Holocene Climate Change and the History of *Acropora* spp. at the Flower Garden Banks

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Special Thanks

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Distribution of Reefs vs Sea Surface Temperature

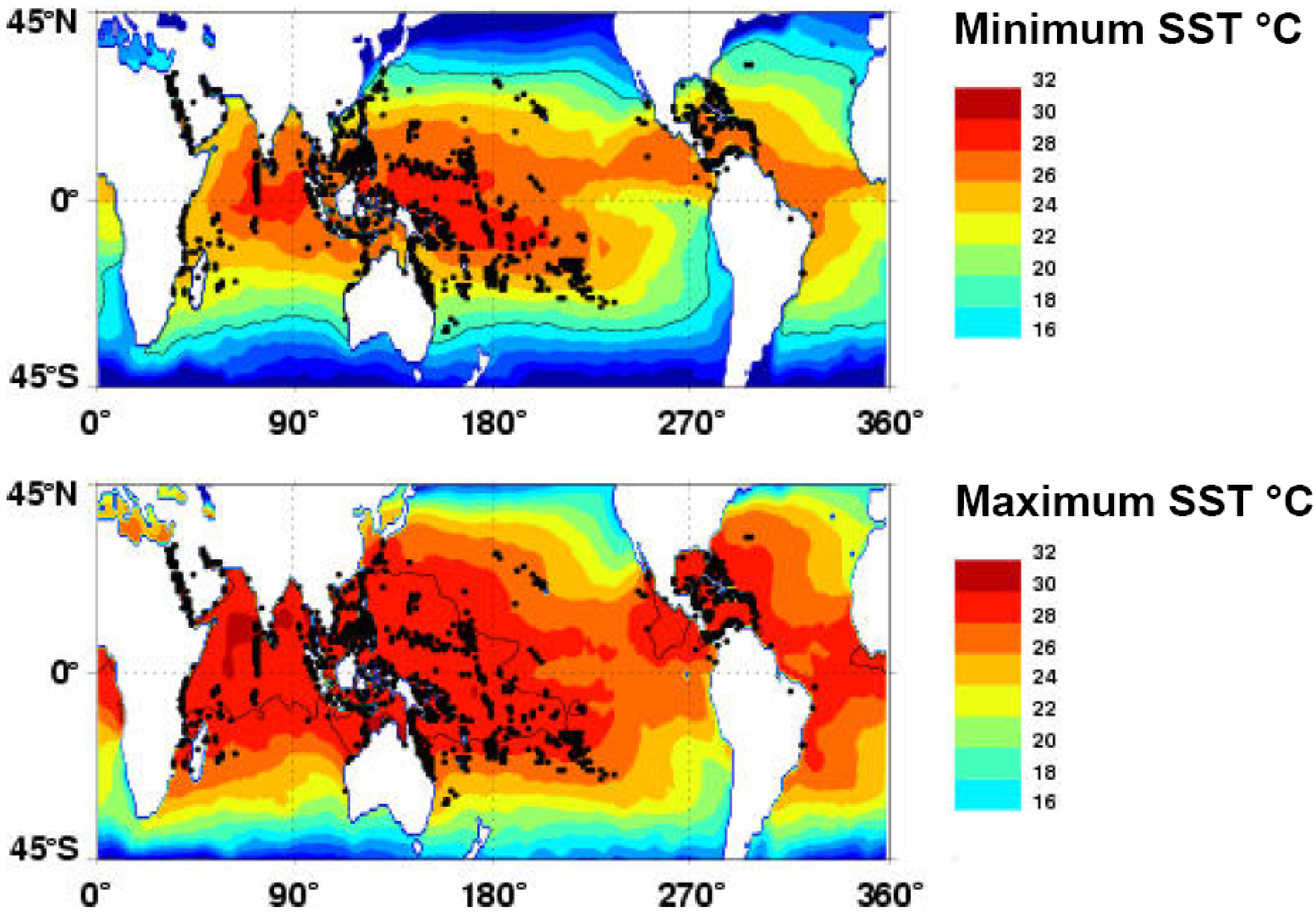


Figure Courtesy Joan Kleypas

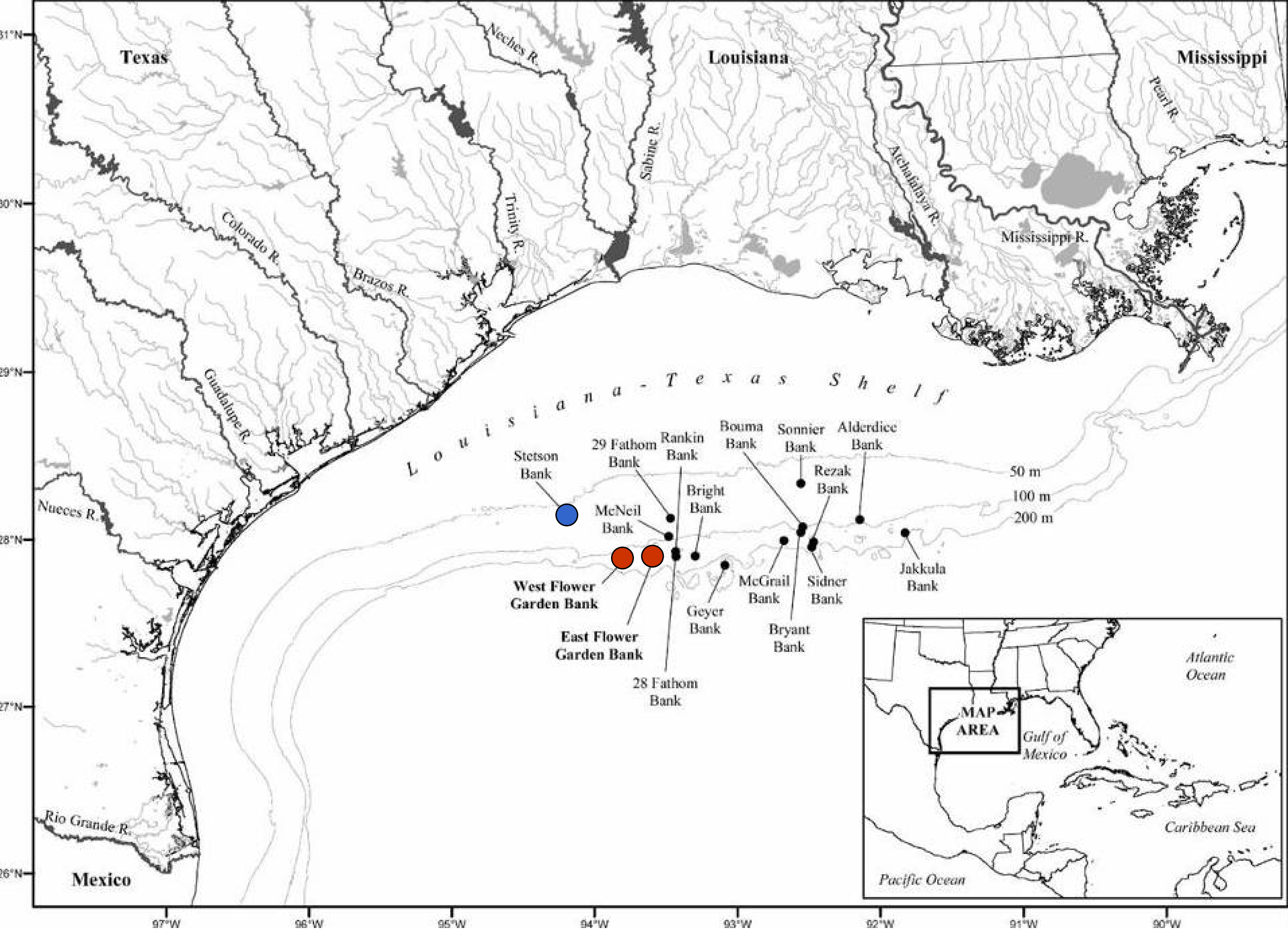


Image Credit: FGBNMS

The Flower Garden Banks

- **East Bank**
  - **Total area is approx. 19.2 sq. miles**
  - **Reef crest is approx. 250 acres**
  - **Active brine seep forms a underwater salt lake about 100 ft. dia and 10 in. deep**

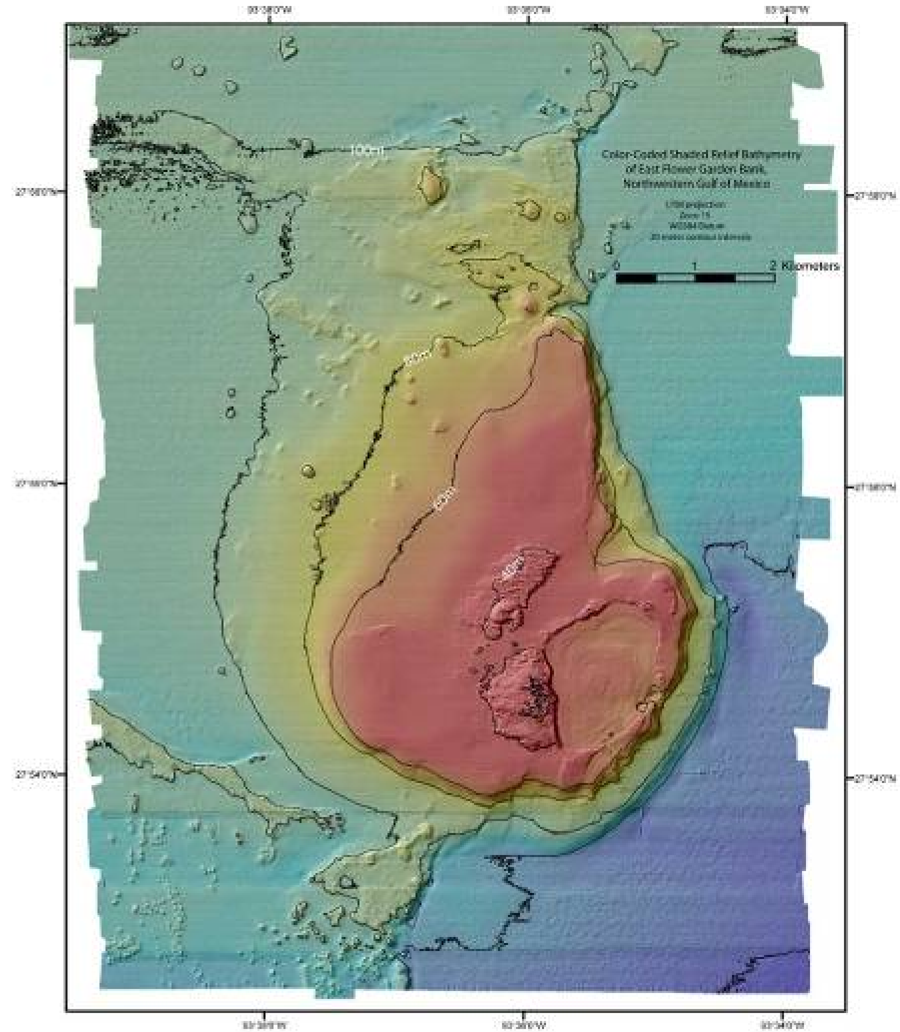


Image Credit: FGBNMS/Doug Weaver

The Flower Garden Banks

- **West Bank**
  - **Total area is approx. 22.5 sq. miles**
  - **Reef crest is approx. 100 acres**

