



TRACKING LIFE ON THE REEF

Monitoring Benthic Communities in FKNMS No-Take Management Zones

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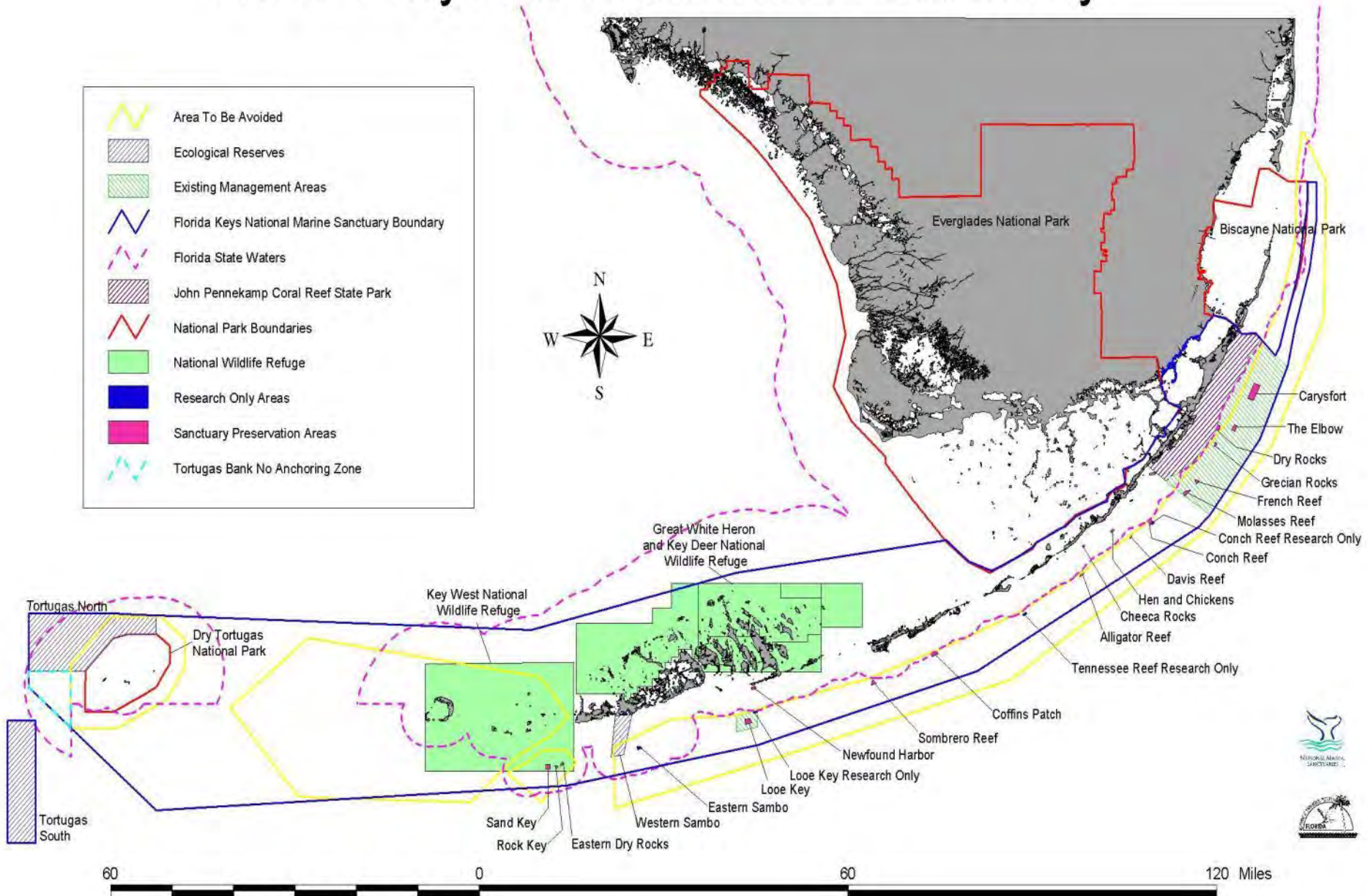


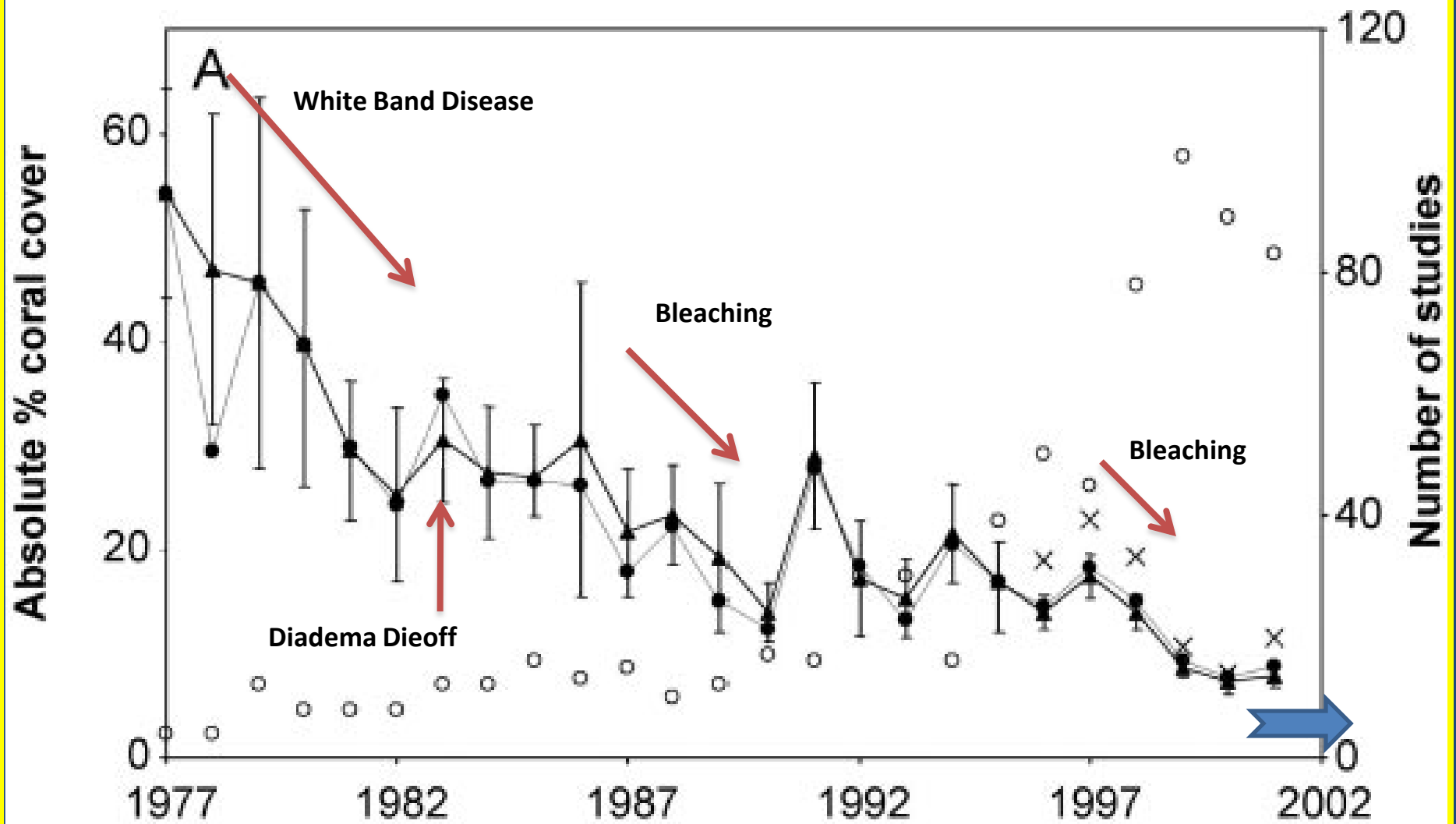
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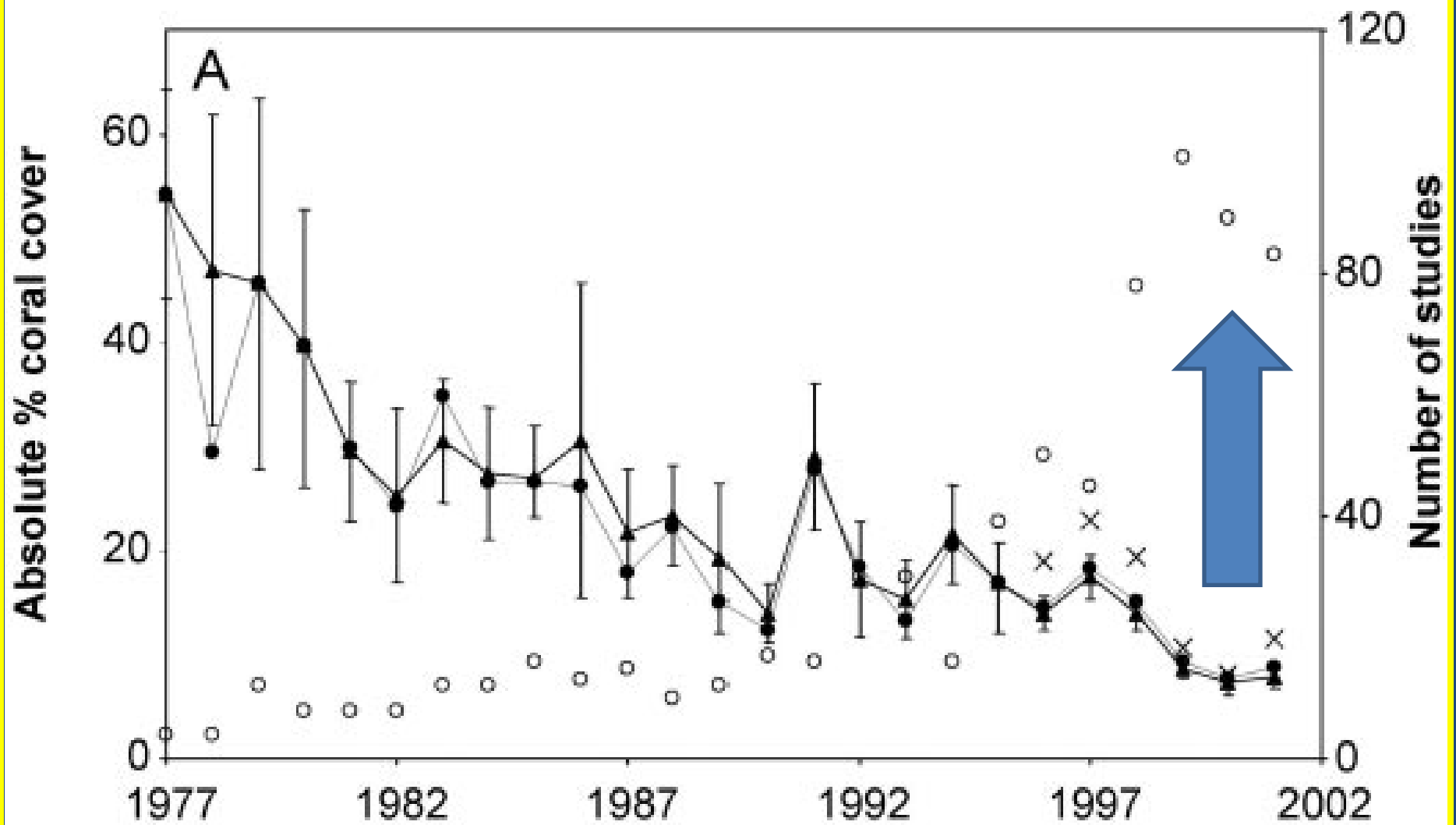


Today

Florida Keys National Marine Sanctuary







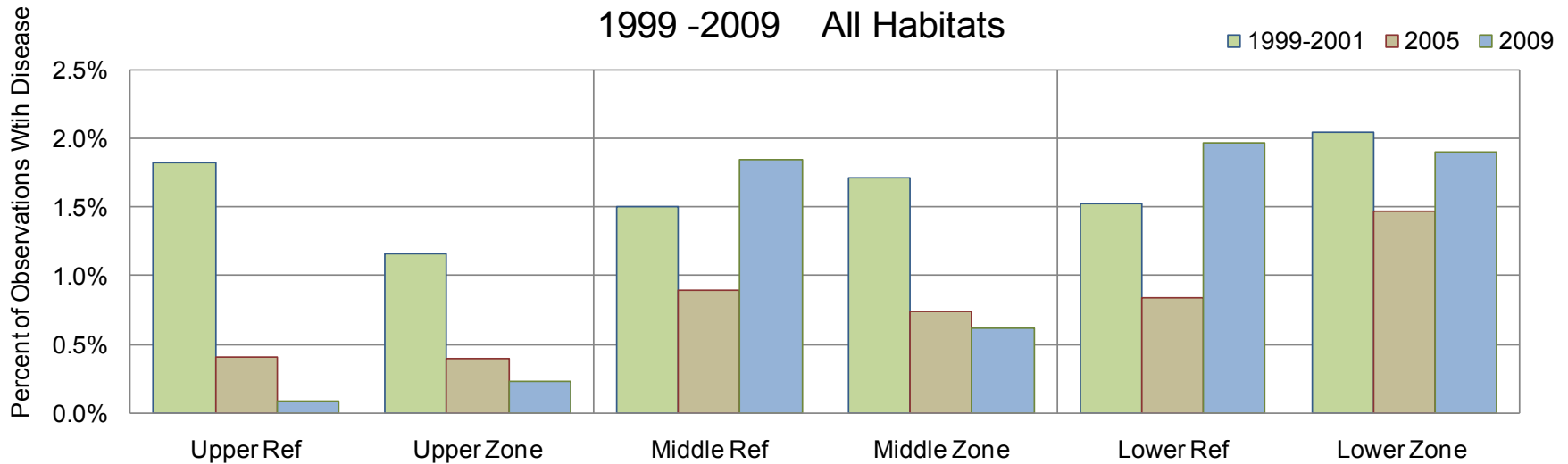
Factors Affecting Coral Reefs in Florida

- Geography (winter cold fronts)
- Hurricanes
- Coral Disease*
- Coral Bleaching*
- Ocean Acidification*
- Pollution (especially nutrients)
- Loss of herbivores (over-fishing and urchin die-off)
- Marine Zoning - if fishing pressure is a major driver of change for the benthos in the FKNMS



Coral Diseases

Scleractinian Disease Prevalence
1999 -2009 All Habitats



White plague (I and II)
Black-band disease
White-band disease
Yellow blotch
Dark spot syndrome

Human Disease Prevalence Statistics

- Corals in the Keys: 0.2 - 1.9%
 - AIDS in North America: 0.45% (2006)
 - Breast Cancer: 0.8% (2007) [12% will be diagnosed lifetime]
 - Prostate Cancer: 0.8% (45-64) [16% will be diagnosed lifetime]
 - Heart Disease: 6.5% woman, 8.2% men (2005)
 - Bubonic Plague (Black Death): 1/3 of Europe's population killed (25 million deaths) 1347-1352



What do we measure?

