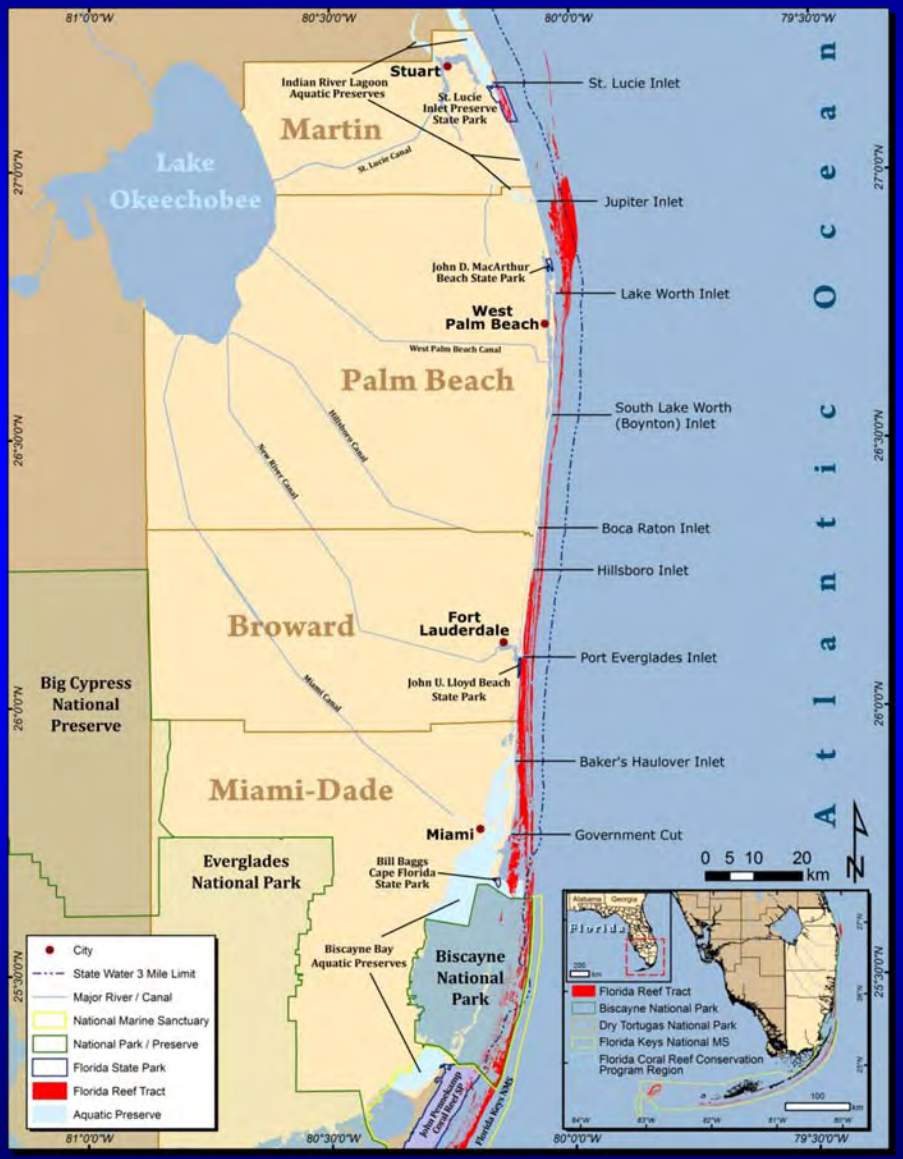
Spatial Analyses of Benthic Habitats to Define Coral Reef Ecosystem Regions and Potential Biogeographic Boundaries along a Latitudinal Gradient.

Brian K. Walker
walkerb@nova.edu

Accepted to PLoS One

Present Regional Descriptors



County Boundaries

- Most widely used.
- Not intended for habitat delineation.
- Boundaries are political.
- No ecological basis.
- Habitats are not homogenous throughout counties.

Biogeography

Basic Definition:

The study of the distribution of species, genera, and ecosystems in space and through geological or evolutionary time.

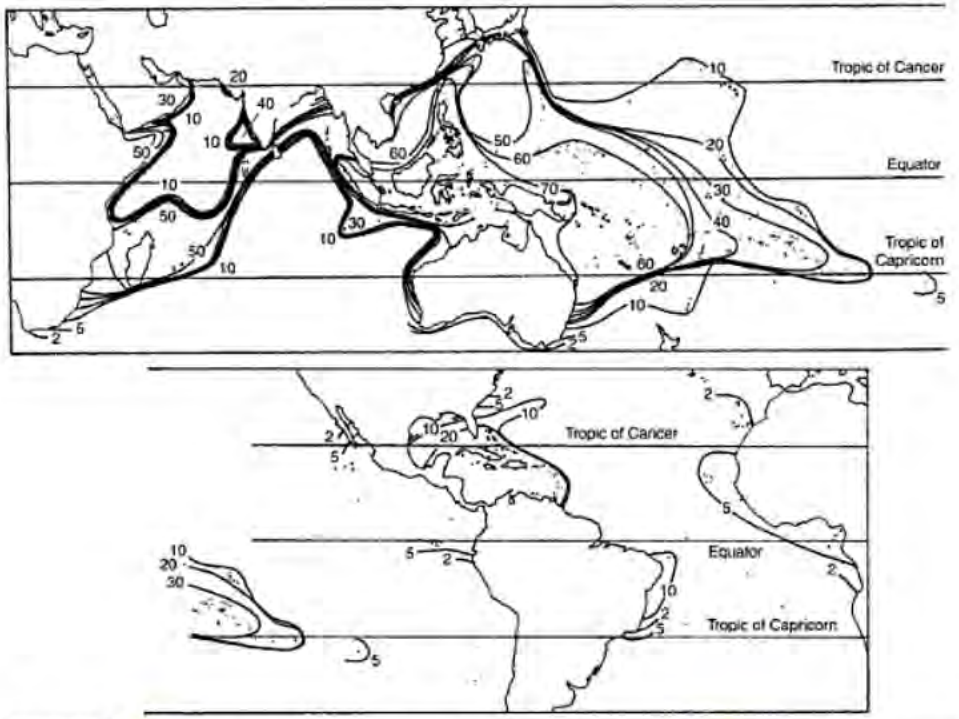
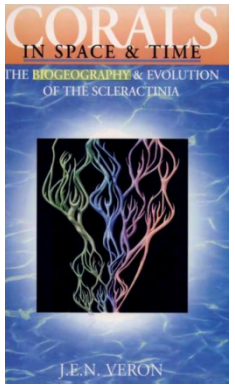
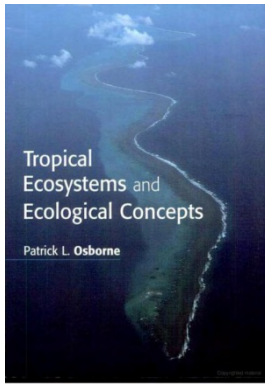
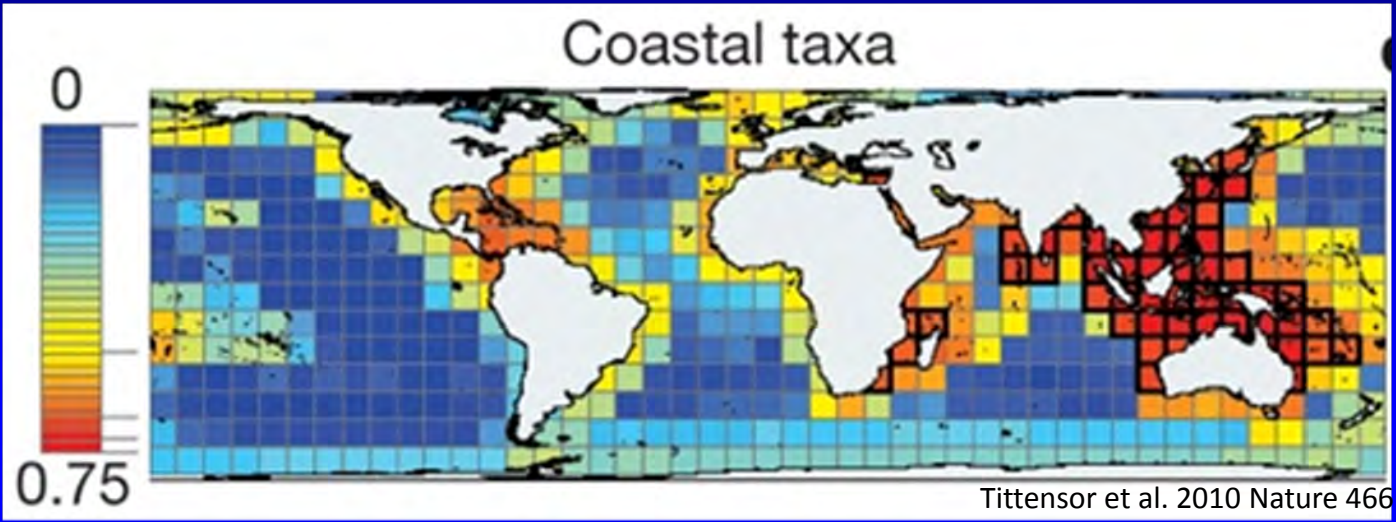


Figure 11.9 Coral generic richness, represented by contour lines. Contours enclose areas with the same approximate number of genera (after Veron 1995 © J.E.N. Veron and the Australian Institute of Marine Science, with kind permission of Cornell University Press and University of New South Wales Press).





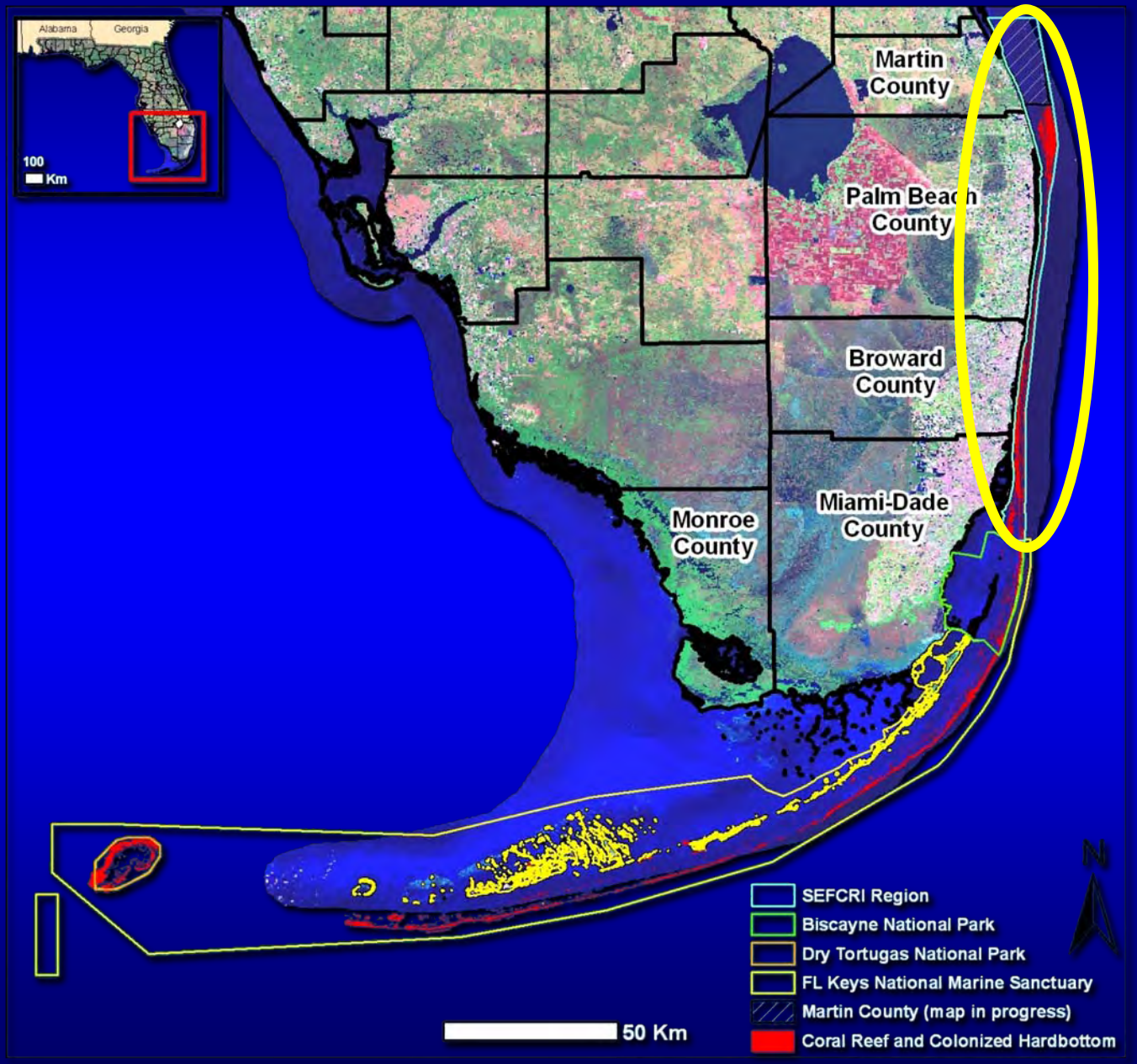
Latitudinal Gradients



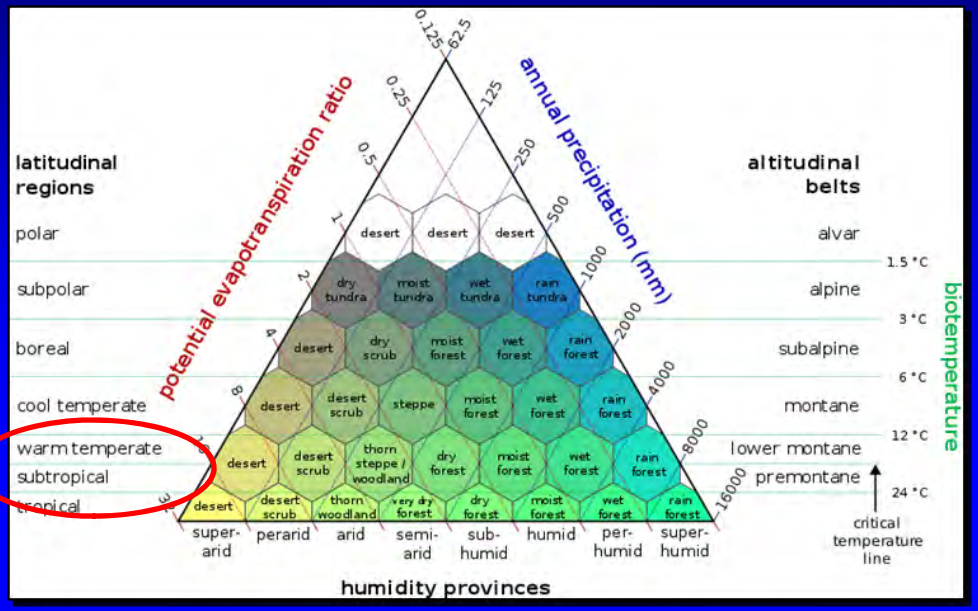
Tittensor et al. 2010 Nature 466

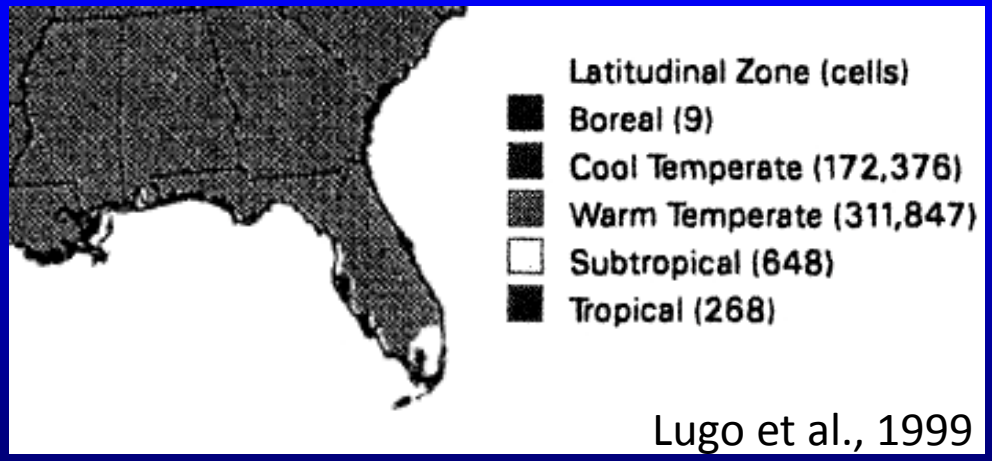
Latitudinal gradients are an indicator for the distribution and diversity of marine organisms where the number of families, genera, and/or species specific to a tropical biogeographic zone generally decreases along a latitudinal gradient as it transitions into colder climates.

