Statistical Survey Design for Assessing Response to MPA Zoning: Application to Reef Fishes in South Florida

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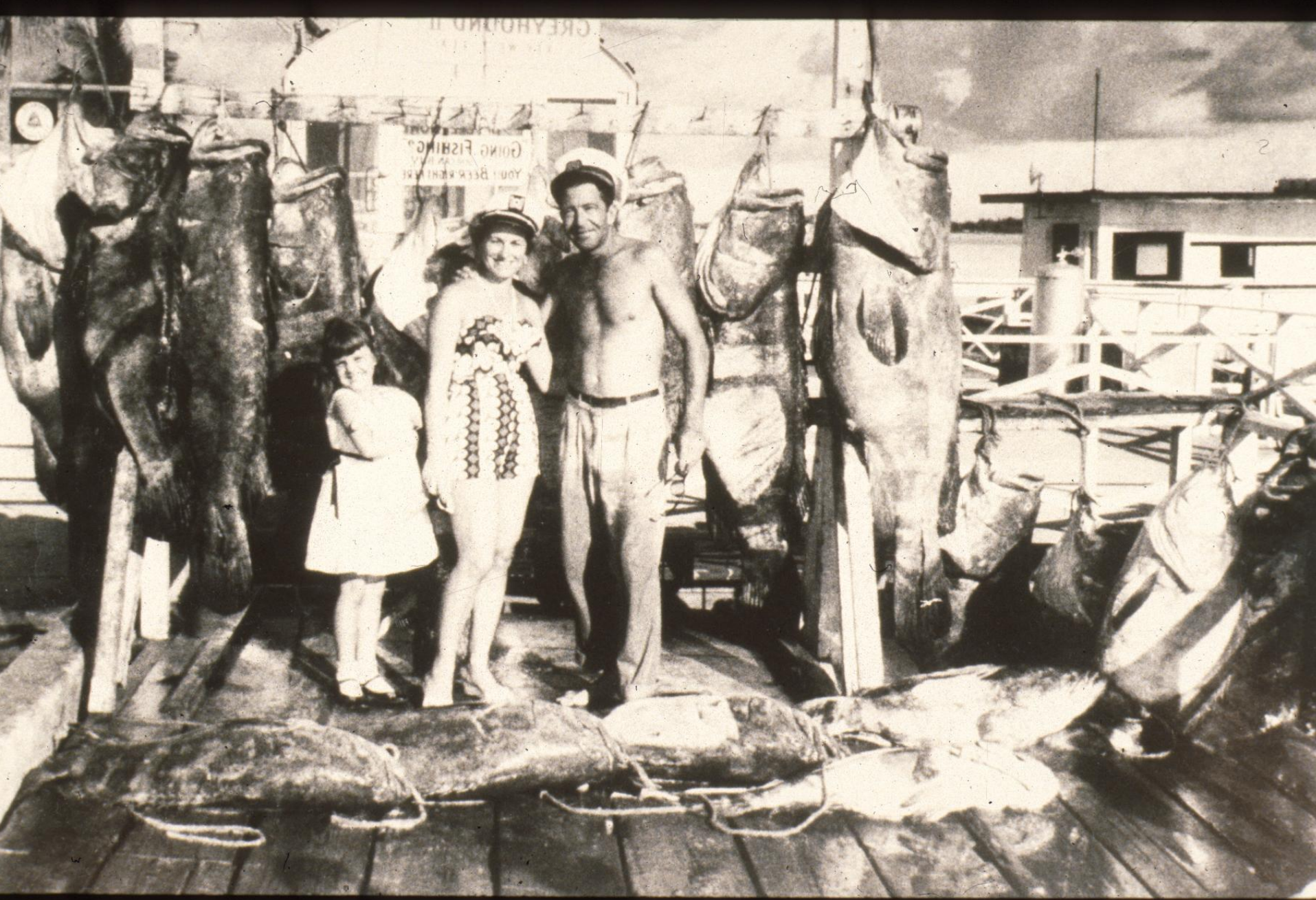
Schooling permit in Tortugas Bank Ecological Reserve, June 2004.



"An average day of grouper fishing in the Keys in the 1930's!"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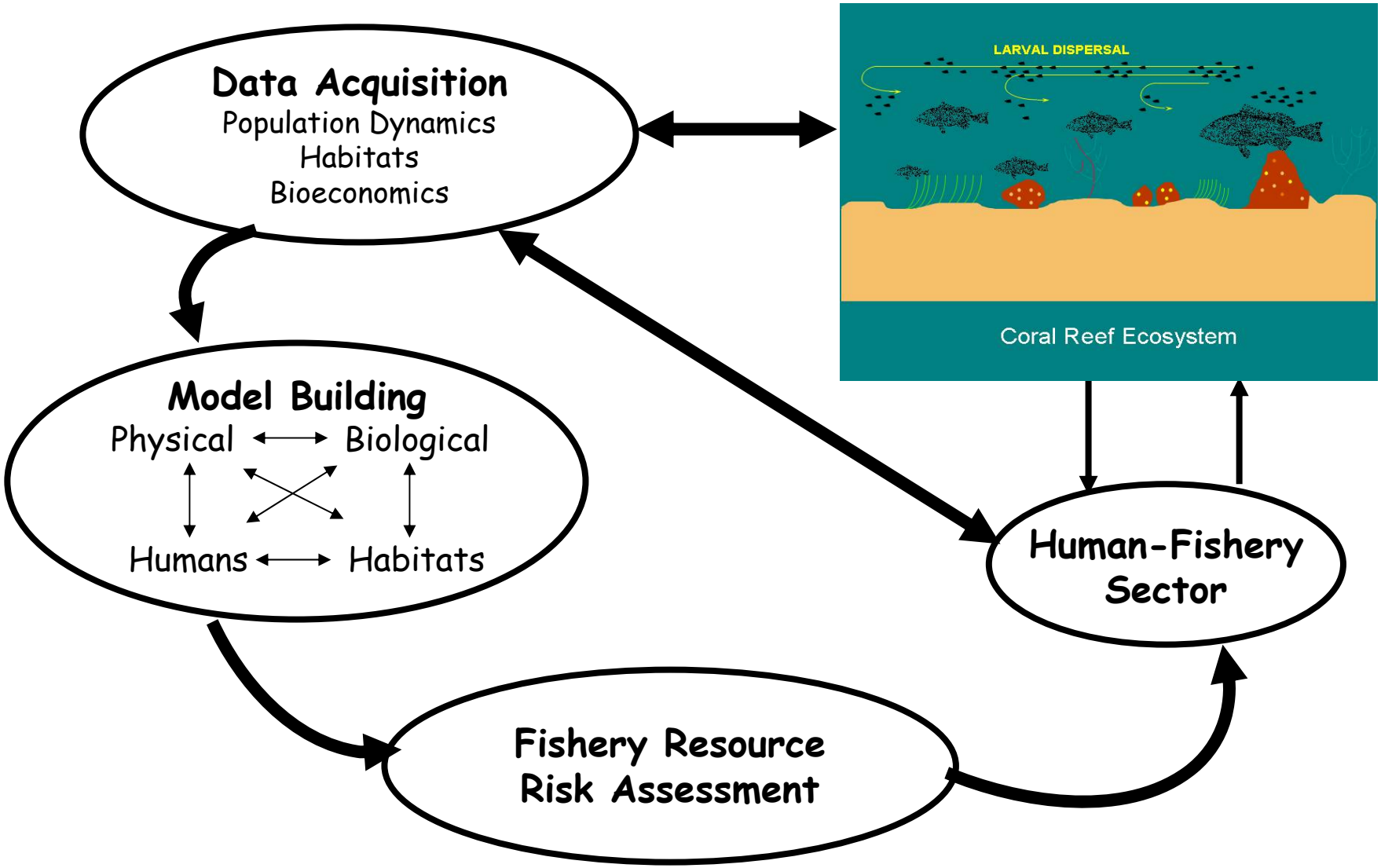
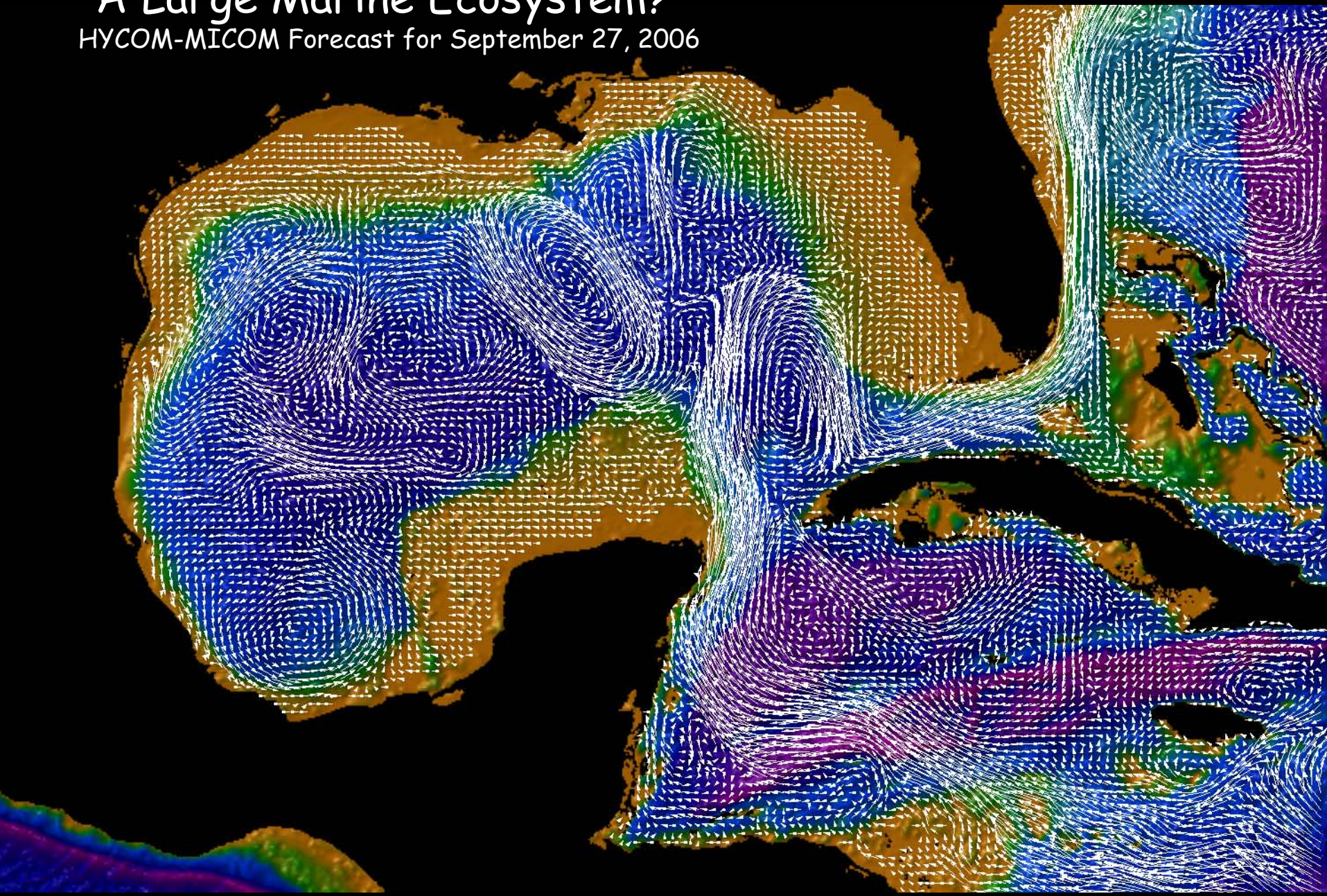
Fishery Systems Science (FSS)



"A Large Marine Ecosystem?"