- 15-m transects for benthic cover
 - point-intercept
 - photo archives for general site descriptions
- 15-m belt transects surveyed for:
 - Species richness (coral, sponge, gorgonian)
 - Gorgonian abundance and height (8-m x 1-m)
 - Juvenile coral abundance and size (20 x 0.312 m²)
 - Adult coral abundance, size and condition (10-m x 1-m)
 - Urchin density and size (15-m x 1-m)
 - Marine ornamental species density (15-m x 1-m)
 - Substratum topography (vertical relief, slope, depth)
 - Debris: density, length and impacts of fishing gear (15-m x 2-m)



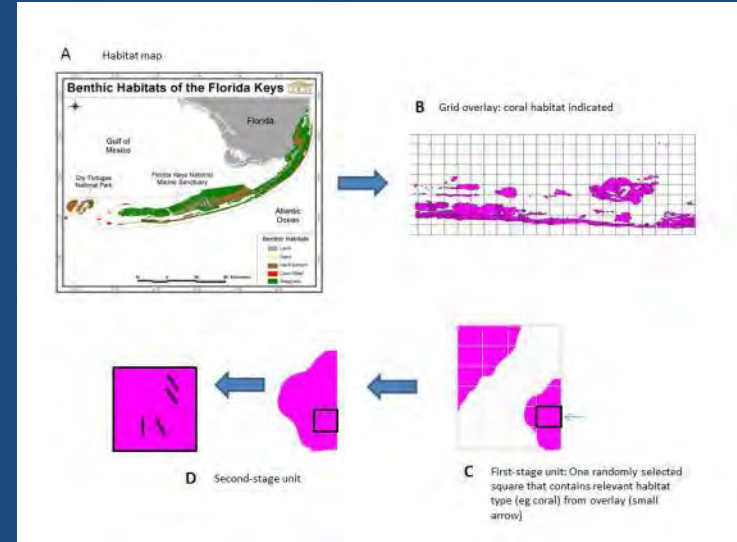
How do We Sample?

1. A two-stage stratified random sampling design is used to allocate effort according to habitat type and depth, along-shelf position, and management zone

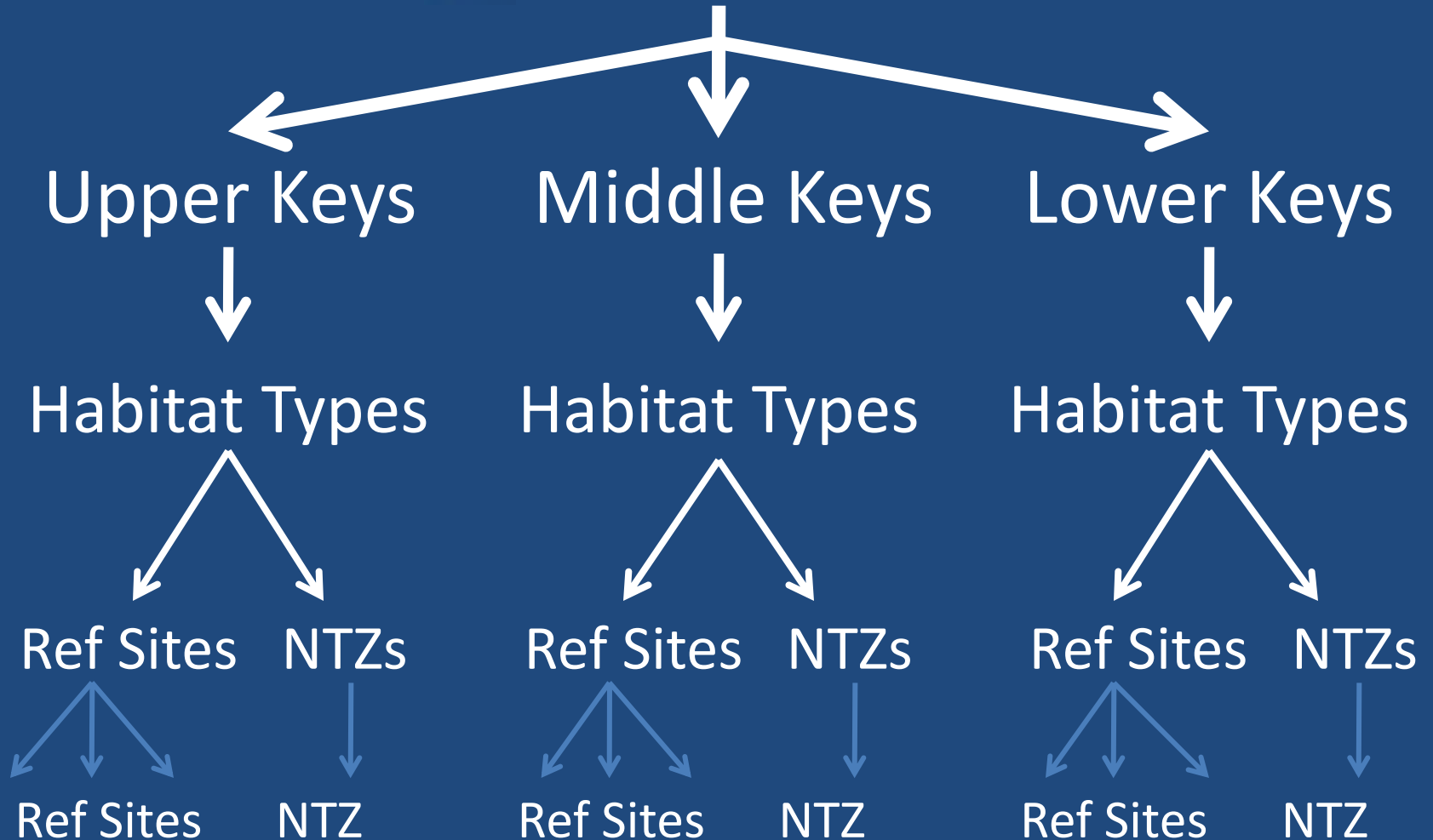
2. Sample Design Statistics – what's important is not how intensely we sample individual sites, but how many sites we can sample while achieving CVs that are acceptable. From density numbers we calculate abundances at the population level.

Symbol	Definition	Computational Formula
k	Stratum identifier	
i	Primary sample unit identifier	
j	Second-stage sample unit identifier	
T_{ik}	Area of i th second-stage unit in primary unit i in stratum k	
M_{ik}	Total possible number of second-stage units in primary unit i in stratum k	
A_{ik}	Area of i th primary unit in stratum k	$A_{ik} = \sum_{j=1}^{M_{ik}} T_{ikj}$
N_k	Total possible number of primary units in stratum k	
A_k	Area of stratum k	$A_k = \sum_{i=1}^{N_k} A_{ik}$
A	Area of entire survey domain	$A = \sum_k A_k$
$N_k M_k$	Total possible number of second-stage units in stratum k	
w_k	Stratum k weighting factor	$w_k = \frac{N_k M_k}{\sum_k N_k M_k}$
C_{ik}	Number of individuals (count estimate) observed in second-stage unit j in primary unit i in stratum k	
D_{ik}	Density (individuals m^{-2}) in second-stage unit j in primary unit i in stratum k	$D_{ikj} = \frac{C_{ikj}}{T_{ikj}}$
D_{ik}	Density of second-stage units sampled in primary unit i in stratum k	
\bar{D}_{ik}	Mean density in primary unit i in stratum k	$\bar{D}_{ik} = \frac{1}{n_{ik}} \sum_{j=1}^{m_{ik}} D_{ikj}$
D_k	Density of primary units sampled in stratum k	
\bar{D}_k	Mean density in stratum k	$\bar{D}_k = \frac{1}{n_k} \sum_{i=1}^{n_k} \bar{D}_{ik}$
s_{ik}^2	Sample variance among primary units in stratum k	$s_{ik}^2 = \frac{\sum_{i=1}^{n_k} (\bar{D}_{ik} - \bar{D}_k)^2}{n_k - 1}$
s_k^2	Sample variance among second-stage units in stratum k	$s_k^2 = \frac{1}{n_k} \sum_{i=1}^{n_k} \left[\frac{\sum_{j=1}^{m_{ik}} (D_{ikj} - \bar{D}_{ik})^2}{m_{ik} - 1} \right]$
\bar{w}_k	Average number of second-stage units sampled per primary unit in stratum k	$\bar{w}_k = \frac{1}{n_k} \sum_{i=1}^{n_k} m_{ik}$

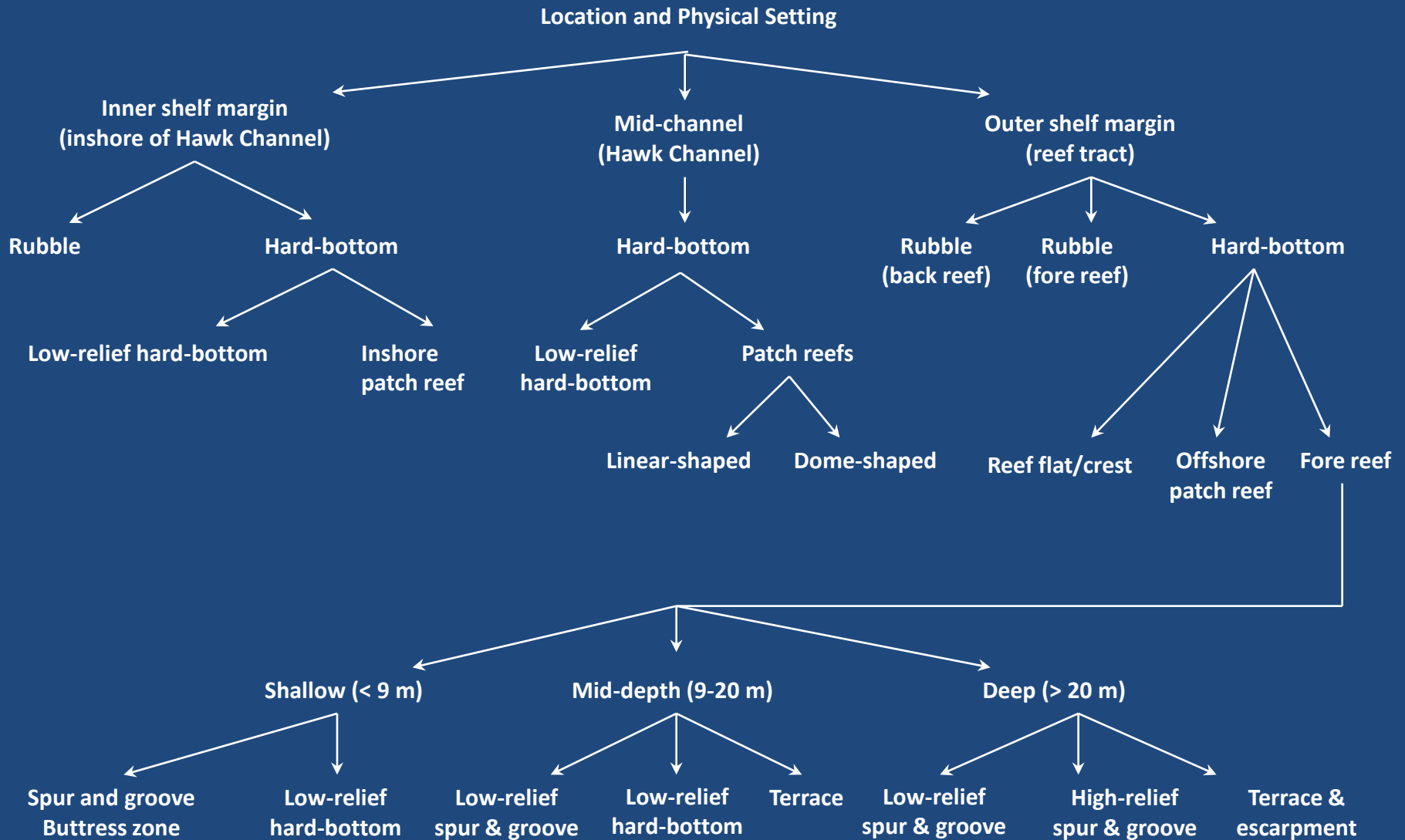
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s_k^2	Sample variance among second-stage units in stratum k	$s_k^2 = \frac{1}{n_k} \sum_{i=1}^{n_k} \left[\frac{\sum_{j=1}^{m_{ik}} (D_{ikj} - \bar{D}_{ik})^2}{m_{ik} - 1} \right]$
\bar{w}_k	Average number of second-stage units sampled per primary unit in stratum k	$\bar{w}_k = \frac{1}{n_k} \sum_{i=1}^{n_k} m_{ik}$
w_k^*	Optimum number of second-stage units sampled per primary unit in stratum k	$w_k^* = \frac{\sqrt{D_{ik}}}{\bar{D}_{ik}}$
$r[\bar{D}_k]$	Design variance for stratum-wide mean density	$r[\bar{D}_k] = k \cdot r[\bar{D}_k] \cdot \bar{D}_k$
s^2	Number of primary units sampled required to achieve a specified variance	$s^2 = \frac{\sum_k w_k^* \left[\sum_{i=1}^{n_k} m_{ik} \cdot s_{ik}^2 + \sum_{i=1}^{n_k} \frac{s_{ik}^2}{m_{ik}} \right]}{r[\bar{D}_k] \cdot \sum_k \frac{w_k^* s_{ik}^2}{N_k}}$
s^{*2}	Optimum allocation of primary units among strata	$s^{*2} = s^2 \left(\frac{\sum_k w_k^*}{\sum_k w_k} \right)$