Southeast Florida Reef Tract



SE FL Holdridge Life Zones





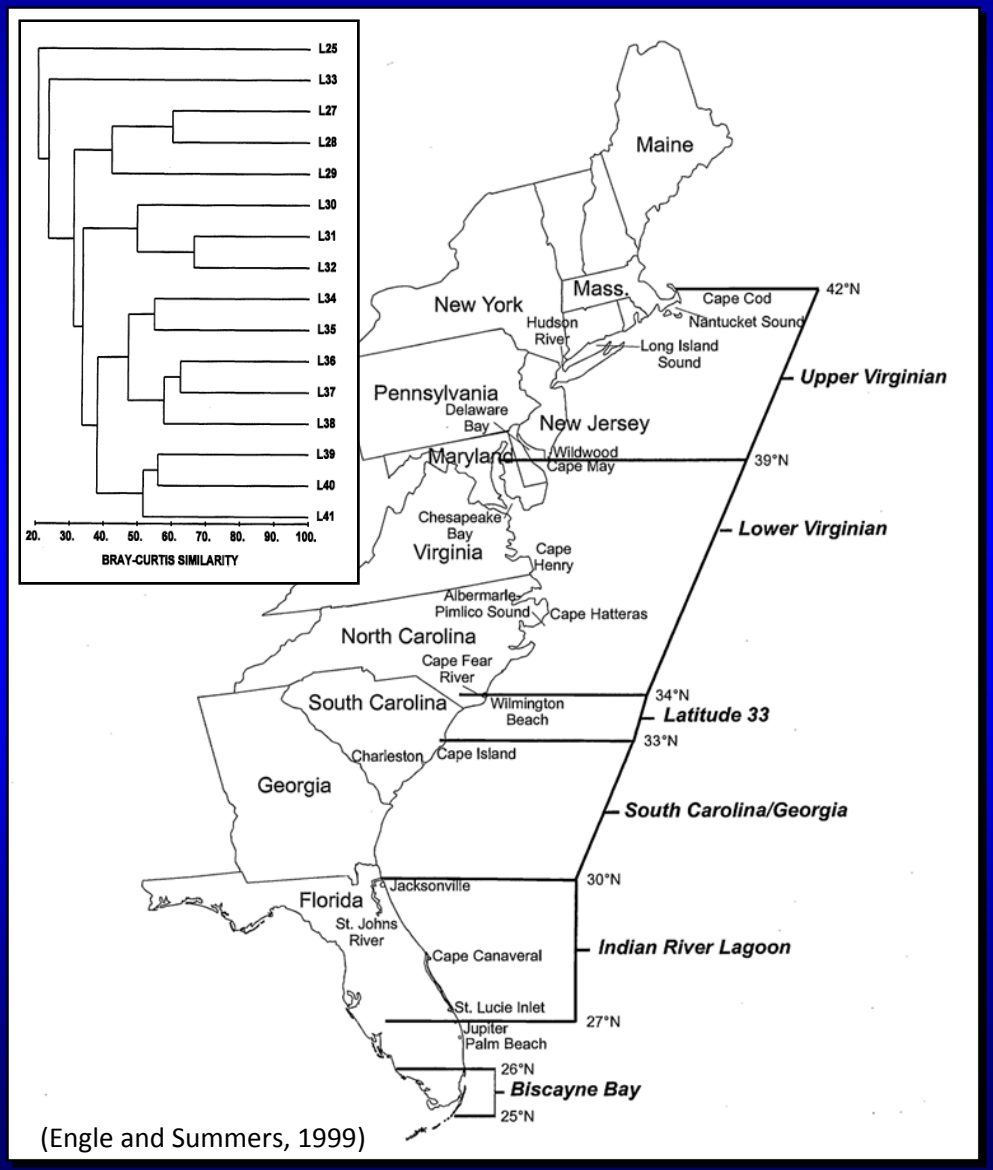
Lugo et al., 1999

Holdridge Life Zone is a global bioclimatic scheme for the classification of land areas based on few empirical data, giving objective mapping criteria. (Holdridge 1967)

SE FL has a recognized terrestrial biogeographic latitudinal gradient.

Transitions from a Subtropical to Warm Temperate Holdridge Life Zone in Palm Beach County.

Estuarine Biogeography



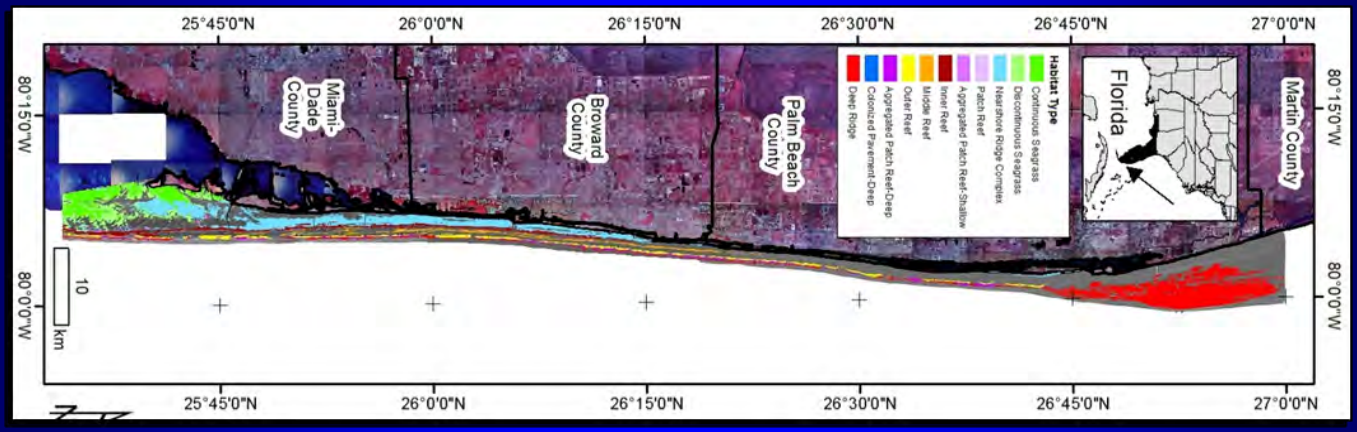
(Engle and Summers, 1999)

Two statistically-derived estuarine biogeographic zones have been identified in Florida (Engle and Summers 1999).

The Indian River Lagoon group spanned from Southern Martin County to Jacksonville.

A data gap between 27° and 26° inhibited characterization.

Biscayne Bay group spanned from South Broward to Key Largo.



Reduced community diversity (Moyer et al., 2003)

Reduced scleractinian diversity (Gilliam, 2007; Karlson, 2002)

Reduced scleractinian growth rates (Dodge, 1987)

Increased macroalgae biomass (CSA International Inc., 2009)

Reduced icthyofauna diversity (Banks et al., 2008; CSA Int. Inc., 2009)

SE FL Reef Biogeography

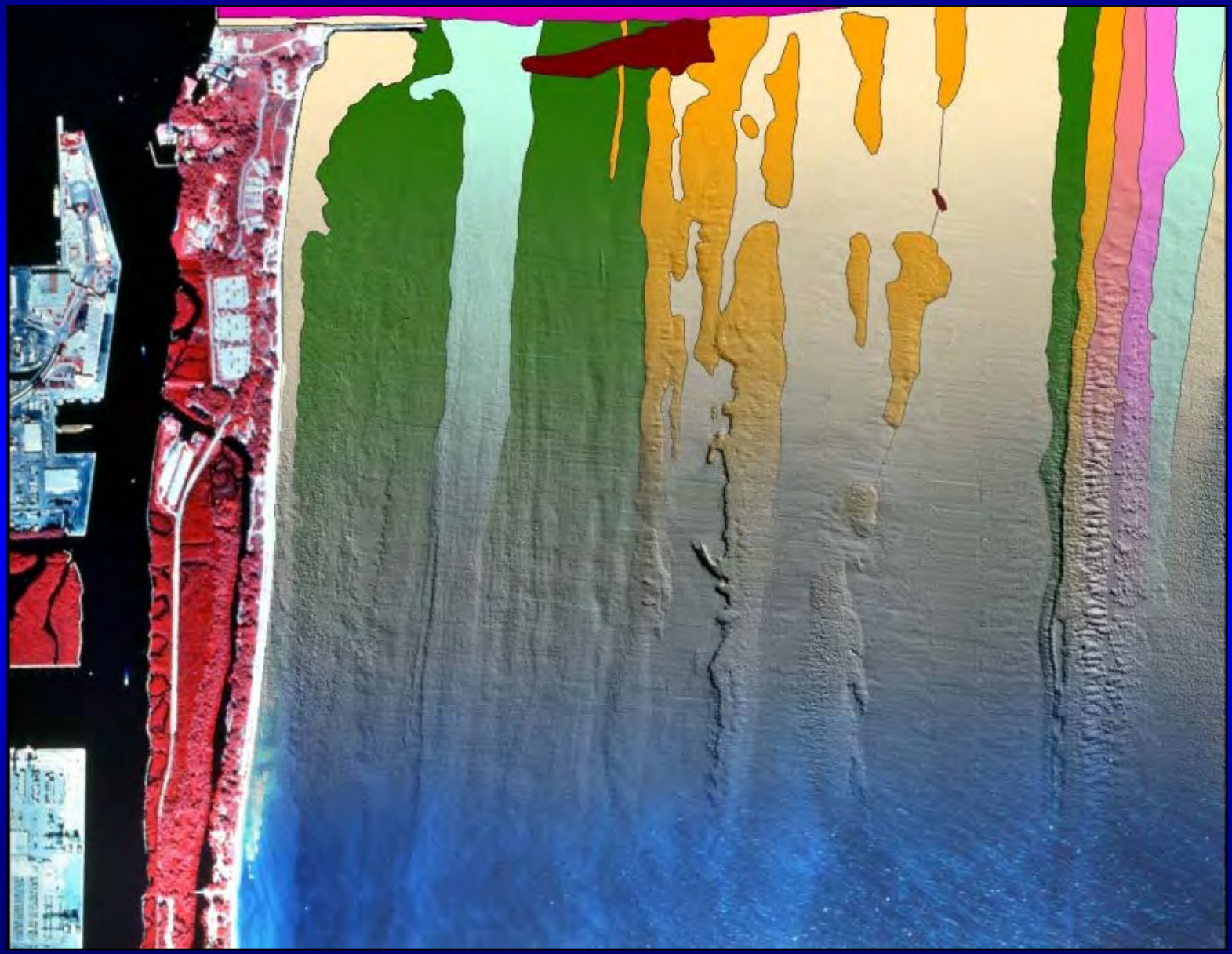
Species Habitat Associations

Since the distribution of many marine species are habitat-specific, mapping data provide valuable information to identify and spatially quantify ecosystem regions and potential spatial biogeographic barriers.

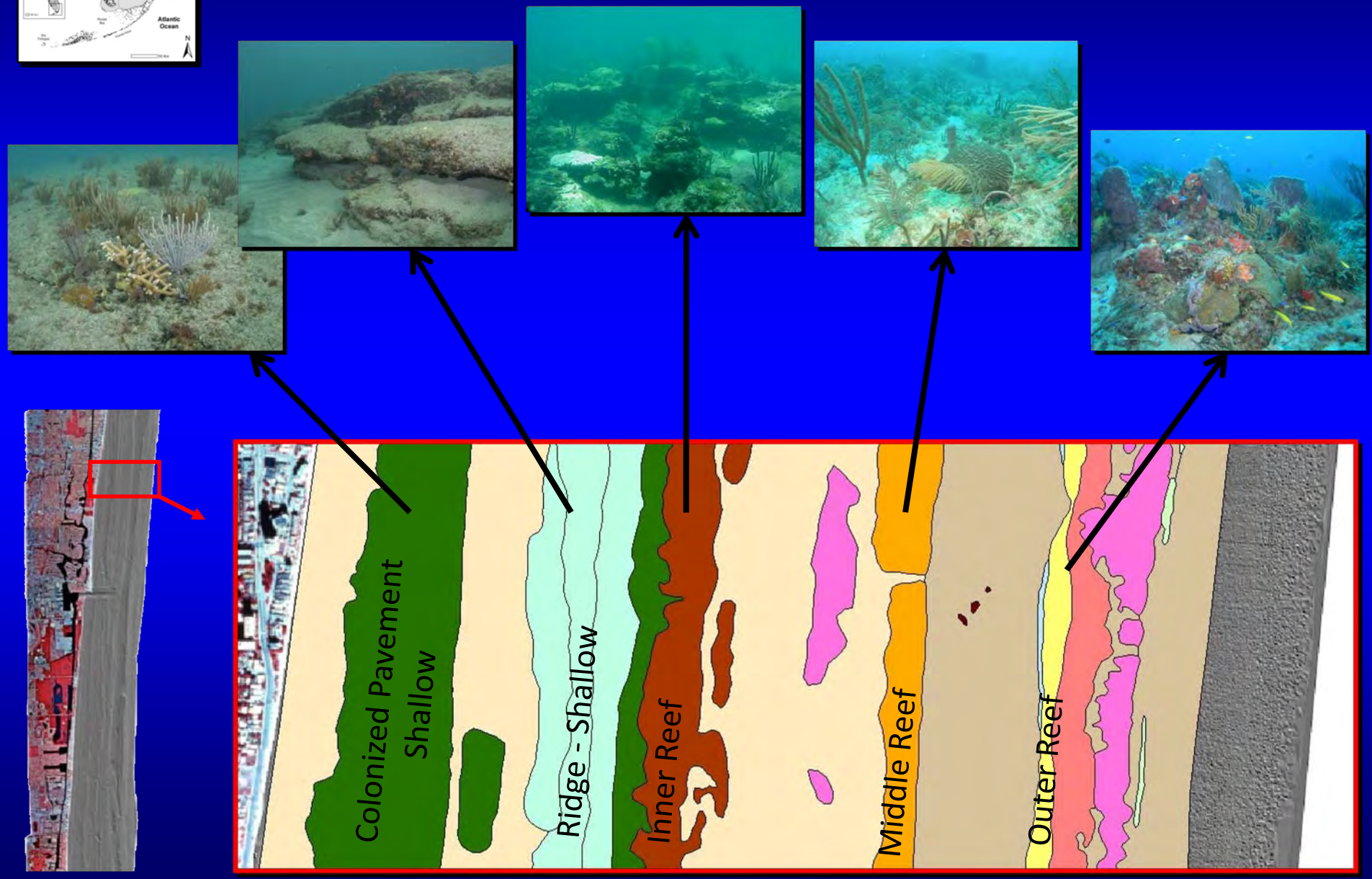
Objective

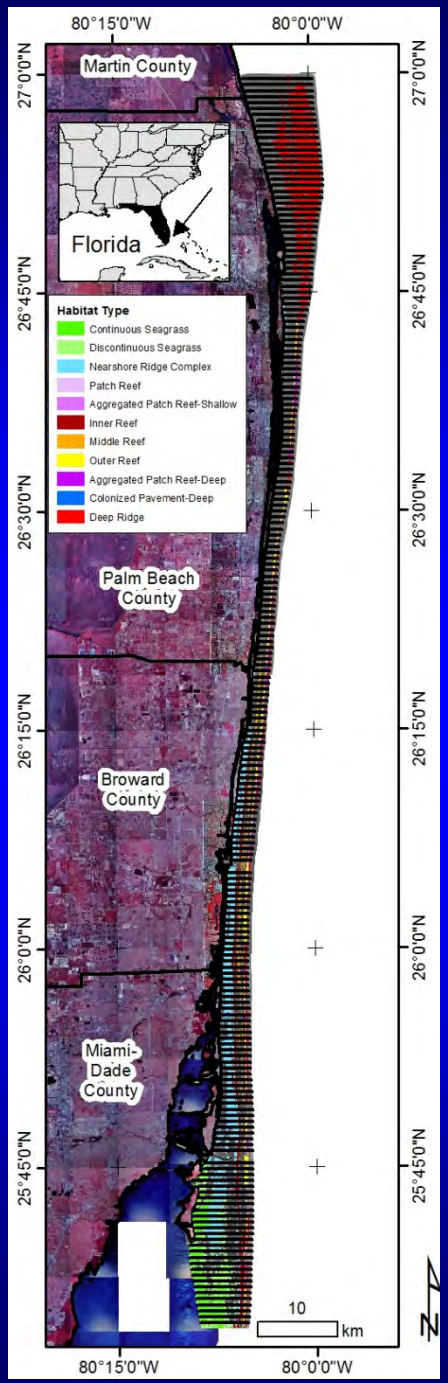
Apply spatial analyses to statistically identify and quantify ecologically similar sub regions in SE FL based on the present-day coral reef community and seagrass habitat morphologies that provides a scientific basis for local marine conservation spatial planning.