HYCOM-MICOM Forecast for September 27, 2006



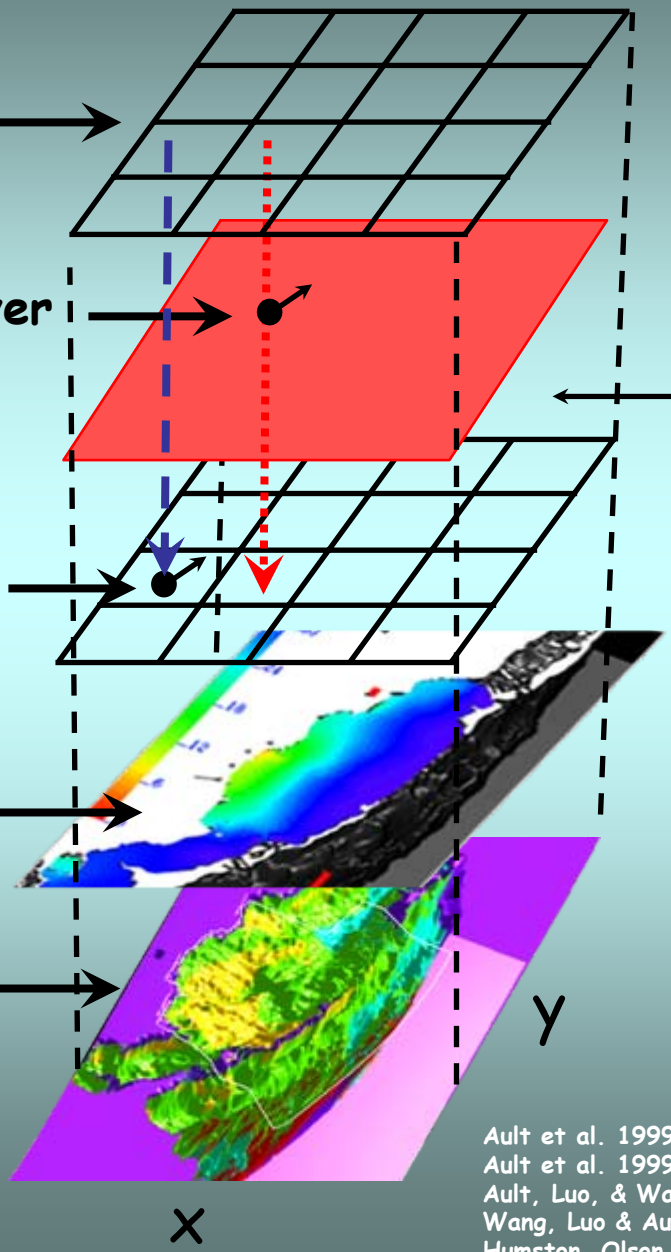
GeoSpatial Model of Biophysical Dynamics

Human Impacts Layer
(fishing, water quality, zoning)

Predator Cohort Patch layer

Age, number, length, weight, biomass, position (x,y), velocity.

Prey Cohort Patch layer



Hydrodynamics layer
(currents, salinity, temperature, DO)

"Habitat" layer
(bathymetry, benthic substrates)

Demographics

- Natural Mortality
- Bioenergetic Growth
- Recruitment
- Movements & Migrations

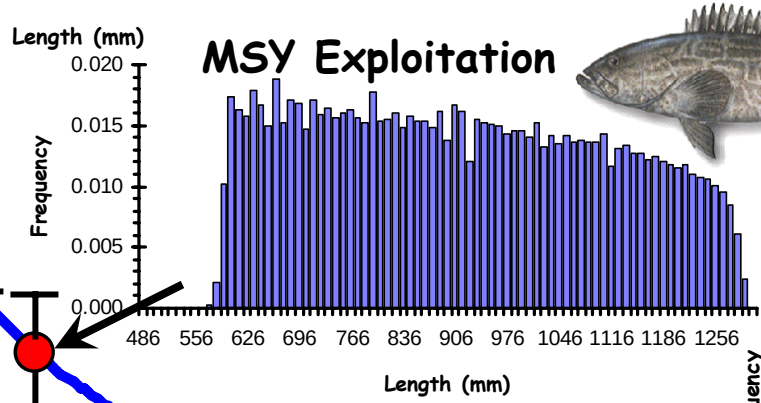
Ault et al. 1999. Can. J. Fish. Aquatic Science 56(S1)
Ault et al. 1999. N. Amer. J. Fish. Mgmt. 19
Ault, Luo, & Wang. 2003. CRC Press
Wang, Luo & Ault. 2003. Bull Marine Science 72(3)
Humston, Olson and Ault. 2004. Trans. Amer. Fish. Soc. 133


31 8:10 AM

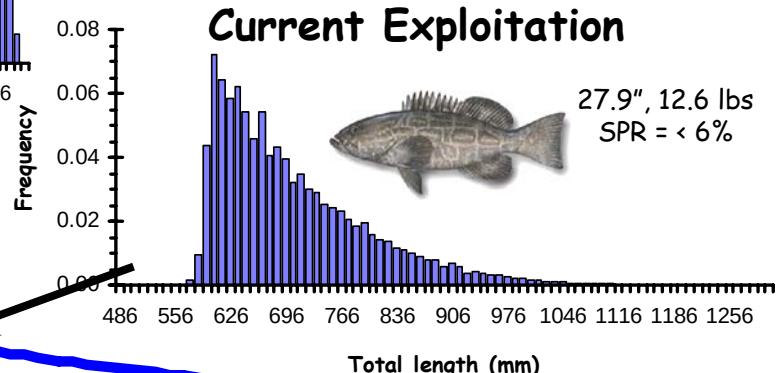
"Observable" Assessment Indicator Variables

40.6", 42.8 lbs
SPR = 100%

$$\bar{L}(t) = \frac{F(t)\int_{a_c}^{a_\lambda} N(a,t)\, L(a,t)\, da}{F(t)\int_{a_c}^{a_\lambda} N(a,t)\, da}$$



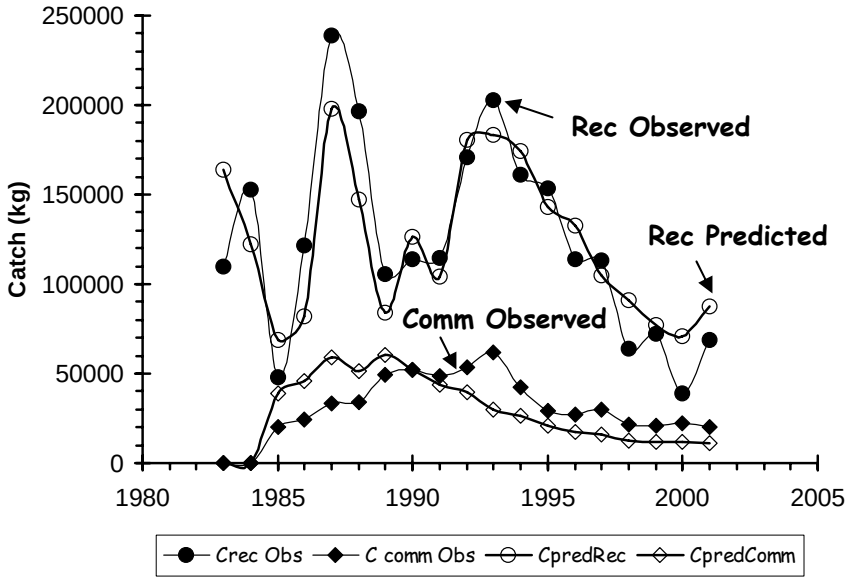
36.4", 30.1 lbs
SPR = 35.1%



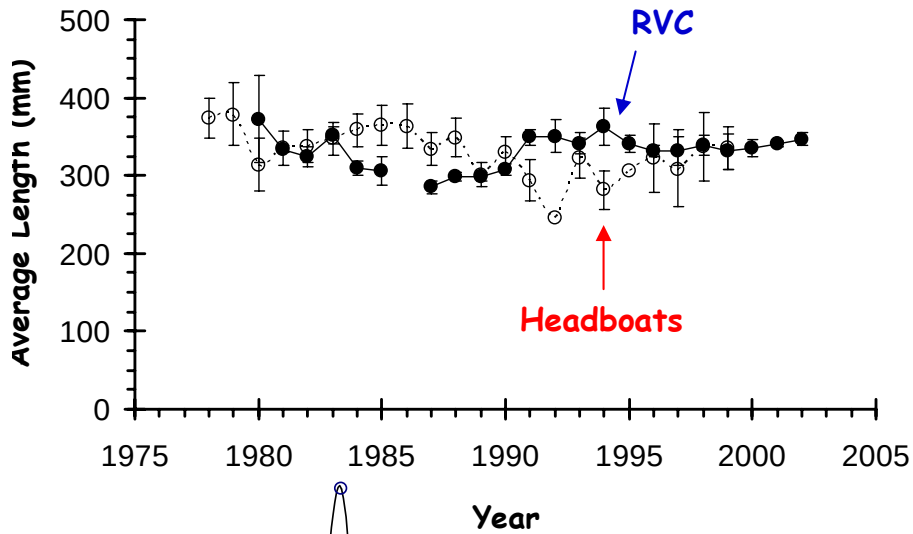
27.9", 12.6 lbs
SPR = < 6%

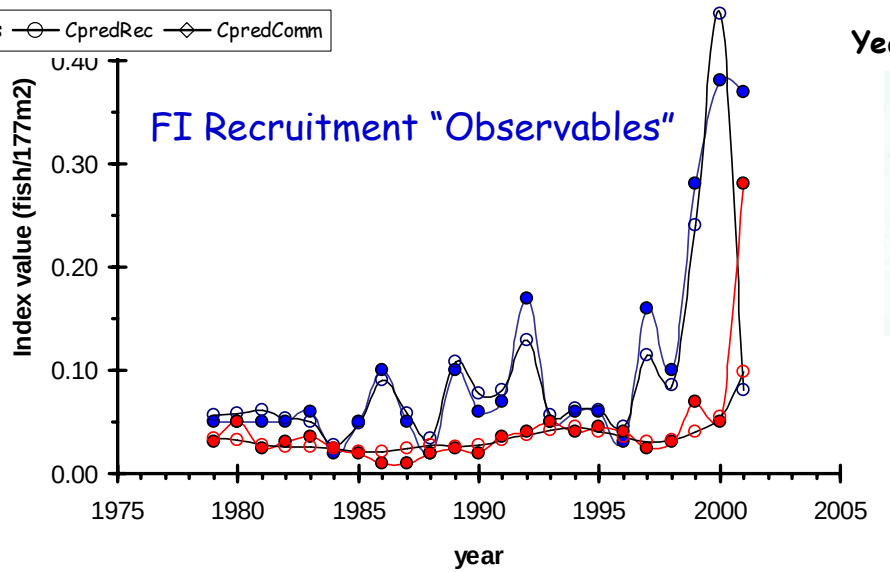
Model Cross-Validations

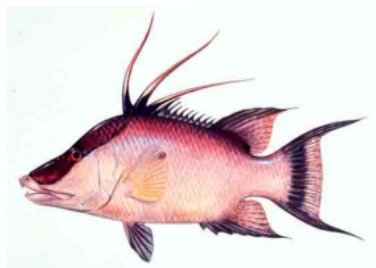
Fishery-Dependent "Observables"

