishing is regulated and development restricted

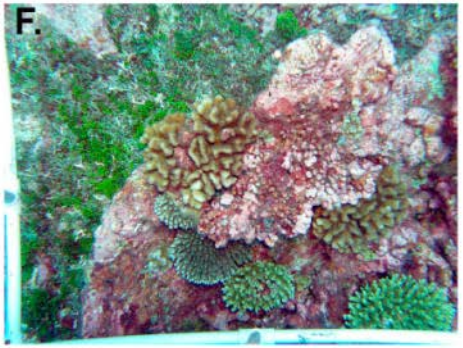
Summary

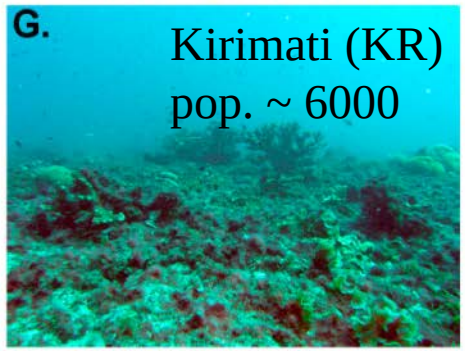
1. 50% overall decline in coral cover since 1970s but several places much healthier than average
2. Primary drivers of coral decline were diseases in the 1970s-1980s and local impacts of overfishing and development in relation to numbers of people
3. Most coral decline occurred before the late 1980s so rising temperatures were not a major factor
4. Macroalgae kill corals and cause coral disease so abundant MA may be responsible for coral death after bleaching.
5. Macroalgae are an overfishing and nutrient pollution problem

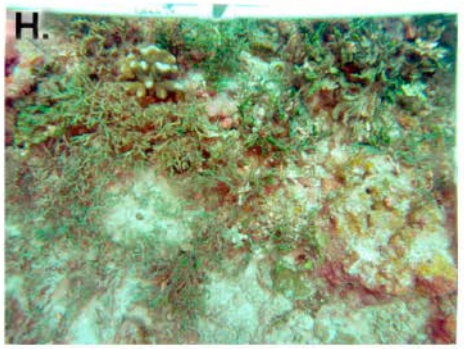
Evidence from Australia and the Central Pacific consistent with Caribbean results

- Mortality associated with extreme heating events appears to be more severe in the Pacific than Caribbean
- Impacts of too many people, overfishing, and coastal runoff are just as severe (e. g., the rapid decline of the GBR)
- Nevertheless, reefs protected from land based pollution and overfishing (or those so remote as to be protected by default) have higher coral cover and recruitment, less disease, and appear to recover more rapidly from coral bleaching

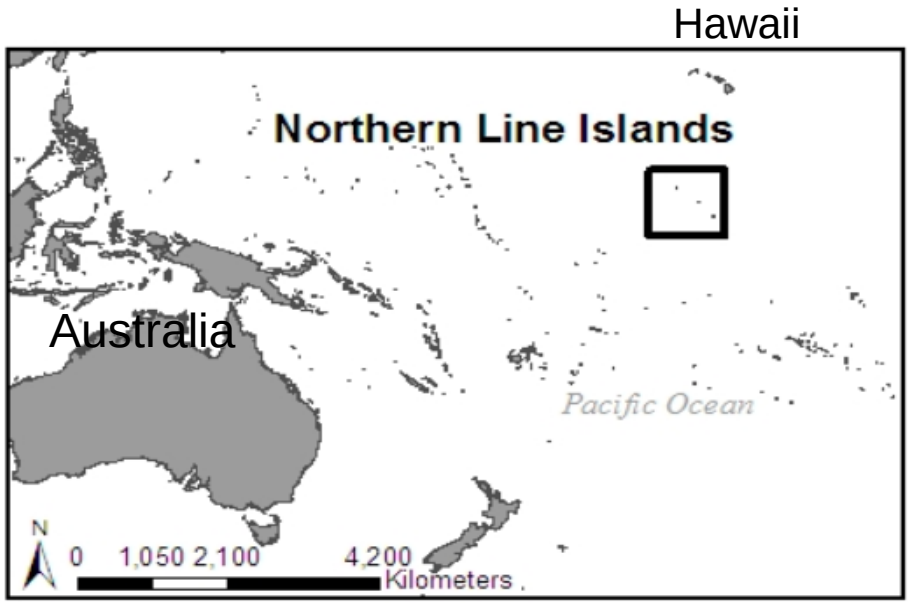








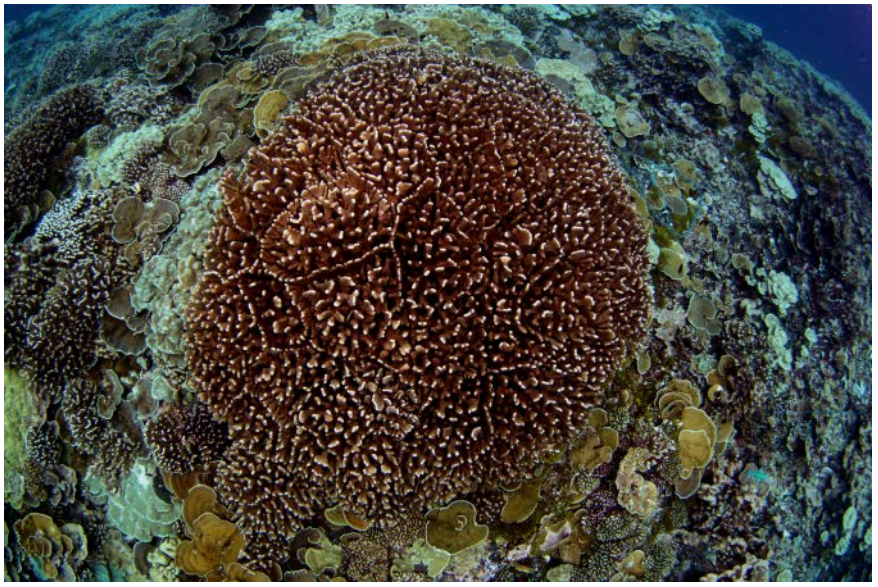
Northern Line Islands example from our Scripps cruise in 2005