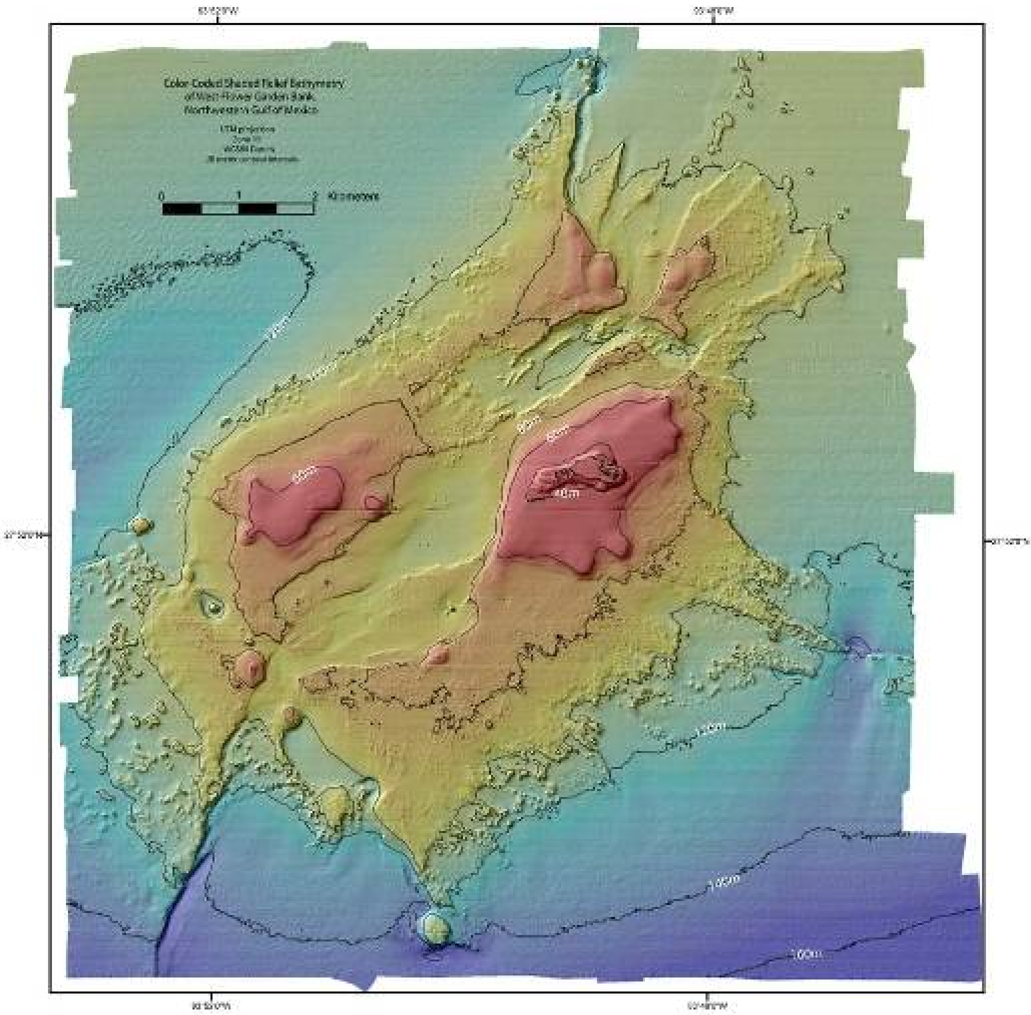
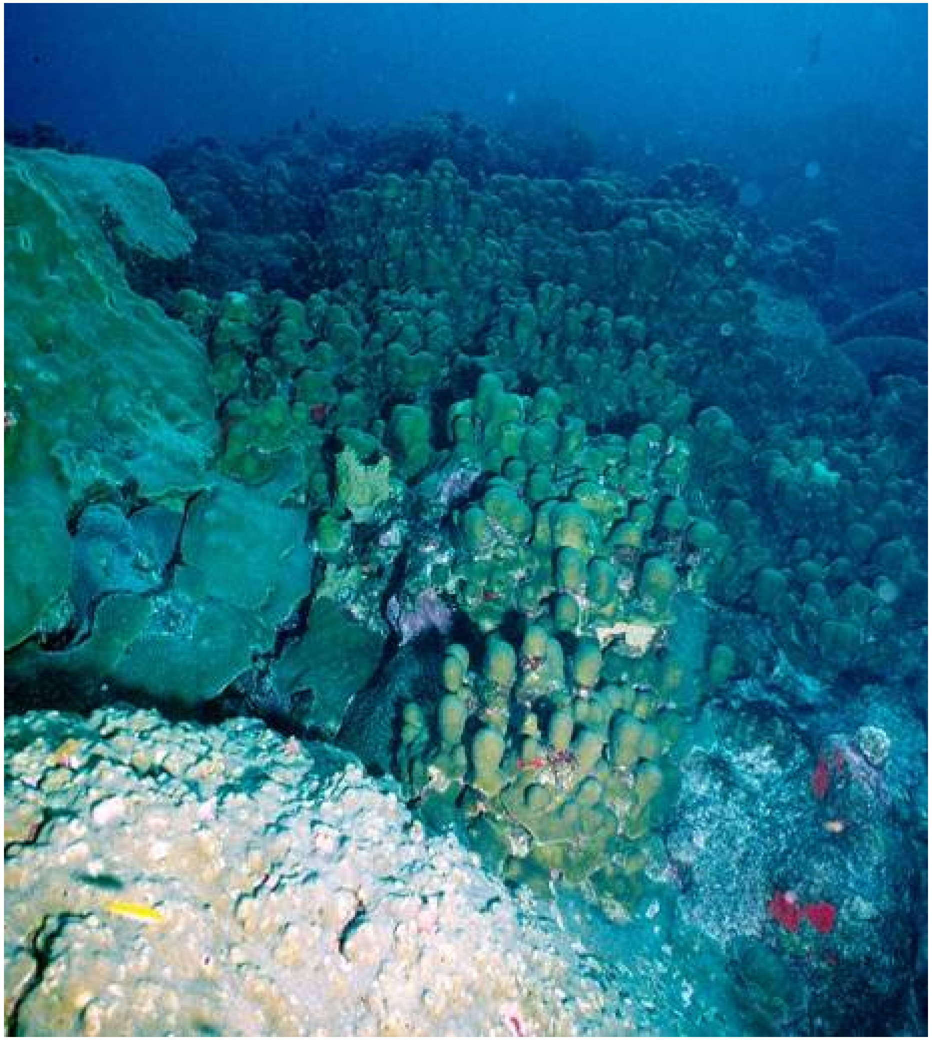
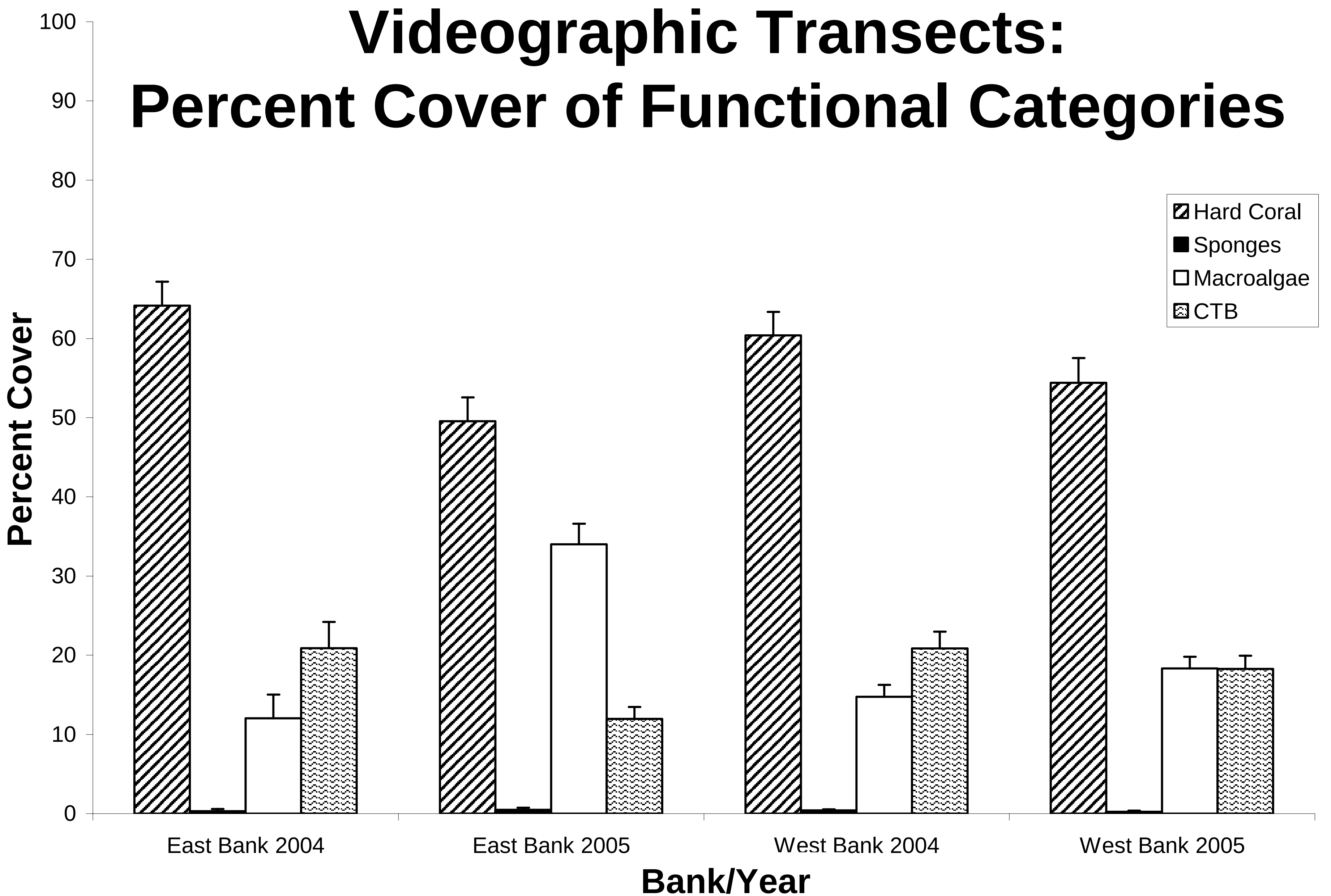


Image Credit: FGBNMS/Doug Weaver

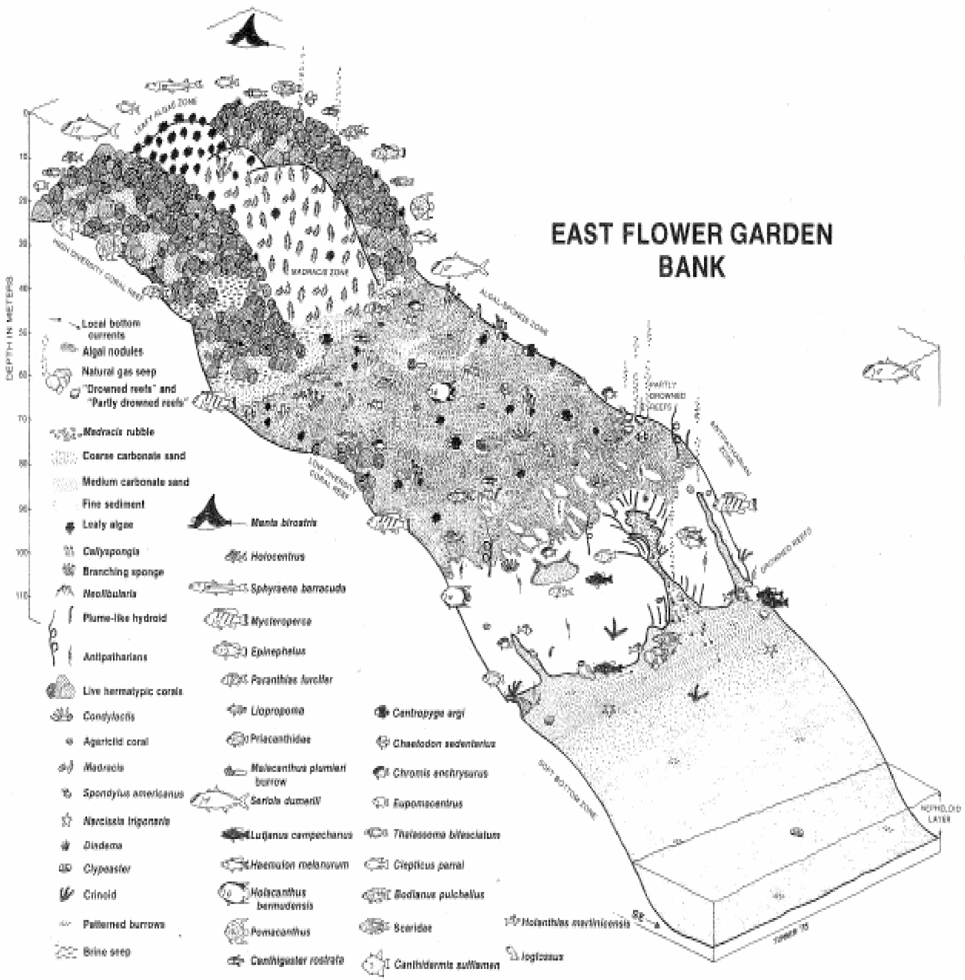
Reefs of the Flower Garden Banks



- Perched atop salt domes
- Northernmost coral reefs in the continental United States
- Reef formed by large, stony corals (e.g. M – D – P complex)
- Acroporid corals absent!
- >50% coral cover
- About 23 coral species
- Over 850 other reef invertebrate species
- ~250 fish species
- 125+ algae species



Videographic Transects:
Percent Cover of Functional Categories
Percent Cover
100
90
80
70
60
50
40
30
20
10
0
Hard Coral
Sponges
Macroalgae
CTB
East Bank 2004
East Bank 2005
West Bank 2004
West Bank 2005
Bank/Year



the submerged reefs atop the East and West Flower Garden Banks 100 NM southeast of Galveston, Texas. Here, coral reefs exist at the crests of the banks at depths of 15 to 52 m. The shallowest (15 to 36 m) are dominated by the star coral *Montastrea annularis*, brain corals *Diploria strigosa* and *Colpophyllia* spp., and the mustard hill coral *Porities astreoides*. About one-third of the species of Caribbean reef-building corals occur on the banks along with several hundred species of reef invertebrates and fishes. There are, however, no shallow-water alcyonarians and no corals of the genus *Acropora*. Although they are the northernmost true tropical coral reefs on the continental shelf of North America, the Flower Garden reefs exist in oceanic water with winter temperatures that do not typically drop below 18 to 19°C, barely above the accepted lower limit for reef development.