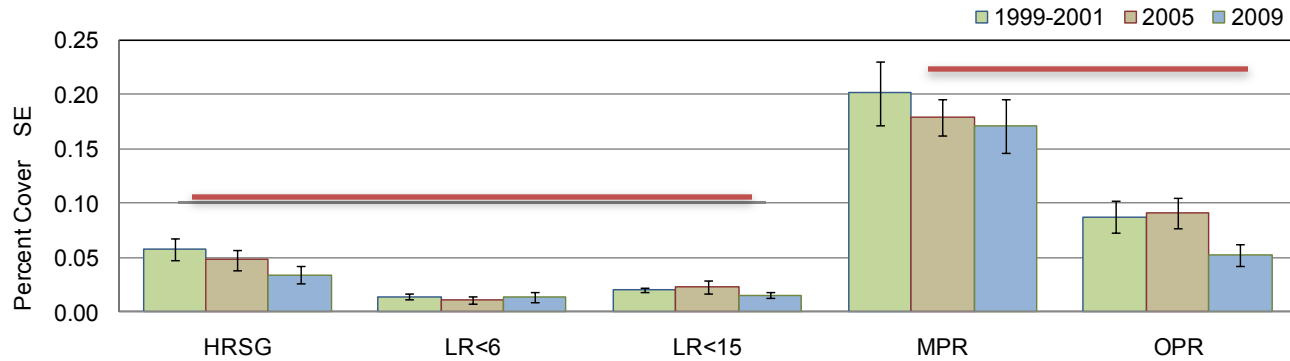
Keys-wide Stratification



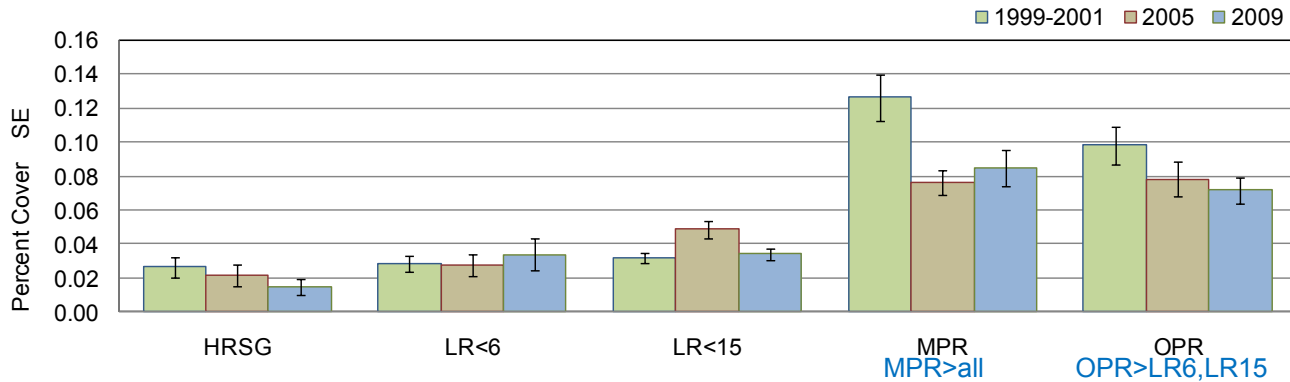
Structural Classification of Florida Keys Hard-bottom Habitats



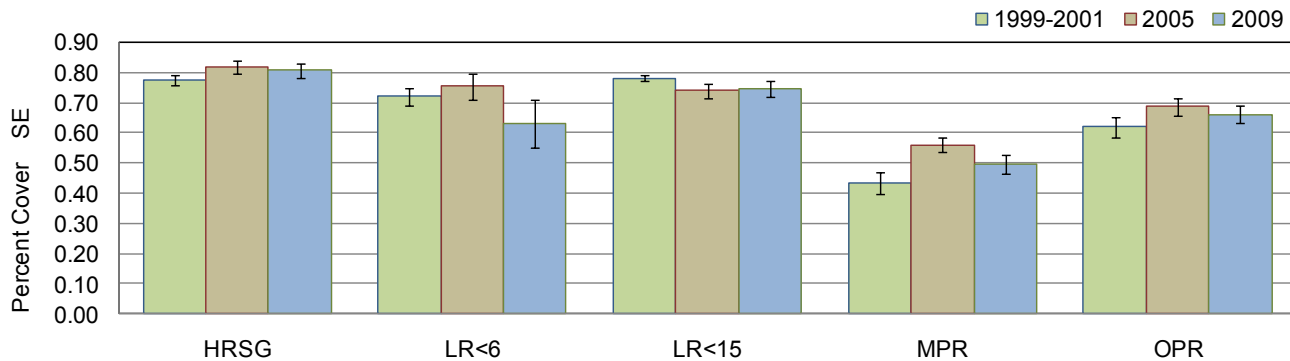
Scleractinian Percent Cover by Habitat



Sponge Percent Cover by Habitat



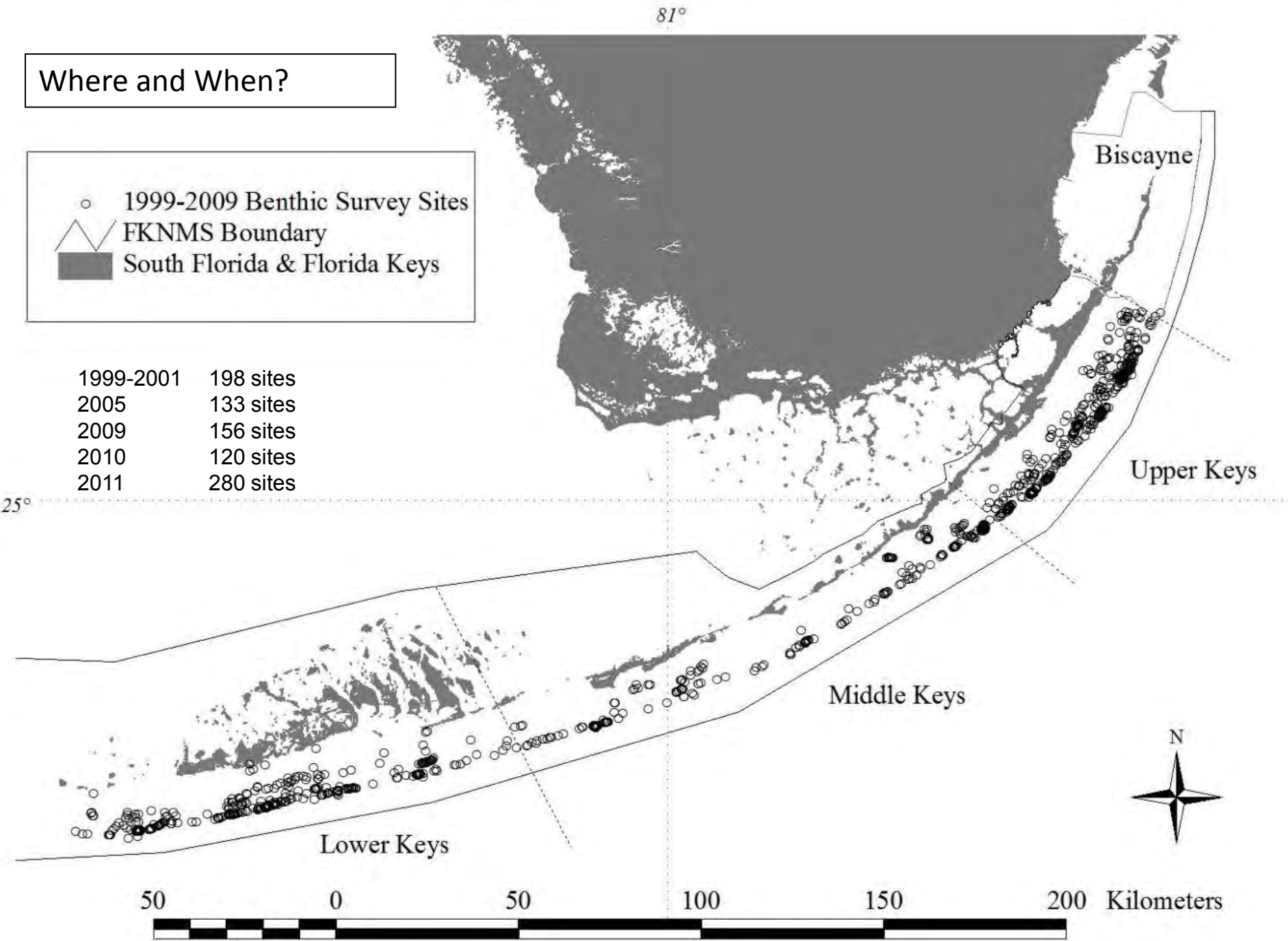
Total Algae Percent Cover by Habitat



Where and When?

- 1999-2009 Benthic Survey Sites
- ▬ FKNMS Boundary
- South Florida & Florida Keys

1999-2001	198 sites
2005	133 sites
2009	156 sites
2010	120 sites
2011	280 sites

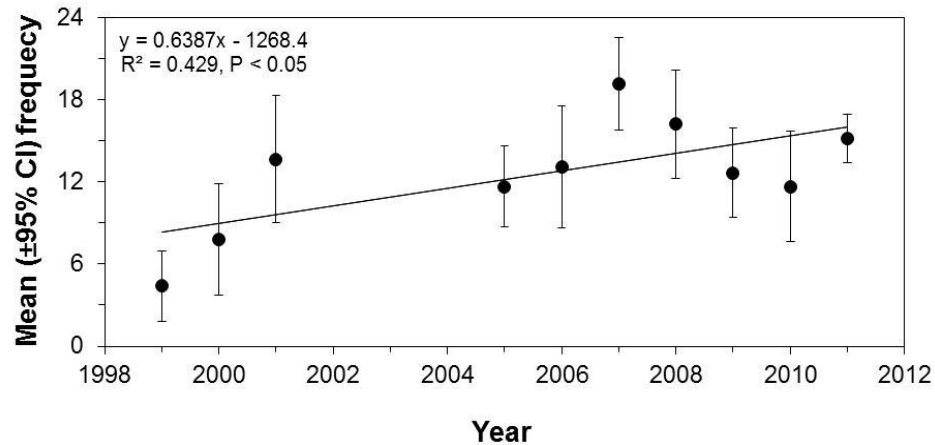


Population summaries and NTZ comparisons

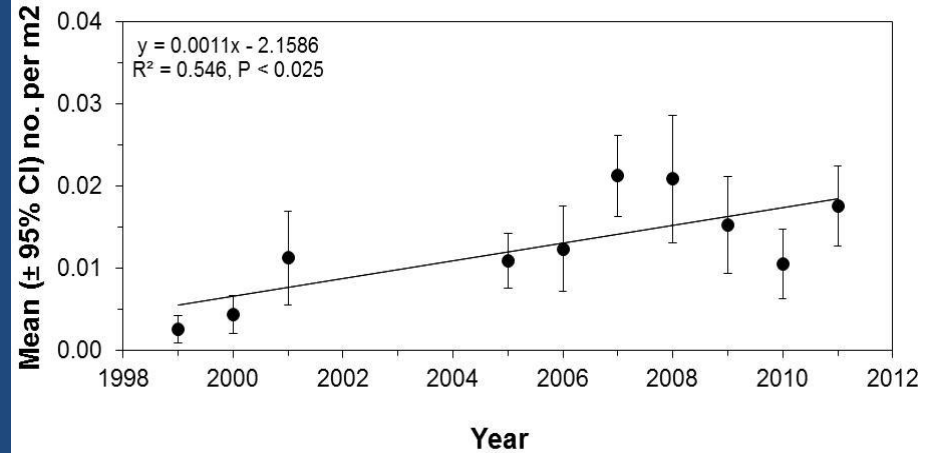
- Diadema
- Marine Debris
- Anemones and Corallimorphs
- NTZs vs Reference sites
- Status update on *Acropora palmata* and *A. cervicornis*
- Future of reefs in Florida
- Ranking of best remaining sites (GIS)

Population trends for *Diadema*

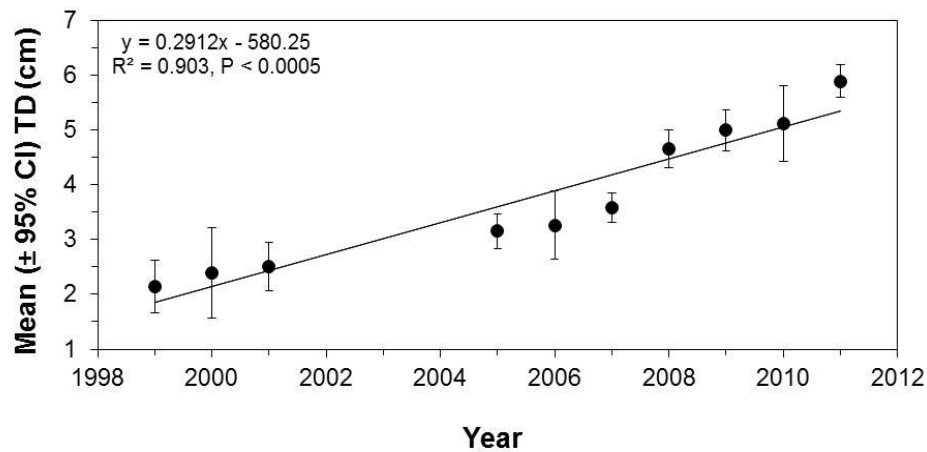
Transect frequency



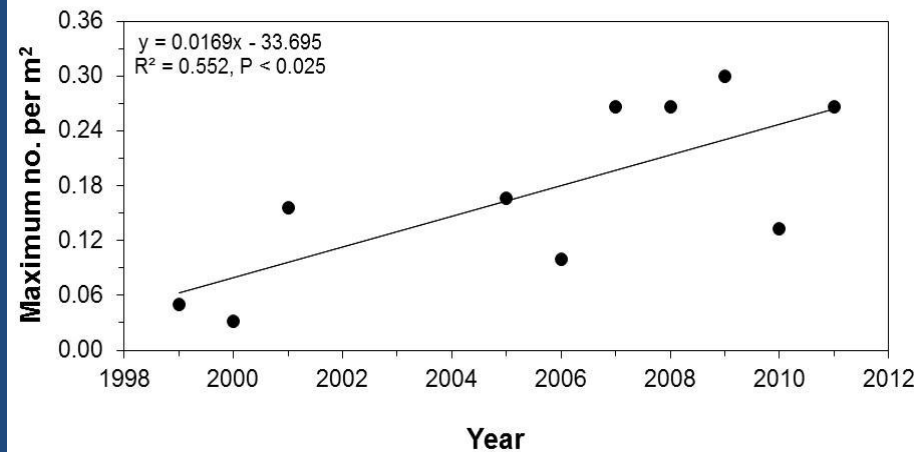
Mean density



Mean test diameter



Maximum density





NTZ vs Ref Sites - *Diadema* stories...