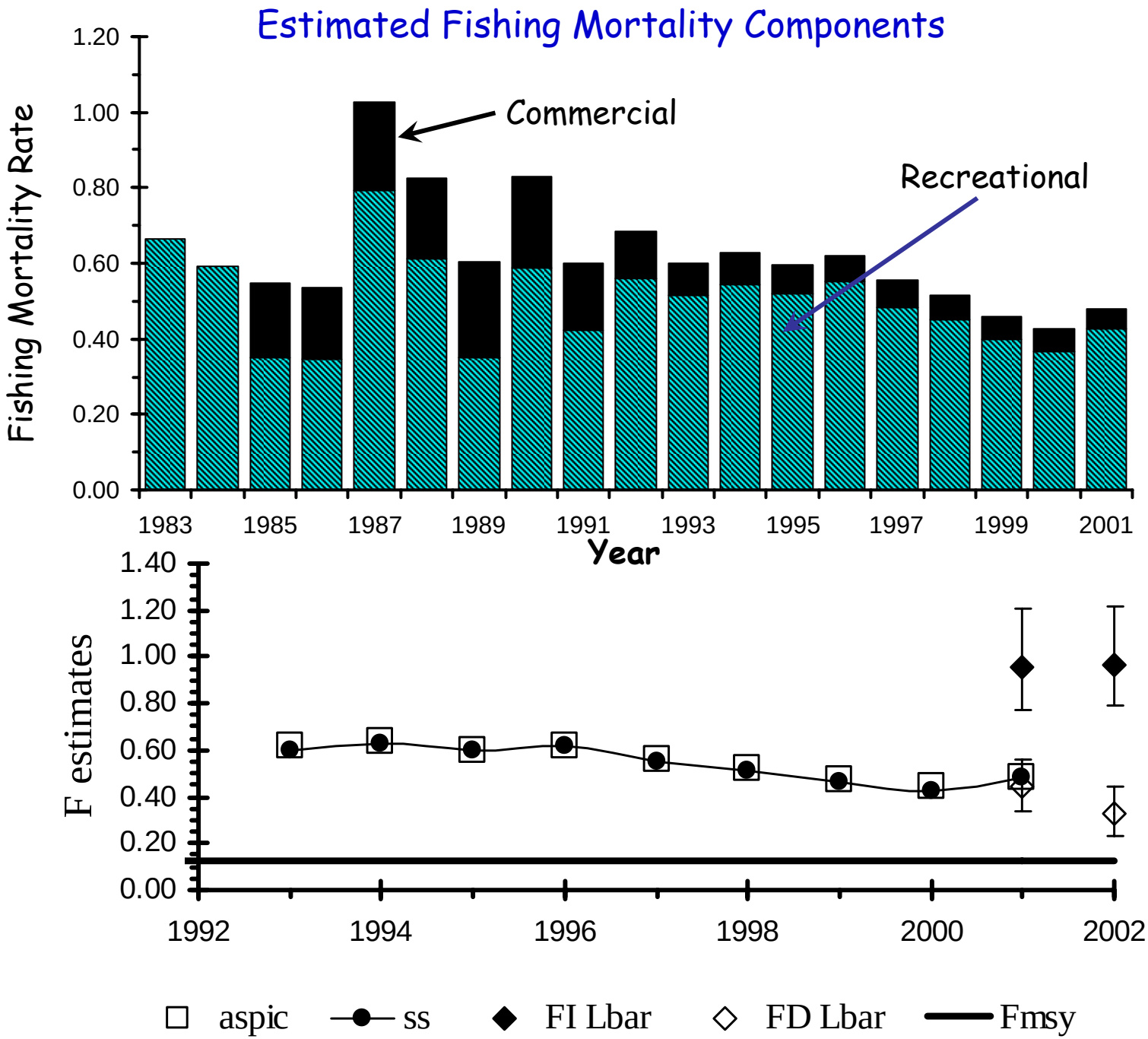


Fishery-Independent "Observables"





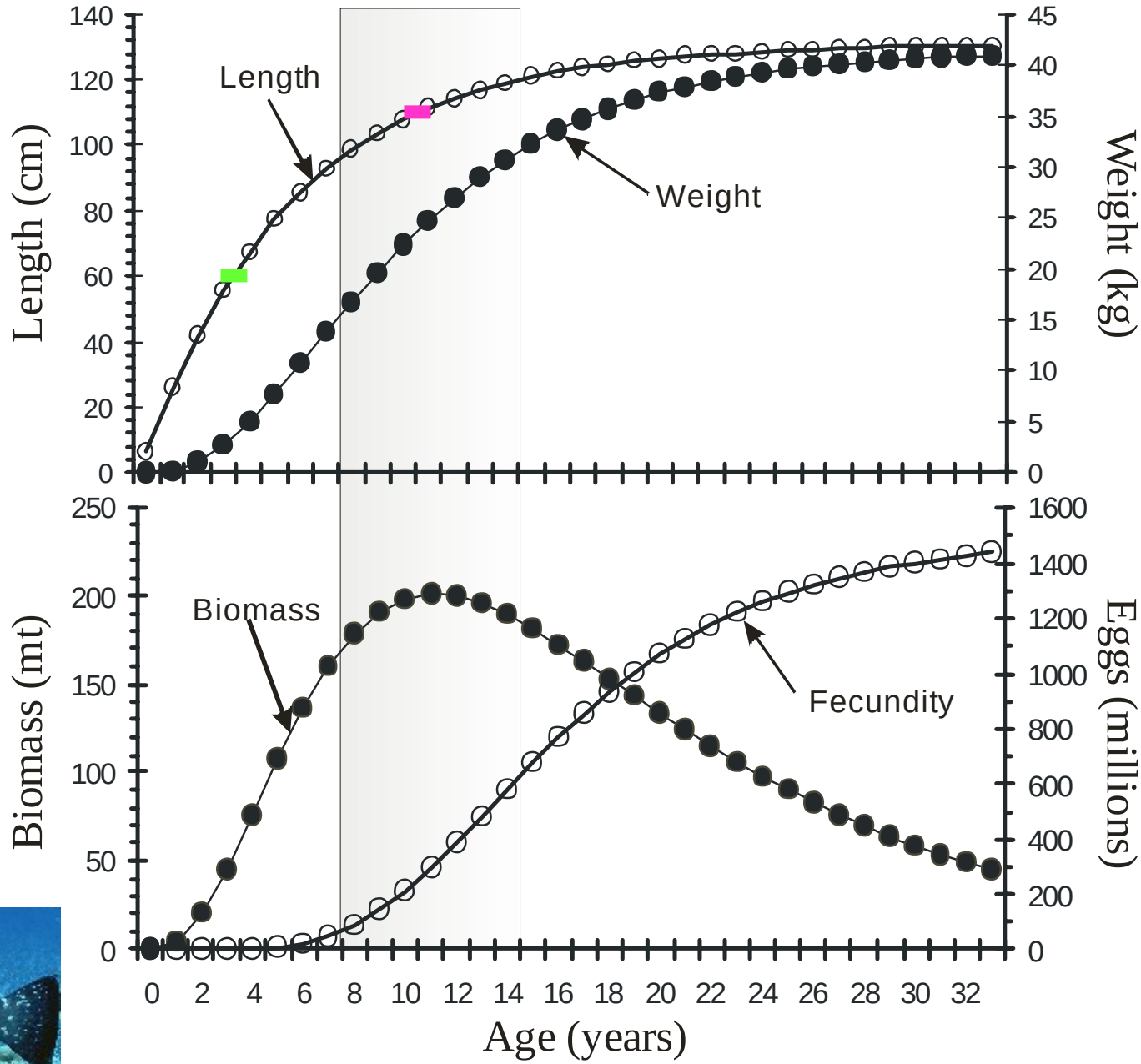



Estimated Fishing Mortality Components
Fishing Mortality Rate
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Commercial
Recreational
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
Year
F estimates
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1992
1994
1996
1998
2000
2002
aspic
ss
FI Lbar
FD Lbar
Fmsy

Bigger is (Biologically) Better!