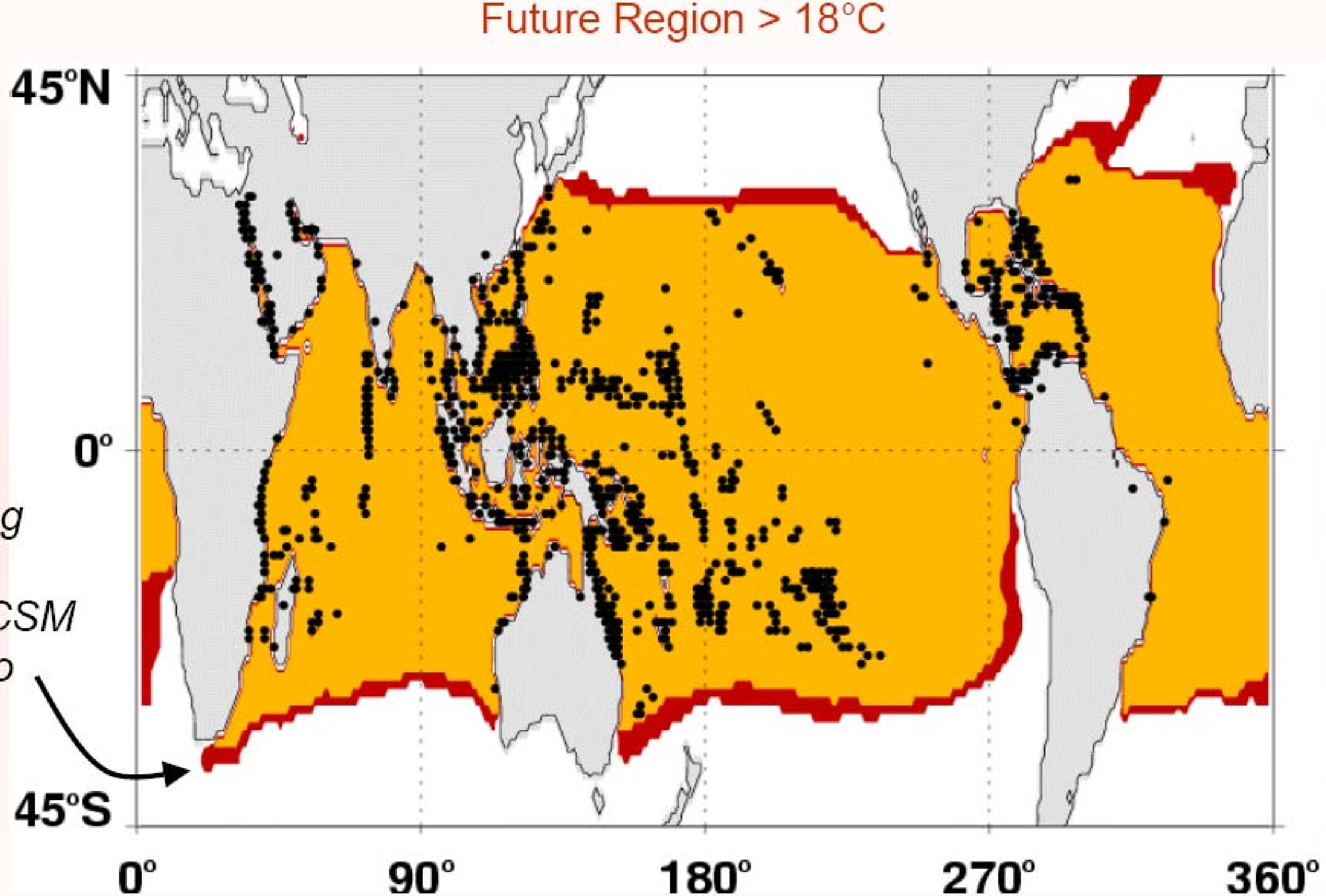
From Rezak, Bright and McGrail (1985)

The Historical Past

The FGB apparently did not have acroporids in recent times; therefore, they had none to lose, and as a result massive corals continuously monopolized the open surfaces of the reef caps. This effect clearly has far more to do with the high-latitude location of the FGB, which excluded *Acropora* spp., than it does with their protected status, considering that the study reefs in Florida are fully protected. Coral assemblages at the FGB are similar to those in Bermuda, where (1) values of coral cover can also reach or exceed 50%, (2) massive corals of the genera *Montastraea*, *Diploria*, and *Porites* dominate, and (3) *Acropora* spp. are absent because the water historically has been too cold during the winter (Dodge et al. 1982; Bright et al. 1984; Logan 1988; Webster and Smith 2002).

From Aronson et al. 2005

Potential Poleward Expansion of Coral Reefs



Warming derived from CCSM scenario runs

Figure Courtesy Joan Kleypas

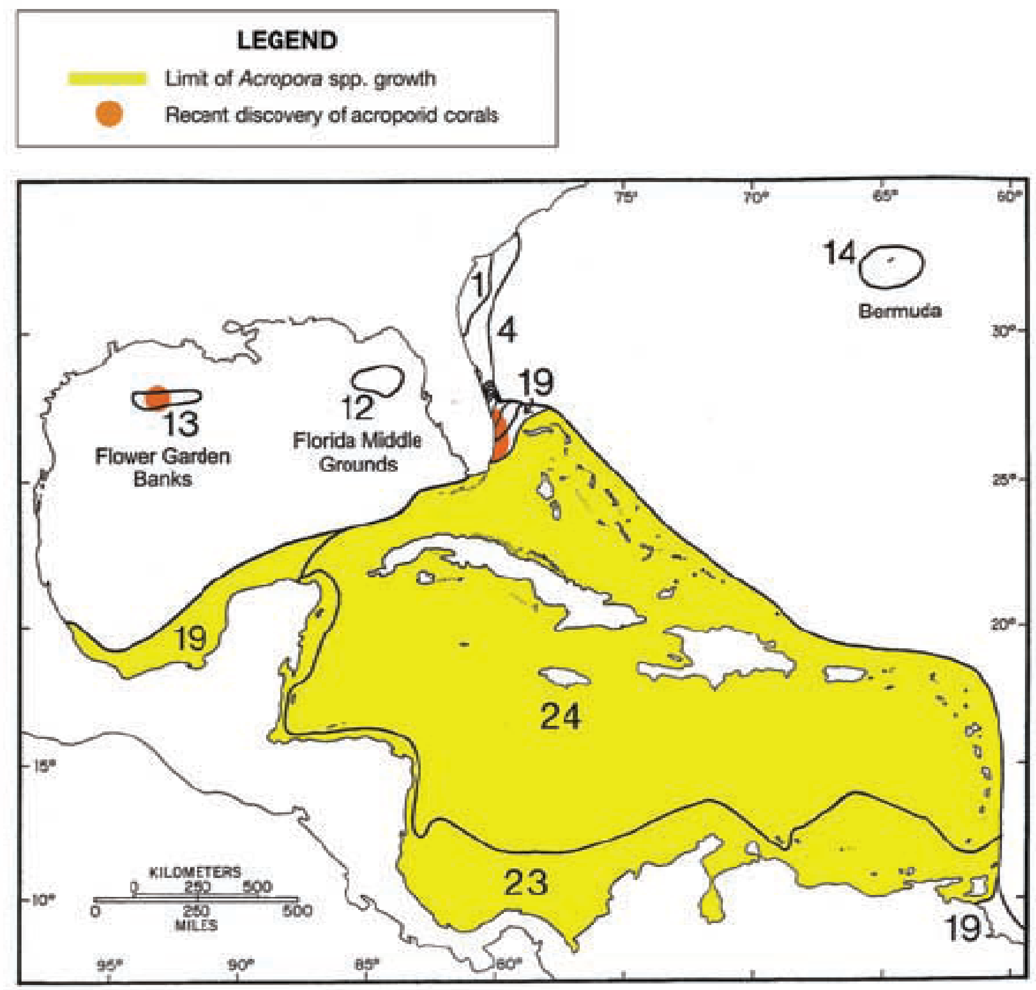
Biological Response

- The fingerprint of global climate change can be mapped via the response of species to changes in their physiographic environmental settings.

- In both marine and terrestrial systems, numerous species have recently responded to warming trends by expanding their ranges to higher latitudes, as well as by changing the timing and duration of their migrations and phenologies.

The northernmost limit of reef-building was equivalent to the northern range of the *Acropora* species.

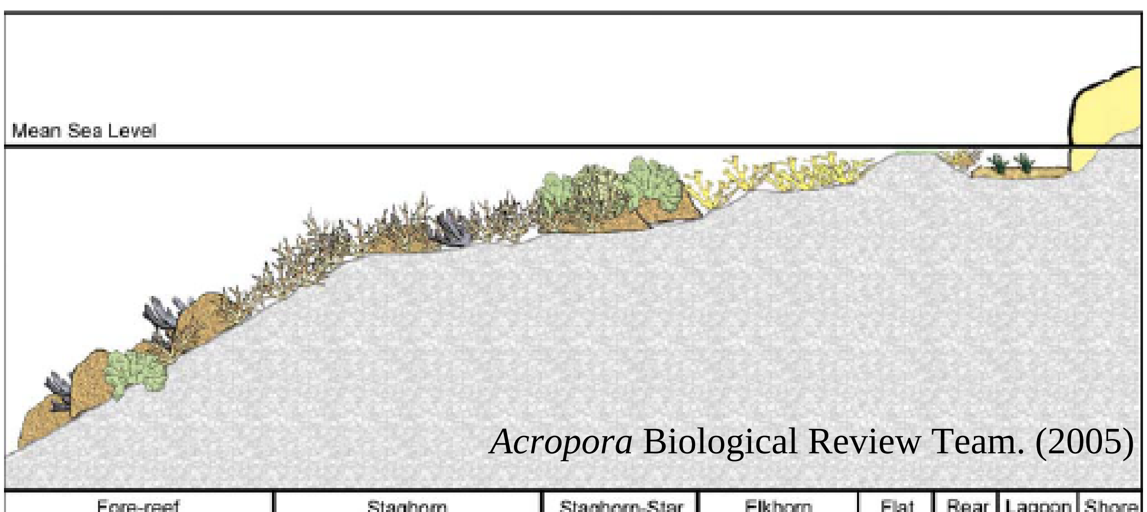
This is located at ~ the 18^{o}C Isotherm.



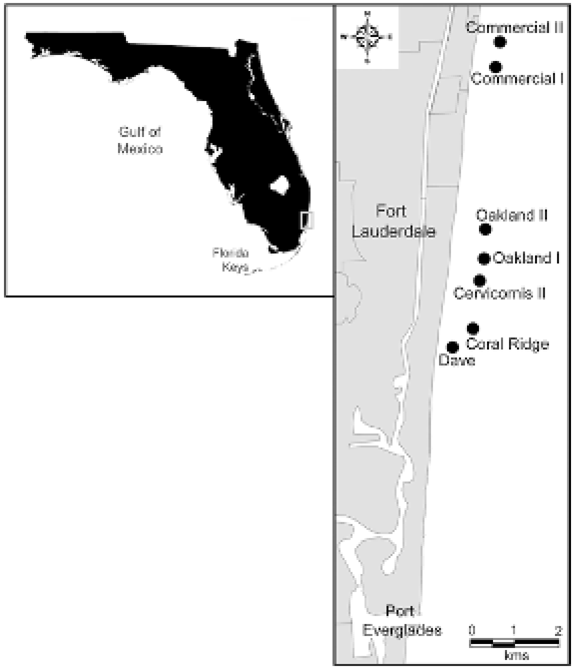
From Precht and Aronson (2004)

Caribbean Acroporids

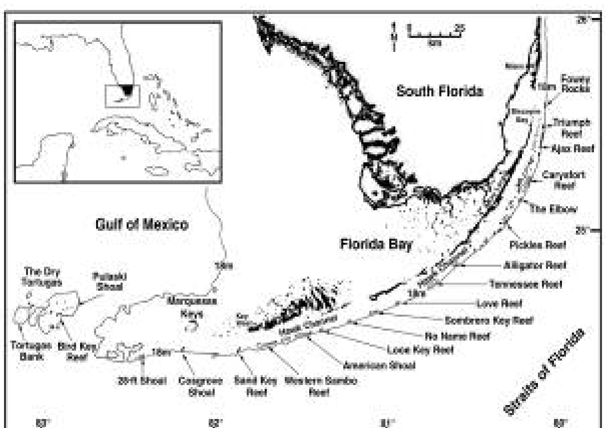
- Extremely thermophyllic
- Temp Range 15–31^{0}C
- Reproductive strategy dominated by asexual fragmentation
- Major framework builders
- High coral cover
- Structurally complex
- Recently listed as threatened under the ESA



Acropora Biological Review Team. (2005)



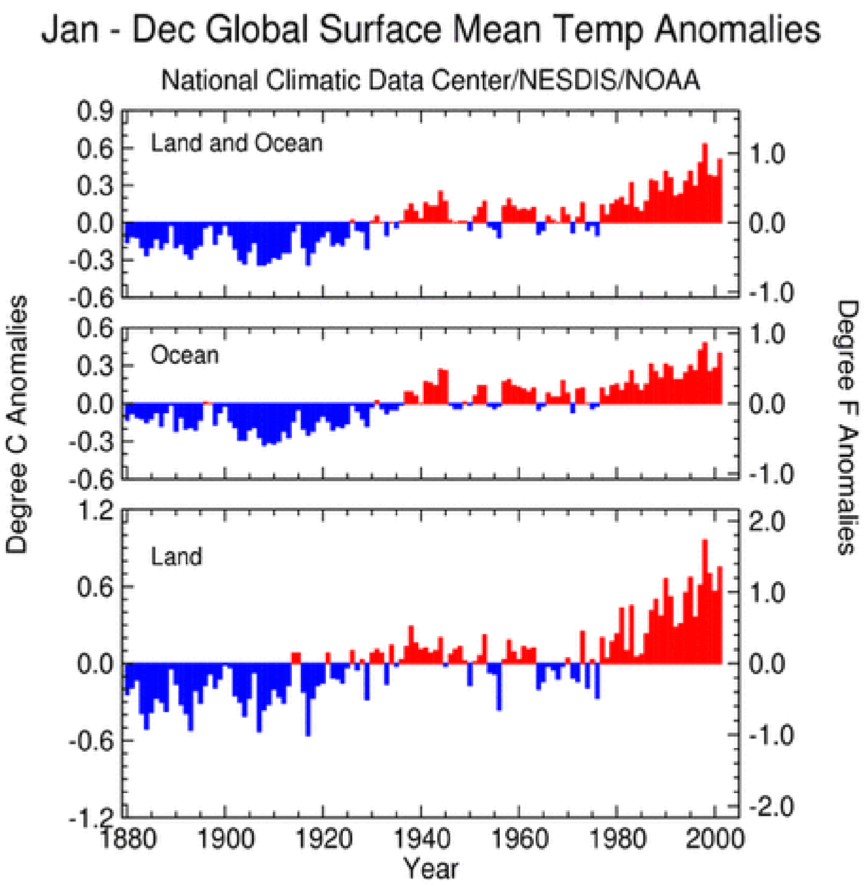
The recent discovery of *A. cervicornis* thickets off Ft. Lauderdale, some 25 km north of Fowey Rocks.



The recent discovery of the northernmost *A. palmata* colony off Pompano Beach on the Broward – Palm Beach County line, some 50 km north of Miami.

Pompano Beach Pier – Northern Broward County – 2003

The appearance of acroporid corals north of their previously-known range are linked with decadal-scale increases in annual sea-surface temperature.