Version 1: historical

Urchin abundance ↓

Algal abundance ↑

Coral recruitment ↓

Version 2: No-Take zones

Fish ↑



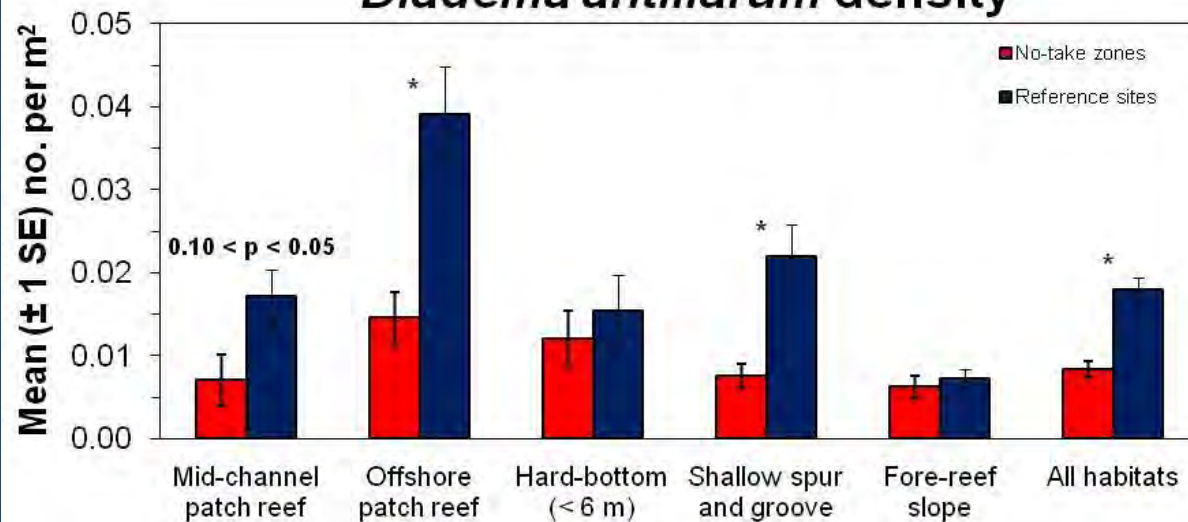
Urchin abundance

Algal abundance

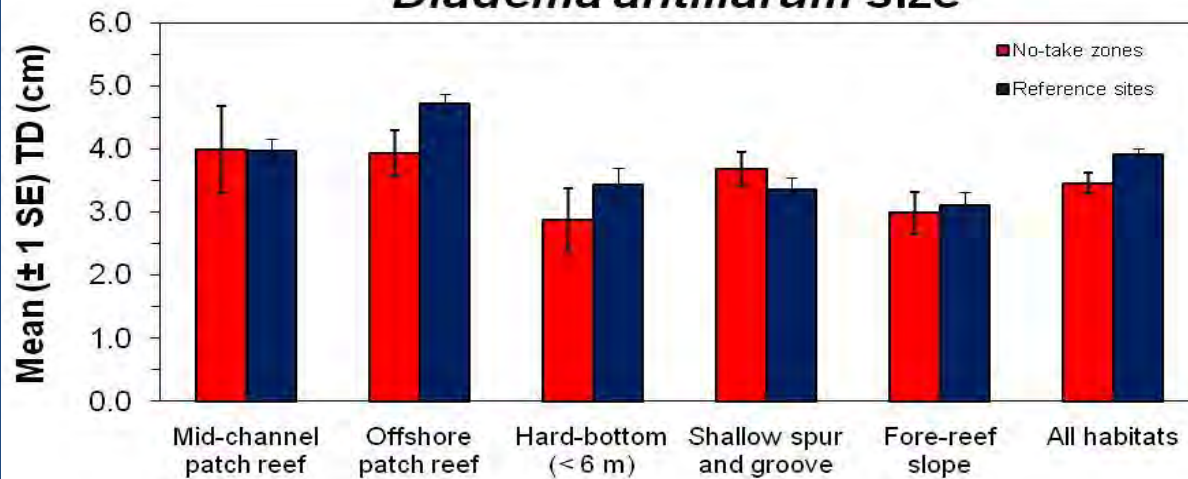
Coral recruitment



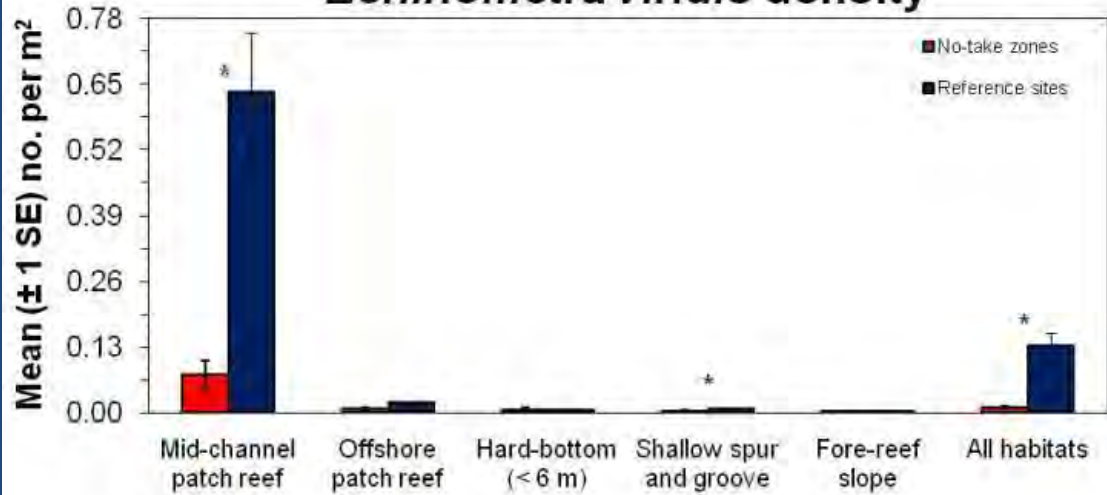
Diadema antillarum density



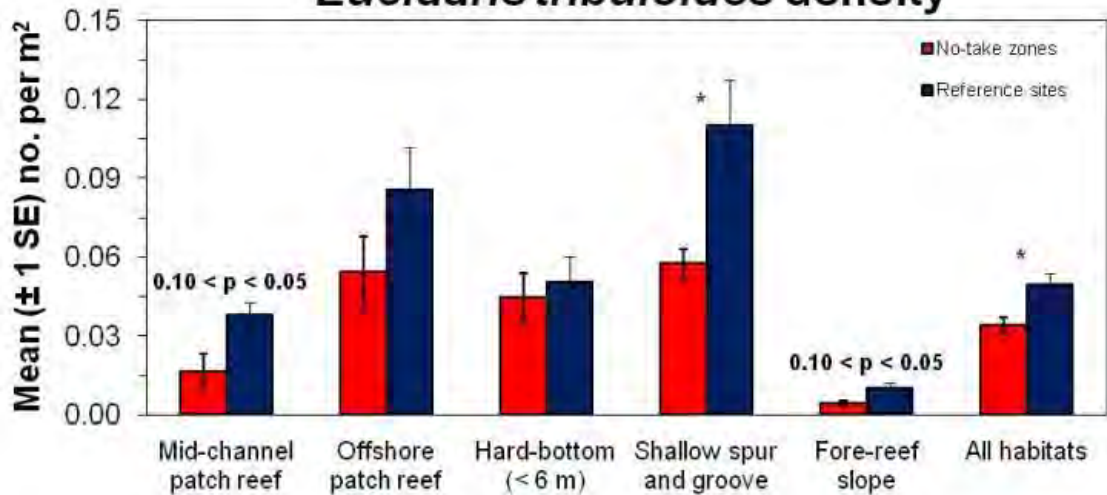
Diadema antillarum size



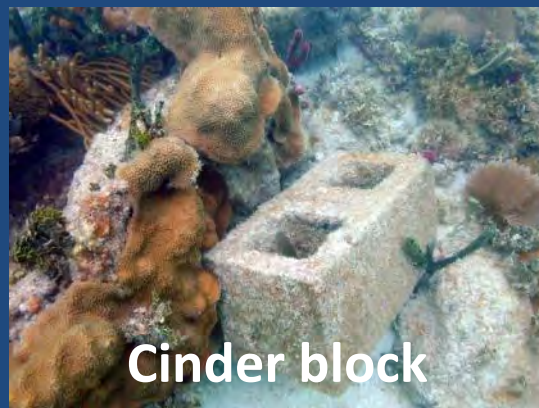
Echinometra viridis density



Eucidaris tribuloides density



Florida Keys Marine Debris: Non-compliance is an ongoing challenge



2011 Angling Debris
Density (items/30m²) from the
BNP Boundary to South Carysfort Reef

Angling Debris Density (items/30m²)

- × Absent
- < 1
- 1 - 3
- 3 - 5
- 5 - 10
- > 10

- △ FKNMS Boundary
- FKNMS No-Take Zones
- South Florida & Florida Keys

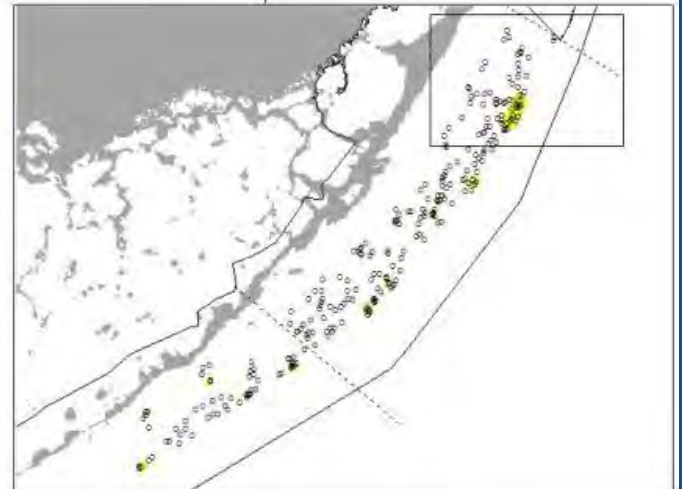
0 2 4 6 Kilometers



Biscayne National Park Boundary

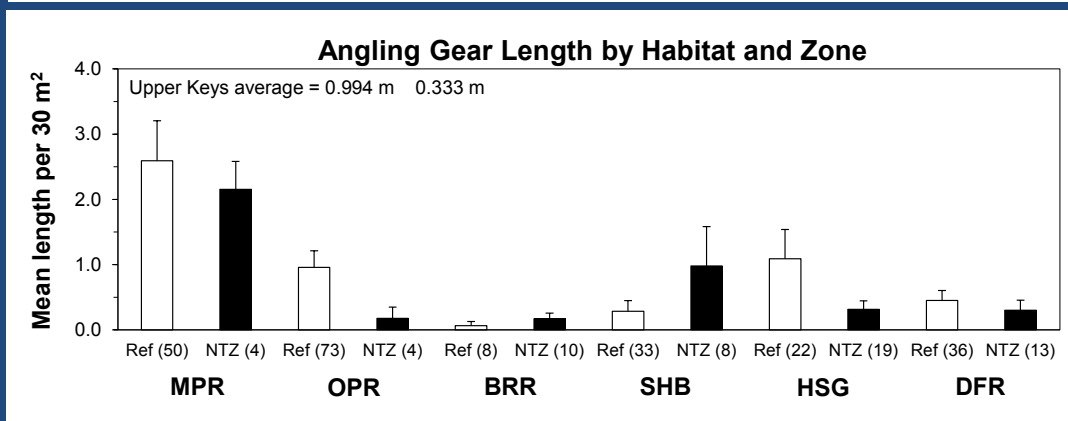
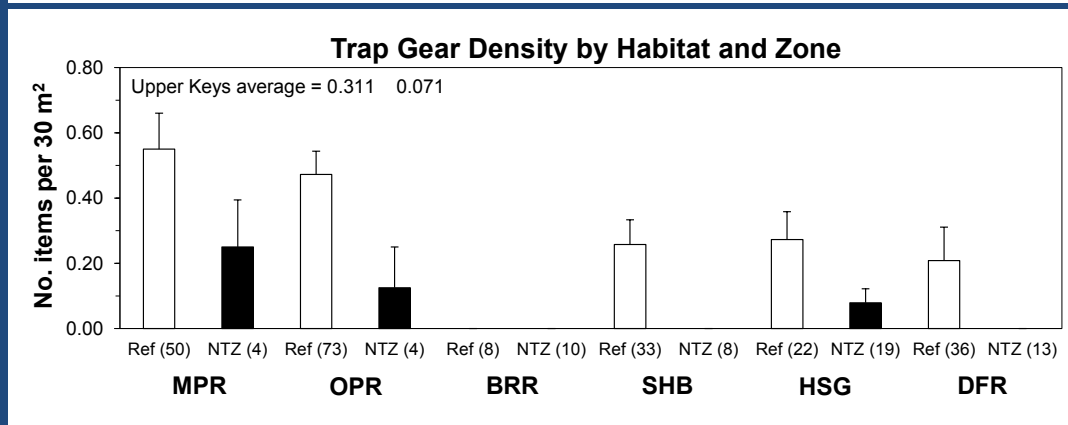
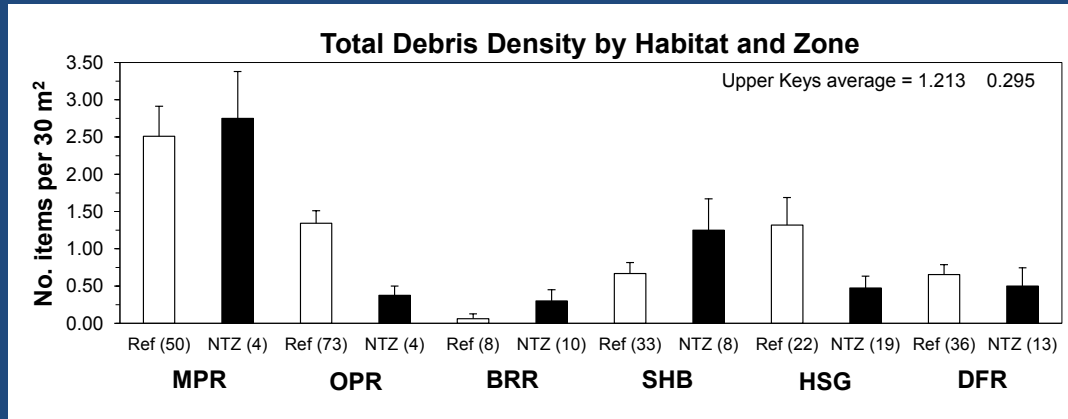
25°20'

80°20'



Marine Debris: NTZs vs Reference Sites

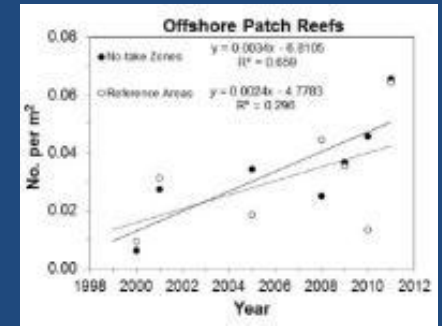
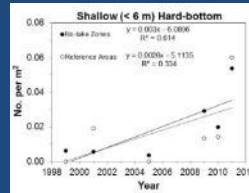
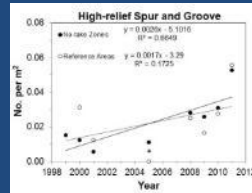
NTZs
 Refs



Anemones and Corallimorpharians

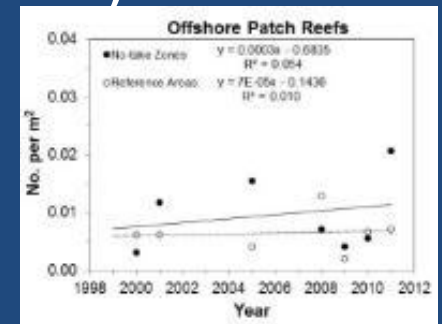
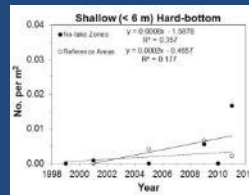
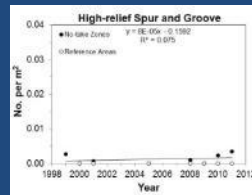
- *Bartholomea annulata* (corkscrew anemone)