Mapping Approach



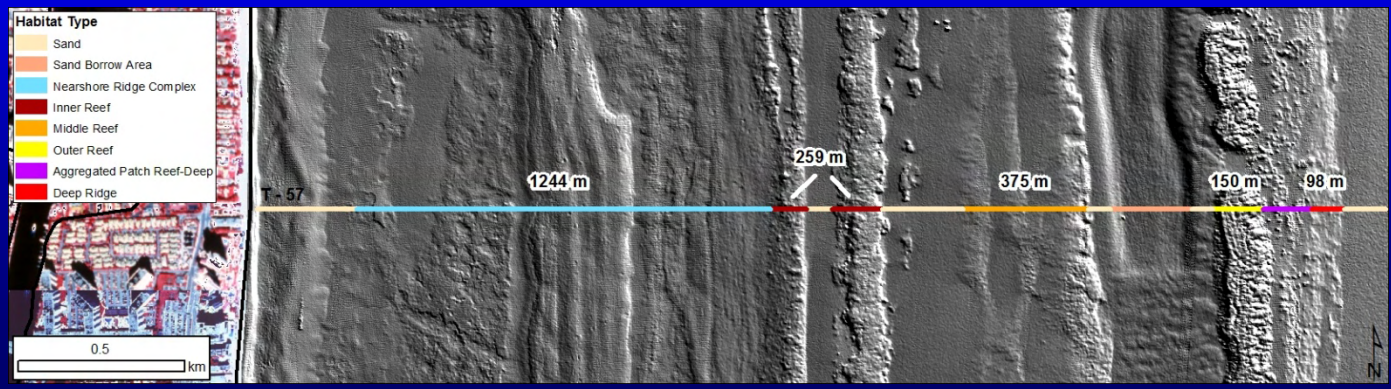
SE FL Mapping Results



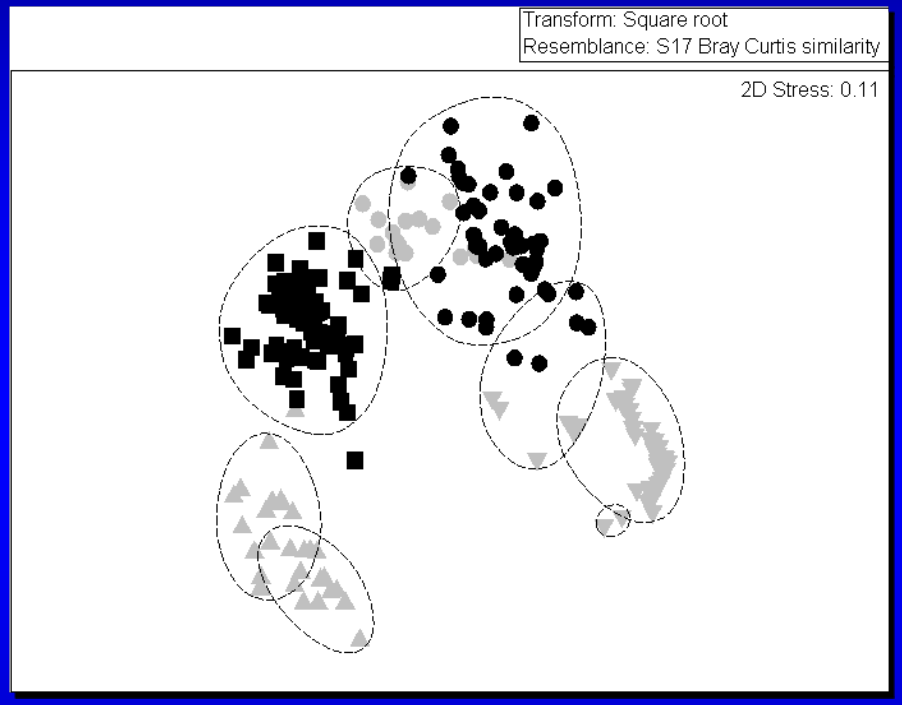


Methods

- 209 parallel, cross-shelf vector-line transects spaced approximately 750 m apart throughout the entire mapped region.
- Intersect was performed between the transects and the benthic habitat polygons.
- Length of each line segment was calculated to determine the linear cross-shelf distance of each habitat.



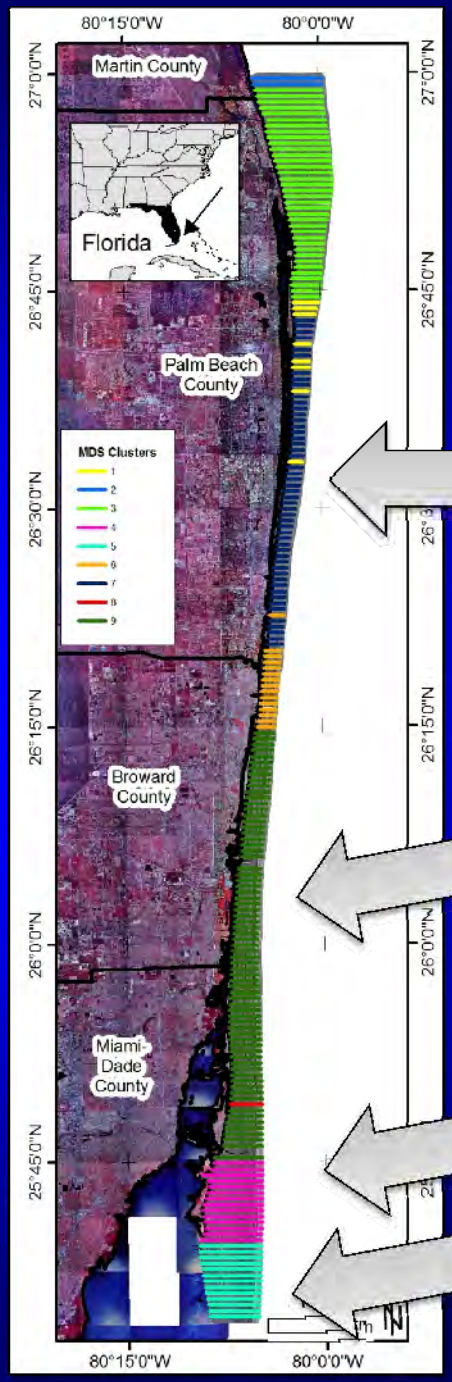
Multivariate Analyses

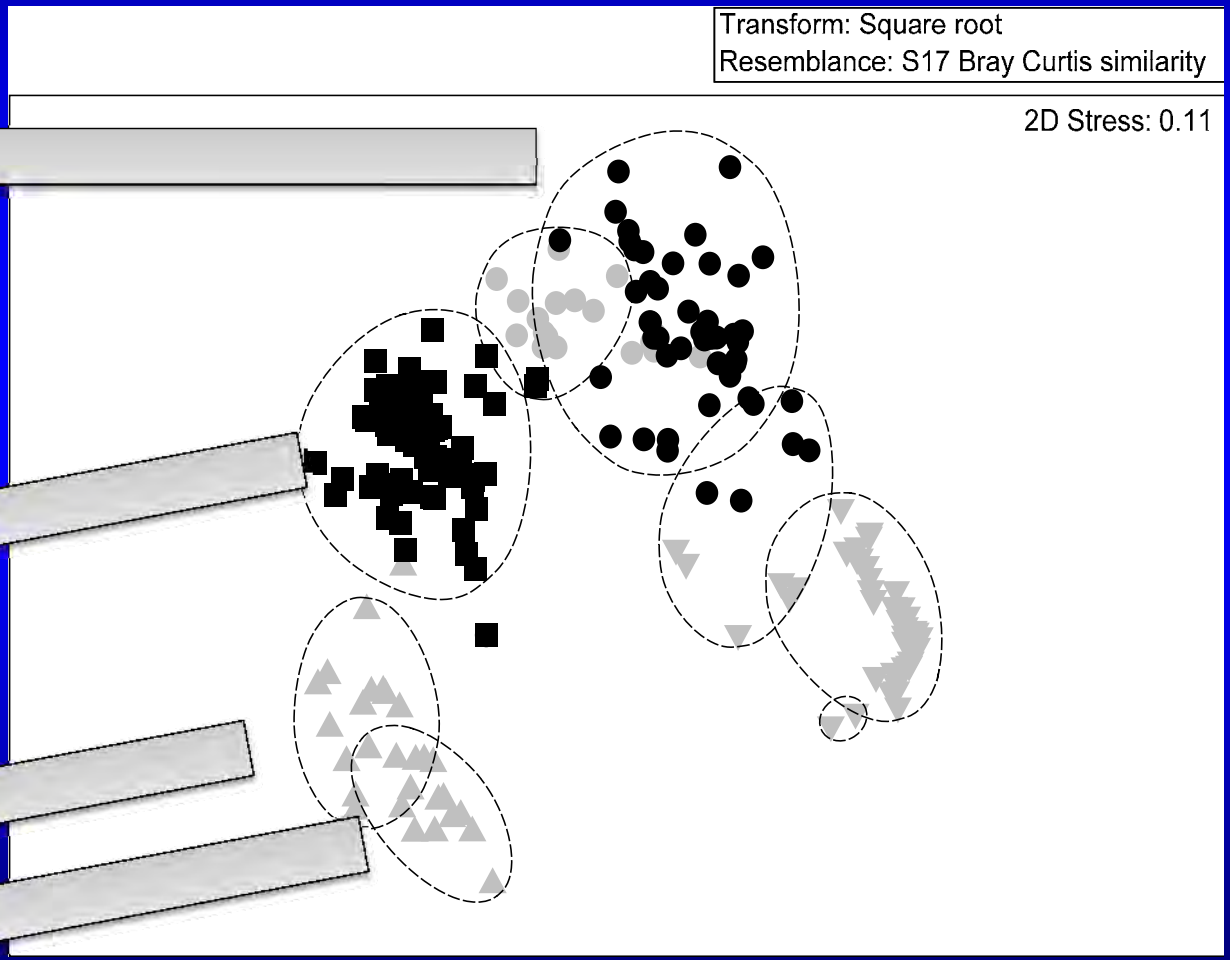


- Cluster analysis using Bray-Curtis similarity indices (PRIMER v6) of the cross-shelf habitat width data to evaluate regions with distinct habitat composition.
- MDS plot was constructed to visualize clusters.

- Transects were then categorized in GIS by the clusters with 75% similarity and visually examined to evaluate the clusters for any spatial grouping consistency.