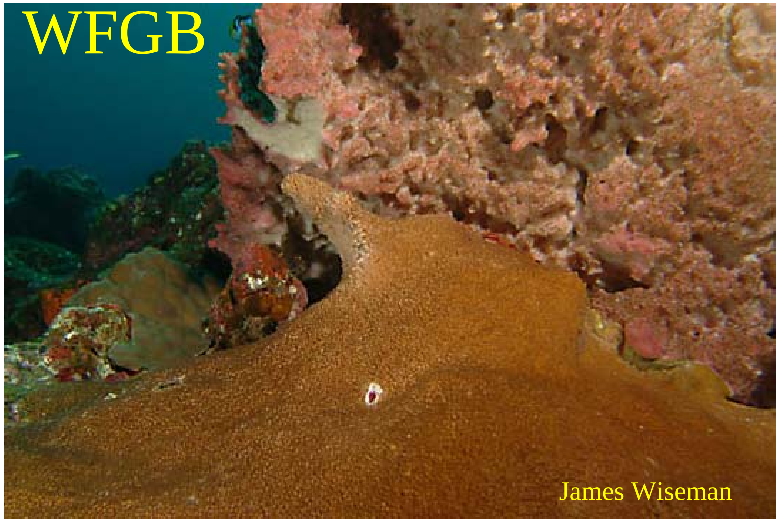


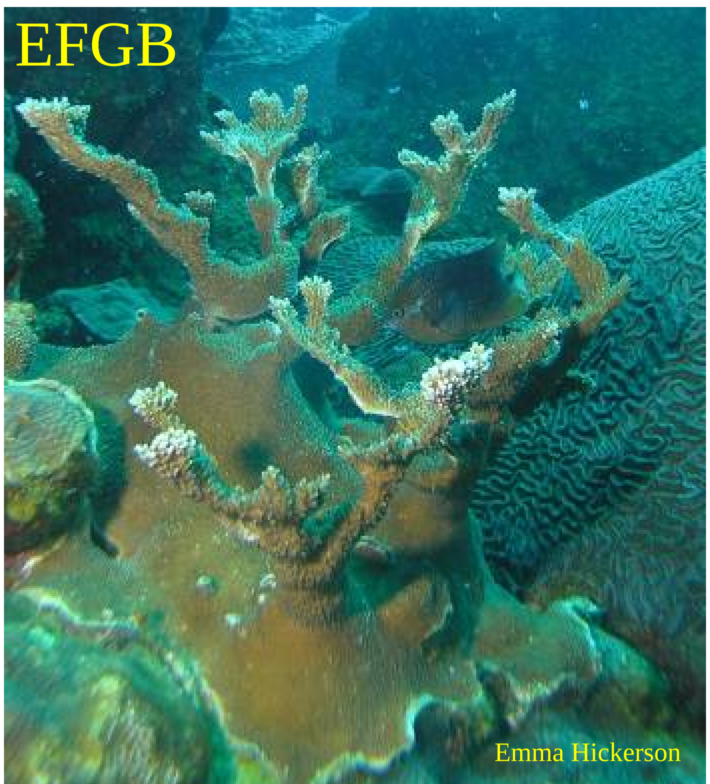
- These are the first known examples of poleward expansion of a Caribbean coral genus.

- These are most probably a response to recent patterns of climatic warming (see Levitus et al. 2000; 2001. *Science*)

New Species Appearing at FGB

- ***Tubastraea coccinea*** **(exotic, ahermatypic)**
- ***Acropora palmata*** **(elkhorn coral; Zimmer et al. 2005)**
- ***Dichocoenia stokesi*** **(East Bank, 2005–06; Emma Hickerson)**
- ***Epinephelus striatus*** **(Nassau grouper, 2006; Emma Hickerson)**





Discovery of *Acropora palmata* at the Flower Garden Banks National Marine Sanctuary, northwestern Gulf of Mexico

Received: 26 July 2005 / Accepted: 23 August 2005

Fig. 1 *Acropora palmata* colony, at 23.5 m depth, East Bank of the Flower Garden Banks National Marine Sanctuary (photo courtesy of G.P. Schmahl)

In the past few decades, corals of the genus *Acropora* have been decimated throughout their range in the Caribbean/Western Atlantic. The U.S. National Marine Fisheries Service has considered listing these corals as 'threatened' under the U.S. Endangered Species Act (Oliver 2005; Precht et al. 2005). Recently, *Acropora* has been observed for the first time in new locations (Precht and Aronson 2006), including northwards along the Atlantic coast of Florida and on the reefs of the Flower Garden Banks National Marine Sanctuary (FGBNMS), in the northwestern Gulf of Mexico (Precht and Aronson 2004).

In July 2003, a colony of *A. palmata* was identified in 21.6 m depth on the coral cap of the West Flower Garden Bank (27°52.4′N, 93°48.8′W). This colony, the first record from FGBNMS, has an encrusting basal plate and one small branch. In May 2005 it measured 0.6 m in width and 0.5 m in height, with a maximum branch length of 8.8 cm. In June 2005, a second colony was discovered at the East Flower Garden Bank (27°54.5′N, 93°36.0′W) at a depth of 23.5 m (Fig. 1). This second colony was 0.5 m in width and 1 m in height, with a maximum branch length of 30 cm. This is the deepest reported record of *A. palmata* from the Caribbean and western Atlantic region.

Acropora palmata has long been thought to be a shallow-water species, occurring primarily in depths <5 m (Lighty et al. 1982). These discoveries of *A. palmata* colonies at depths >20 m should lead to reconsideration of this commonly held view. It may be that these deep colonies represent a refuge for *A. palmata*. While it is presumed from earlier studies that the dispersal potential of *A. palmata* is only 5 days to 2 weeks (Baums et al. 2005), the remote location of the FGBNMS (640 km from the nearest Mexican reefs and 1,120 km from the Florida Keys) requires long-distance dispersal and migration of viable larvae. Future research will address the biogeographic origins of these newly discovered corals.

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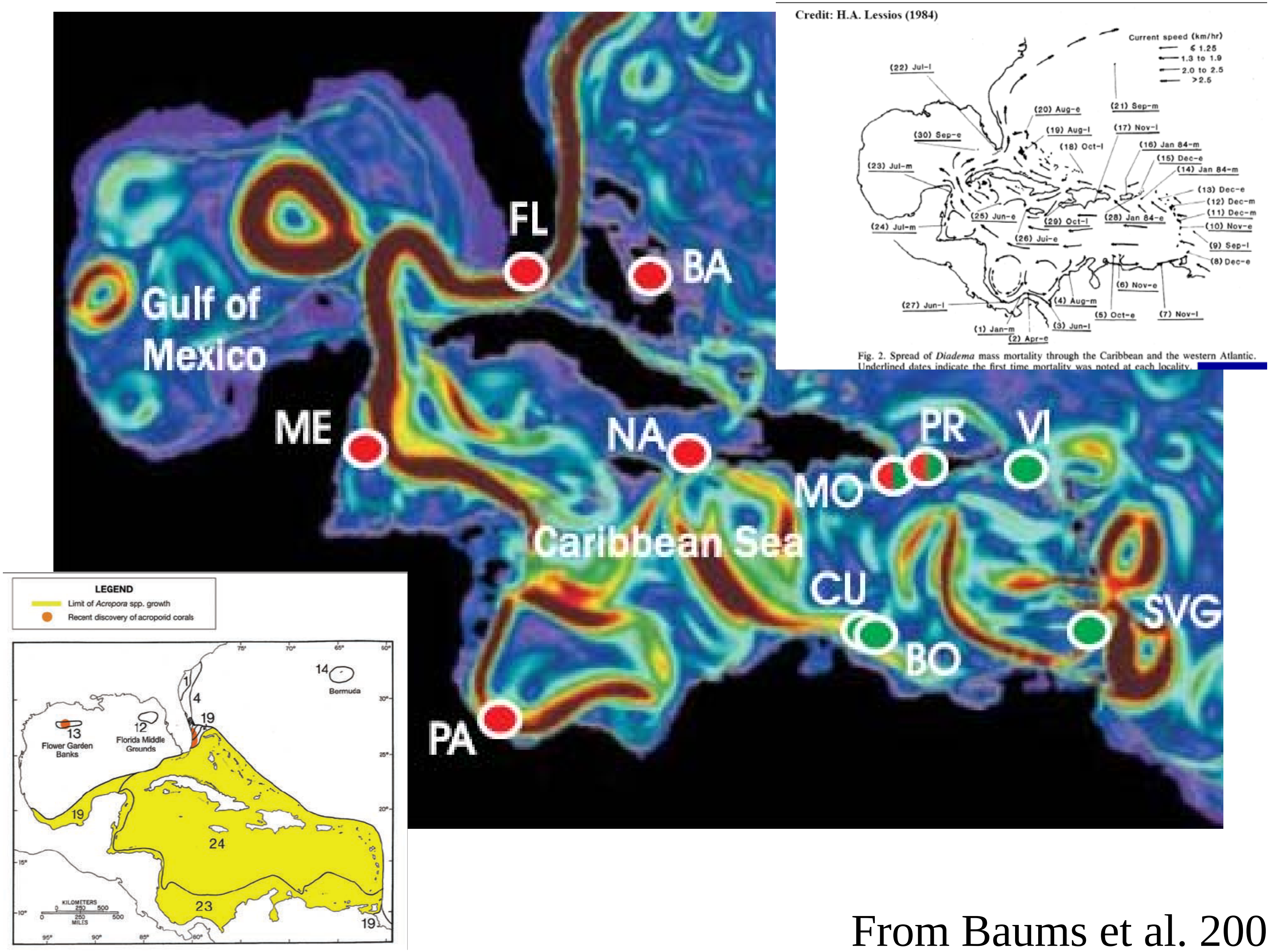
Reef sites

Coral Reefs (2006)
DOI 10.1007/s00338-005-0054-9



From Baums et al. 2005

A. palmata releases gametes into the water column once a year, generally after the August full moon, in a synchronized spawning effort.

Each colony simultaneously releases eggs and sperm in bundles that float to the surface where they break apart and mix with gametes from other colonies (*A. palmata* is a poor self-fertilizer).

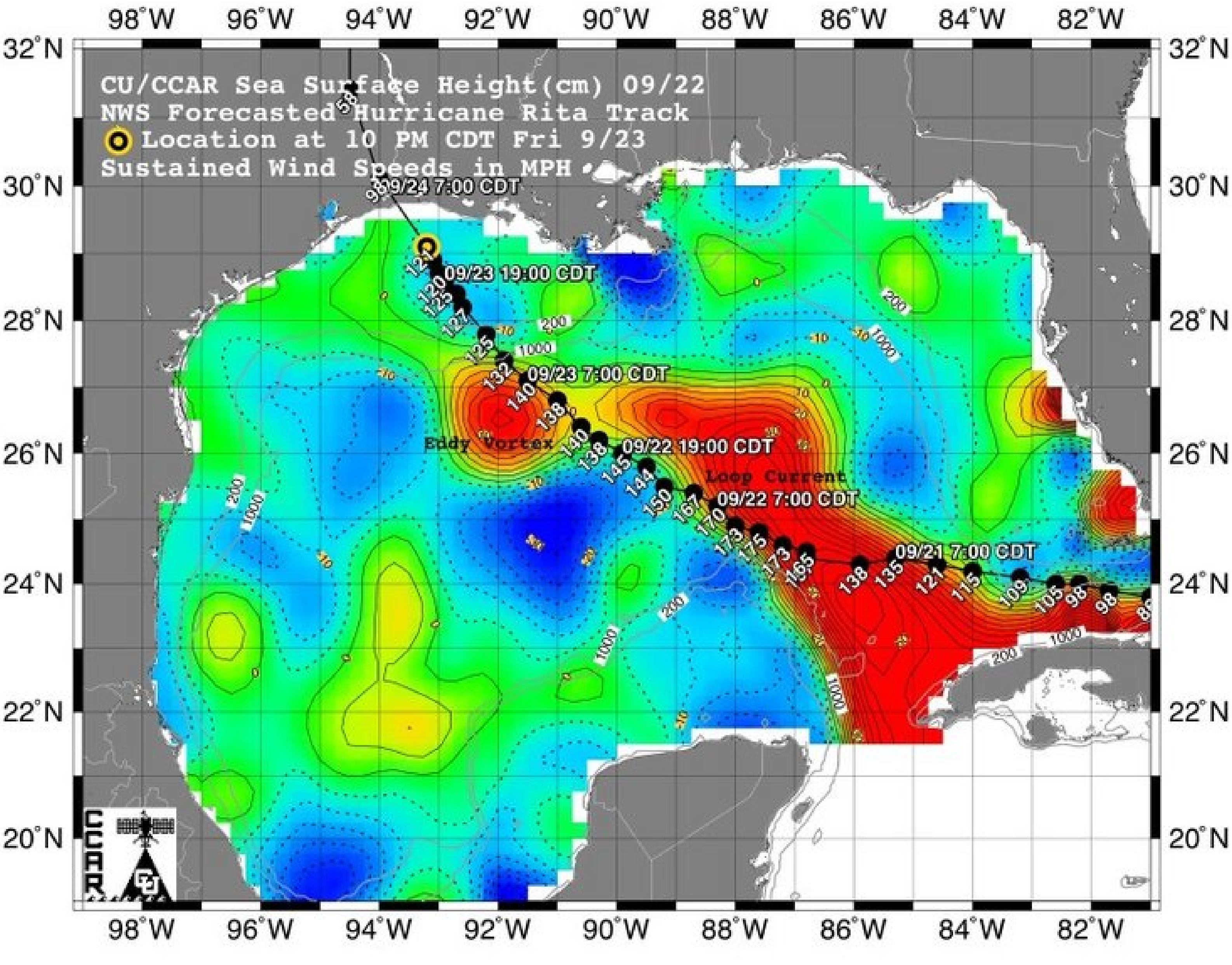
After fertilization, *A. palmata* larvae undergo a 78-h period of development before showing first signs of motility.