Increasing Keys-wide, both inside and outside zones



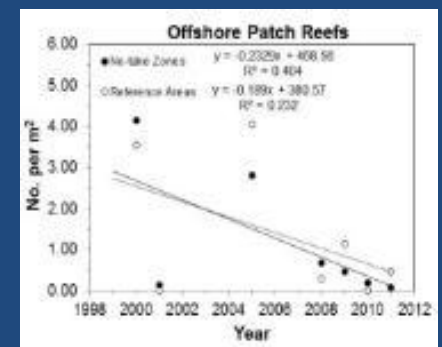
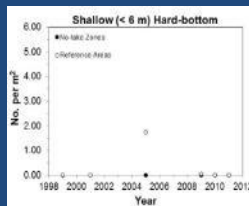
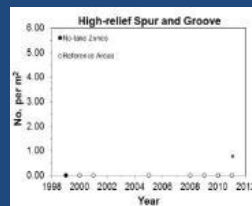
- *Condylactis gigantea* (pink-tipped anemone)

Low abundance, little change, but MPR Upper Keys ↓

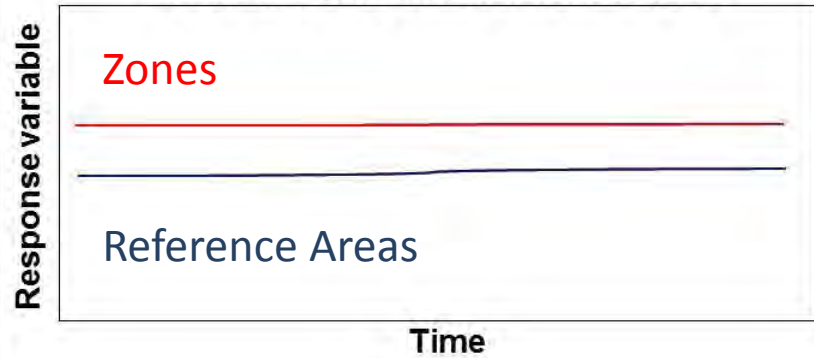


- *Ricordea florida* (Florida corallimorph)

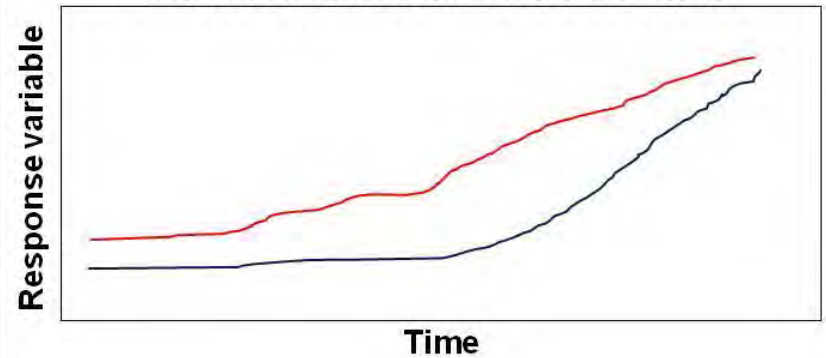
Decreasing Keys-wide, both inside and outside of zones



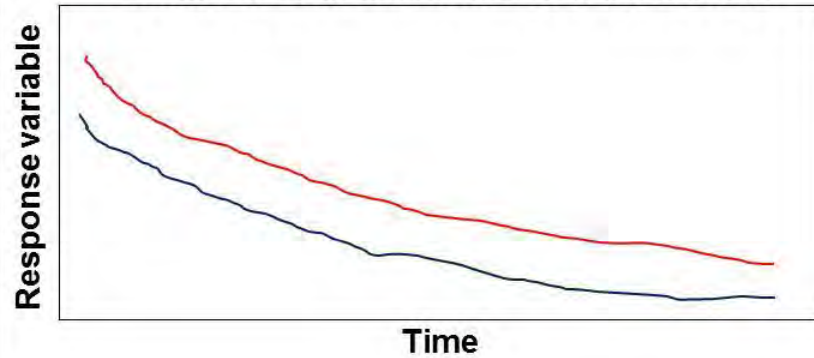
Stasis in Zones and Reference Areas



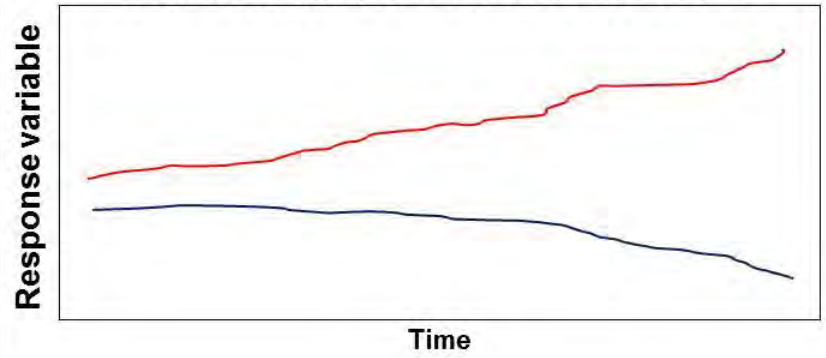
Increase in Zones and Reference Areas



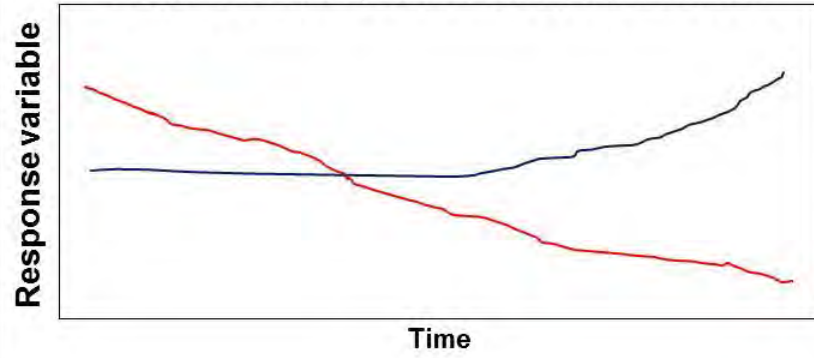
Decline in Both Zones and Reference Areas



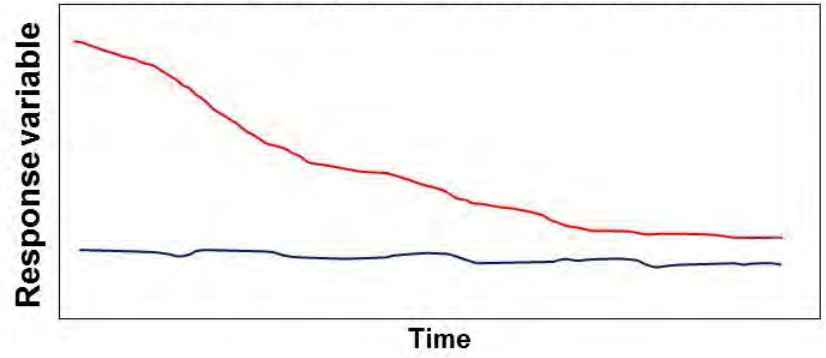
Zones Increase, Reference Areas Decline



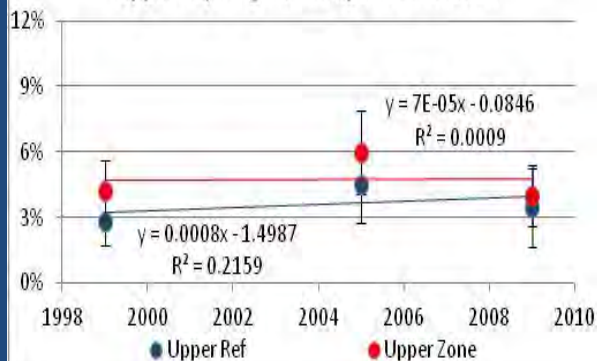
Zones Decrease, Reference Areas Increase



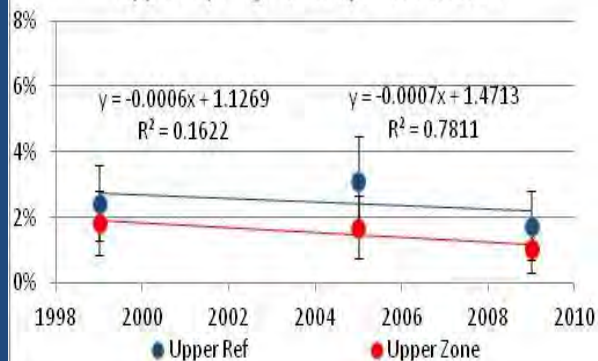
Zones Become Similar to Reference Areas



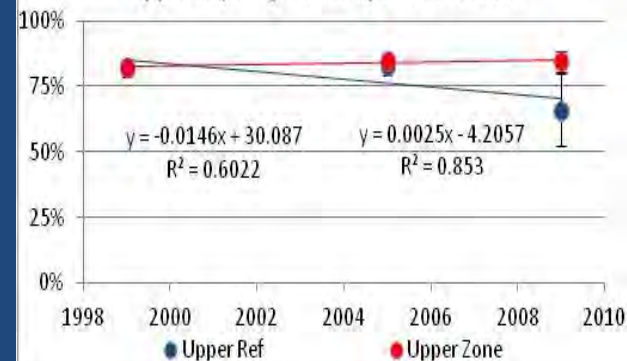
Scleractinian Percent Cover (±SE):
Upper Keys High Relief Spur and Groove



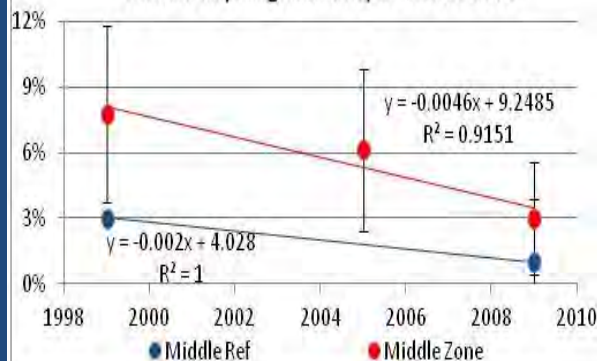
Sponge Percent Cover (±SE):
Upper Keys High Relief Spur and Groove



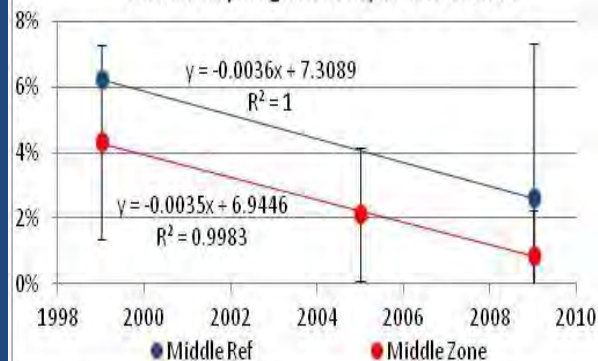
Total Algae Percent Cover (±SE):
Upper Keys High Relief Spur and Groove



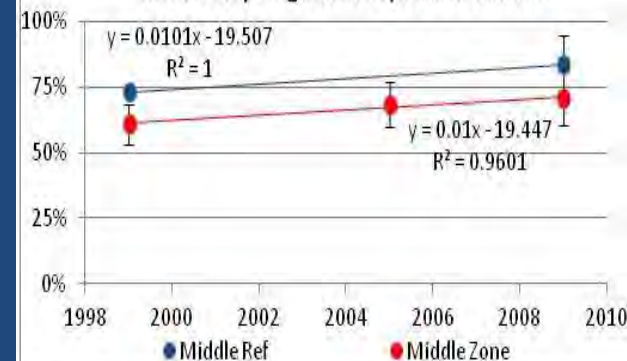
Scleractinian Percent Cover (±SE):
Middle Keys High Relief Spur and Groove



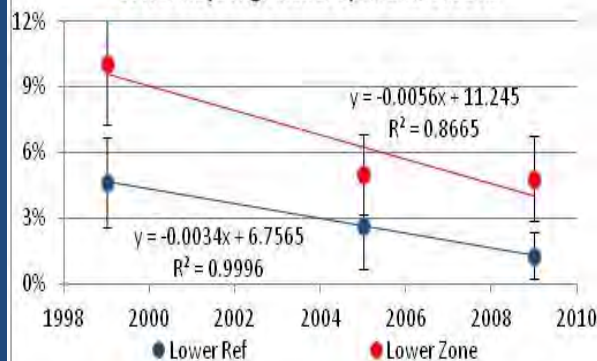
Sponge Percent Cover (±SE):
Middle Keys High Relief Spur and Groove



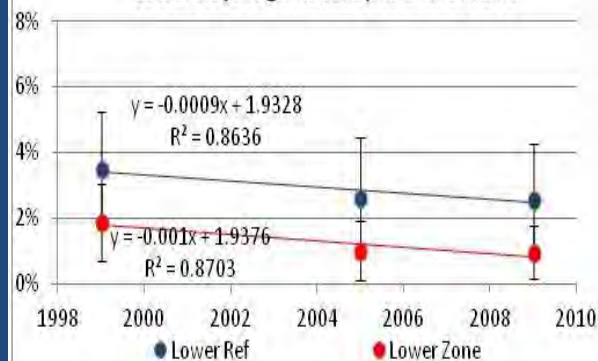
Total Algae Percent Cover (±SE):
Middle Keys High Relief Spur and Groove



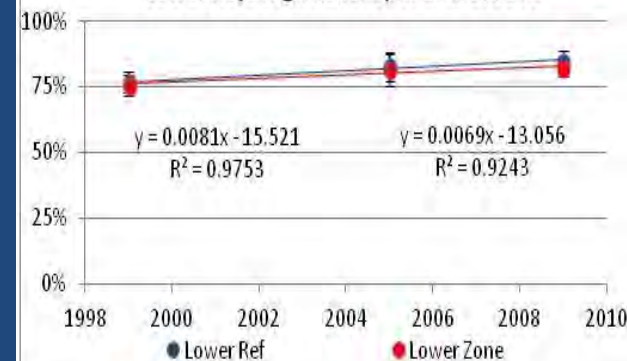
Scleractinian Percent Cover (±SE):
Lower Keys High Relief Spur and Groove