Cluster Analysis by Transect



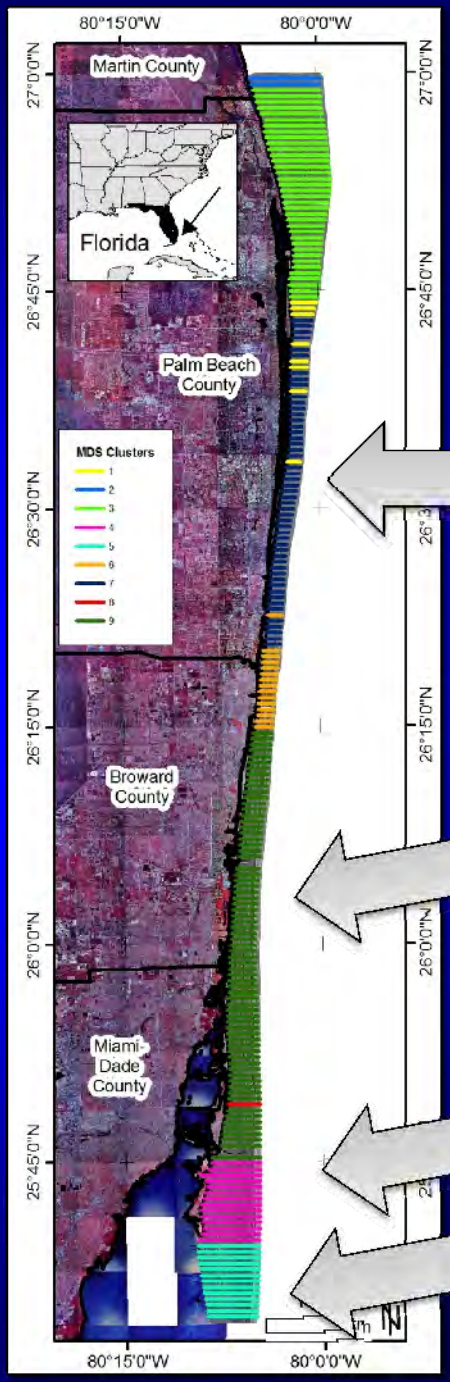


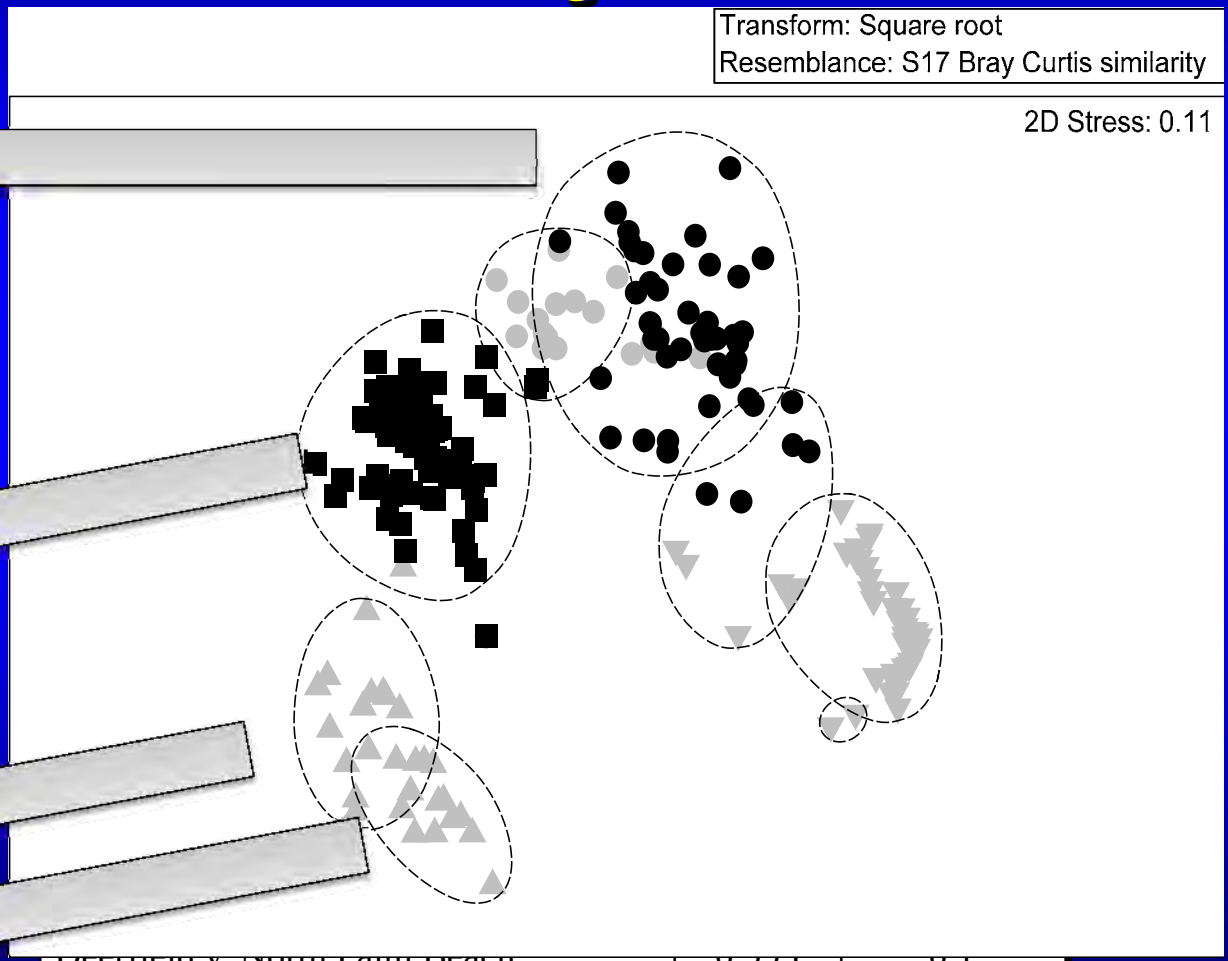
Cluster Analysis by Transect

Cluster Analysis by Transect

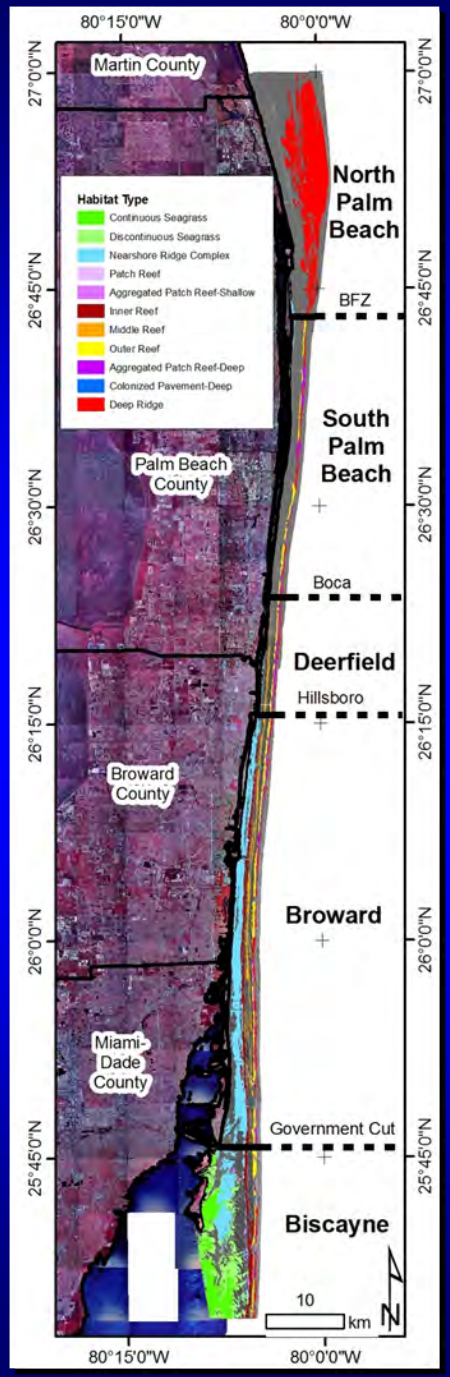
- 9 MDS clusters at 75 % similarity

condense to 5 regions of distinct



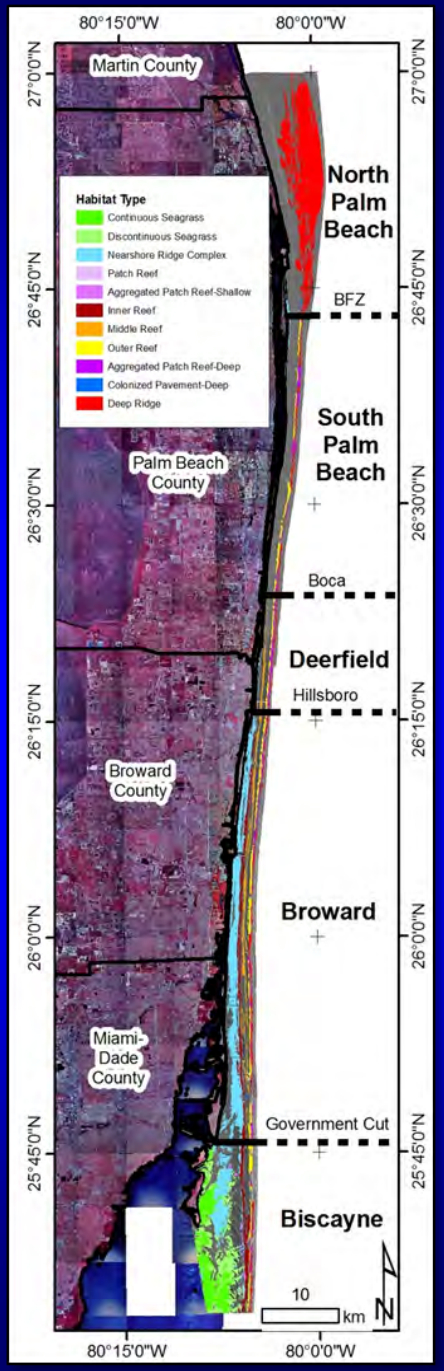


Deerfield v. North Palm Beach	0.995	0.1
South Palm Beach v. North Palm Beach	0.924	0.1



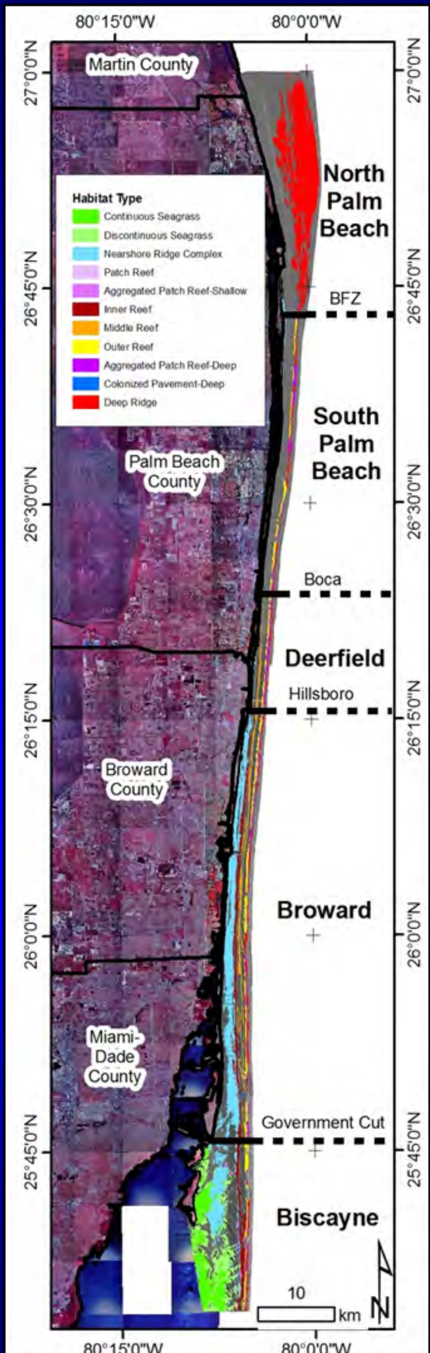
ANOVA by Region

- Analysis of variance was used to analyze for significance of feature width, feature depth, distance from shore, and distance from Inner Reef between regions.
- Then a Student-Newman-Keuls (SNK) post-hoc test between means was performed.
- A *p* value <0.05 in both ANOVA and SNK were accepted as a significant difference.



Decreased Number of Habitats

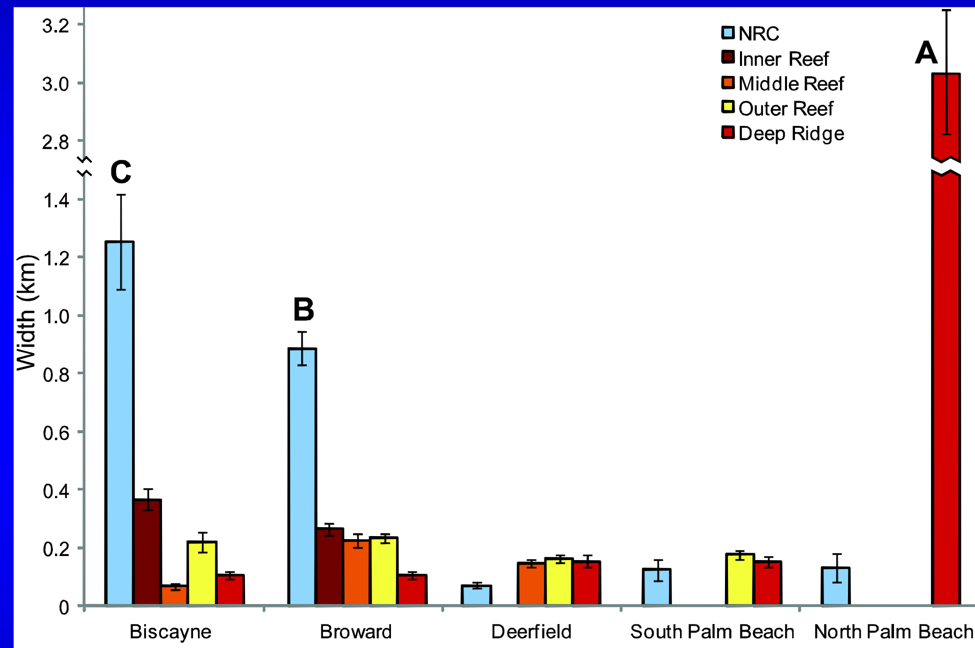
	No. of Habitats	Total Area (rank)	Habitat Type	Area (km²)	% within Region
North Palm Beach	4	175.48 (1)	NRC	0.62	0.35%
			Patch Reef	0.12	0.07%
			Deep Ridge	74.23	42.30%
			Sand	100.51	57.28%
South Palm Beach	5	60.05 (4)	NRC	0.58	0.97%
			Patch Reef	0.04	0.07%
			Outer Reef	4.52	7.53%
			Deep Ridge	3.22	5.36%
			Sand	51.69	86.08%
Deerfield	6	25.27 (5)	NRC	0.37	1.46%
			Patch Reef	0.00	0.01%
			Middle Reef	1.74	6.88%
			Outer Reef	2.31	9.14%
			Deep Ridge	0.78	3.07%
			Sand	20.07	79.44%
Miami-Dade/Broward	7	167.53 (2)	NRC	49.31	29.43%
			Patch Reef	0.05	0.03%
			Inner Reef	12.18	7.27%
			Middle Reef	9.21	5.50%
			Outer Reef	9.61	5.74%
			Deep Ridge	4.04	2.41%
			Sand	83.13	49.62%
Biscayne	9	144.72 (3)	Cont. Seagrass	26.59	18.38%
			Discont. Seagrass	26.37	18.22%
			NRC	16.97	11.73%
			Patch Reef	0.31	0.22%
			Inner Reef	6.78	4.69%
			Middle Reef	0.29	0.20%
			Outer Reef	3.14	2.17%
			Deep Ridge	1.91	1.32%
			Sand	62.36	43.09%