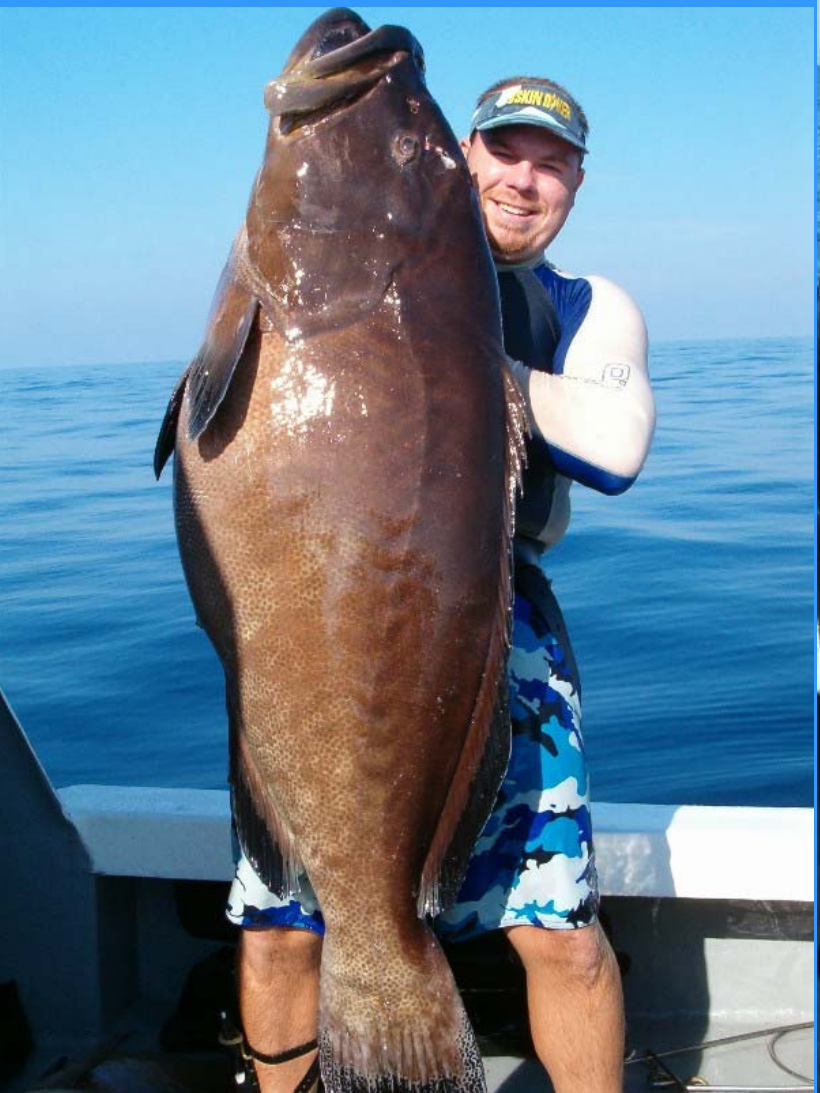
Individual

Population

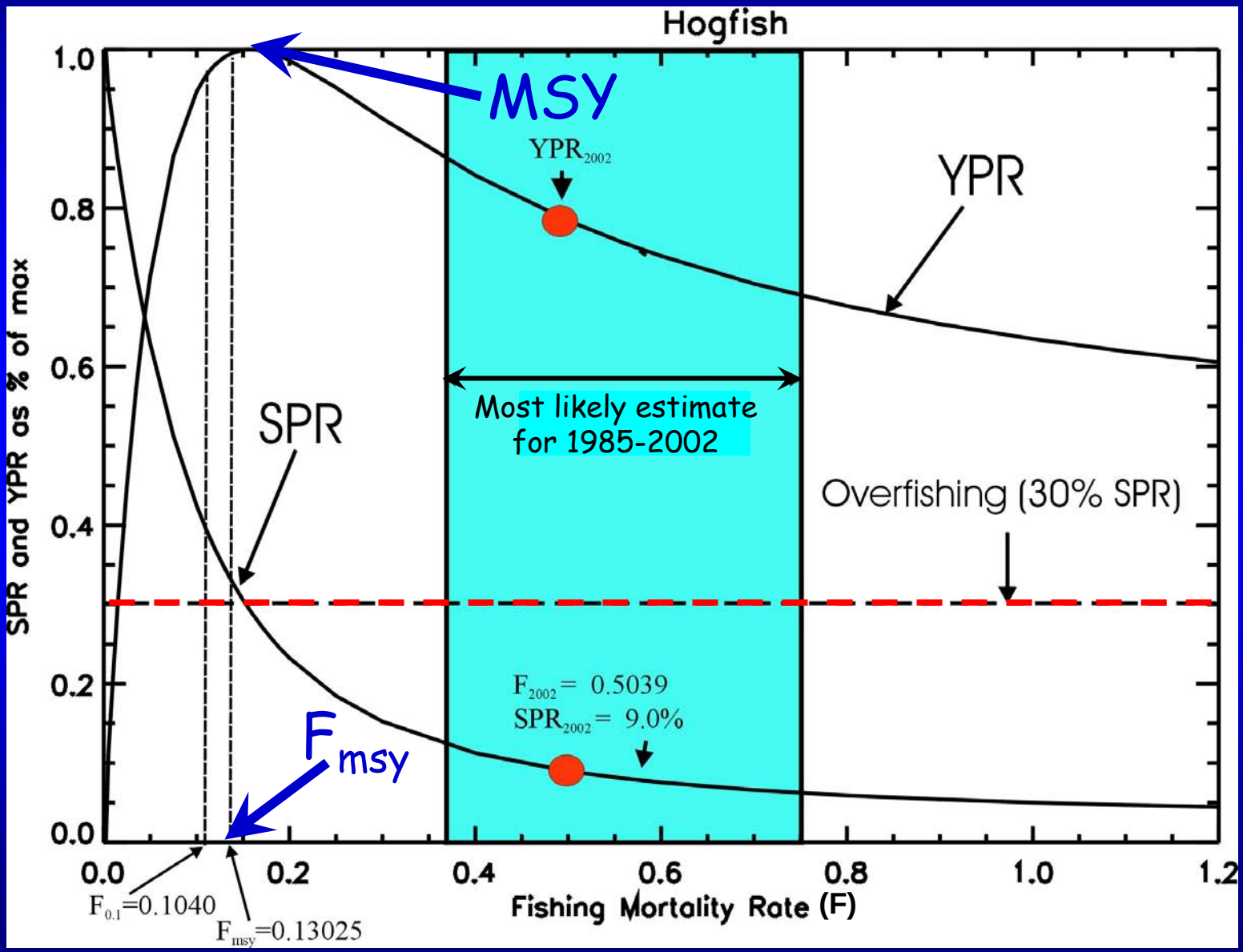


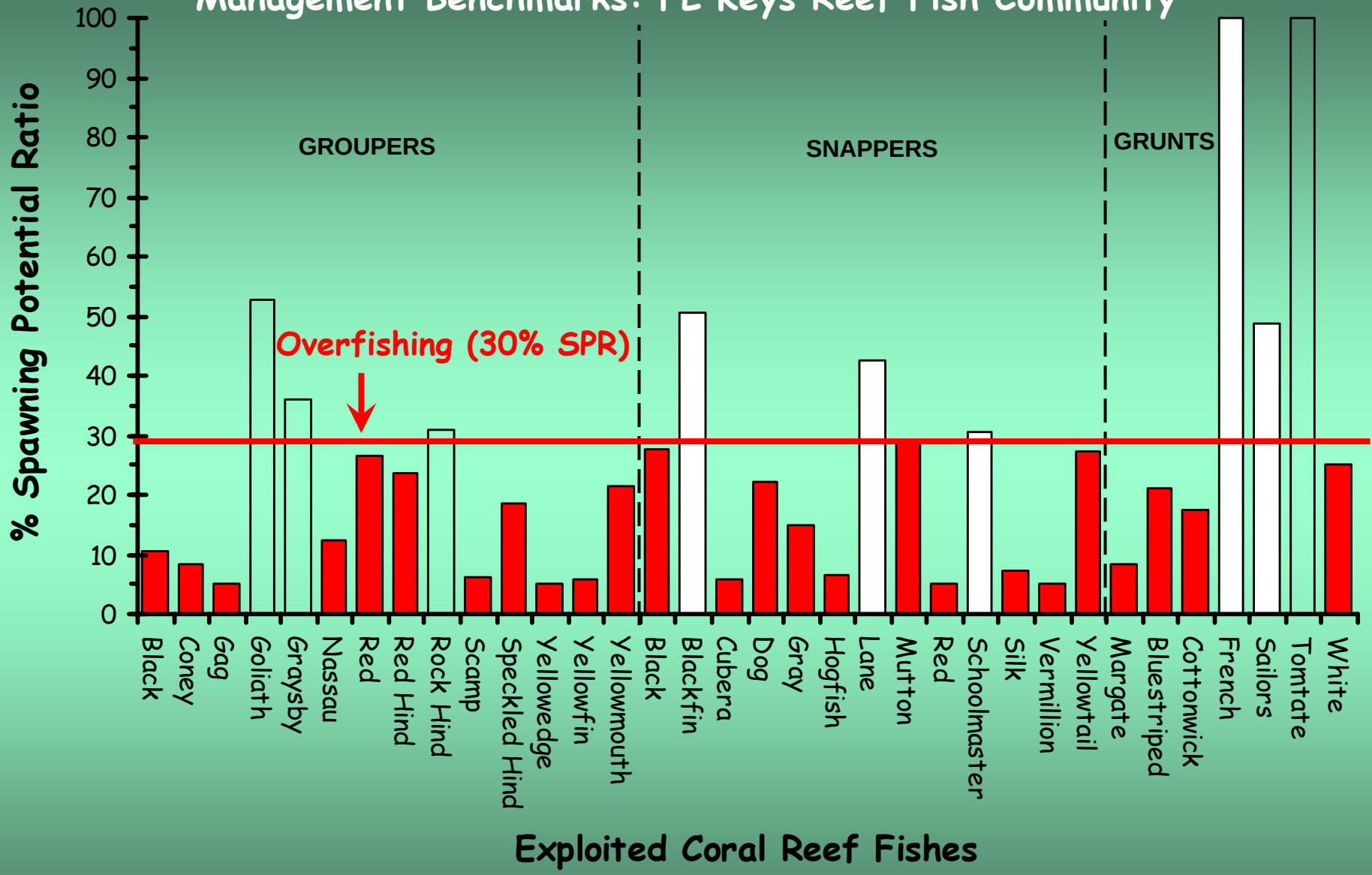
Black Grouper

But, …
BIGGER is Better!!



Fishery Sustainability Decision Metrics

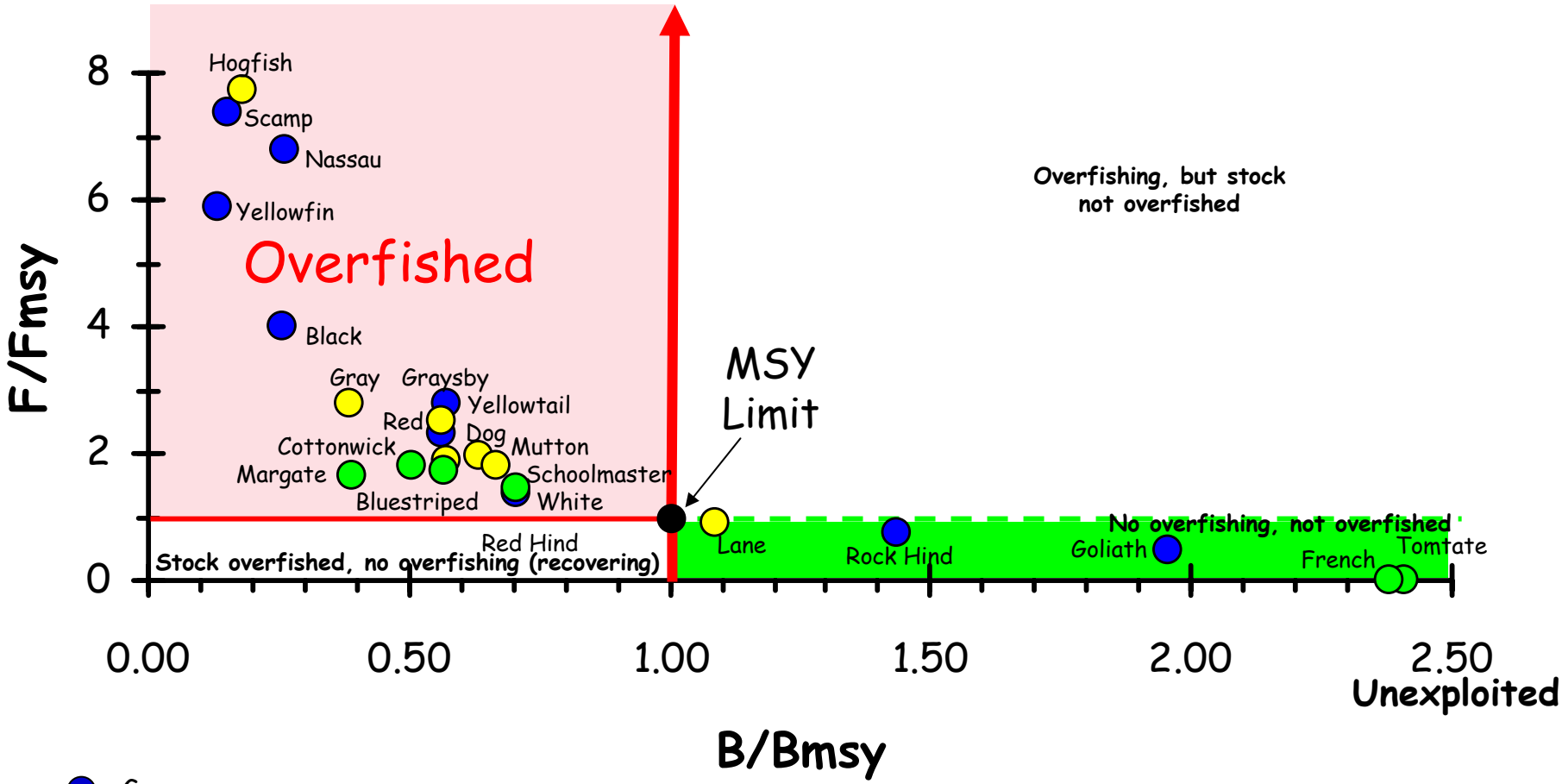




Ault, J.S,, Bohnsack, J.A., and G.A. Meester. 1998. Fishery Bulletin 96: 395-414
(Best Publication Award 1998, NOAA NMFS Scientific Publication Office)

Ault, J.S., Smith, S.G., and J.A. Bohnsack. 2005. ICES Journal of Marine Science 62: 417-423

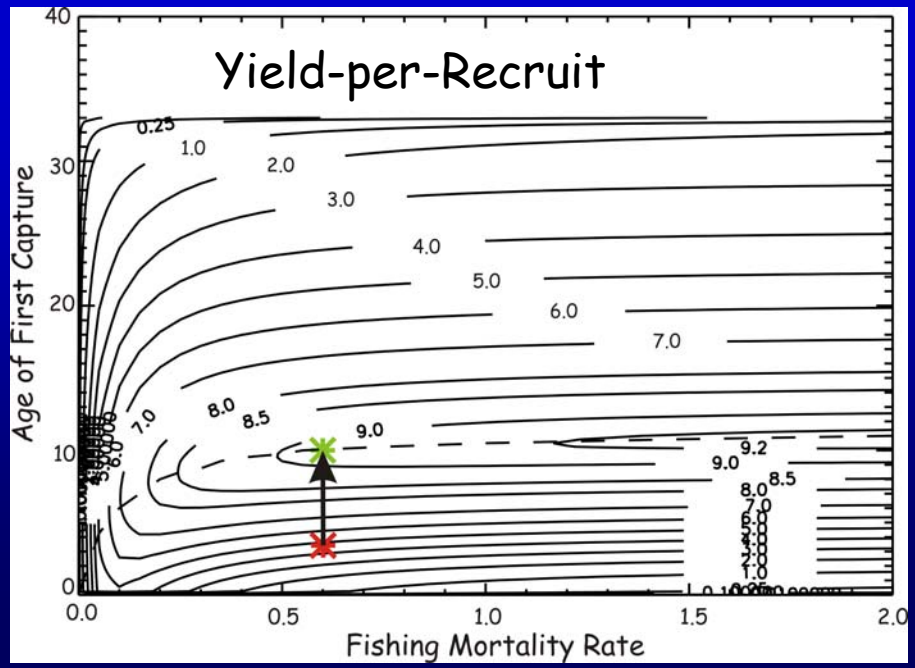
Florida Keys Reef Fish Community Limit Control Rule