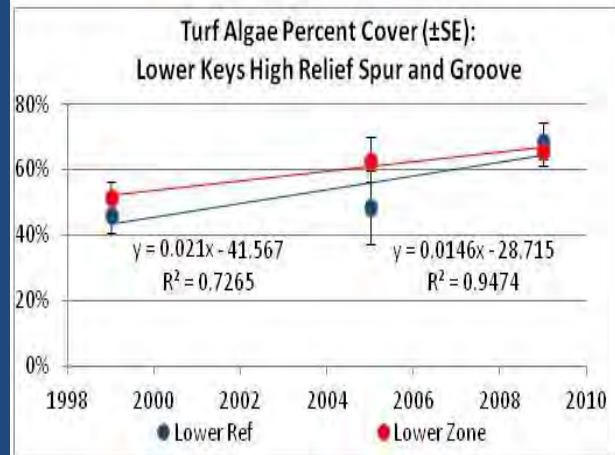
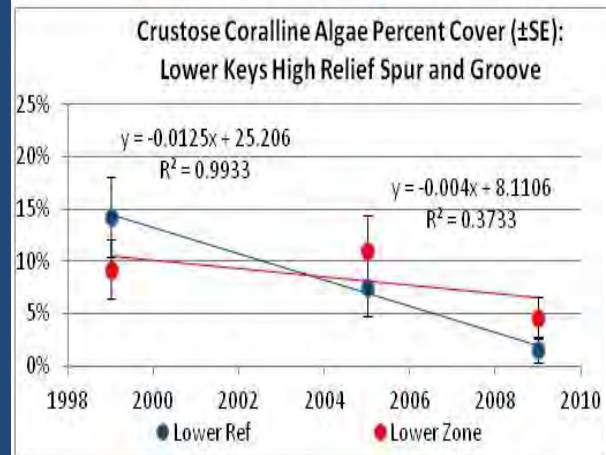
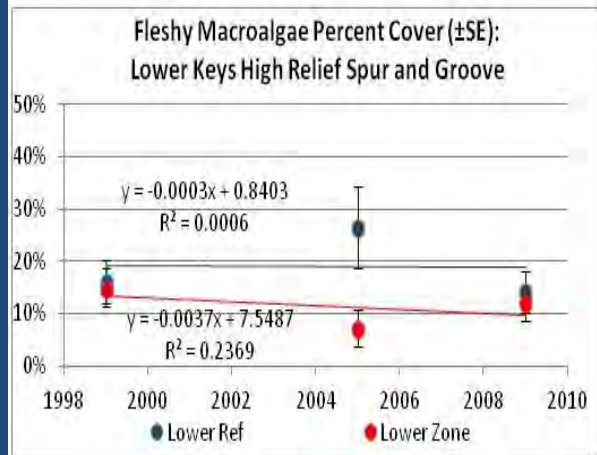
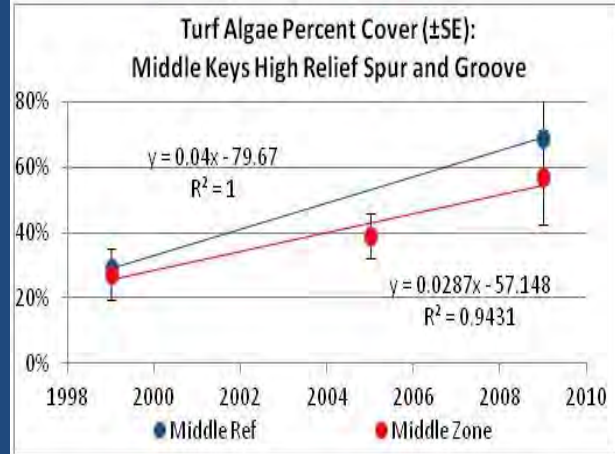
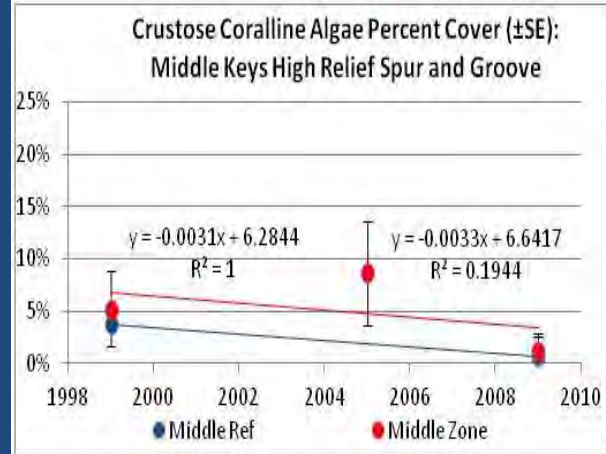
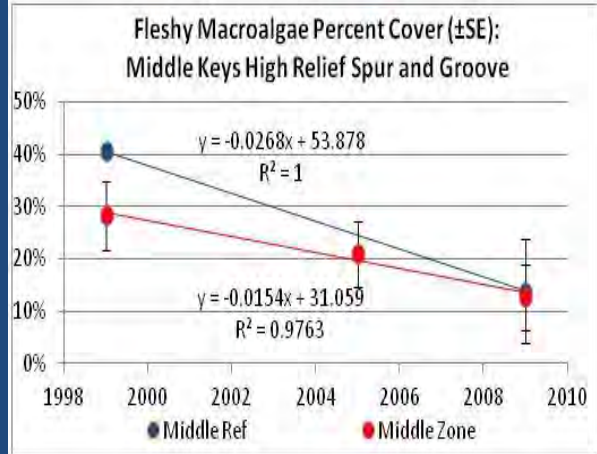
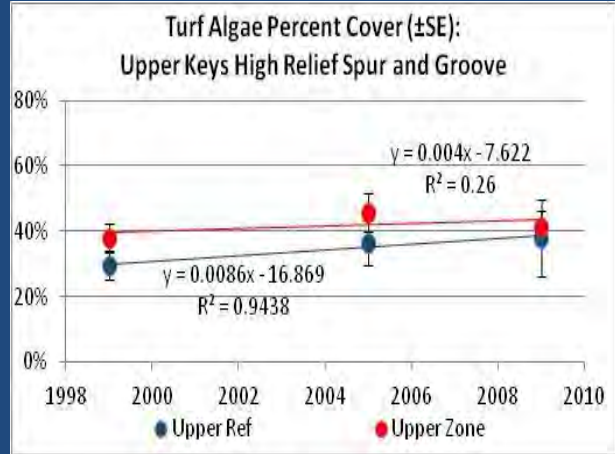
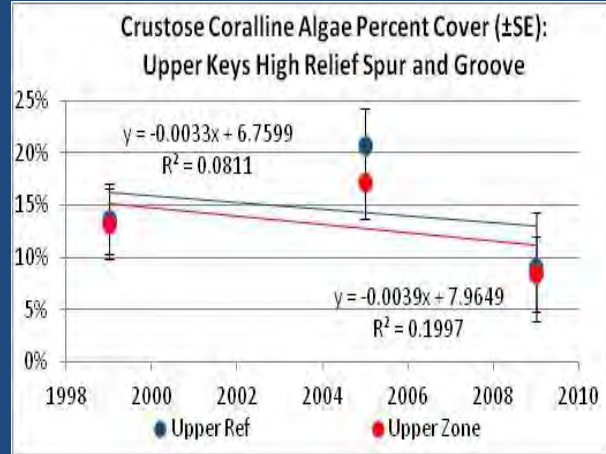
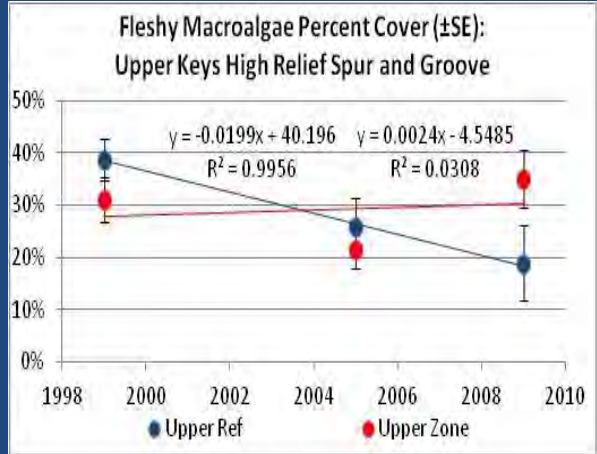


Sponge Percent Cover (±SE):
Lower Keys High Relief Spur and Groove



Total Algae Percent Cover (±SE):
Lower Keys High Relief Spur and Groove

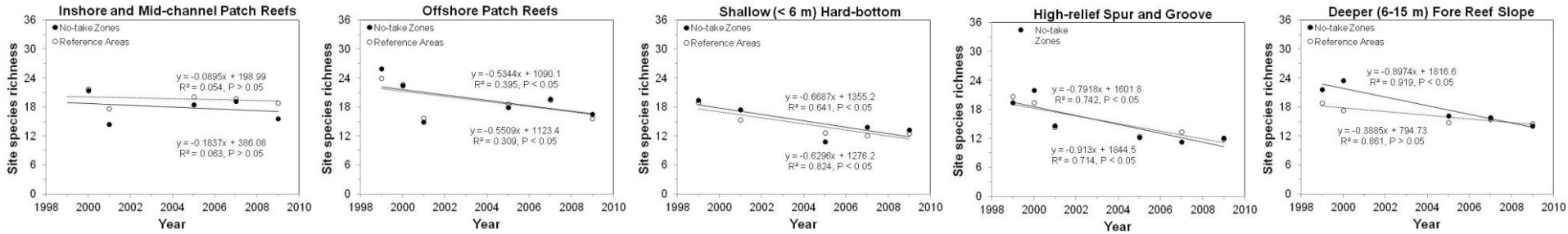




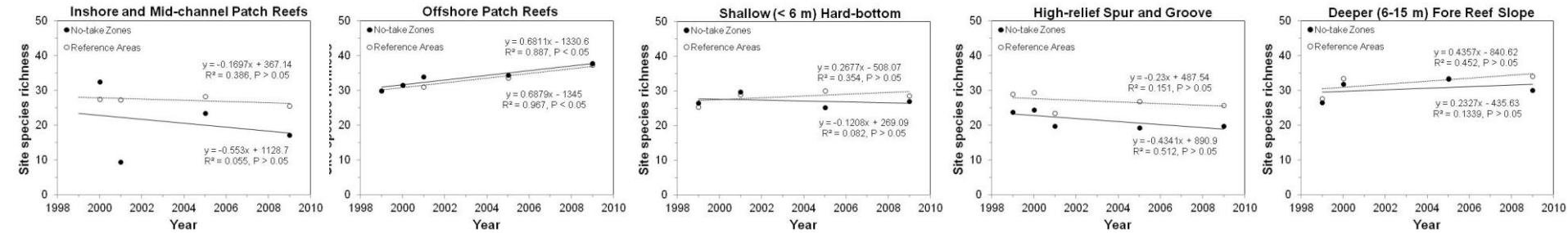
Species Richness (1999-2009)