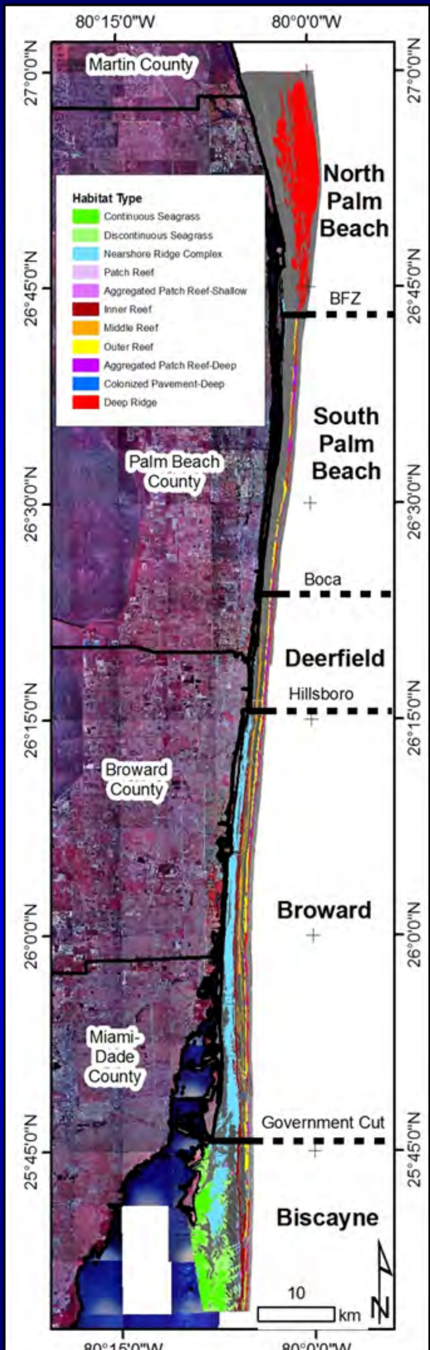


Decreased Number of Habitats

Decreased NRC Width

Increased Deep Ridge Width



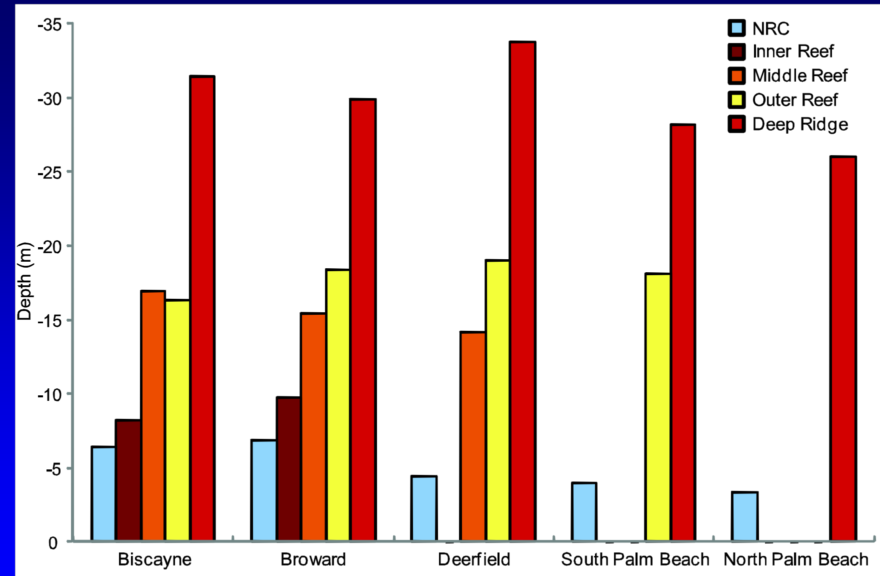


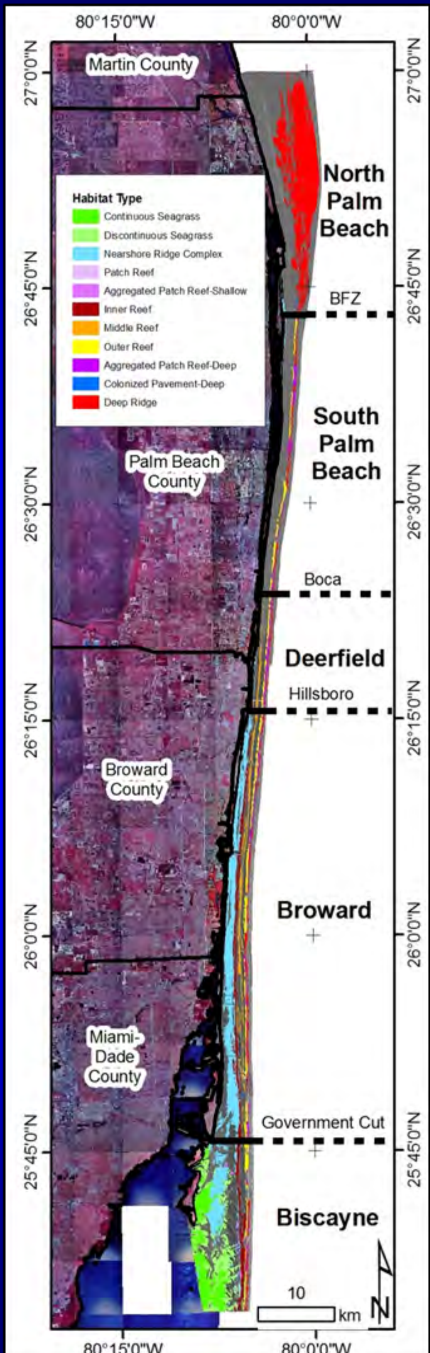
Decreased Number of Habitats

Decreased NRC Width

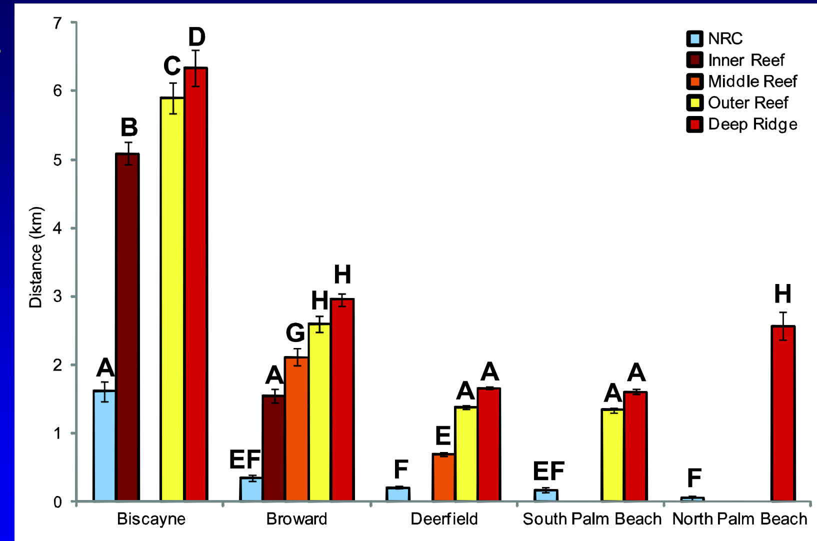
Increased Deep Ridge Width

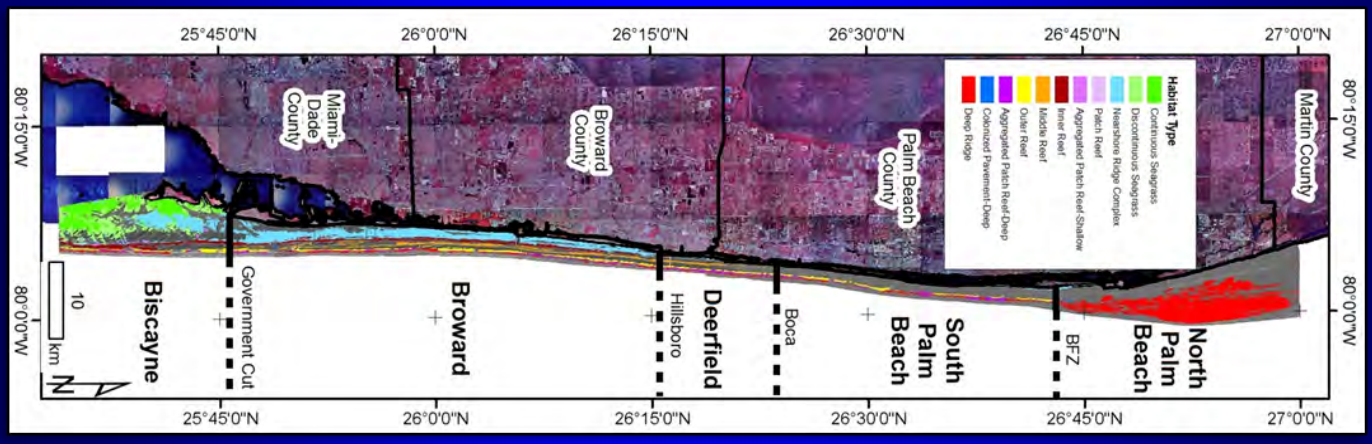
Increased Inner & Outer Reef Depth




80°15'0"W
80°0'0"W
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
26°0'0"N
25°45'0"N
Martin County
North Palm Beach
Habitat Type
Continuous Seagrass
Discontinuous Seagrass
Nearshore Ridge Complex
Patch Reef
Aggregated Patch Reef-Shallow
Inner Reef
Middle Reef
Outer Reef
Aggregated Patch Reef-Deep
Colonized Pavement-Deep
Deep Ridge
BFZ
South Palm Beach
Palm Beach County
Boca
Deerfield
Hillsboro
Broward County
Broward
Miami-Dade County
Government Cut
Biscayne
10 km
N


Decreased Number of Habitats
Decreased NRC Width
Increased Deep Ridge Width
Increased Inner & Outer Reef Depth
Decreased Distance from Shore


Distance (km)
0
1
2
3
4
5
6
7
NRC
Inner Reef
Middle Reef
Outer Reef
Deep Ridge
A
B
C
D
EF
A
G
H
H
F
E
A
A
EF
A
A
F
H
Biscayne
Broward
Deerfield
South Palm Beach
North Palm Beach



Decreased Number of Habitats

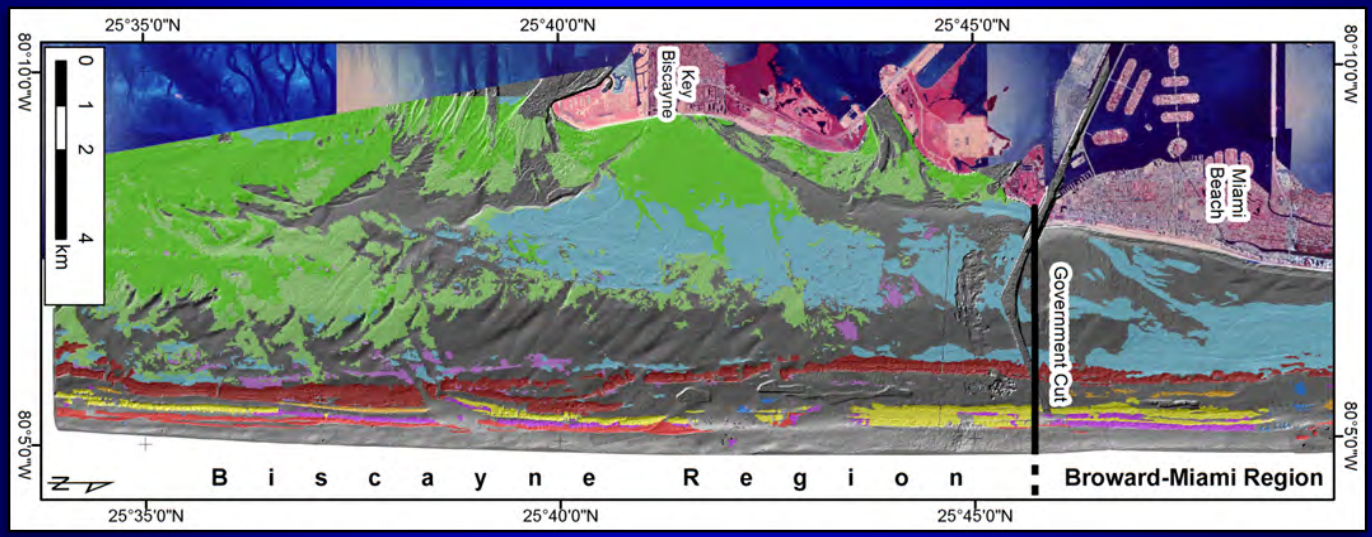
Decreased NRC Width

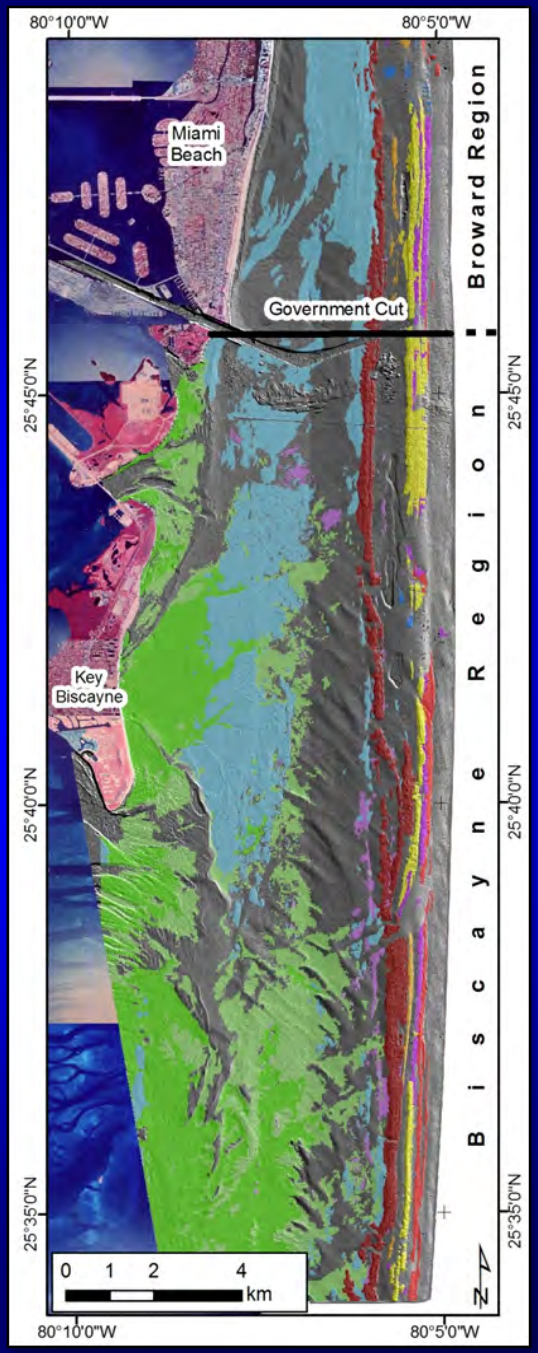
Increased Deep Ridge Width

Increased Inner & Outer Reef Depth

Decreased Distance from Shore

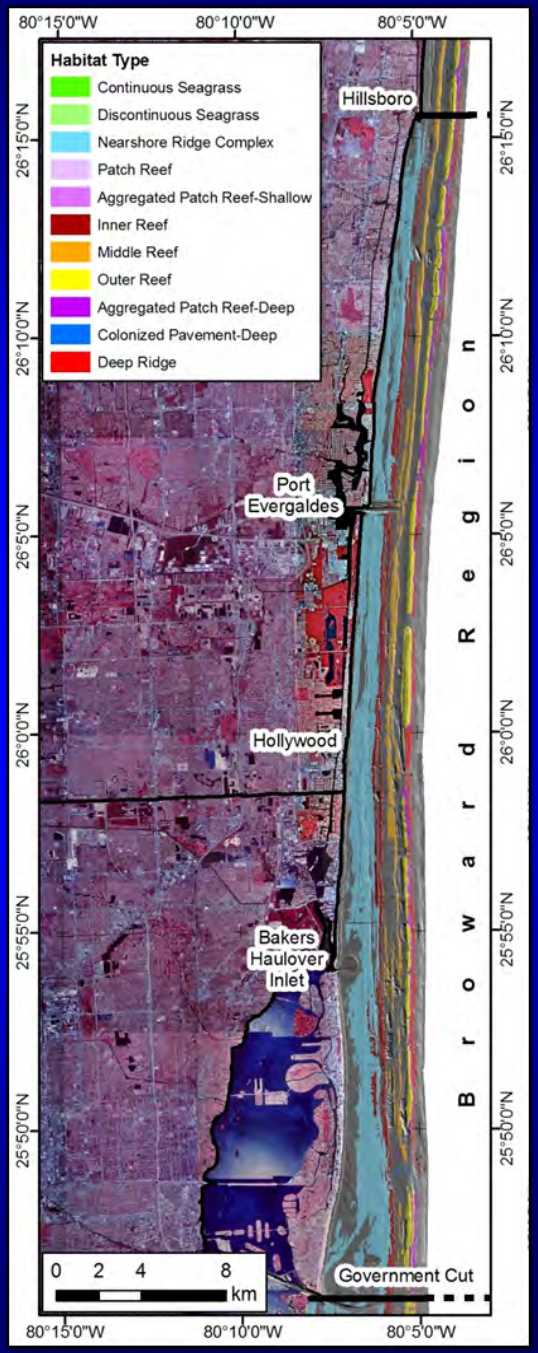
Increased Distance between IR & OR





Gov. Cut Transition

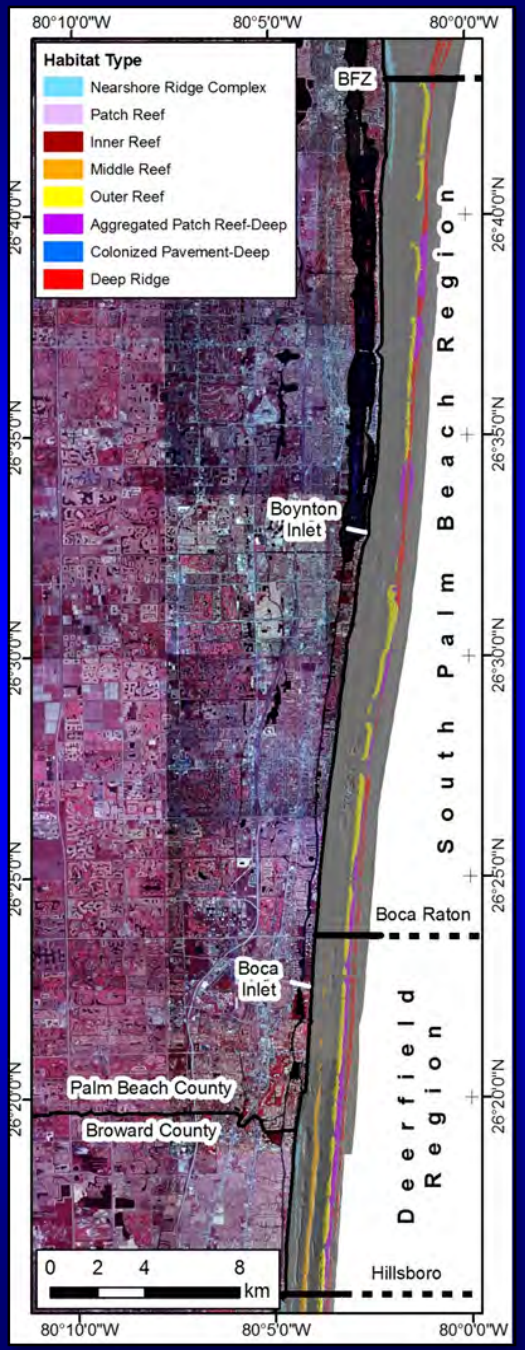
- Northern biogeographical limit of large *Thalassia* and *Syringodium* seagrass meadows seaward of the oceanic coast/beach.
- Serves many ecological functions including significant production of carbon, sediment stabilization, water baffling, and juvenile habitat for many species.
- *Thalassia* and *Syringodium* are exclusive to the estuaries further north.
- These are limited to shallow, protected, lower saline environments and likely have different associated communities.