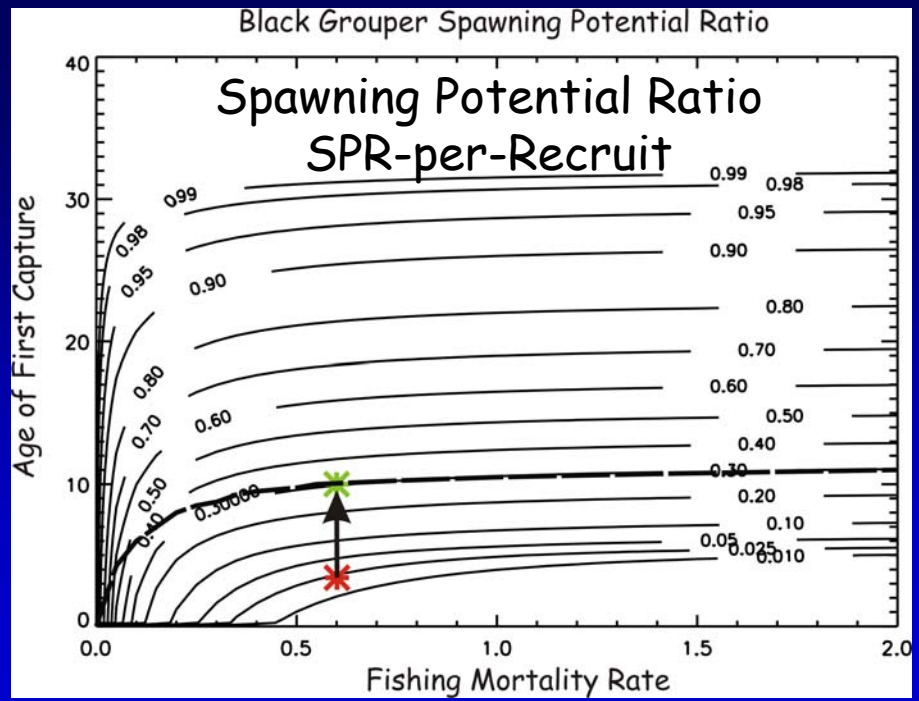
Grouper
Snapper
Grunt

Ault, Bohnsack, and Meester. 1998. Fishery Bulletin 96(3): 395-414. (Best Publication Award)
Ault, Bohnsack, Smith, and Luo. 2005. Bulletin of Marine Science 78(3): 633-654.
Ault, Smith, and Bohnsack. 2005. ICES J. Marine Science 62: 417-423.

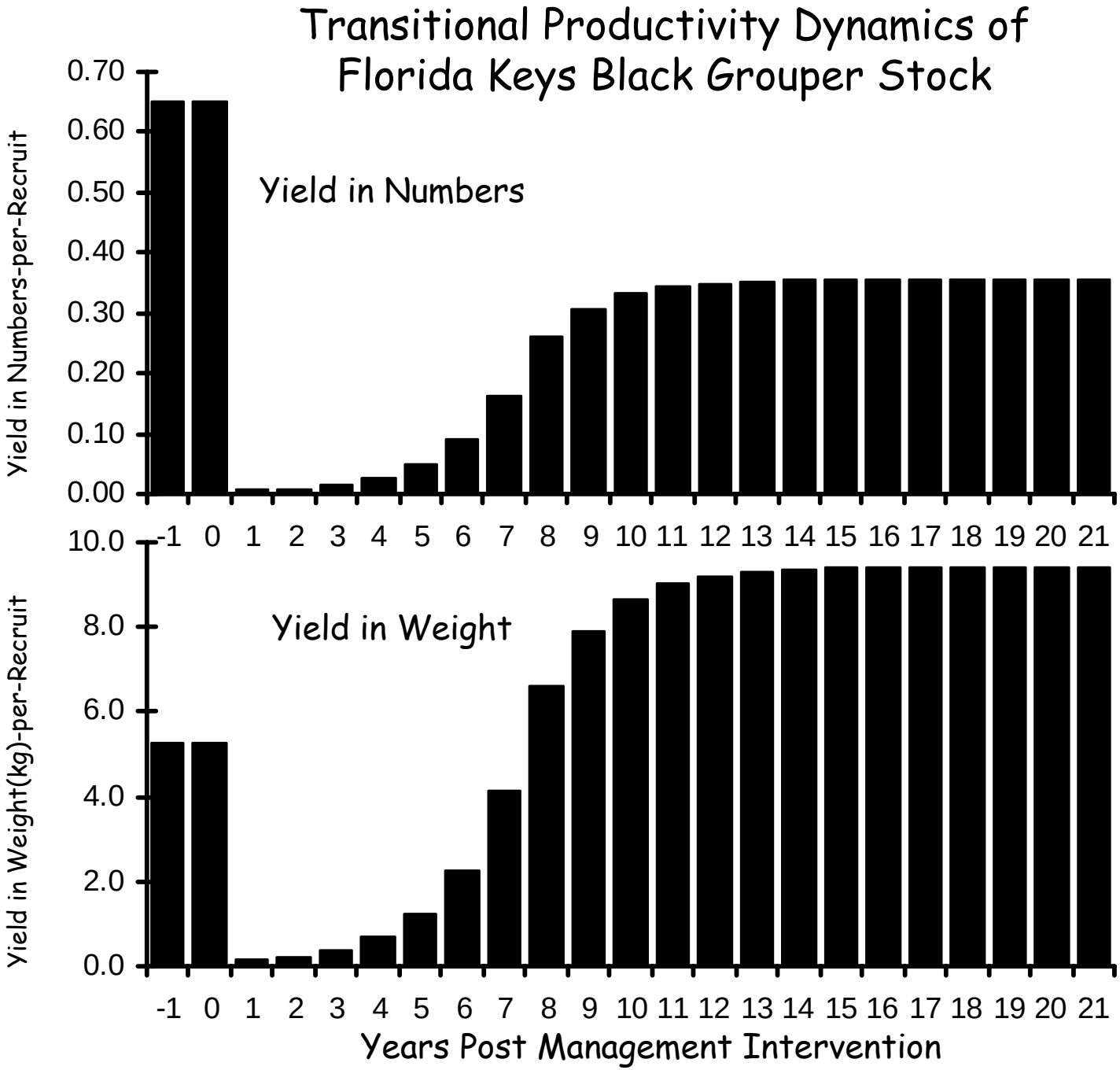
Traditional
Fishery Management
Benchmarks & Controls



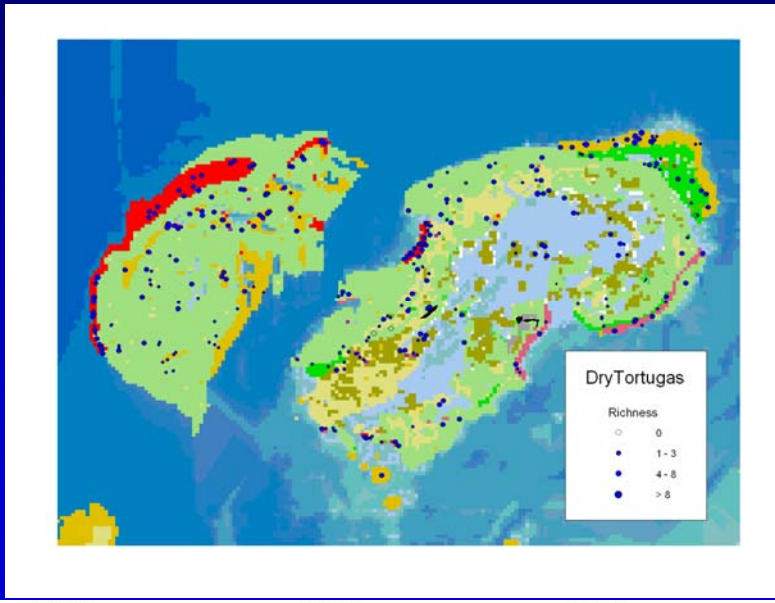
Yw/R:
4.77 -> 9.14 kg
92% increase

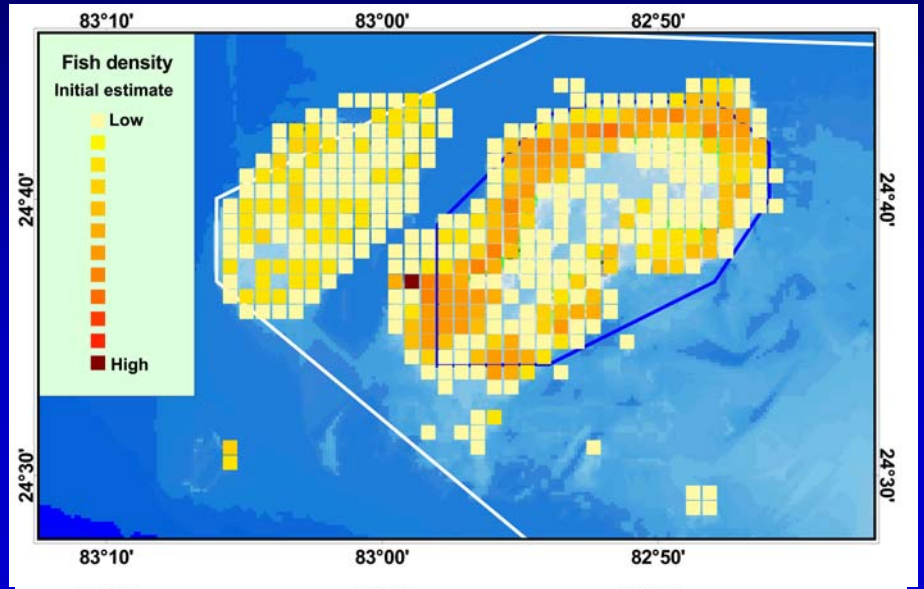


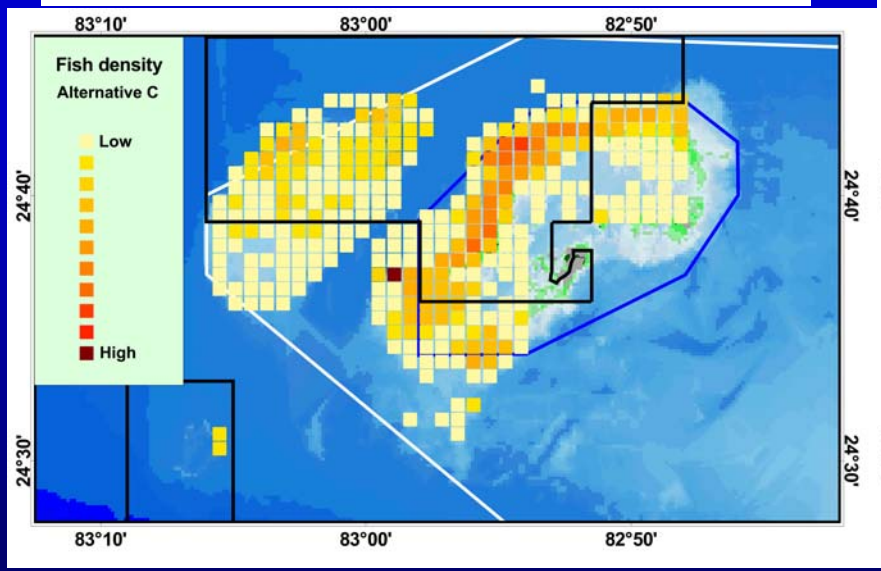
SPR:
0.022 -> 0.305
1286% increase

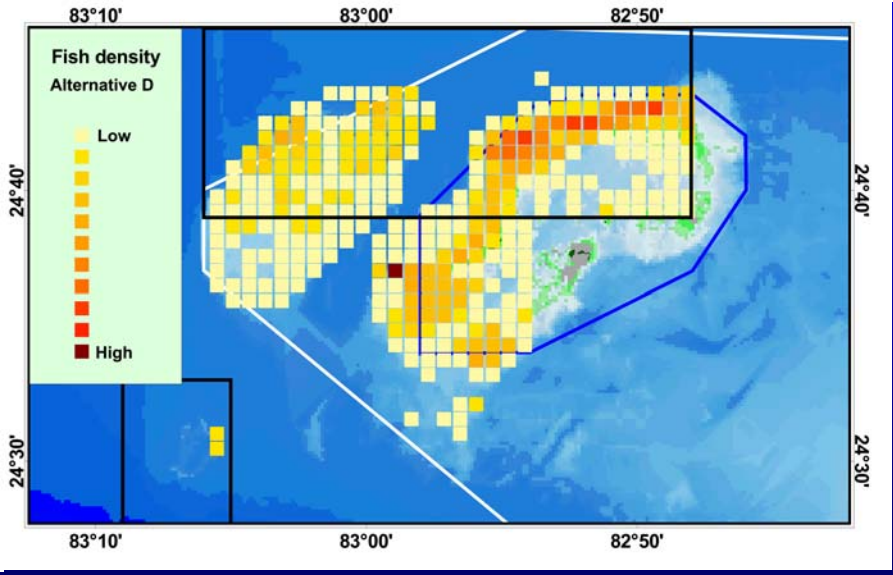

Transitional Productivity Dynamics of
Florida Keys Black Grouper Stock
Yield in Numbers
Yield in Numbers-per-Recruit
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Yield in Weight
Yield in Weight(kg)-per-Recruit
10.0
8.0
6.0
4.0
2.0
0.0
-1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Years Post Management Intervention