Pelagic larvae become competent to settle within 5 d, but can remain planktonic for up to 20 d.

From Baums et al. 2005

A. palmata larvae is pelagic for ~ 20 days (Baums et al., 2005) and it takes 55-135 days to get to the FGB. The 135-day trip along route 1 implies a very low probability of recruitment since coral larvae are viable for only 120 days. If it is assumed that the release of larvae occurs in August, then the 135-day estimated travel time falls in winter when temperature stress and the high wave and strong currents could combine to exert large stresses on the larvae, making recruitment and dispersal arduous.

Lugo-Fernandez 2006

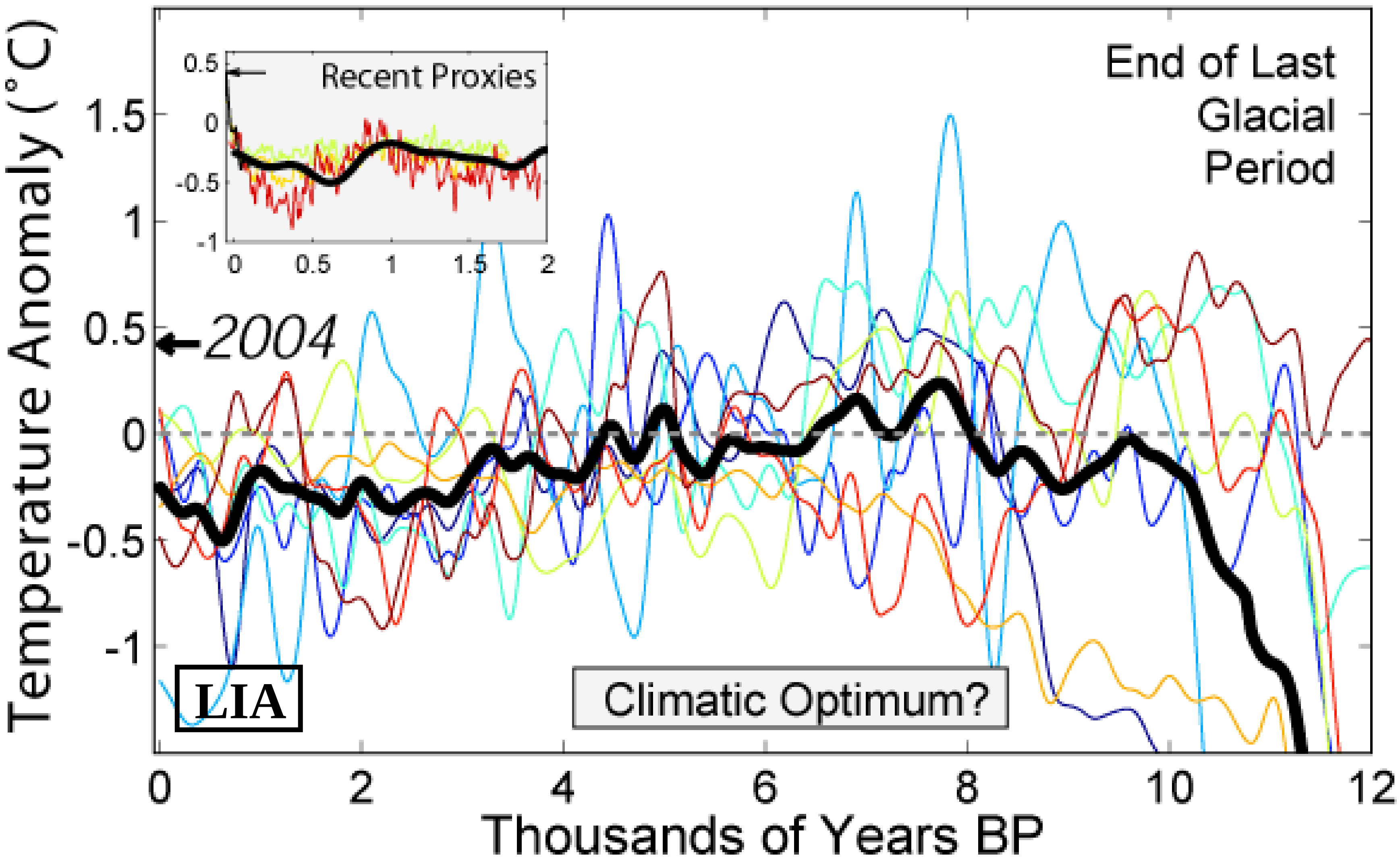


CU/CCAR Sea Surface Height(cm) 09/22
NWS Forecasted Hurricane Rita Track
Location at 10 PM CDT Fri 9/23
Sustained Wind Speeds in MPH
09/24 7:00 CDT
09/23 19:00 CDT
09/23 7:00 CDT
09/22 19:00 CDT
09/22 7:00 CDT
09/21 7:00 CDT
Eddy Vortex
Loop Current
98°W
96°W
94°W
92°W
90°W
88°W
86°W
84°W
82°W
32°N
30°N
28°N
26°N
24°N
22°N
20°N
CCAR

The Holocene Thermal Optimum

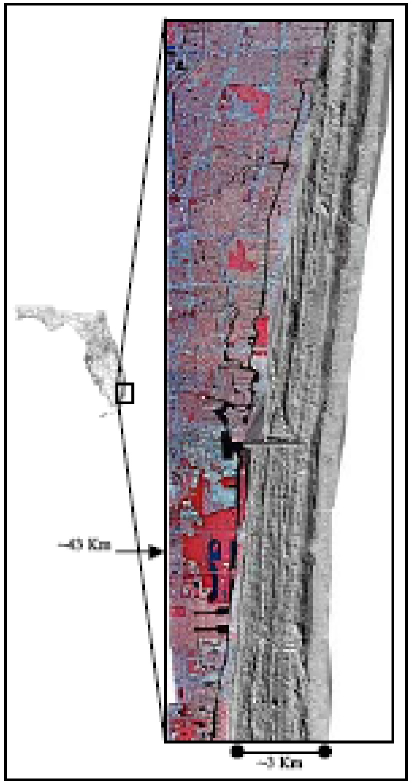
Evidence from both terrestrial and coastal environments shows that the millennial-scale, high-amplitude climate flicker during the early to mid-Holocene caused many organisms to increase their ranges northward.

Holocene Temperature Variations

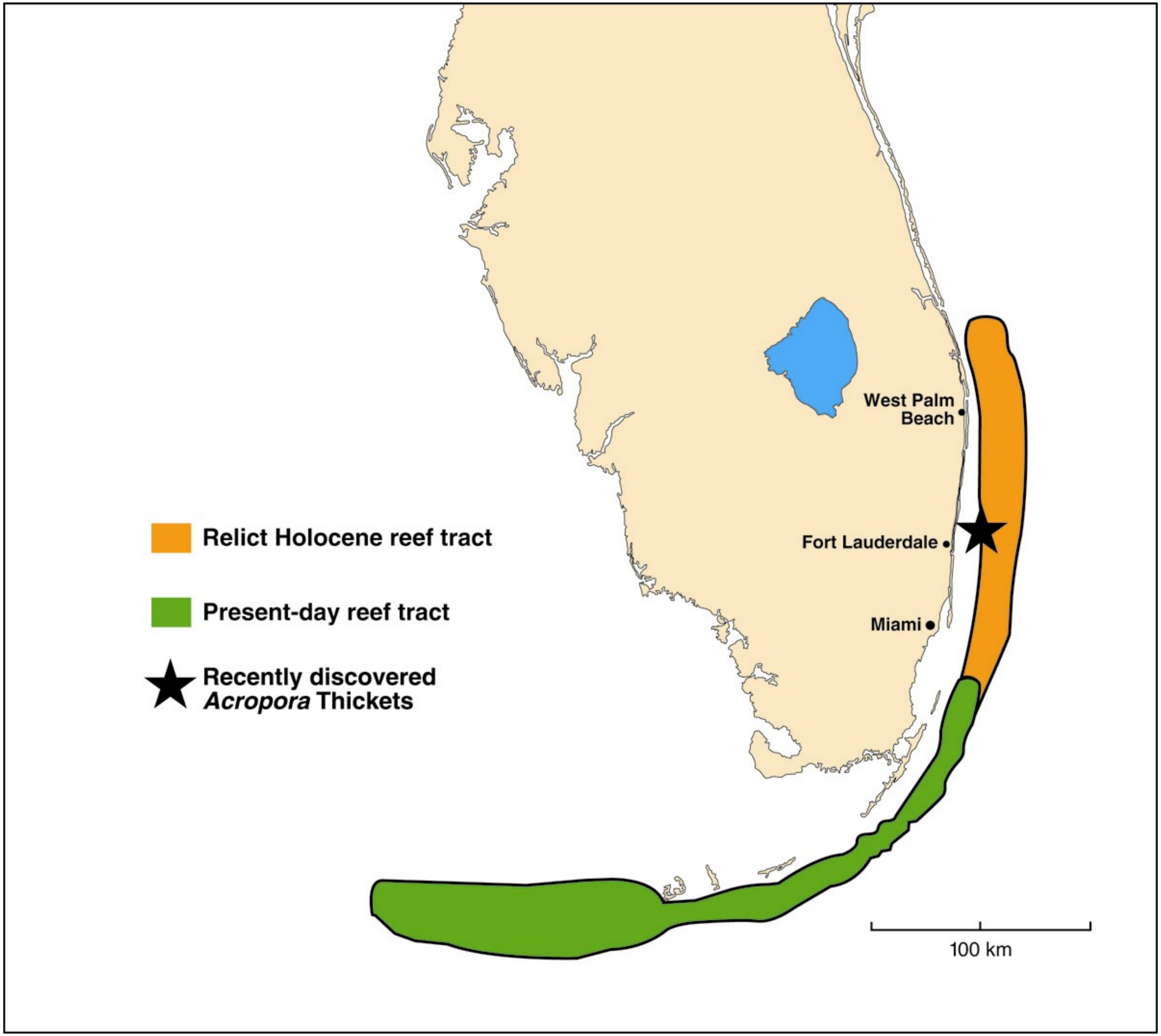


IPCC

- During the early to middle Holocene (10,000 to 6,000 years before present), oceanic conditions favored the growth and accumulation of *A. cervicornis* and its congener, the elkhorn coral *A. palmata*, along the shelf margin of the Florida reef tract some 150 km north of its known historical range.



Acropora spp. Distribution in Florida



- The accumulation of thick deposits dominated by *Acropora* as far as 150 km north of their present limit implies that *Acropora* spp. are capable of responding rapidly to climate change through range expansions.

- As temperatures cooled after the mid-Holocene, the northern limit of acroporid reef growth in the Atlantic regressed south to the northern Florida Keys (Fowey Rocks).

- The mid-Holocene climate flicker resulted in poleward range shifts of numerous marine and coastal species including :
  - Boreal molluscs in Greenland
  - Warm water oysters and scallops off Sable Island

(Funder and Weidick 1991; Clarke et al. 1967)

- The mid-Holocene climate flicker also correlates with the northernmost expansion of coral reefs in the Pacific.

(Taira 1979; Veron 1992)

- Using the known latitudinal expansion of fossil acroporid reefs in the early-middle Holocene with the extent and thickness of the late Pleistocene-to-recent reef sediments capping the structures of the FGB and the post-glacial record of bank flooding and submergence, we speculated that an *Acropora*-dominated reef could underlie and form the foundation of the living reef community at the FGB.