by cross-shelf habitat type by site management zone

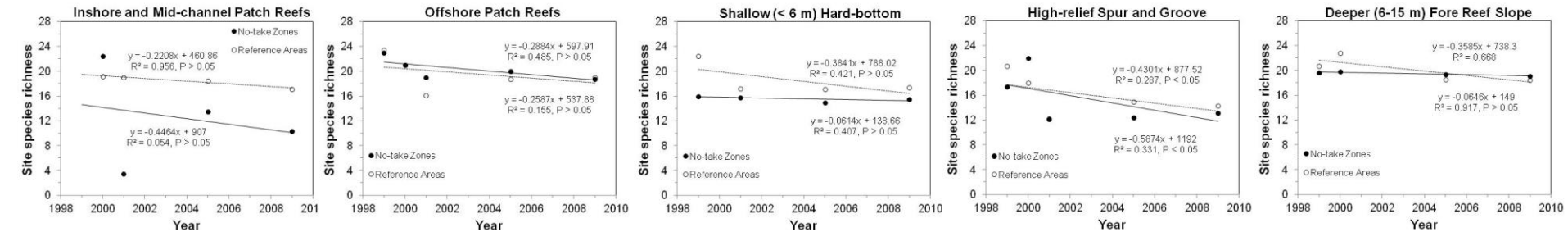
Coral



Sponge

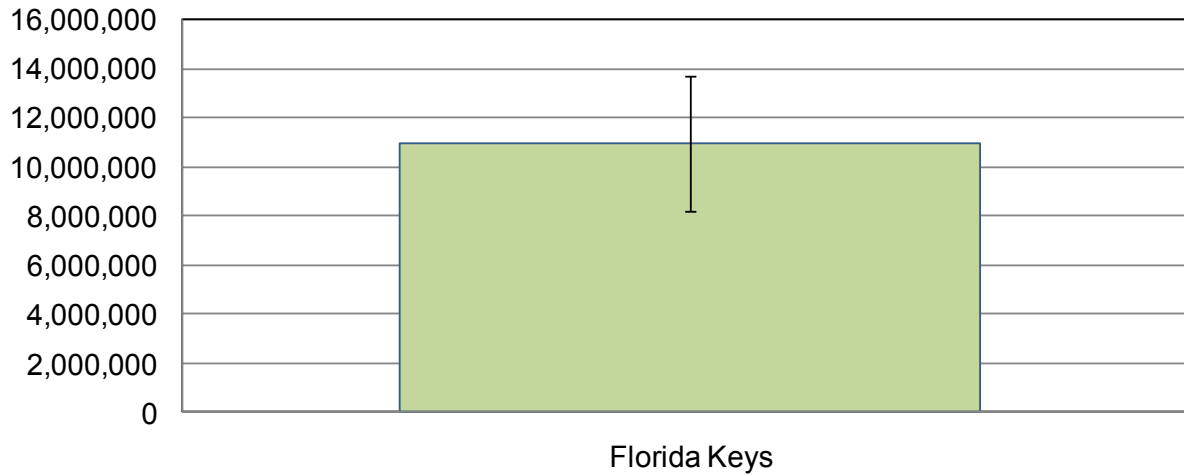


Gorgonian

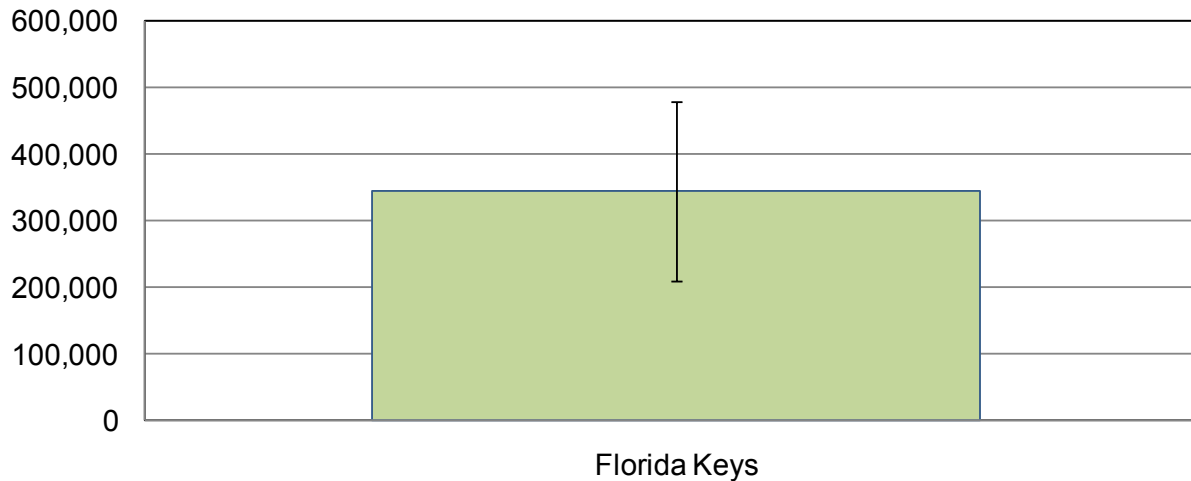


Florida Keys *Acropora* Coral Populations

A. cervicornis Abundance 1999-2009

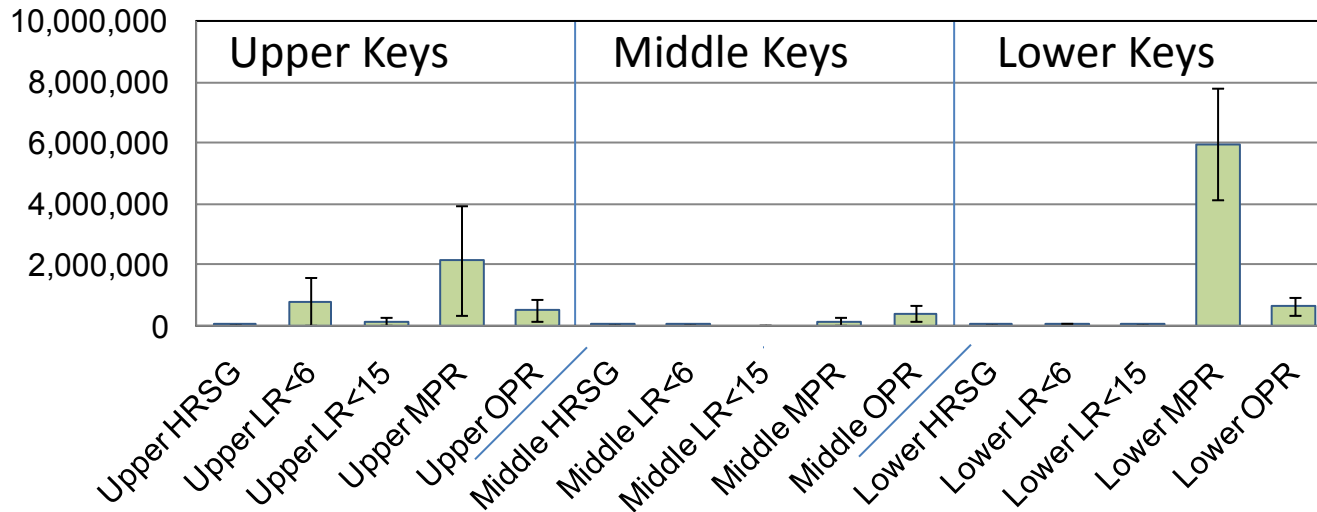


A. palmata Abundance 1999-2009

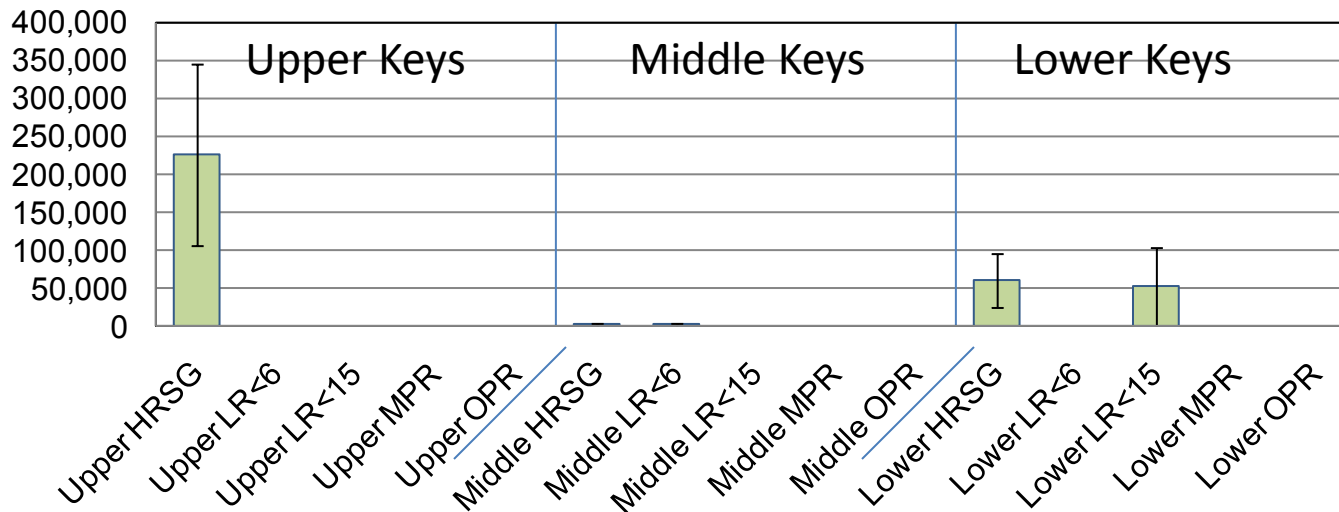


Acropora Coral Populations by Region and Habitat Type

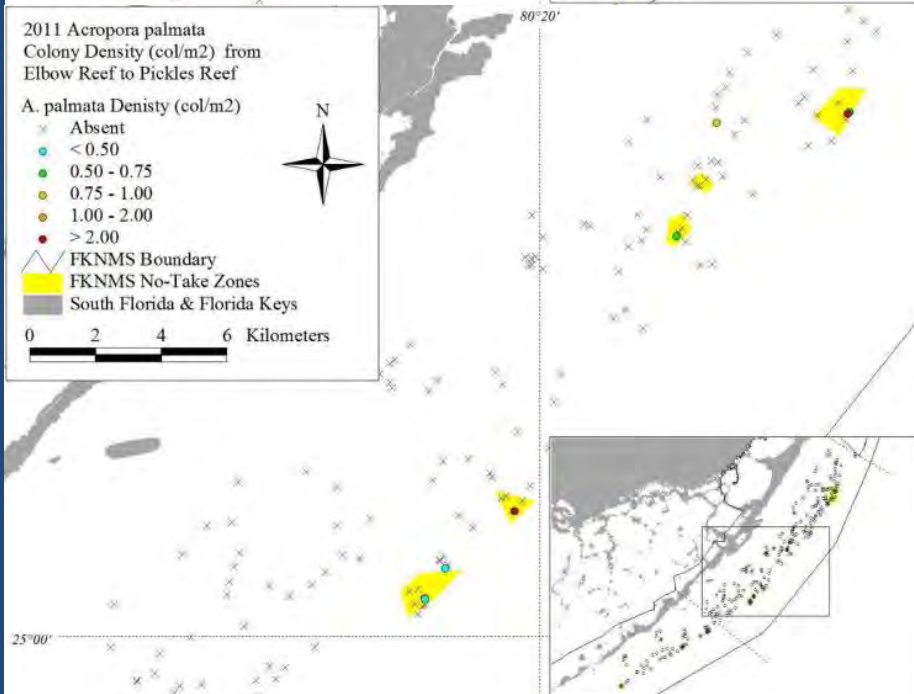
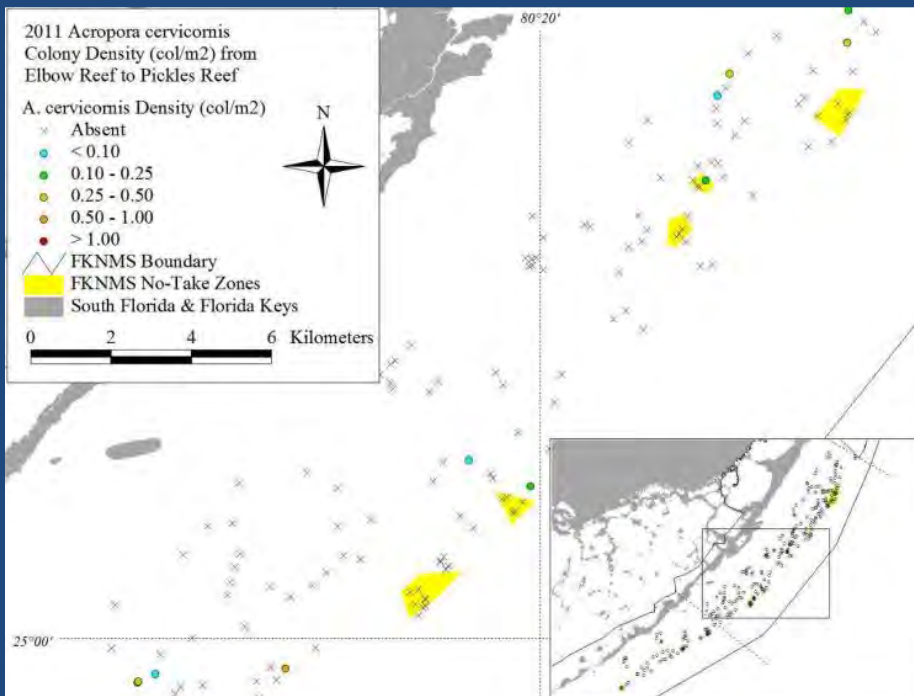
A. cervicornis Abundance 1999-2009