Designing the Tortugas No-Take Marine Reserves



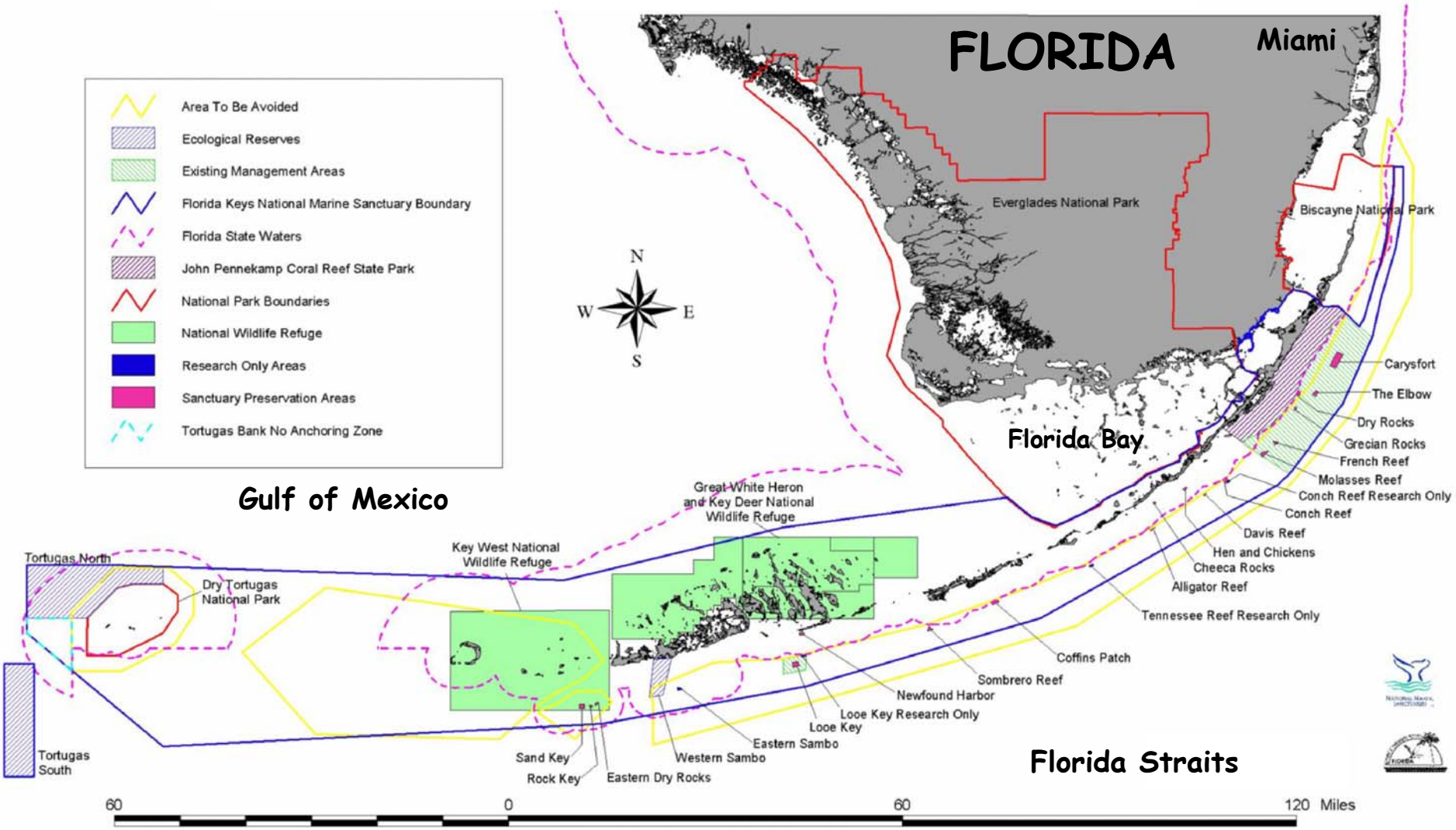




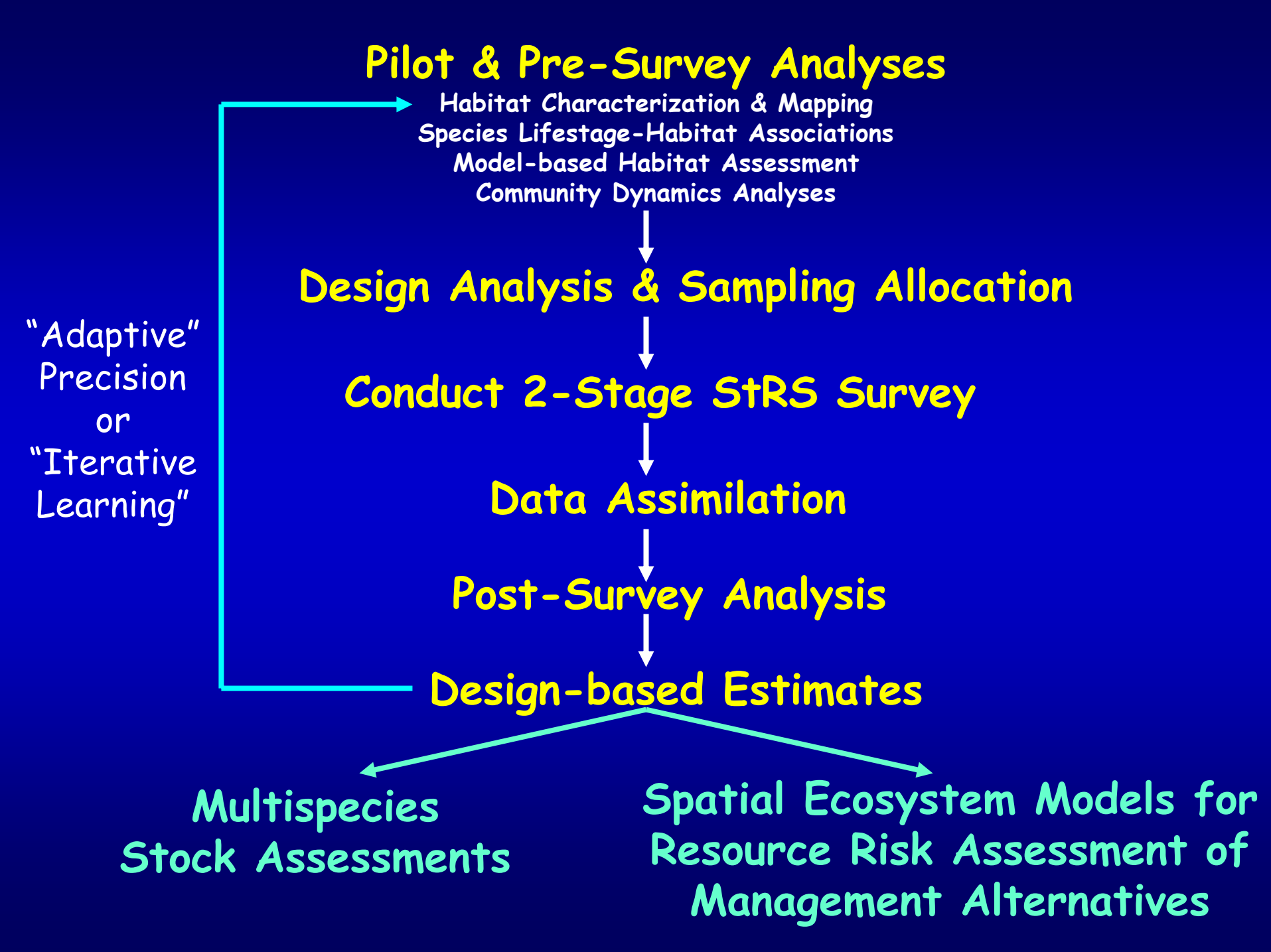


Meester, Ault, Smith, Mehrotra. 2001. Sarsia 86: 543-548.
Meester, Mehrotra, Ault, Baker. 2004. Management Science 50: 1031-1043.

The Managed Florida Keys Coral Reef Ecosystem



created by Kevin Kirsch & Ben Richards 11/31/01


Pilot & Pre-Survey Analyses
Habitat Characterization & Mapping
Species Lifestage-Habitat Associations
Model-based Habitat Assessment
Community Dynamics Analyses
Design Analysis & Sampling Allocation
Conduct 2-Stage StRS Survey
Data Assimilation
Post-Survey Analysis
Design-based Estimates
"Adaptive" Precision or "Iterative Learning"
Multispecies Stock Assessments
Spatial Ecosystem Models for Resource Risk Assessment of Management Alternatives

Sampling Survey Design

Goal: Estimate population & community metrics
Accurate, precise, low-cost

Proportions (presence-absence, cover)
Means (density, richness)
Totals (abundance)

Species and Size composition
metrics by life-stage (juvenile,adult,exploited)

Key Properties
Finite population within finite area
Distribution-free

Domain

"Mapped" Holocene Reefs (live coral habitat)

Broward-Palm Beach: 195 km^2

Florida Keys: 500 km^2

Tortugas: 325 km^2

Design Variable

Density (representative suite of species, life stages)