GOM Sea Level Curve

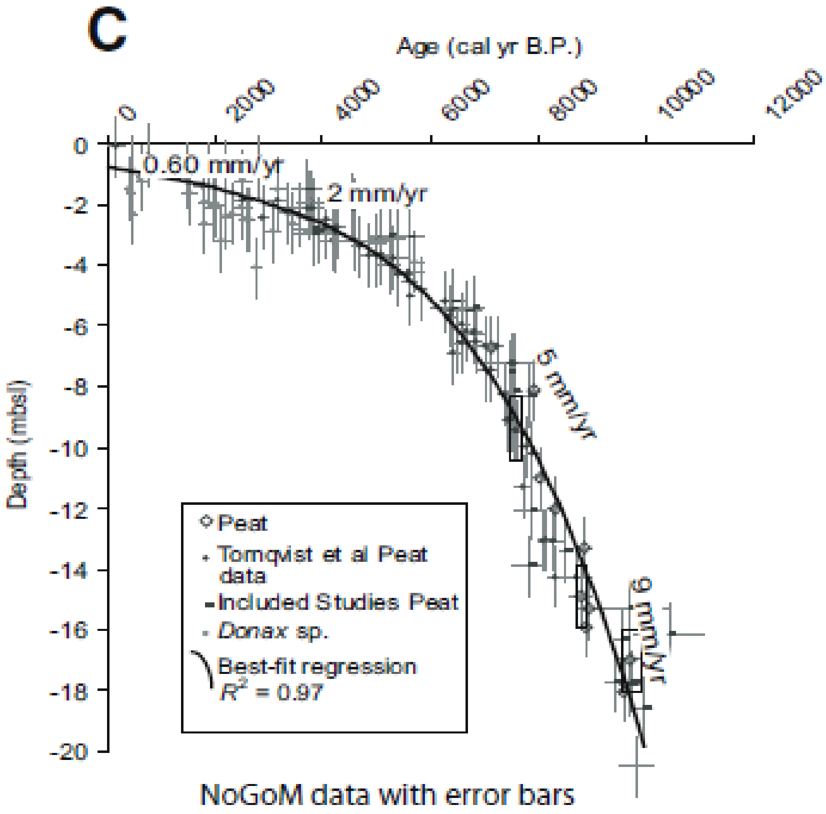
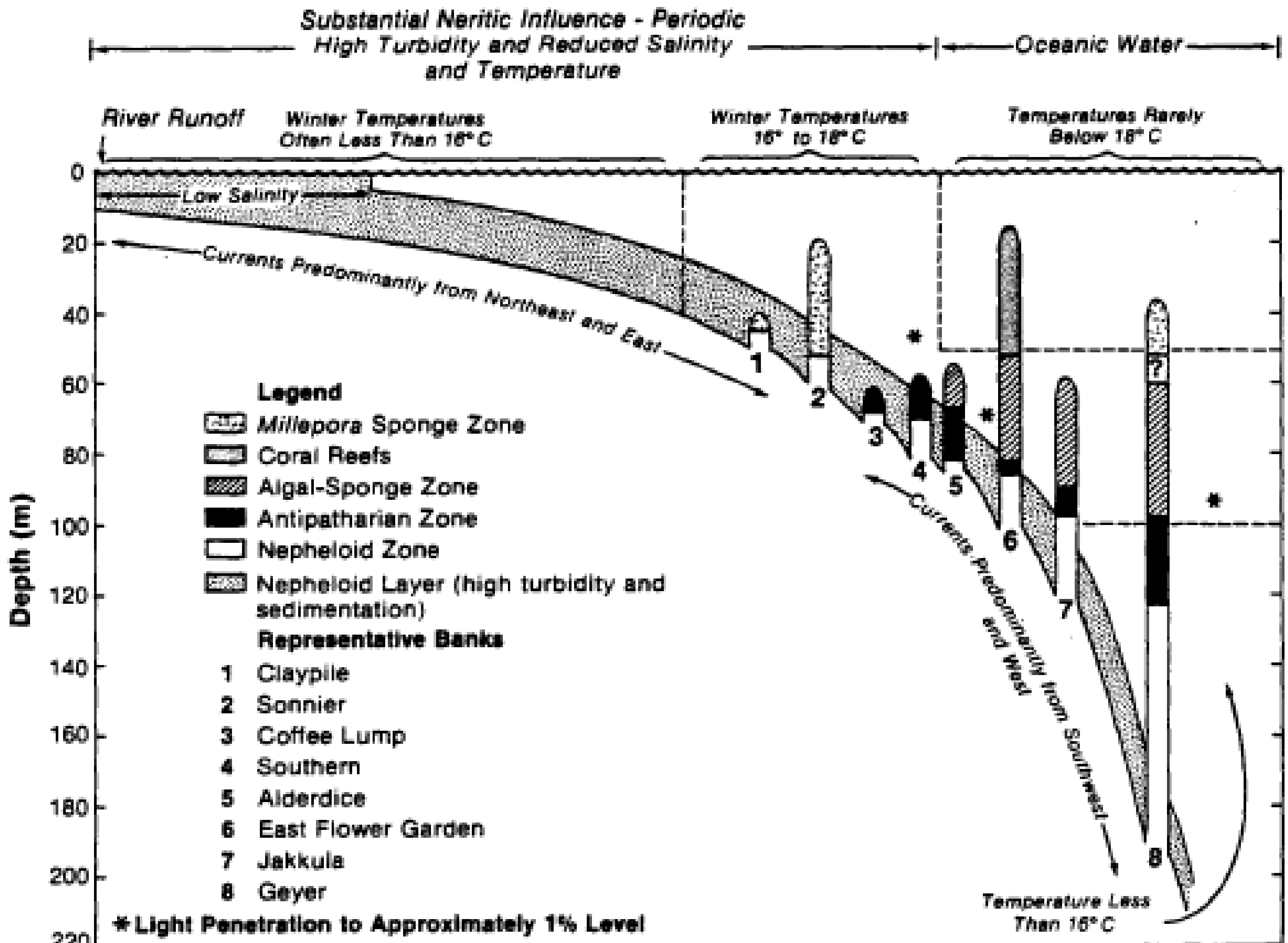


Figure 3. (A) Age-depth relationships of estuary, marsh, and swash-zone depositional environments for the northern Gulf of Mexico (mbsl—meters below sea level), illustrating that peat and swash-zone depositional environments are more useful as sea-level datums than bay samples. (B) Age-depth relationship of northern Gulf of Mexico sea-level indicators (peat and *Donax* sp.), along with sea-level curves from the peripheral Gulf of Mexico, Barbados, Tahiti, and the Sunda Shelf. Comparison of the northern Gulf of Mexico with other sea-level curves shows the similarity of the data from 8000 yr B.P. to present. (C) Age-depth relationship of peat and swash-zone samples and associated horizontal and vertical errors. The best-fit nonlinear regression is drawn (Törnqvist et al., 2004, 2005, 2006). NoGoM—northern Gulf of Mexico.

Milliken et al. 2008



From Rezak, Bright and McGrail (1985)

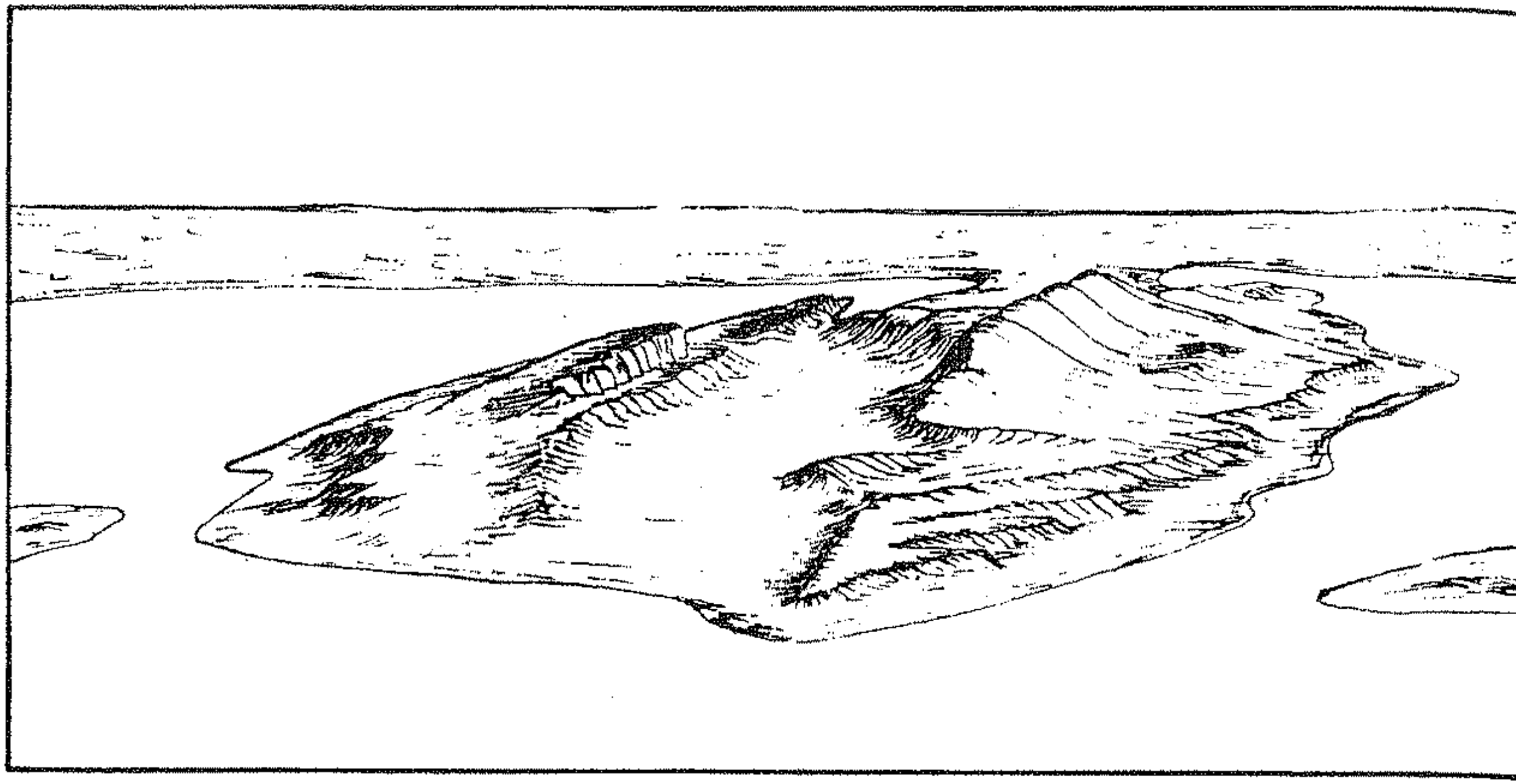
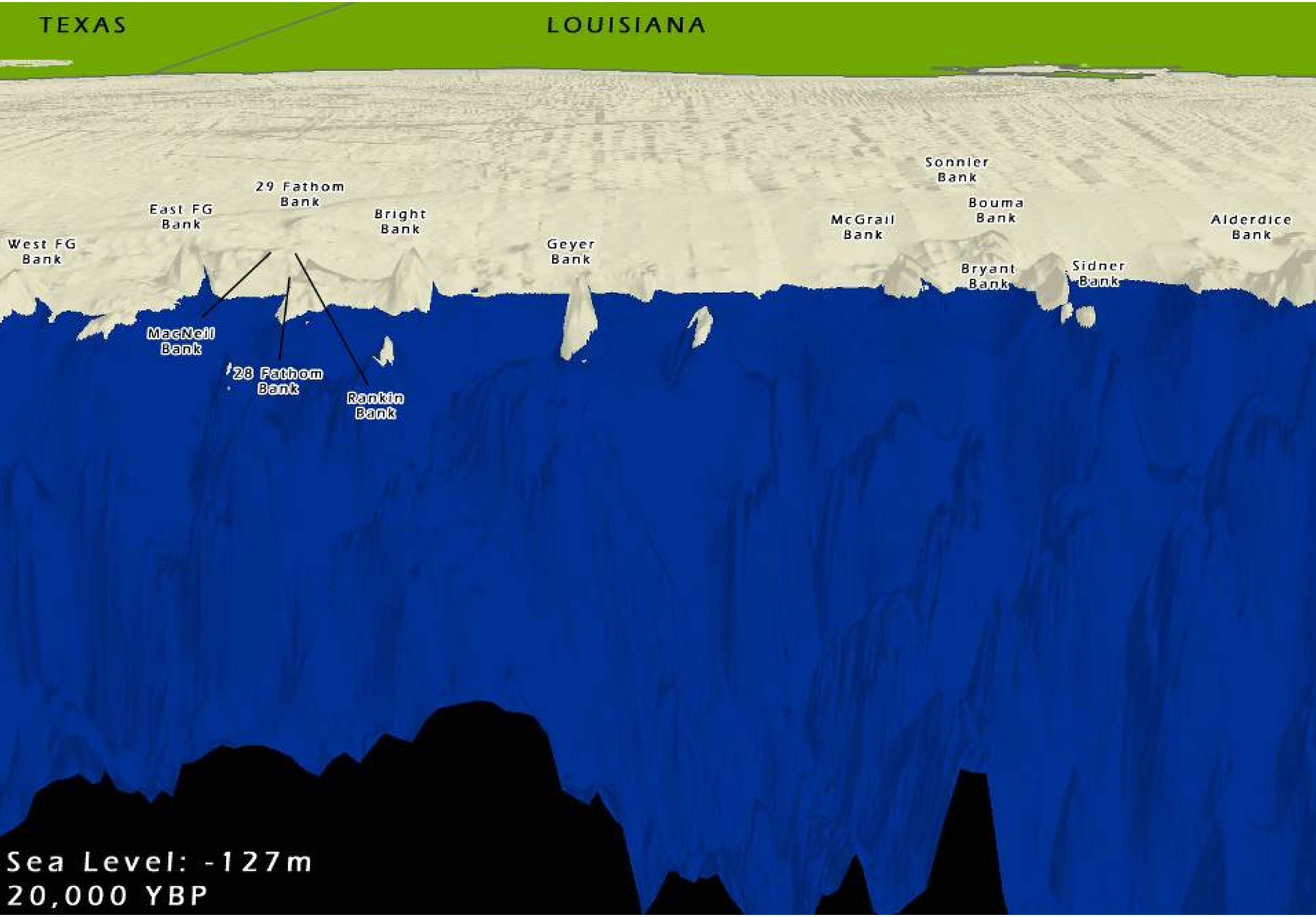
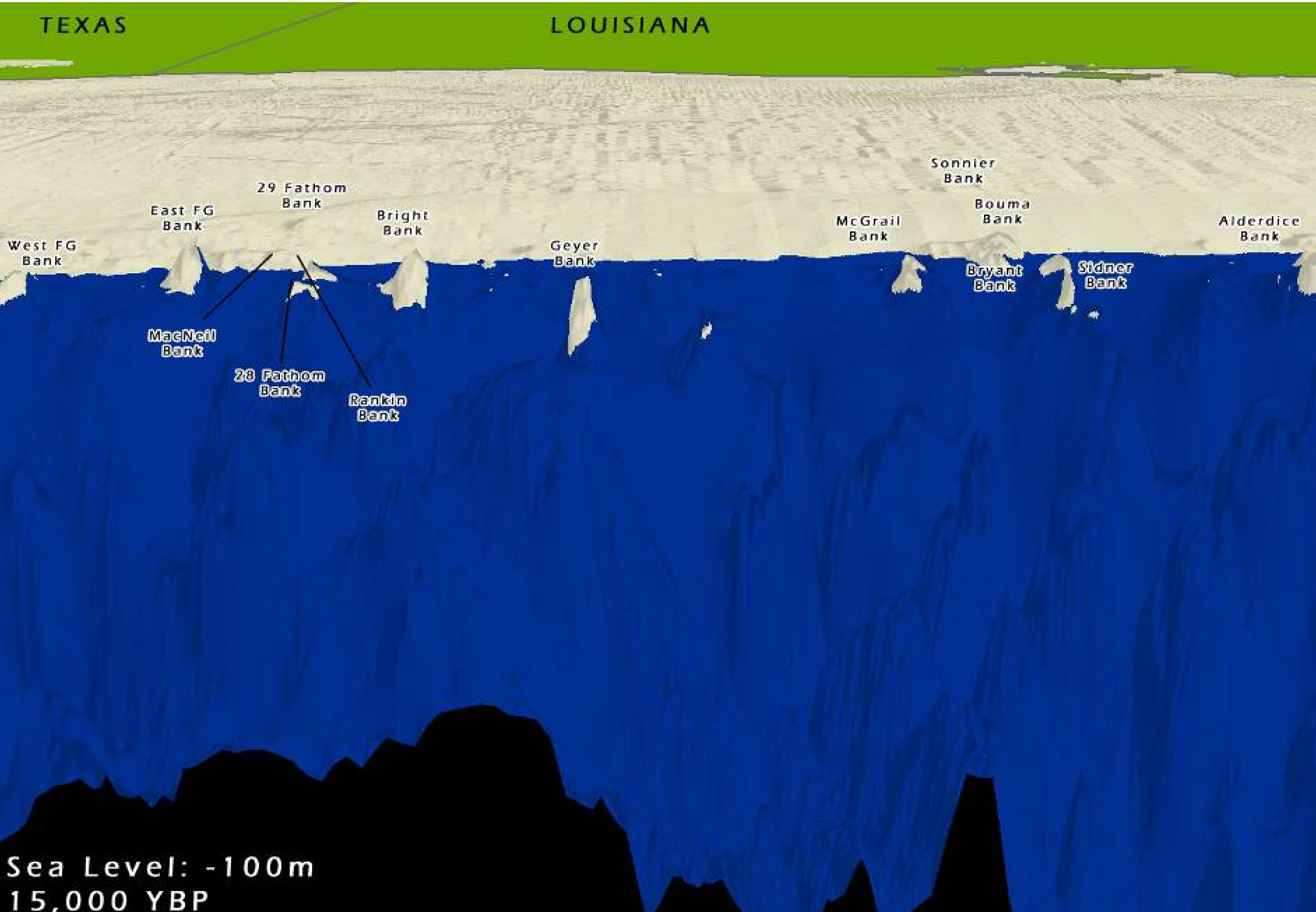
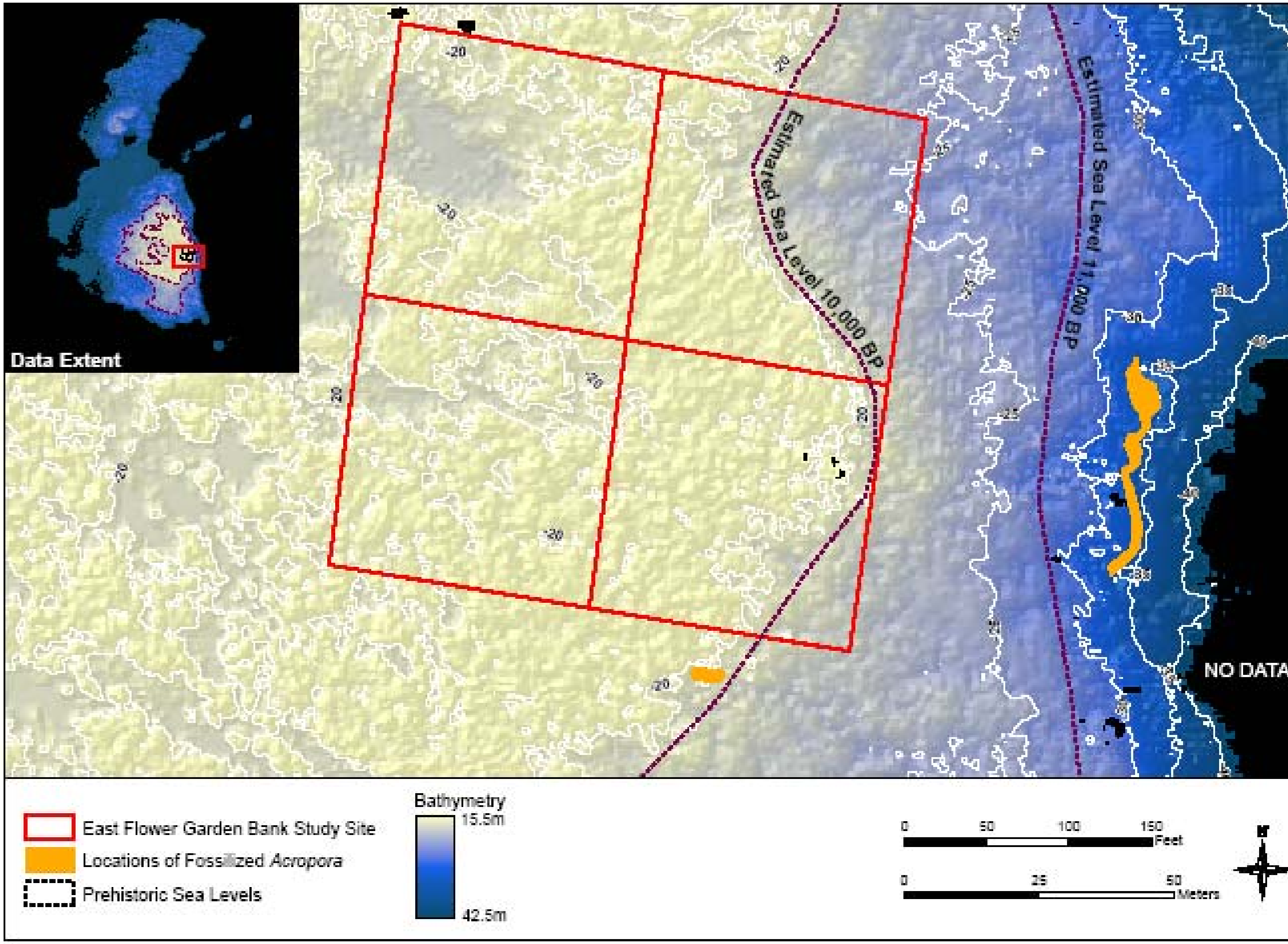