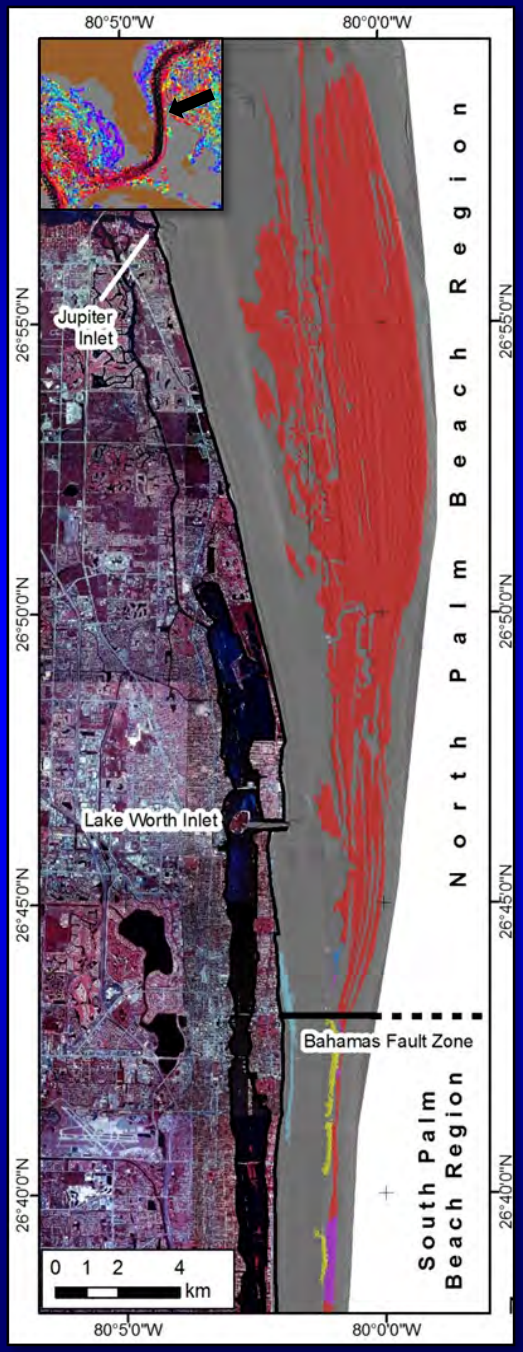
Hillsboro Transition

- Northern limit of Inner Reef and extensive expanses of Nearshore Ridge Complex.
- NRC has statistically different benthic and fish populations than the Middle and Outer reefs
- Disproportionately high abundances juvenile fishes have been found on the NRC.
- Absence of NRC and IR causes a significant reduction of shallow water biomass that likely significantly changes the nearshore food web and its linkages to deeper habitats.

Boca Raton Transition

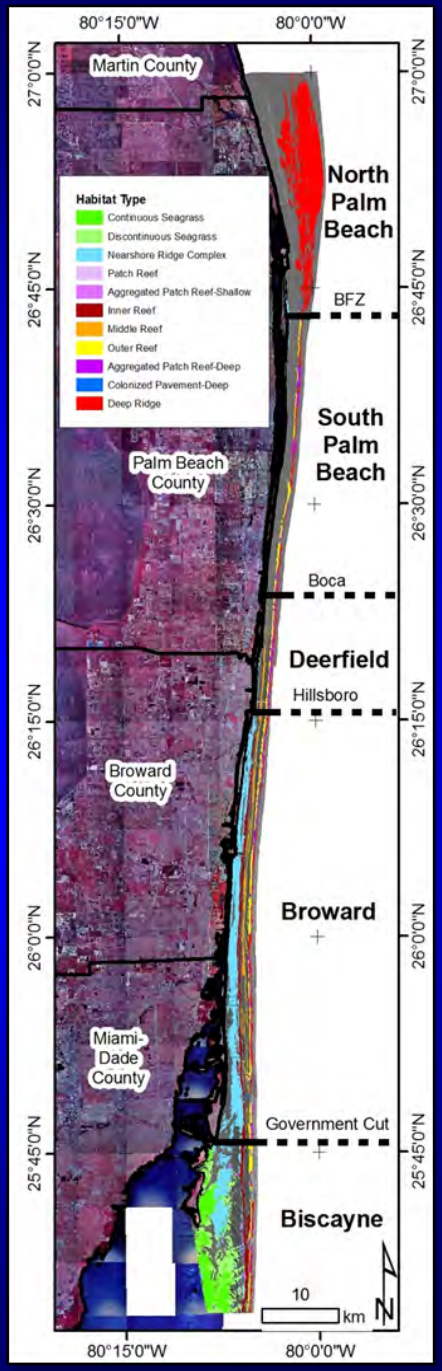


- Northern limit of all significant amounts (> 1 acre) of NRC and Middle Reef.
- Northward of this transition, there is a 36 km stretch of coast without significant hardbottoms outside of the intertidal zone that are shallower than 15 m depth.
- Ecosystem functions associated with the NRC that are presumably drastically reduced in the Deerfield region are absent in South Palm Beach, making Boca Raton a major biogeographic transition.



BFZ Transition

- Marks the northern terminus of historic Outer Reef morphology.
- Location where the FL current extends further from shore and the coastal shelf widens.
- Not an obvious spatial barrier because hardbottom habitat occurs in similar depths in both regions
- Coincides with differences in fish species richness between regions.
- Analysis of 2440 surveys showed, of the 400 total species seen, 43 species were exclusive to the North PB region and 56 exclusive to the South.



In Summary

- 5 regions have been statistically defined based on benthic habitat morphology.
- The number of benthic habitats decreased with increasing latitude from 9 to 4 and many habitat metrics differed between regions.
- Three biogeographic barriers were found at the Boca, Hillsboro, and Biscayne, where specific shallow-water habitats and oceanic seagrass beds were absent further north.
- These regions should be considered in future management decisions and marine conservation planning efforts.

Acknowledgements

FL DEP Coral Reef Conservation Program

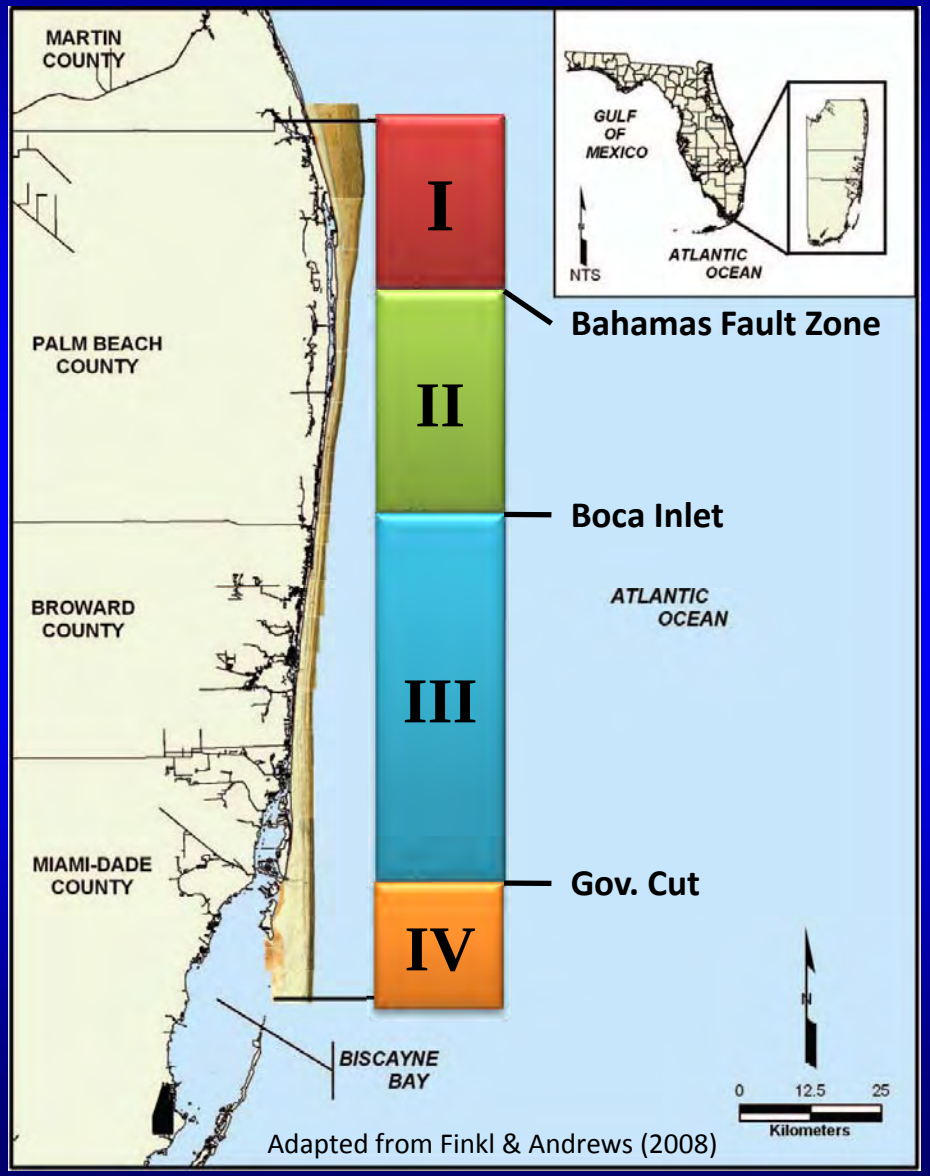
NOAA Coral Reef Conservation Program

Thank you

Previous Efforts

- Previous work along the southeast Florida coast has identified several distinct areas based on geomorphology (Banks et al., 2007; Finkl and Andrews, 2008), yet a statistical evaluation of the living coral reef communities has not been performed.

Present Regional Descriptors

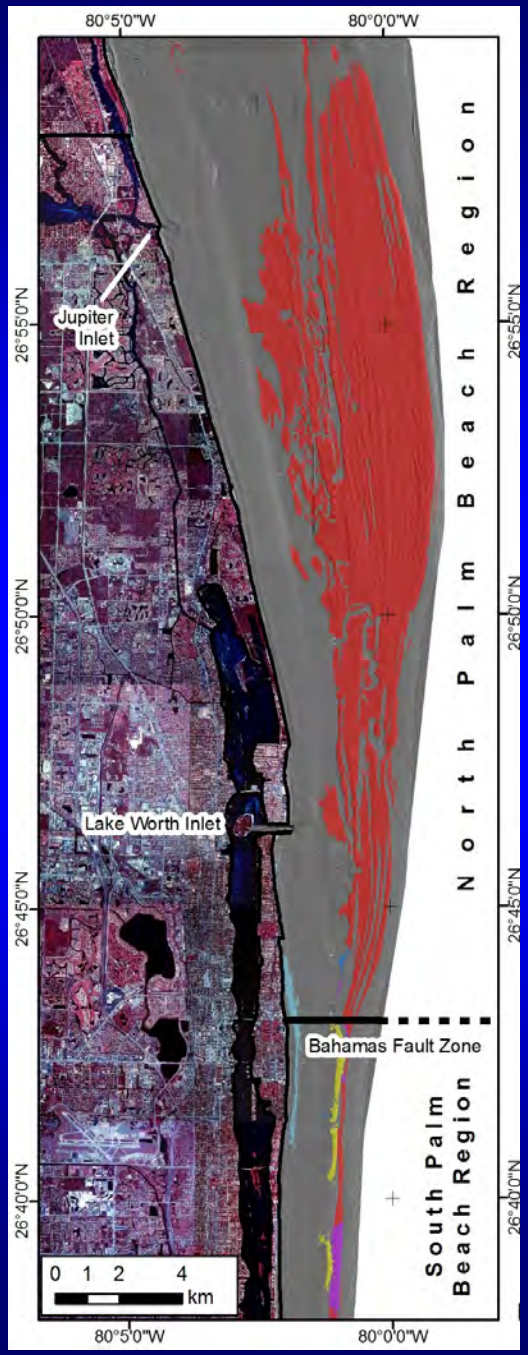


Adapted from Finkl & Andrews (2008)

Coastal Reaches

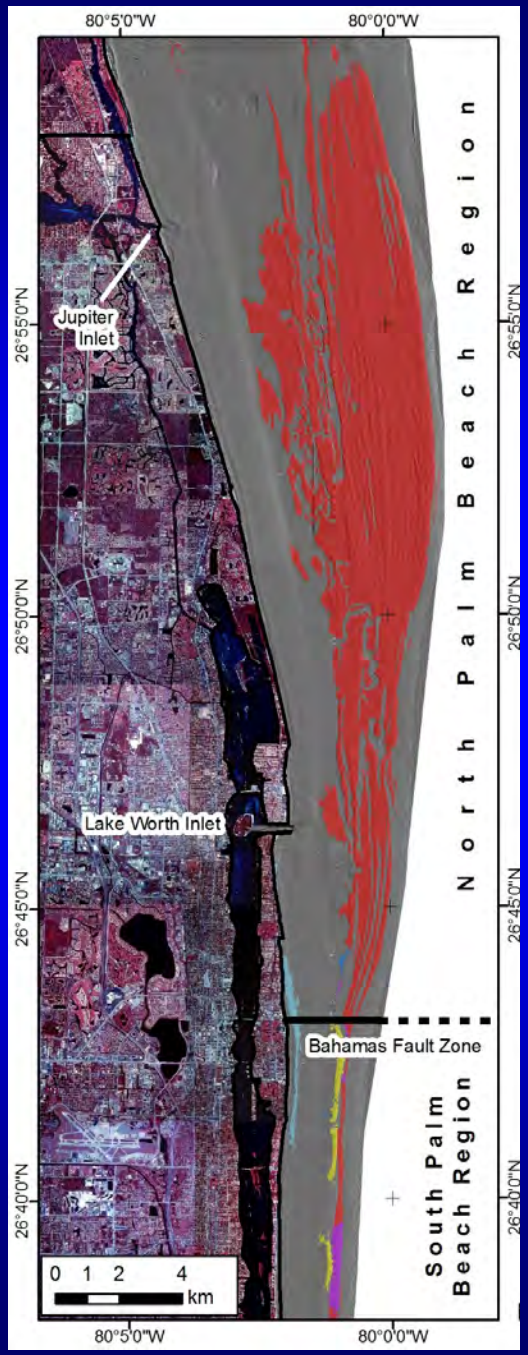
(Finkl & Andrews 2008)