Sandin *et al*. 2008. *PLoS One* 3(2):e 1548

Remote reefs in Southern Line Islands

Scripps Southern Line Island cruise 2013



Conservation Implications for Caribbean Reefs

- Much could be done to restore Caribbean reefs by strict and effective regulation of fishing and coastal development
- Overemphasis on climate change distracts attention from well-documented impacts of local stressors
- Overemphasis on climate change also provides a convenient excuse for political inaction
- Bermuda, the Flower Garden Banks, and to a lesser extent Bonaire and Curacao are striking examples of the effectiveness of strictly enforced local protections

In contrast, the Florida Reef Tract epitomizes the worst case scenario

1. Unprecedented excessive population growth
2. Grossly inadequate governance and regulations in the water and on the land

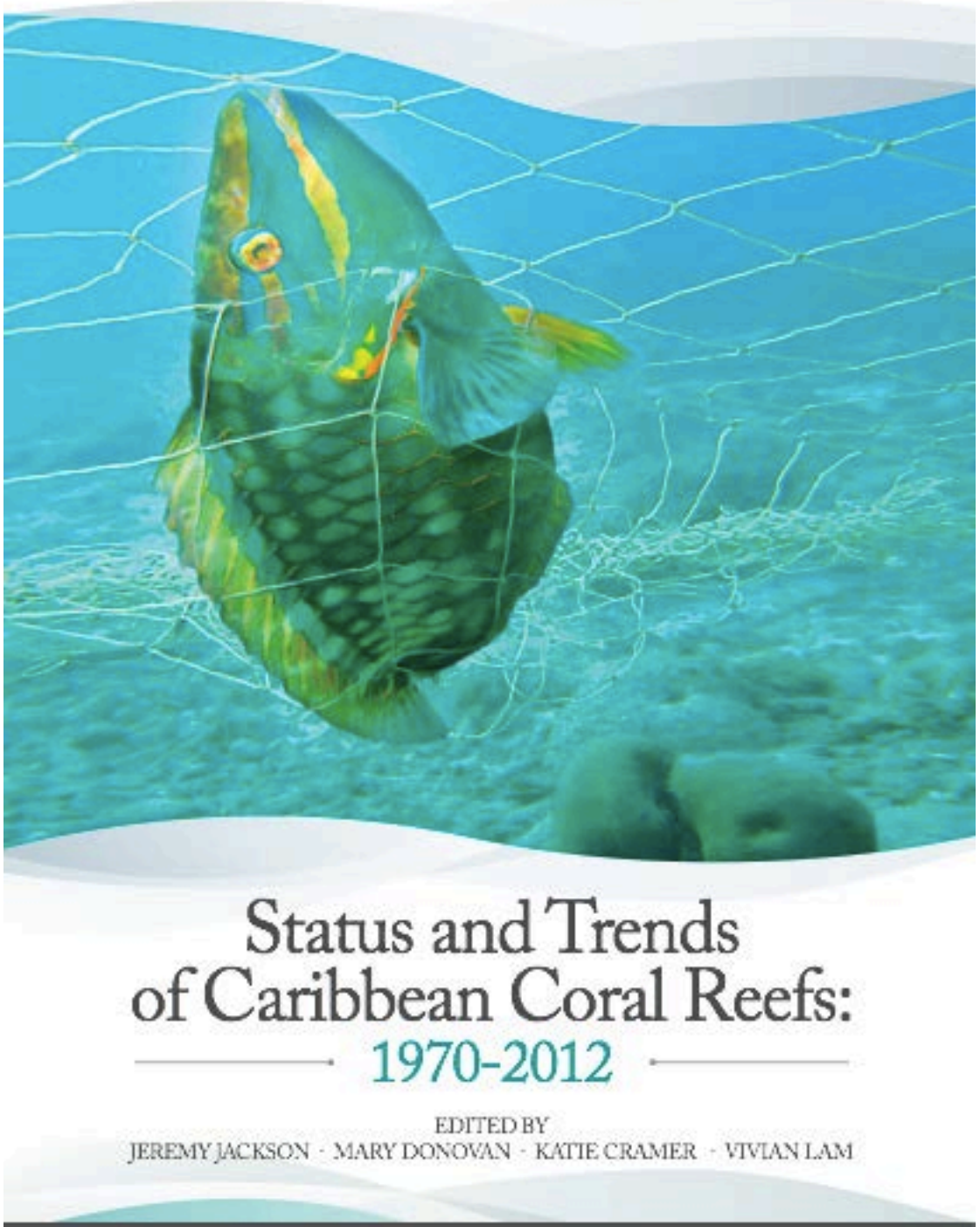
→critical endangerment of the entire marine coastal ecosystem

The science is crystal clear.

Localized and immediate management actions to severely curtail fishing, development, and tourism will be essential for coral reef survival

*The **science** says that to save the Florida Keys you need to:*

1. Declare one third of the entire reef tract and adjacent habitats as off limits to any form of fishing, diving, or anchoring.
2. Enact absolute protection everywhere of all grazing fishes and all spawning aggregations
3. Curtail all development
4. Cap the numbers of visitors and cruise ships to some number much lower than today



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