Figure 4.20. Sketch of the West Flower Garden Bank as it may have looked during the 121-to-134-m stillstand of the Gulf of Mexico (Edwards 1971).

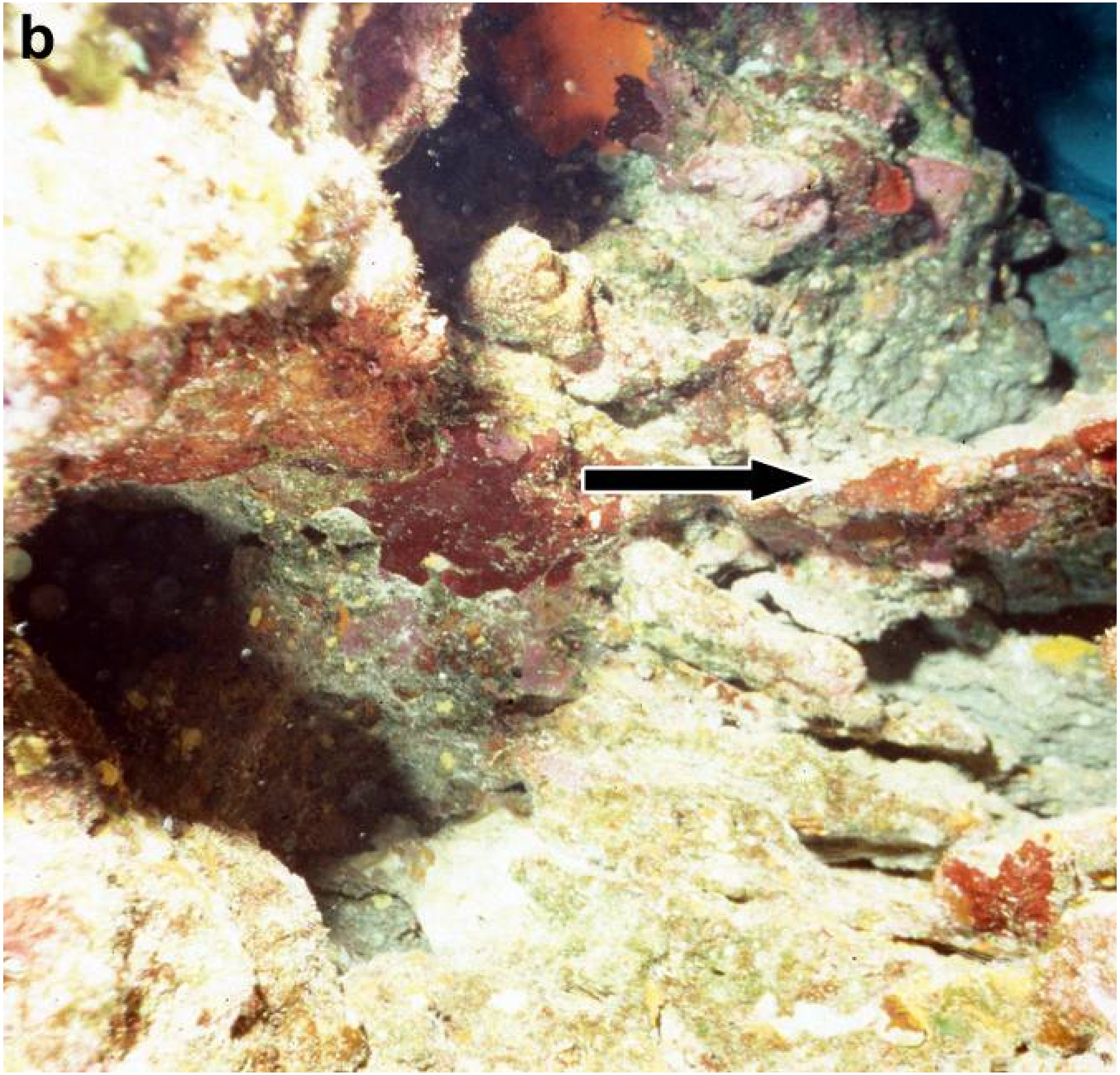
From Rezak, Bright and McGrail (1985)


TEXAS
LOUISIANA
29 Fathom Bank
Sonnier Bank
East FG Bank
Bright Bank
McGrail Bank
Bouma Bank
Alderdice Bank
West FG Bank
Geyer Bank
Bryant Bank
Sidner Bank
MacNeil Bank
28 Fathom Bank
Rankin Bank
Sea Level: -127m
20,000 YBP


TEXAS
LOUISIANA
Sonnier Bank
29 Fathom Bank
East FG Bank
Bright Bank
Bouma Bank
McGrail Bank
Alderdice Bank
West FG Bank
Geyer Bank
Bryant Bank
Sidner Bank
MacNeil Bank
28 Fathom Bank
Rankin Bank
Sea Level: -100m
15,000 YBP



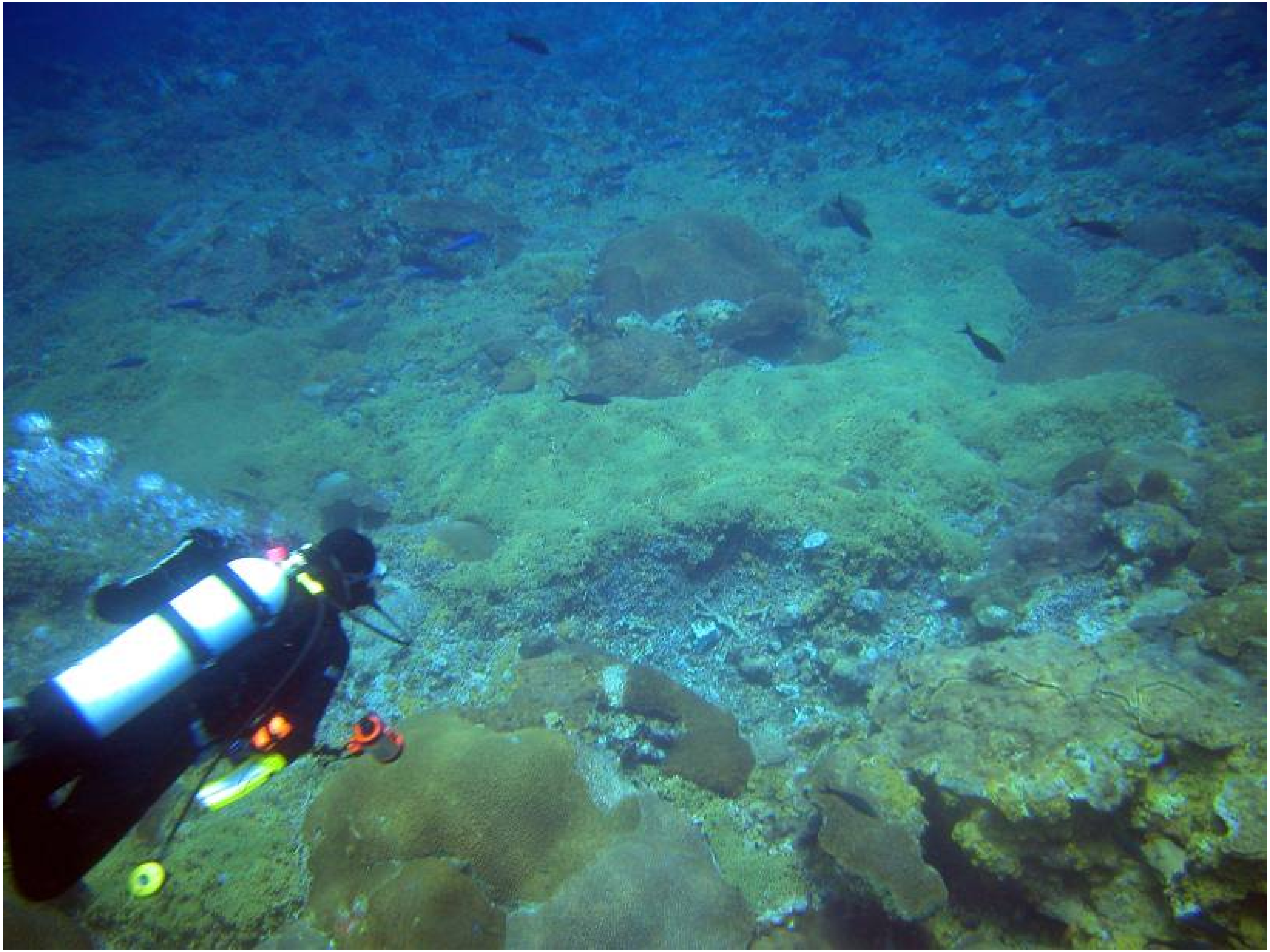
Data Extent
Estimated Sea Level 10,000 BP
Estimated Sea Level 11,000 BP
NO DATA
East Flower Garden Bank Study Site
Locations of Fossilized *Acropora*
Prehistoric Sea Levels
Bathymetry
15.5m
42.5m
0 50 100 150 Feet
0 25 50 Meters
N