- "…based on spatial interrelationships between interpreted seafloor mapping units, where dominant patterns are discernable."
- Defined by geomorphology
- No ecological basis
- Not statistically determined



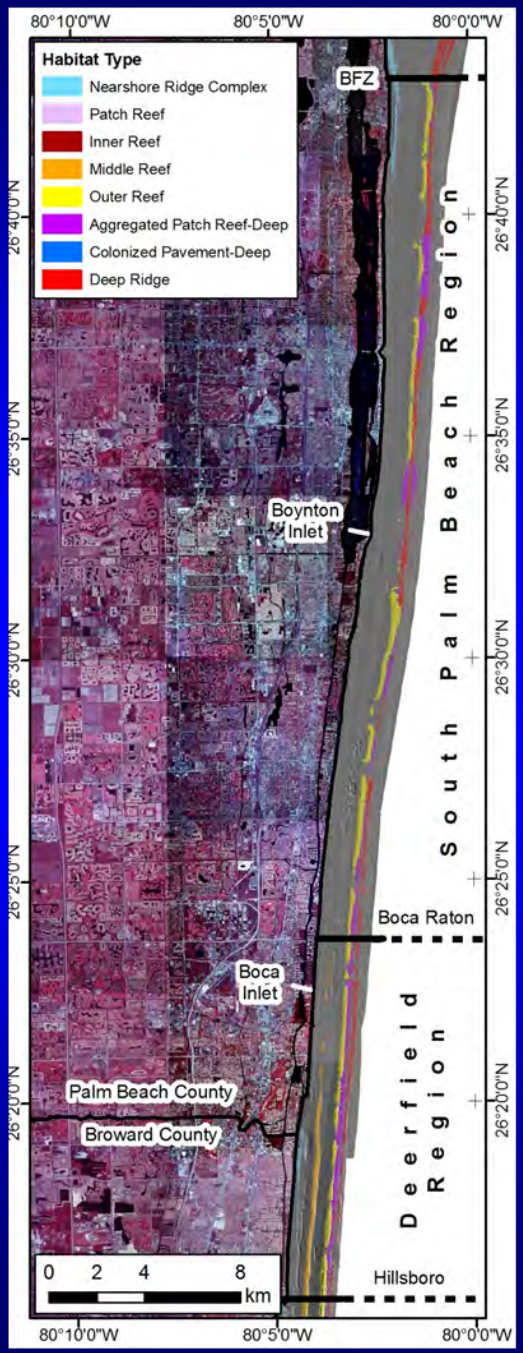
North Palm Beach Region

- Spans approximately 32 km of coastline.
- Corresponded to Reach I in Finkl and Andrews (2008).
- The transition at the southern boundary marks the northern terminus of the Linear Reef-Outer, which is located just south of Palm Beach harbor (Banks et al., 2007; Finkl and Andrews, 2008; Riegl et al., 2005).
- This is also the point where the Florida current extends further from shore (Engle and Summers, 1999) and a widening of the coastal shelf is apparent (Finkl and Andrews, 2008).
- Lack of coral reef topography was conspicuous.
- The present-day coral communities in this region appear to be growing on cemented paleoshorelines (Ginsburg, 1953) and not antecedent coral reefs.



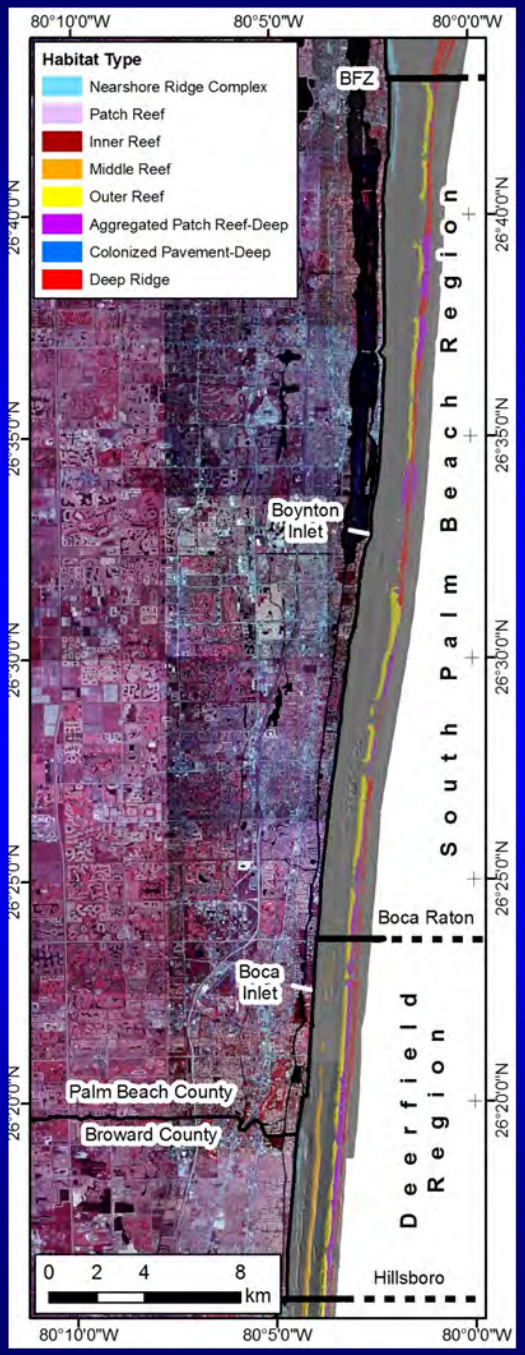
North Palm Beach Region

- Ranked first in size - 175.48 km^2.
- 4 major habitat types, Nearshore Ridge Complex, Patch Reef, Deep Ridge, and Sand.
- 99.58% of the area was Sand and Deep Ridge.
- NRC was small (0.62 km^2) and limited.
- The Deep Ridge was significantly widest and shallowest.
- The Inner, Middle, and Outer Reefs and Seagrass were absent.



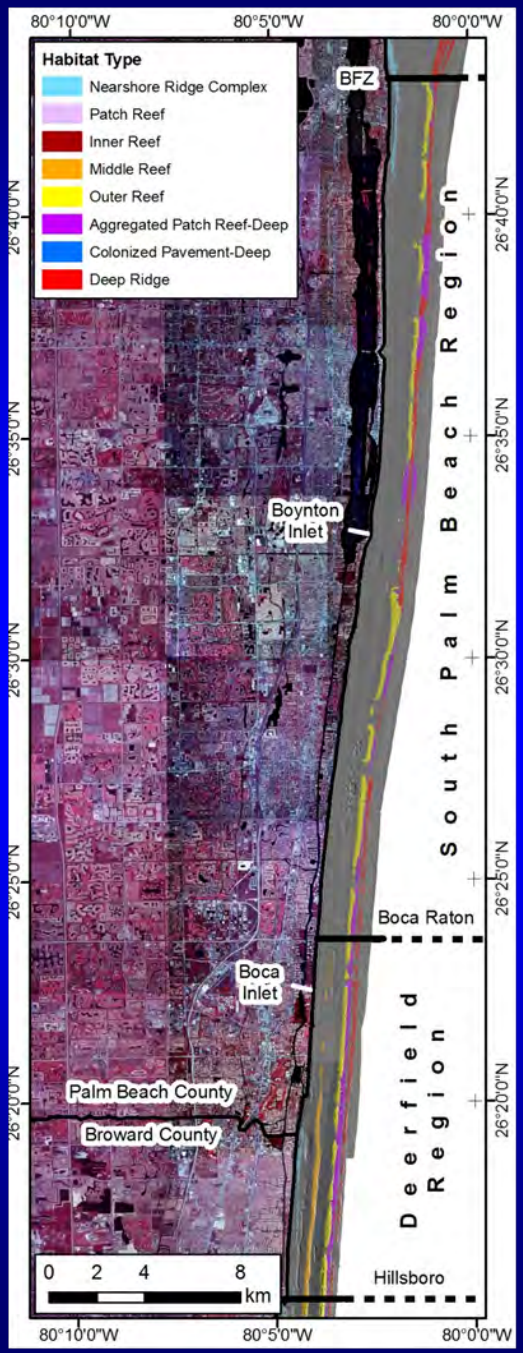
South Palm Beach Region

- Spans approximately 36 km of coastline.
- Similar to Reach II in Finkl and Andrews (2008); however this region stopped 6.5 km north of Boca Inlet instead of extending to Hillsboro Inlet (21.5 km further south).
- The boundary at Boca Raton marks the northern terminus of the Middle Reef.
- Ranked fourth in size - 60.05 km^2.
- 5 major habitat types.



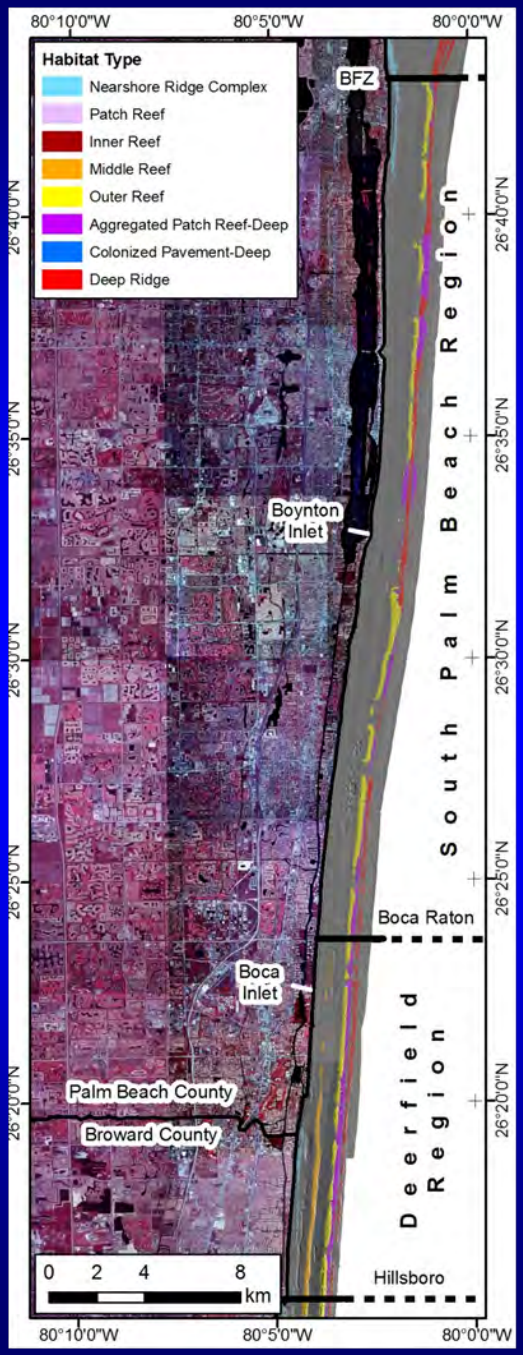
South Palm Beach Region

- The Outer Reef ranked second among the regions in planar area (4.52 km^2).
- Outer Reef and Deep Ridge were significantly closer to shore than all regions except Deerfield.
- The mean distance from shore to the Outer Reef was not statistically distinct from Broward's Inner Reef and Biscayne's NRC.
- Contained the 2nd highest percentage of Deep Ridge and very little NRC and Patch Reef.
- Middle Reef, Inner Reef, and Seagrass habitats were absent.



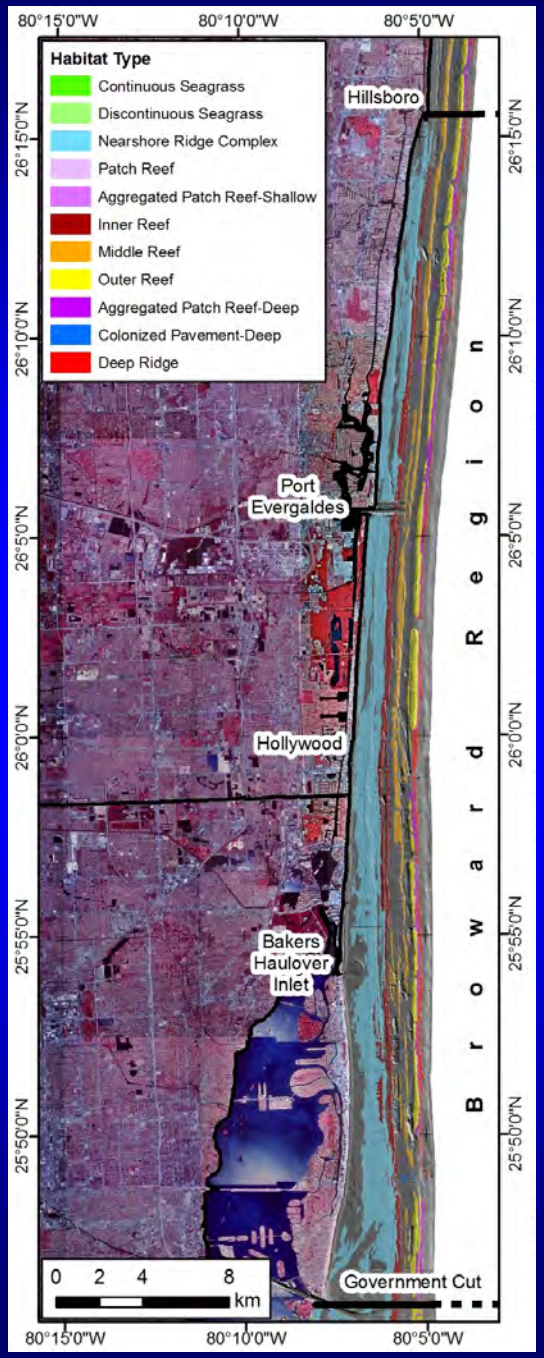
Deerfield Region

- Spans approximately 15 km of coastline
- Bounded by the Boca Raton boundary and Hillsboro Inlet.
- The smallest region - 25.27 km^2.
- 6 major habitat types.
- The southern boundary marked the northern terminus of the Inner Reef which has been previously identified in a geologic context (Banks et al., 2007).