A. palmata Abundance 1999-2009



Distribution and Abundance of *Acropora* corals in the Upper FKNMS



Upper Keys

Acropora palmata 39.1%
Acropora cervicornis 1.5%

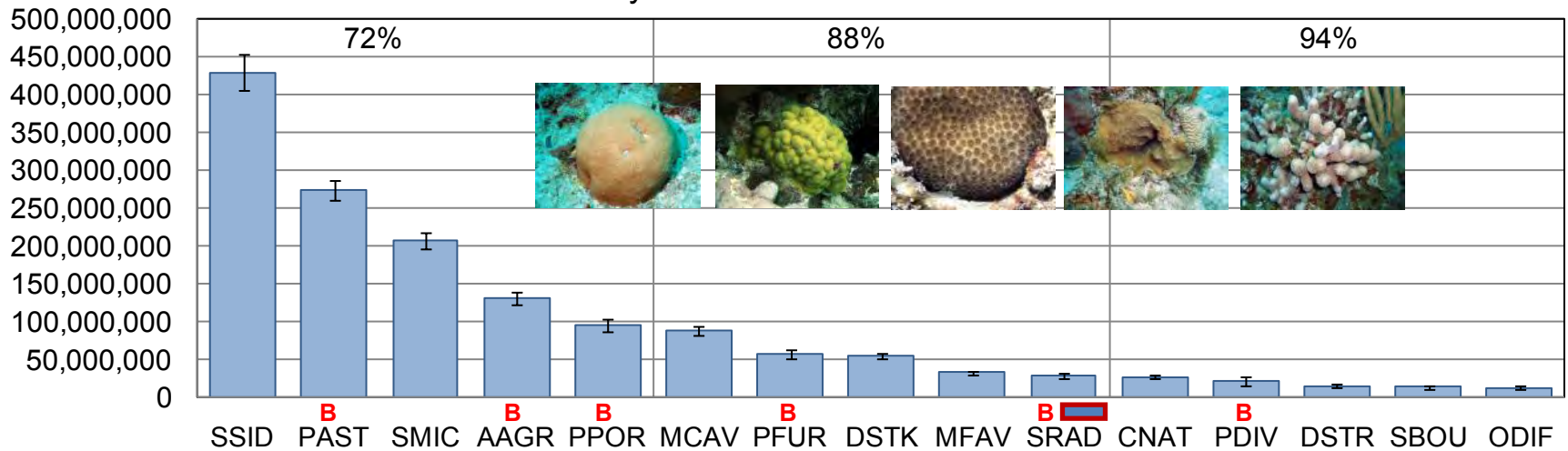
Protected Keys-wide

Acropora palmata 33.3%
Acropora cervicornis 4.3%

The Future of Coral Reefs in the FKNMS

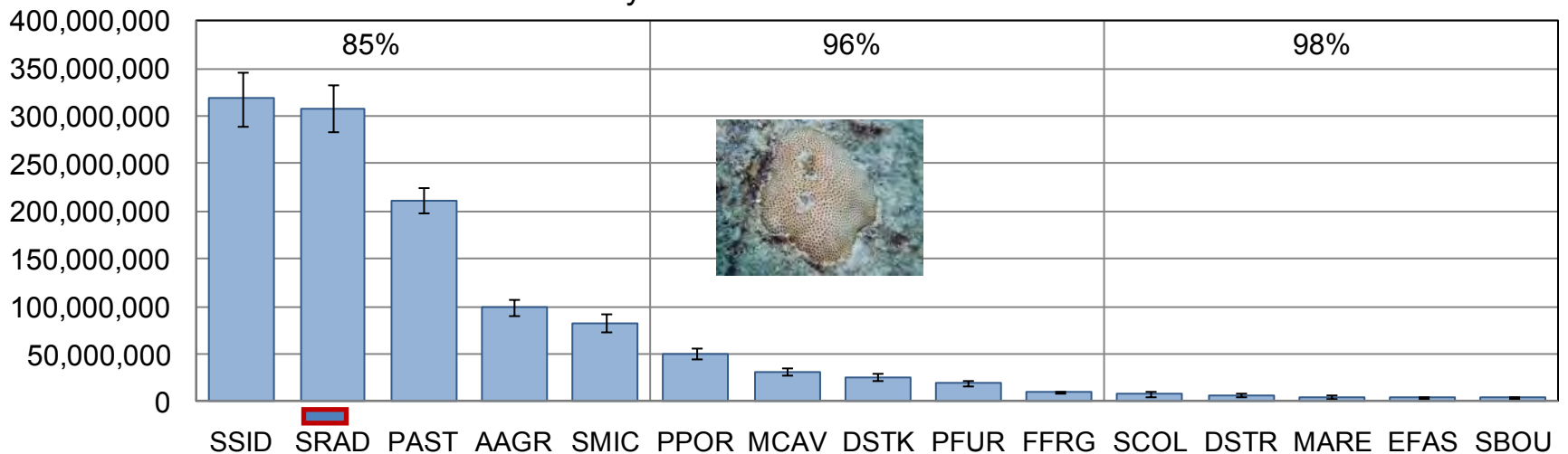
Scleractinian Abundance: Top 15 species

Florida Keys 1999-2009 All Habitats



Juvenile Scleractinian Abundance: Top 15 species

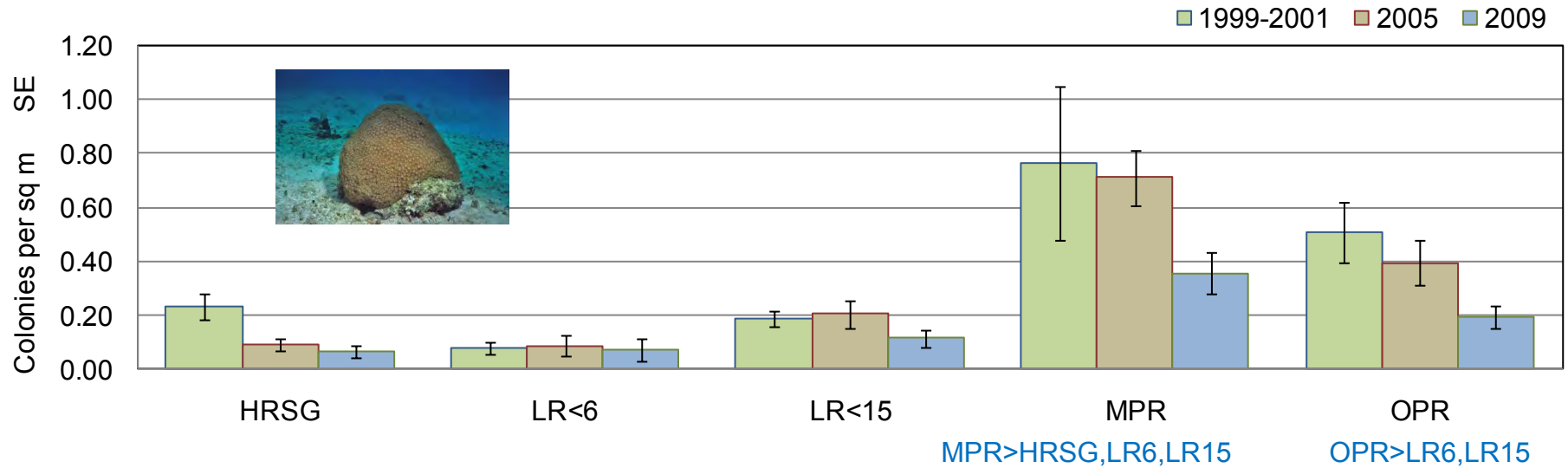
Florida Keys 1999-2009 All Habitats



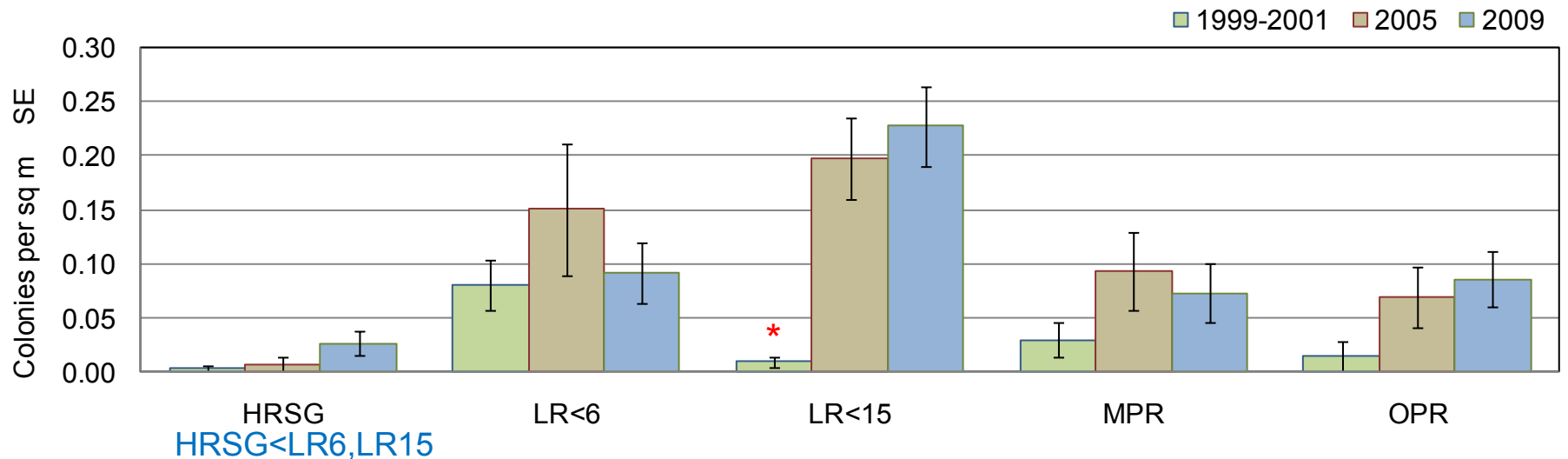
Is this the future of coral reefs in the Florida Keys?



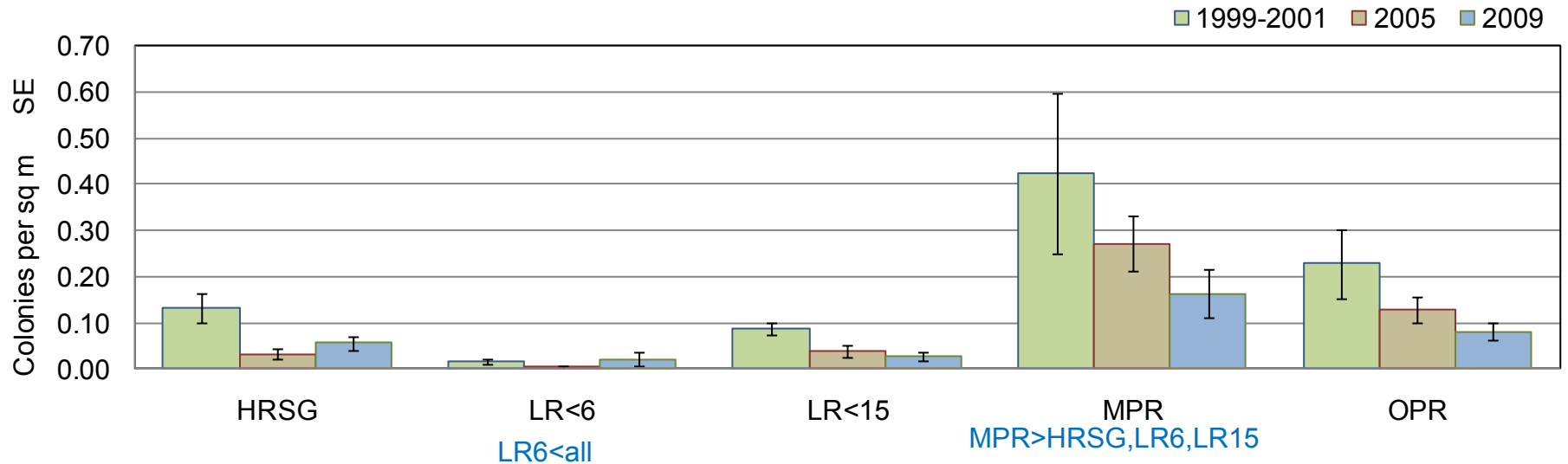
Montastraea cavernosa Colony Density by Habitat



Montastraea cavernosa Juvenile Density by Habitat



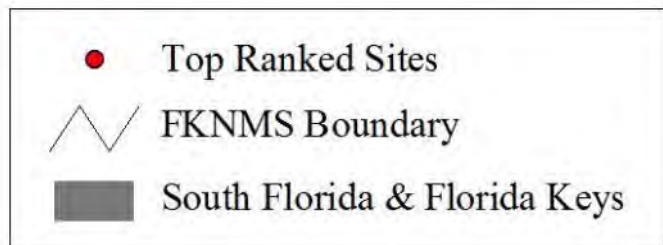
Montastraea faveolata Colony Density by Habitat



No juvenile observations for
Montastraea faveolata

81°

Keyswide Top Ranked Sites



25°

Biscayne

Upper Keys

Middle Keys

Lower Keys



100

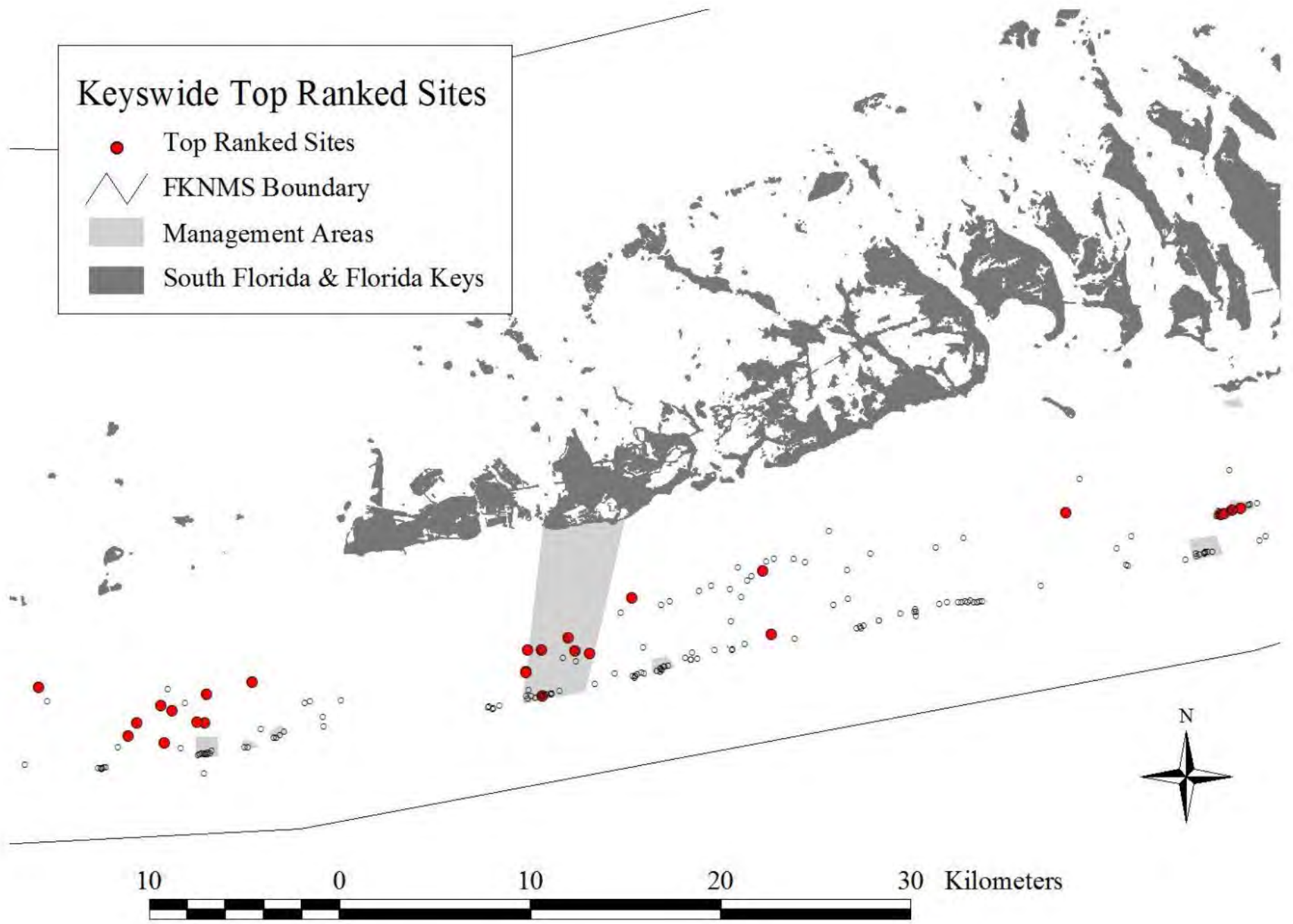
0

100 Kilometers



Keyswide Top Ranked Sites

- Top Ranked Sites
- ∩ FKNMS Boundary
- Management Areas
- South Florida & Florida Keys



Next Steps

- Field work this summer, Keys-wide for Acropora, corals and urchins, expanding into Dade and Broward.
- Sample allocations for USVI/PR
 - Integration of our data with NOAA/FWC Geographical Information System (GIS)
 - Spatial Analyses and GIS development to contribute to the FKNMS Management Plan Review
- Publications related to distribution and abundance of corals, gorgonians, and sponges throughout the FKNMS

Conclusions

- System-wide, related to some of the iconic species found in the sanctuary, such as *Diadema* and the *Acroporids*, populations are increasing or stable the ten years. This is good news.
- Substantial decline has occurred over several decades related to coral cover. Some species that were resistant previously are now in decline too. This is bad news.
- Related to NTZs, it's a mixed bag. We've seen some interesting results, but community-level effects are likely to take a long time, if they occur at all.
- Results should help inform discussions about NTZ design factors in the FKNMS, especially related to their location and enforcement. Size and connectivity are also important.

Management Relevance

- NOAA/National Marine Sanctuary Program
 - Abundance estimates as they relate to coral collecting permits
 - FKNMS Condition Report
- NOAA/Office of Protected Species
 - Status of *Acropora* coral populations
 - Status of other stony coral populations (upcoming workshop)
- State of Florida/FWC/FWRI
 - Population status of *Condylactis gigantea* and *Ricordea florida*
 - Population status and trends in *Diadema antillarum*
 - GIS Development (NOAA too)
- Mote Marine Laboratory
 - Status and trends in sea urchin populations
- Florida Sea Grant/RSMAS-University of Miami
 - Status and trends in subtidal marine debris
- IUCN
 - Caribbean-wide assessment of marine protected areas (upcoming workshop)
- Program Development
 - Florida Reef Resiliency Program, USVI/PR Acropora Program

No-Take-Zones in the Sanctuary

- No-take zones were not randomly selected
 - Encompass many of the best-developed reefs
 - Most were designed to separate incompatible uses and to protect well-developed fore reef areas and some patch reefs
 - Large areas of patch reefs, low-profile hard-bottom, and deeper fore-reef not protected
 - Some zones include more than one habitat type
 - High intra- and inter-site variability
 - Different disturbance histories
 - Regional variations due to continental influence



Coral Species	Keys-wide Protection	Abundance
<i>M faveolata</i>	10.68%	27,705,353
<i>M annularis</i>	16.97%	4,397,919
<i>M franksi</i>	12.39%	3,016,993
<i>A cervicornis</i>	4.29%	8,593,852
<i>A palmata</i>	33.27%	605,808
<i>D stokesii</i>	4.15%	49,735,917
<i>D cylindrus</i>	11.80%	151,452

Preliminary
Draft

Coral Species Richness: Regional Summary

Species Richness	Upper Keys			Middle Keys			Lower Keys		
	1999	2005	2009	1999	2005	2009	1999	2005	2009
Total Richness	29	37	34	40	38	35	50	45	39
Abundant Species	14	15	15	15	15	15	15	15	15
Scarce Species	15	22	19	25	23	20	35	30	24

Coral Species Richness: Keys-wide and No-Take Zone Summaries

Species Richness	1999-2001 (198)	2005 (133)	2009 (156)
Total Richness	50	47	41
Abundant Species	15	15	15
Scarce Species	35	32	26
Added		MYCT	PHYL
Lost		AGRA, ALAM, MCAR, PCOL	AHUM, IRIG, ISIN, MFOR, MSEN, PBRA
Previously Lost in 2005			AGRA, ALAM, MCAR, PCOL

Species Richness	Reference Sites			No-Take Zones		
	1999	2005	2009	1999	2005	2009
Total Richness	50	46	39	48	38	38
Abundant Species	15	15	15	15	15	15
Scarce Species	35	31	24	33	23	23