b

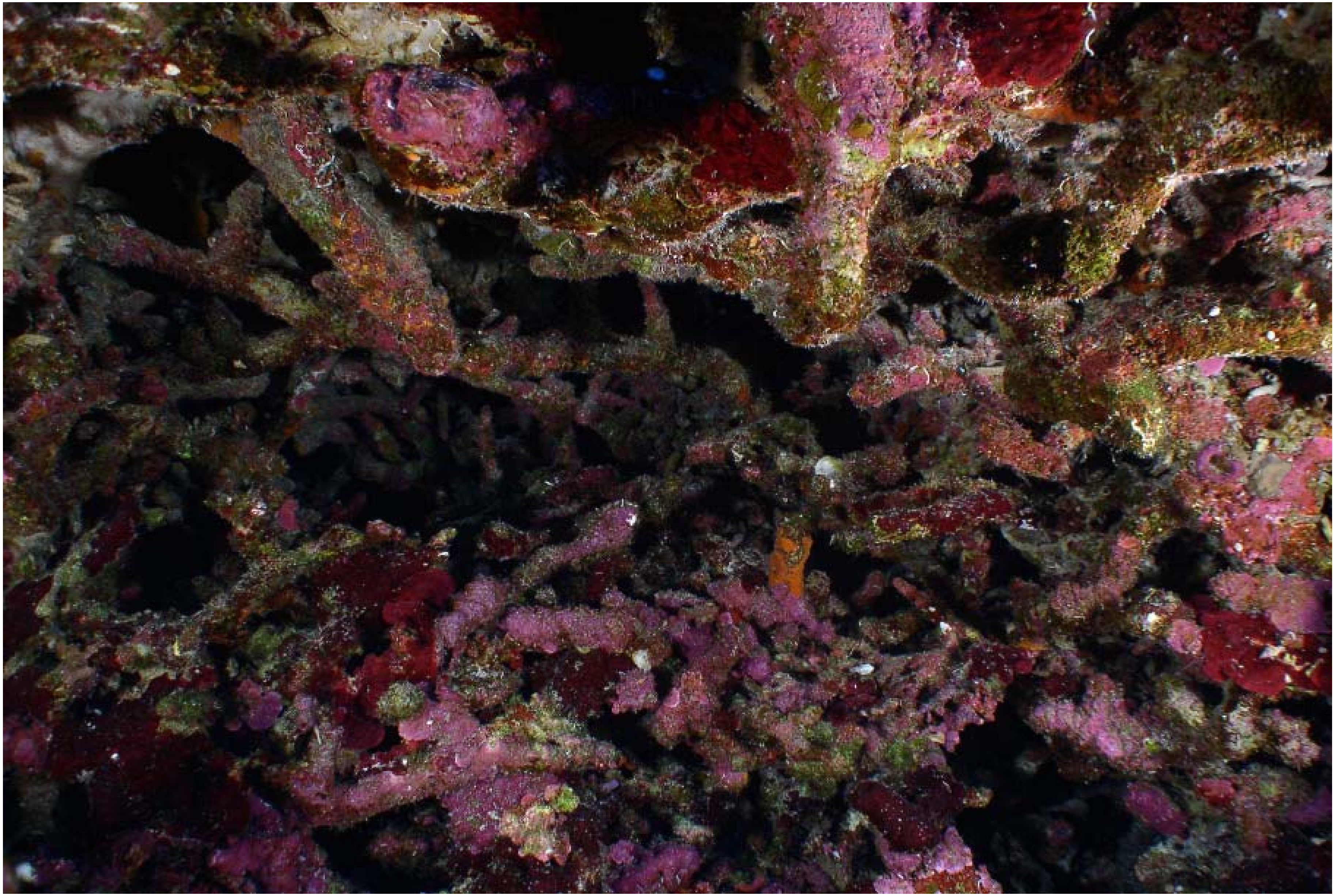
- Radiocarbon dating of the *Ap* branches revealed calibrated corrected ages between 10,230 to 6,650 BP. This age is within the window of dates recovered from the northernmost fossil *Acropora*-reefs in Florida and also corresponds with the Holocene Thermal Optimum.

The banks supported a shallow, warm-water, reef-coral assemblage up until ~6000 years ago. This community lagged behind rapidly rising sea level in the middle Holocene. As sea temperatures cooled in the late Holocene the reef was capped by a eurythermal deeper-water assemblage dominated by massive corals, which persists to this day.

Hey Ken, do you see what I see?



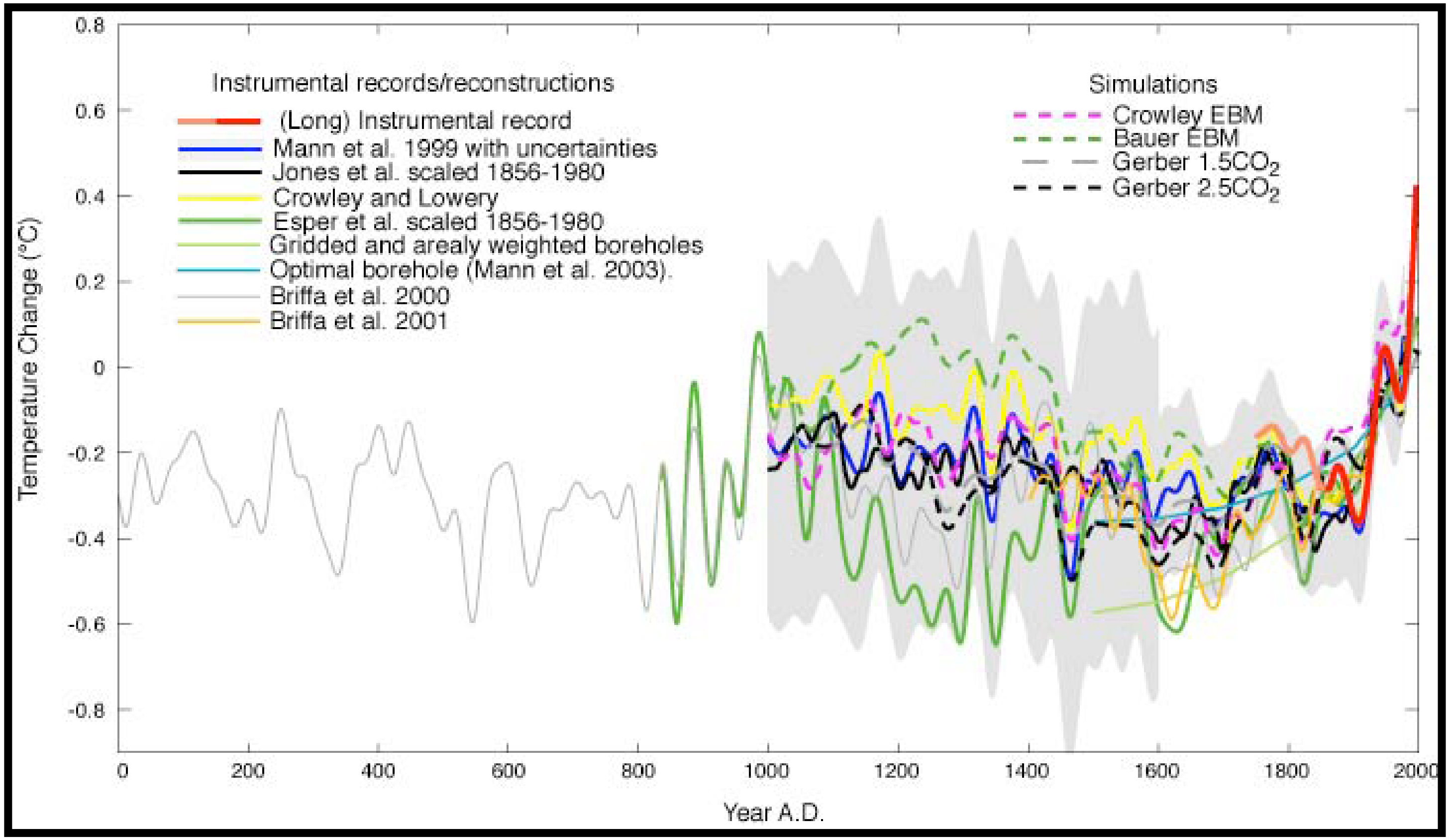
Ac – EFGB 88 ft



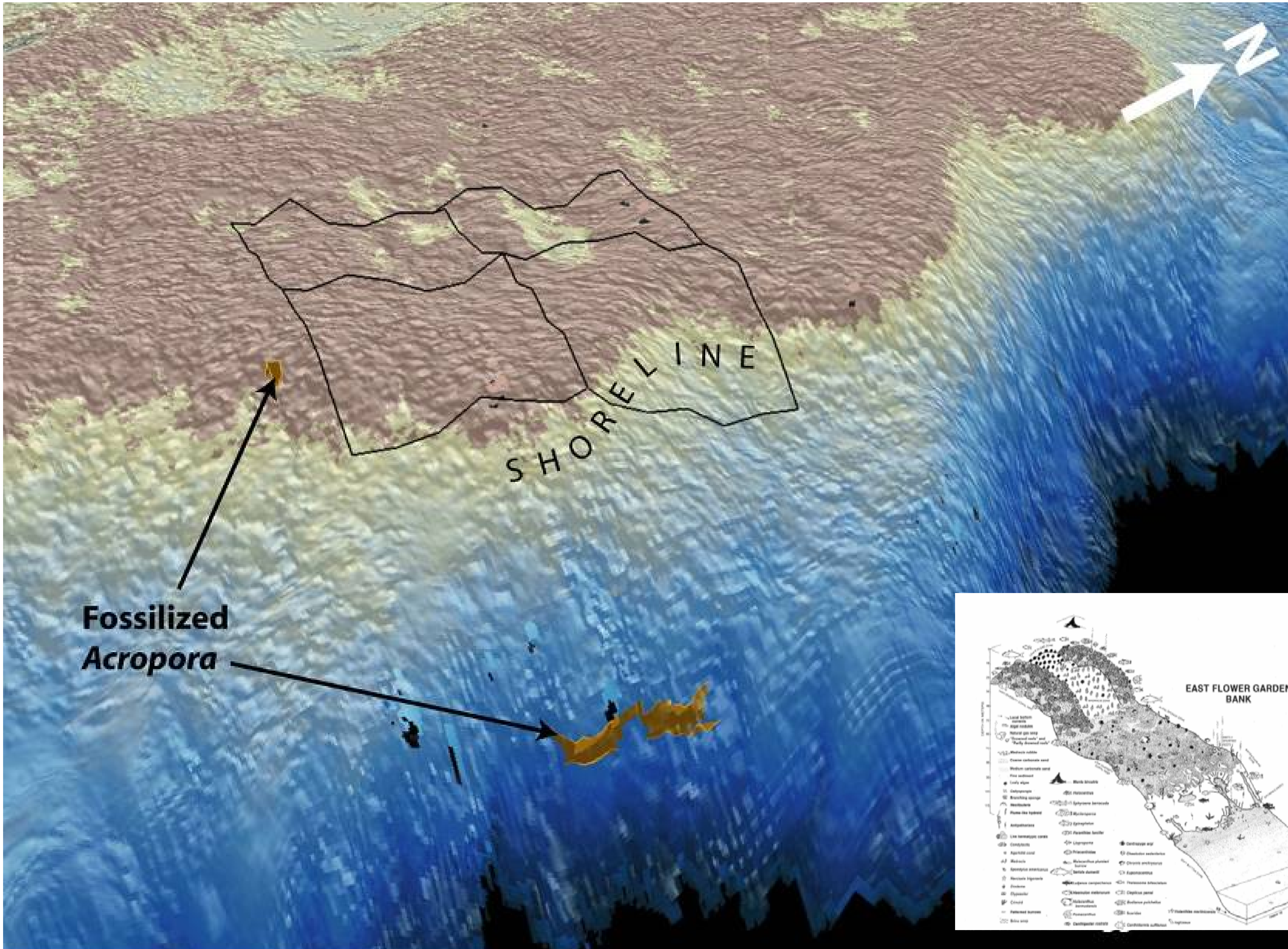
Radiocarbon dating of the *Ac* branches revealed calibrated corrected ages between 1,250 to 425 BP. The termination of *Ac* at the East Bank appears to coincide with cooling associated with the Little Ice Age.

Latest view of last 2000 years of Northern Hemisphere Temperature Change

(Mann et al. 2003)



Little Ice Age



East Flower Garden Bank 3D Scene - 10,000 Years BP

Conclusions

- The discovery of fossil *Acropora* has profound implications for understanding the history of reef development at the FGB and puts the discovery of extant colonies on the Banks in context.

Conclusions (continued)

- Reconstructing the development of the FGB reefs in light of this new information shows there is a deepening-upwards succession from a shallow reef community that evidentially lagged behind the rapidly rising sea level of the early-middle Holocene and was eventually drowned and subsequently capped by the present reef community.

Conclusions (continued)

- While this discovery raises more questions than it answers, especially with regard to the local turn-on and turn-off mechanisms of the *Acropora* reef facies, it shows that *Acropora* species have a history of responding to local changes in environmental conditions, especially temperature, throughout the Holocene.

What Next?

Core, core, core!!!!

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