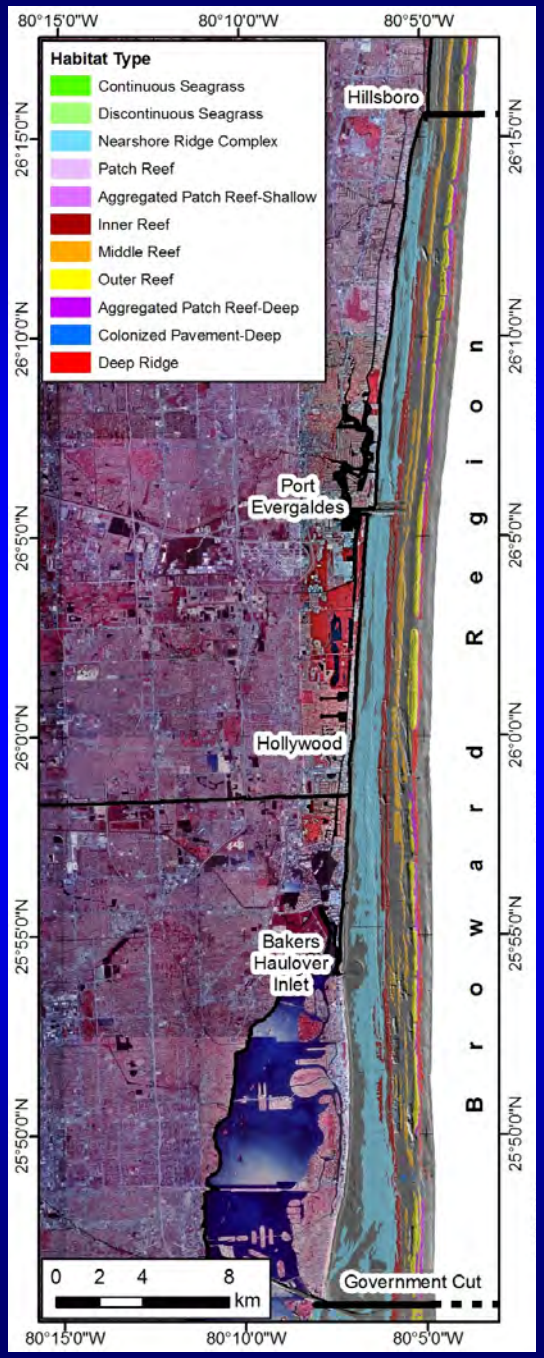
Deerfield Region

- 2nd highest percentage of Sand
- Highest percentage of Middle Reef and Outer Reefs.
- The Middle Reef was significantly closest to shore than in any other region.
- Did not statistically differ in distance to shore from Broward NRC.
- The Inner Reef and Seagrass habitats were absent.



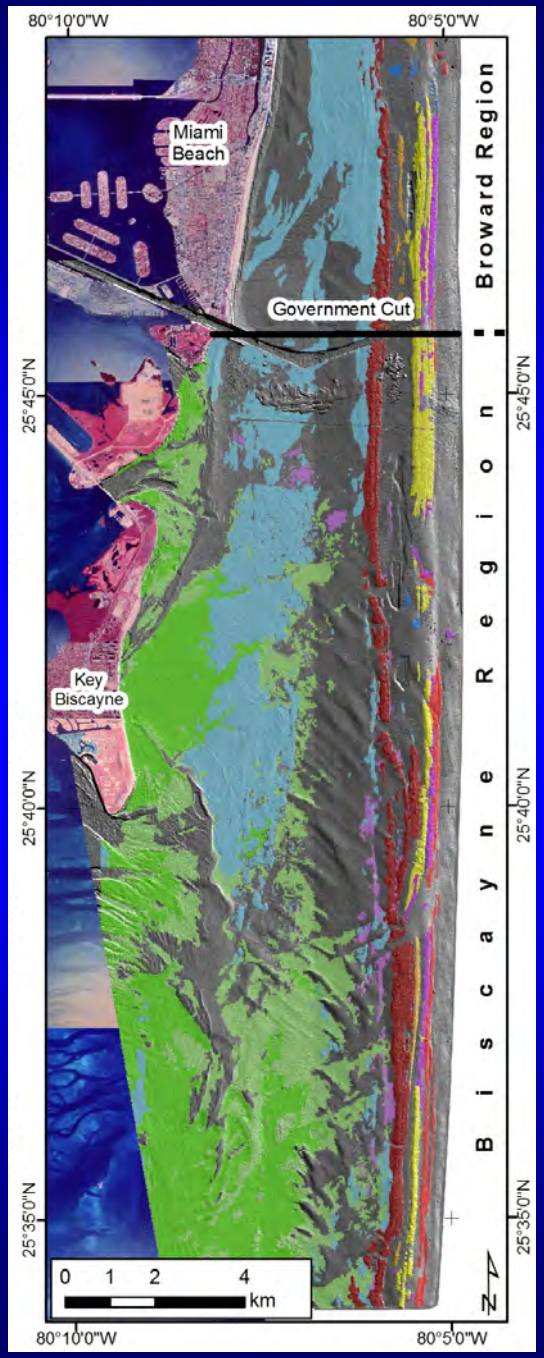
Broward - Miami Region

- Spans approximately 48 km of coastline.
- Mostly corresponds with Reach III of Finkl and Andrews (2008).
- 2nd in size - 134.67 km^2; 7 major habitat types.
- Middle Reef, Outer Reef, and the Deep Ridge were significantly further from shore than in South Palm Beach and Deerfield.
- NRC was significantly wider than in Deerfield, South Palm Beach, and North Palm Beach.
- Seagrass habitats were absent.



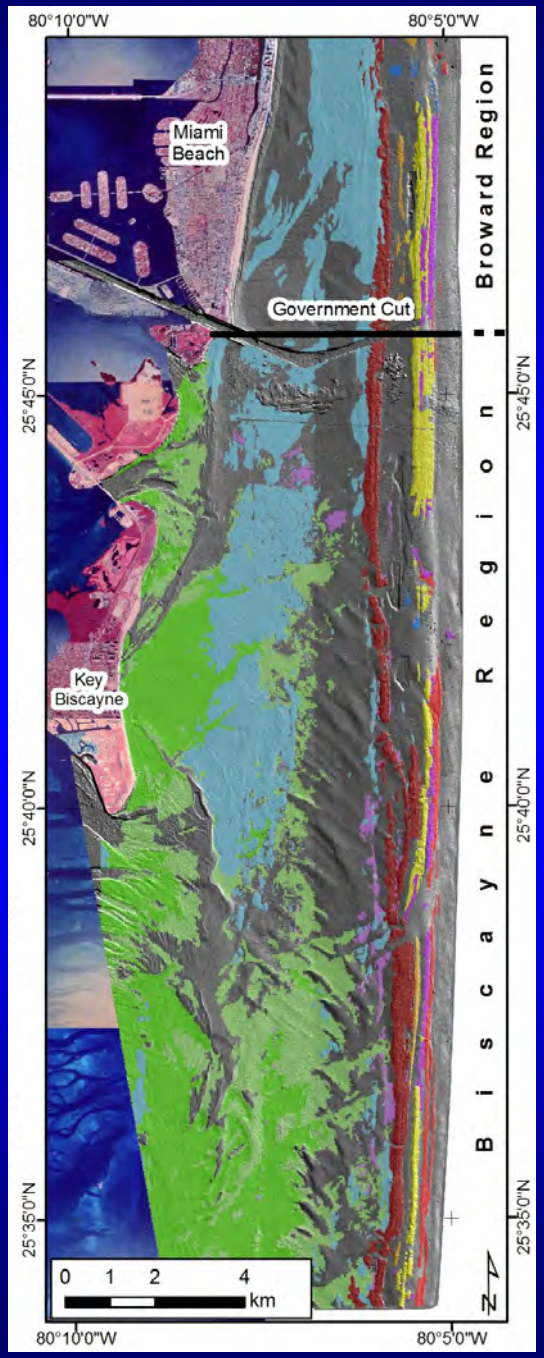
Broward - Miami Region

- Distance between the Inner and Outer reefs significantly decreased between Miami-Dade Broward and Biscayne.
- The features began converging at the same latitude where examination of pre-developed shoreline maps showed a previous natural river inlet named Boca Ratones mapped by DeBrahm in 1770 that closed pre-1887 (Austin and McJunkin, 1981; Cantillo et al., 2000; Chardon, 1982; Chardon, 1978).
- The reefs converge off Key Biscayne, where the Inner Reef appears to be growing atop the Outer Reef.
- This convergence could be of importance to future geologic studies.



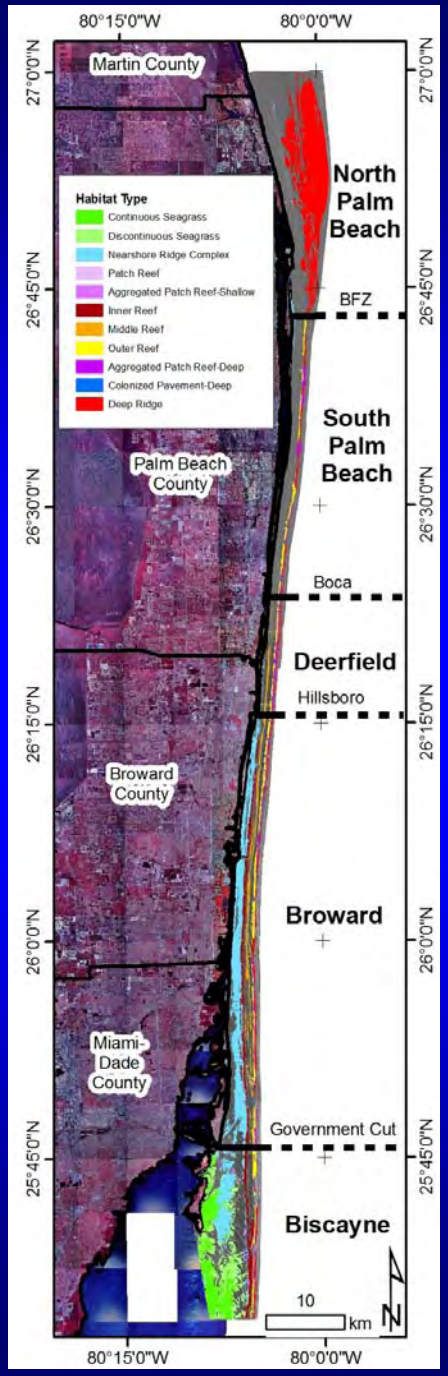
Biscayne Region

- Spans approximately 22 km of coastline.
- Bounded by Government Cut (north) and the end of the mapped area (south).
- Corresponded to Reach IV in Finkl and Andrews (2008).
- This region ranked third in size with an area of 144.72 km² and contained nine major habitat types.
- The northern boundary at Government Cut marked the northern extent of known seagrass beds on the ocean side of the coast.
- Continuous and Discontinuous Seagrass combined comprised 36.6% of the area.



Biscayne Region

- Patch Reef habitat area ranked first between all regions.
- Contained a large amount of NRC and IR but proportions were lower than Broward-Miami.
- The Middle Reef was barely evident.
- Reef habitats were significantly farther from shore (Key Biscayne) than their respective counterparts in all other regions.
- Outer Reef was 56% farther from shore than Broward and 77% farther than Deerfield and South Palm Beach.
- The NRC was significantly widest in Biscayne.



Depth Trends

- The NRC was deeper in Broward-Miami and Biscayne than northern regions.
- Patch Reefs were shallower in Biscayne (7.6 ± 2.2 m) than any other region.
- Broward-Miami patch reefs (12.3 ± 4.3 m) were deeper than more northern regions.
- Mean Inner Reef (8.2 ± 2.2 m) and Outer Reef depths (16.3 ± 4.5 m) were shallowest in Biscayne.

Conclusions

- Coincident with coastal morphology and potential spatial barriers, there is an obvious change in water temperatures and currents from Biscayne to North Palm Beach (Banks et al., 2008). The northward flowing warm waters of the Florida current that bathe the southern regions diverge from the coast near the Bahamas Fault Zone (Engle and Summers, 1999). Monthly surface water temperatures vary latitudinally and temporally, but are consistently lower further north (Gilliam, 2007; Locarnini et al., 2006). For example, in 2008-2009, Miami Beach (southern Broward region) monthly-averaged surface water temperatures ranged from 21.7°C in Jan to 30°C in July, whereas Stuart Beach (north of the North Palm Beach region) temperatures ranged from 19.4°C in January to 27.2°C in September (National Oceanographic Data Center, 2009). Deep upwelling colder water regularly occurs along the coast and appears more frequent in the north (CSA International Inc., 2009). Frequent cold water pulses are evident on the reefs and mean daily temperatures differ nearly 4°C between Miami-Dade (24.5°C) and Martin (20.8°C) counties for the same period (Gilliam, 2007). It is likely that drastic water temperature differences along this relatively short coastline is the main cause for latitudinal flora and fauna differences, however major morphologic changes in the seascape also contribute. The absence of shallow water hardbottom in the South Palm Beach region creates a spatial barrier for all shallow-water-habitat-associated species where NRC communities further north (in the North Palm Beach region) are noticeably different likely due to more frequent interaction with colder water.

Conclusions

- Spatial barriers coincident with significant changes temperature and currents could have an influence on short-term range expansion of benthic species. Warmer temperatures have shifted the ranges of many species worldwide and are expected to continue over the next century (Karl et al., 2009; Parmesan, 2006). Previous studies have shown that coral reef poleward range shifts have occurred in warmer periods (Kiessling, 2001; Kleypas, 2007) and may be occurring now (Precht and Aronson, 2004), however coastal morphology must support such shifts. In SE Florida, there is little exposed structure for shallow (<15 m) coral communities to recruit to in a poleward range expansion.
-
- Historically in southeast Florida, reefs initiated on beach ridges inundated by coastal flooding during the Holocene transgression (Banks et al., 2007; Ginsburg, 1953; Lidz and Shinn, 1991; Lighty et al., 1978). As sea level rose, it flooded the coastlines and submerged cemented beach dunes upon which corals grew. Presently coastal development and the regular practice of beach renourishment impede the natural coastline erosion and flooding process, thus impeding new available substrate for colonization. The lack of present Nearshore Ridge Complex in the South Palm Beach region and increased sedimentation from beach nourishments will be a large hurdle for many shallow-water coral reef species to overcome in a poleward expansion.

Conclusions

- Analyses of present-day reef depths between regions revealed that the Outer Reef is significantly shallower in Biscayne than more northern regions. Present-day Outer Reef mean depths in the Biscayne region were over 2 m shallower, indicating that either historical erosion or reef growth varied between regions.
-
- Increased erosion in the north is possible due to the location of the Florida Current. Historical Florida Current location and rates are unknown, but the distance between the Outer Reef and present Florida Current lessens northward along the coast as the shelf thins. Assuming the historical current was similar in location and strength, it is plausible that the northern Outer Reef had more interaction with the current over the past 8,000 years and thus eroded more.
-
- Variable historical reef growth could explain latitudinal differences in depth along the Outer Reef as well. This elicits two scenarios: 1) reef accretion terminated earlier in the north or 2) accretion occurred at a slower pace in the north. These growth scenarios suggest that climatic variability along the southeast Florida latitudinal gradient affected reef growth during the Holocene. Previous Outer Reef ages came from one site near the Hillsboro transition (Lighty et al., 1978), thus latitudinal variability of reef growth and termination ages along the northern Florida reef tract remain unknown.
-
- The first historical growth scenario may be supported by present-day reef morphology. In the Biscayne region (where the Outer Reef is shallowest), the Inner and Outer Reefs appear to converge offshore of Key Biscayne (Figure 4). Here the Inner Reef grows immediately adjacent to and perhaps on top of the Outer Reef. This may be an area where reef accretion did not terminate 8,000 years ago. Geologic confirmation is needed on latitudinal differences in reef thicknesses and ages to determine how they relate to historical reef growth. If confirmed, then historical reef growth did not simultaneously terminate along the northern extent of the Florida reef tract as previous research has indicated.

Conclusions

- the analyses herein provide a scientific basis for local marine conservation spatial planning. According to Lourie and Vincent (2004) "…biogeography should be at the forefront of determining spatial priorities for proactive marine conservation planning. The spatial distribution and scale of biodiversity, the processes maintaining it, and the threats to it need to be understood so that appropriate conservation measures may be initiated." The analyses defined regions at a scale appropriate to regional management decisions that relate to benthic habitat morphology and potentially to regional biogeography. This information will strengthen systematic marine conservation planning by furnishing necessary, relevant spatial distribution information that provides an objective, scientific foundation for decision making. As more regional biological data become available, the regions defined herein can be tested to better understand how the benthic fauna and ichthyofauna composition differ and how they are affected by differences in the major spatial relationships and sea floor morphologies