Stratified Random Design

Heterogeneous Spatial Distribution

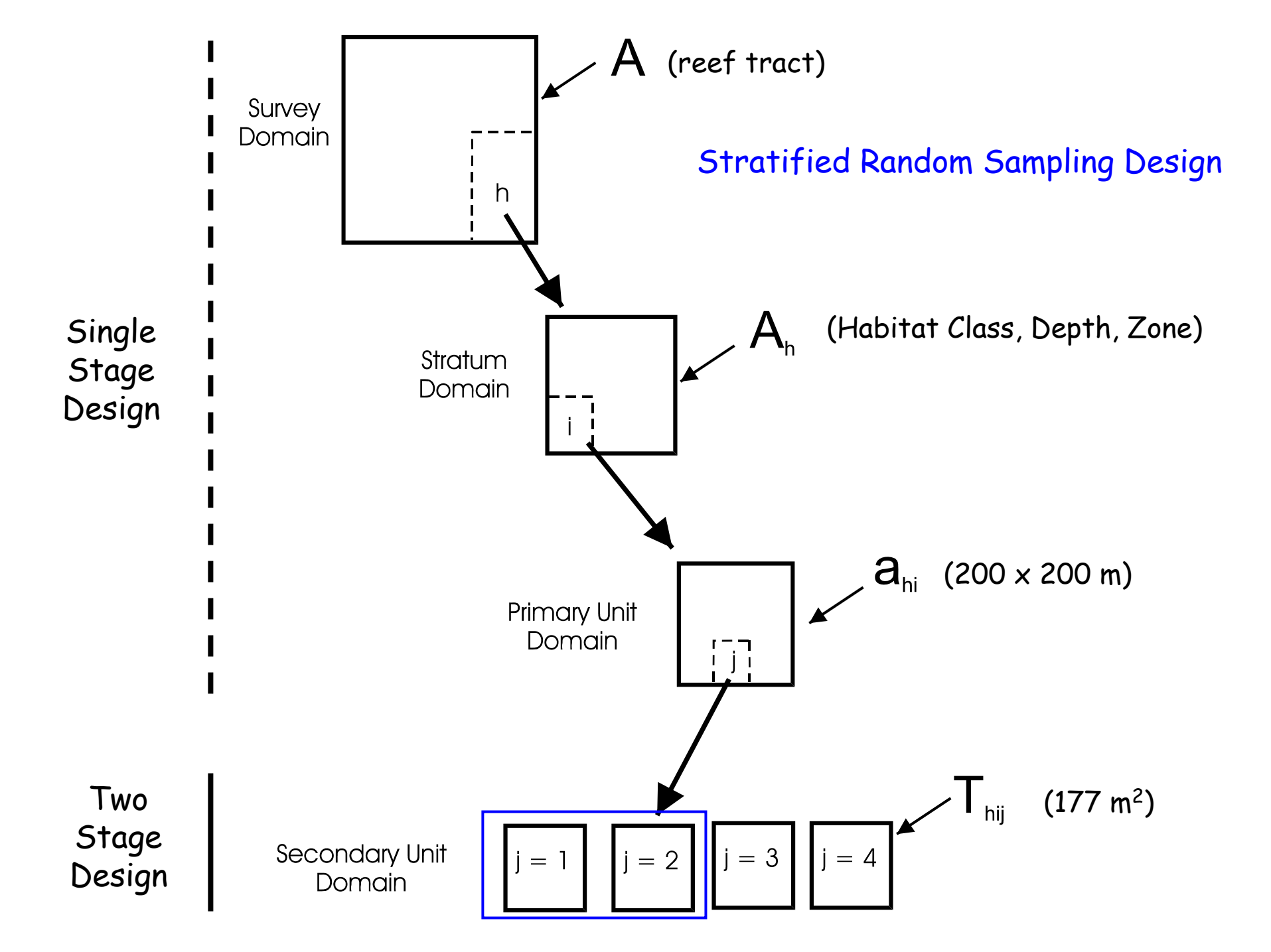
Stratification Variables

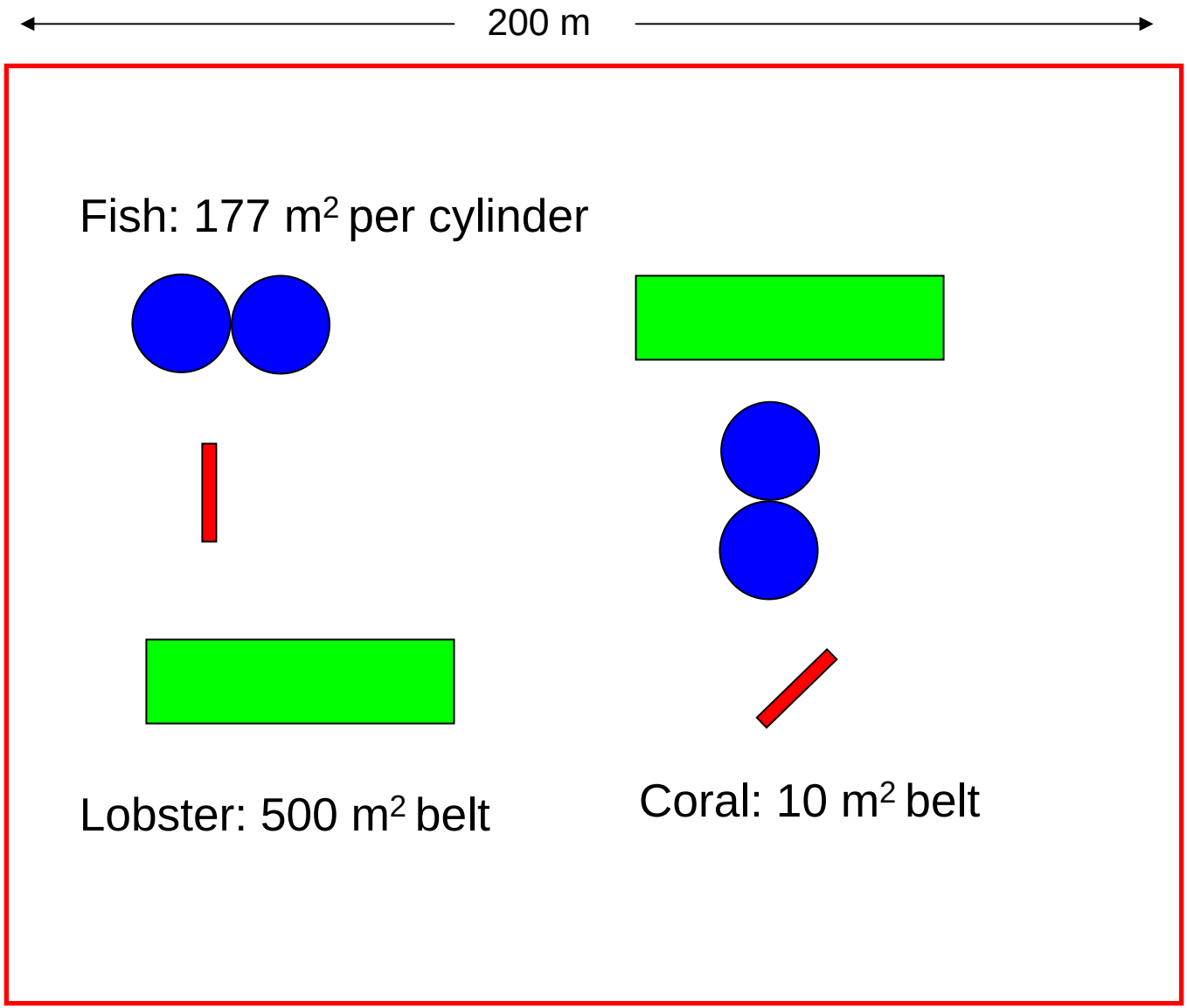
Reef Habitat Class

Depth

Geographical Subregion

Spatial Management Zone (e.g, no-take reserves)


Survey Domain
A (reef tract)
h
Stratified Random Sampling Design
Single Stage Design
Stratum Domain
A_h (Habitat Class, Depth, Zone)
i
a_{hi} (200 x 200 m)
Primary Unit Domain
j
Two Stage Design
T_{hij} (177 m^2)
Secondary Unit Domain
j = 1
j = 2
j = 3
j = 4


200 m
Fish: 177 m2 per cylinder
Lobster: 500 m2 belt
Coral: 10 m2 belt

Precise, Cost-Effective Survey Designs

Stratification Scheme:

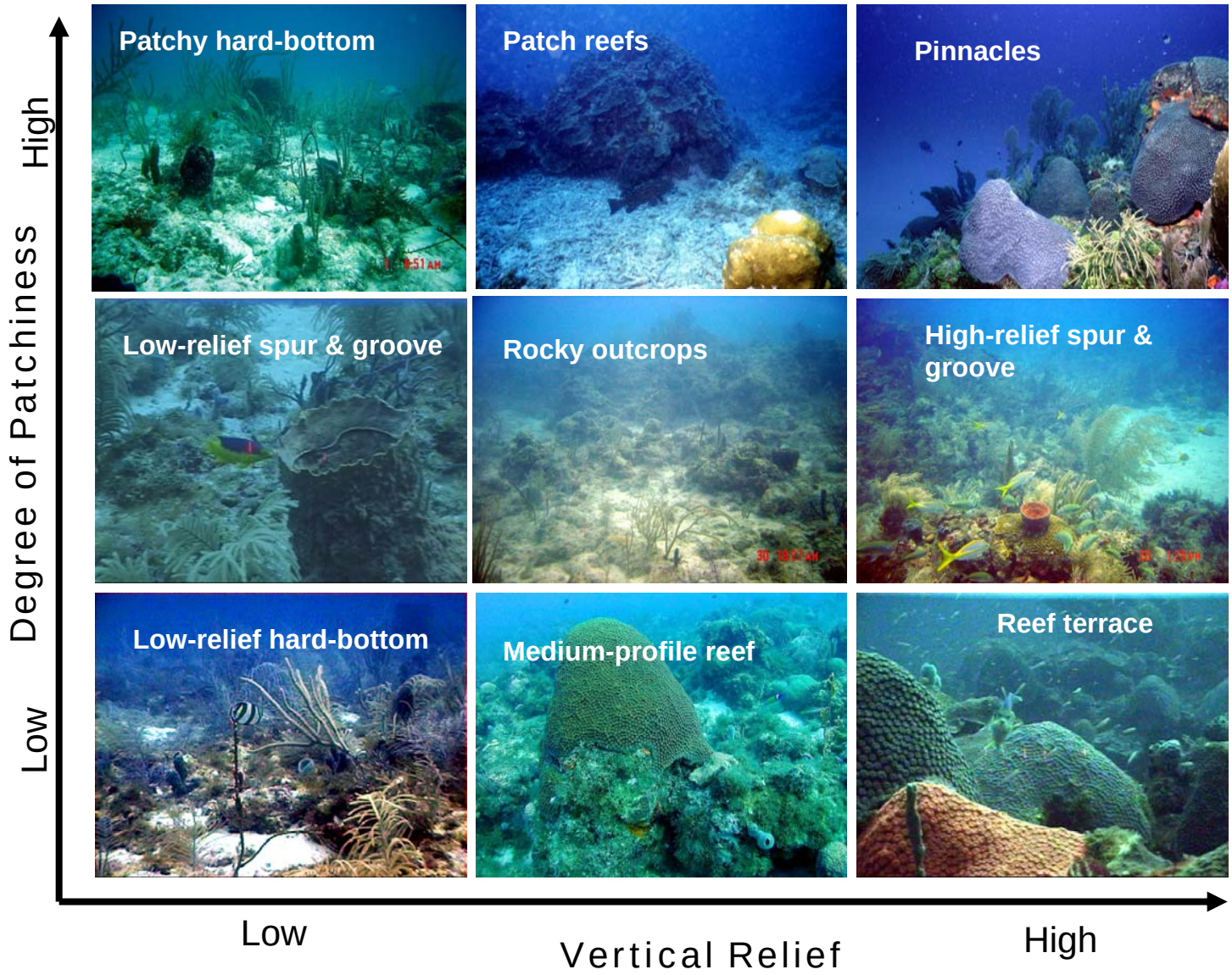
Partitions survey domain into subregions of low, moderate, and high variance

Allocation Scheme:

Allocation based on stratum size and variance

- More samples in larger strata
- More samples in higher variance strata

Linking Reef Fish Spatial Abundance & Benthic Habitats



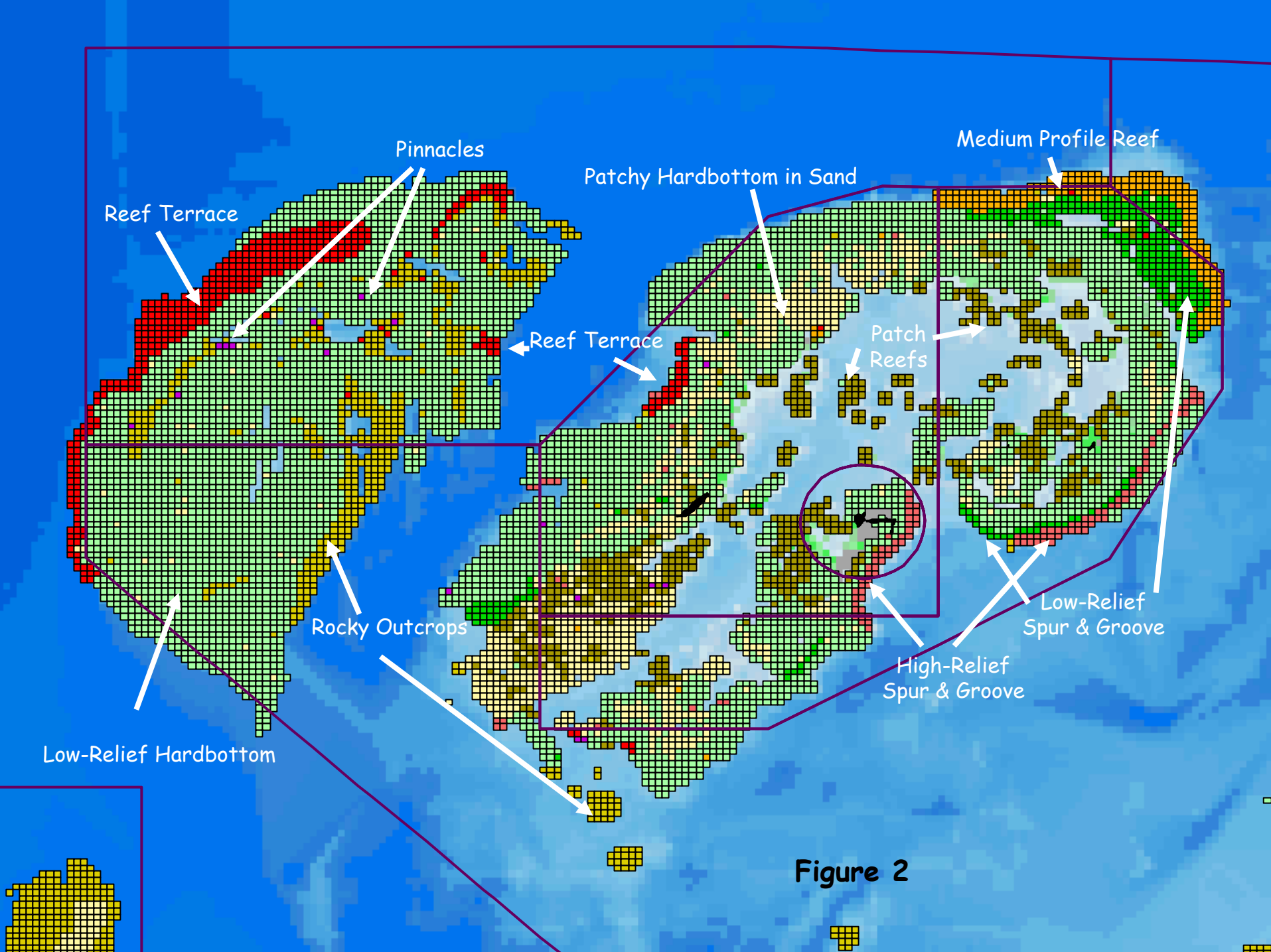
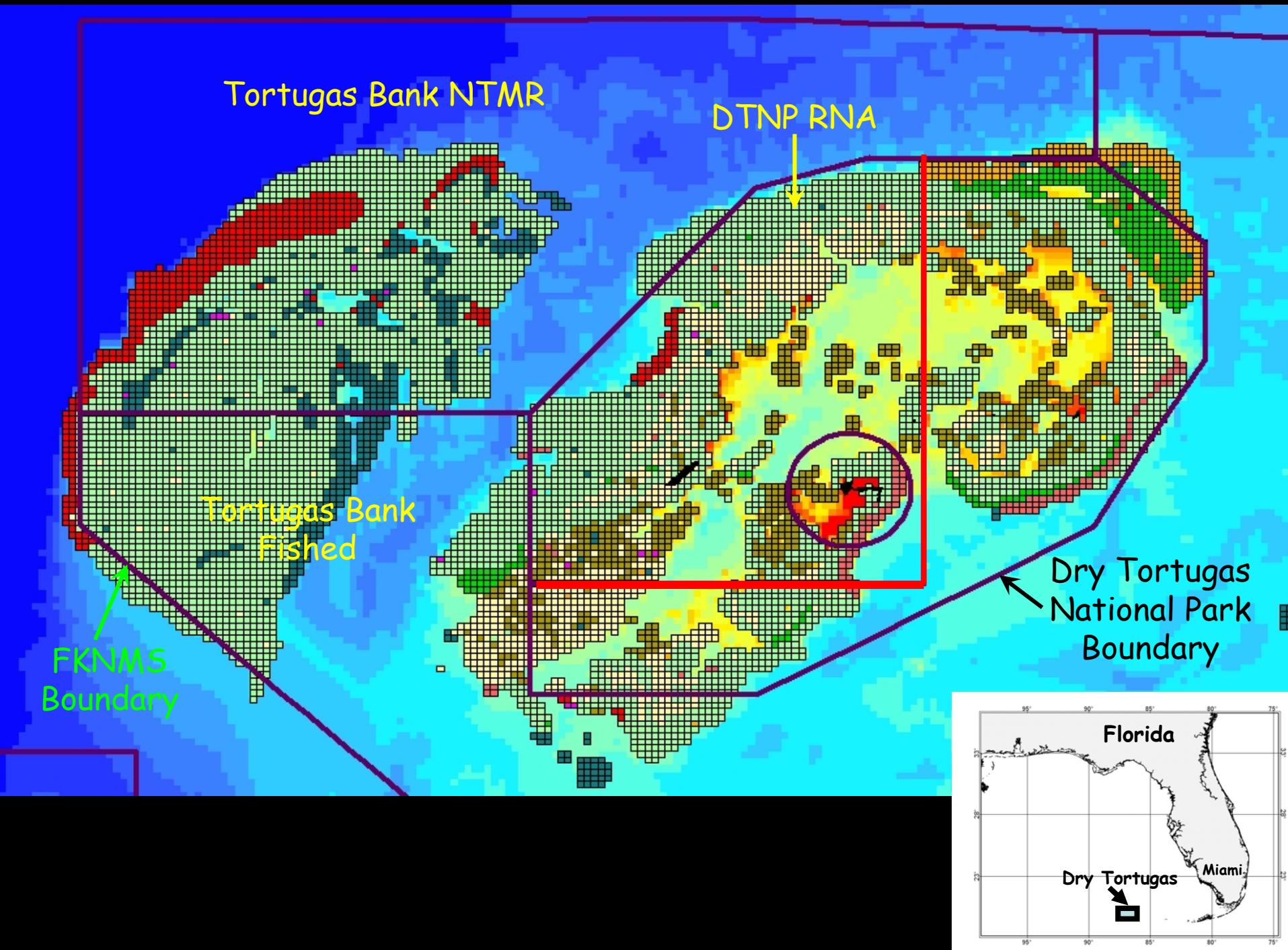
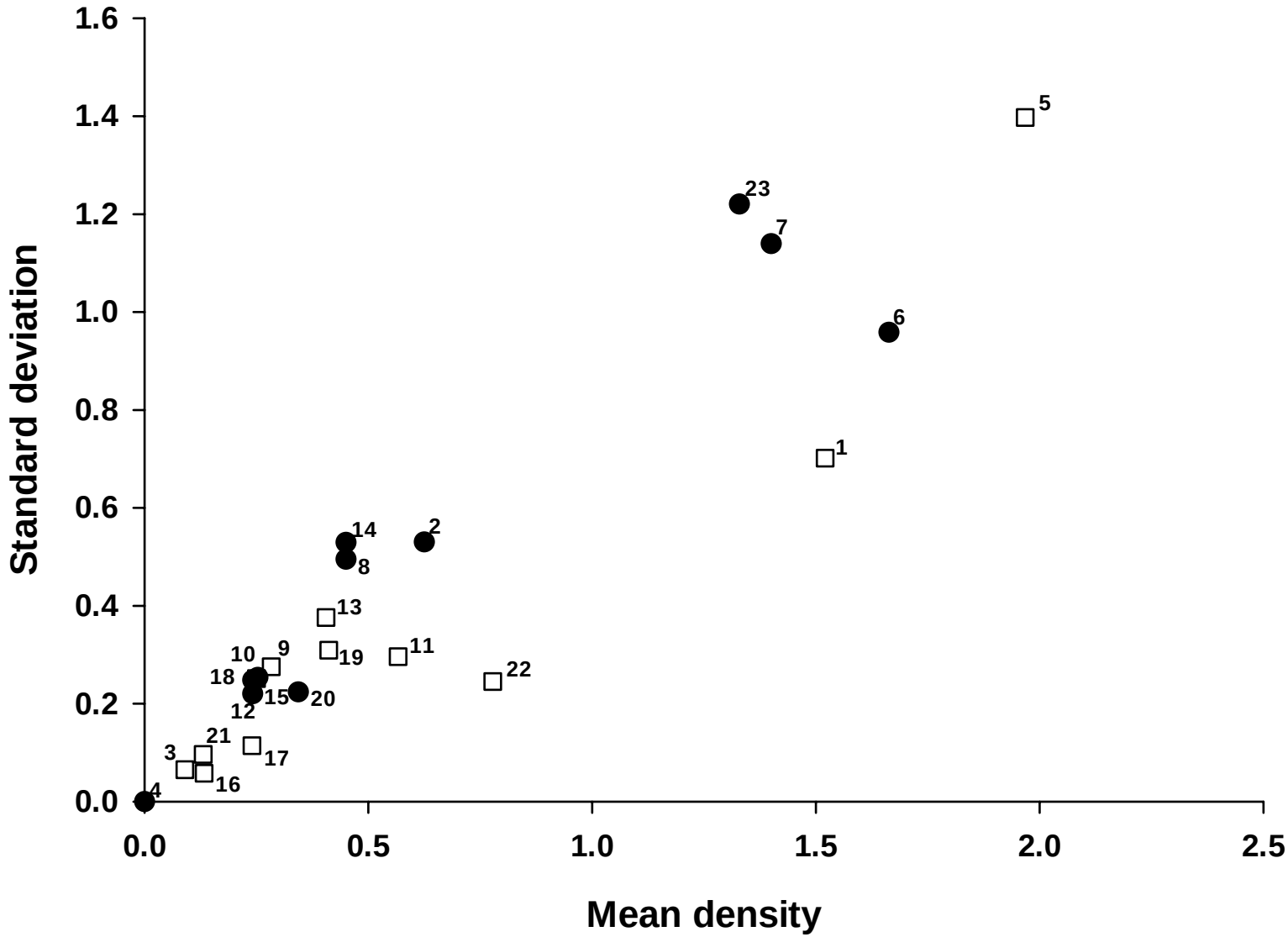

Pinnacles
Reef Terrace
Patchy Hardbottom in Sand
Medium Profile Reef
Reef Terrace
Patch
Reefs
Rocky Outcrops
Low-Relief
Spur & Groove
High-Relief
Spur & Groove
Low-Relief Hardbottom

Figure 2


Tortugas Bank NTMR
DTNP RNA
Tortugas Bank
Fished
FKNMS
Boundary
Dry Tortugas
National Park
Boundary
Florida
Miami
Dry Tortugas


Standard deviation
Mean density
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.0
0.5
1.0
1.5
2.0
2.5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Randomization—Guards Against Bias

Stratum-Level Estimates

- Second-Stage Units Within Primary Units
- Primary Units Within a Stratum

Equal probability of selection for each sample unit

Domain-Wide Estimates

- Stratum Weighting Factor

Further guard against bias in domain-wide estimates for spatially heterogeneous populations

Performance Measures

$$CV\left[\overline{D}\right] = \frac{SE\left[\overline{D}\right]}{\overline{D}}$$

Ability to detect differences = 95% CI for avg density = approx. 2 SEs or twice the CV

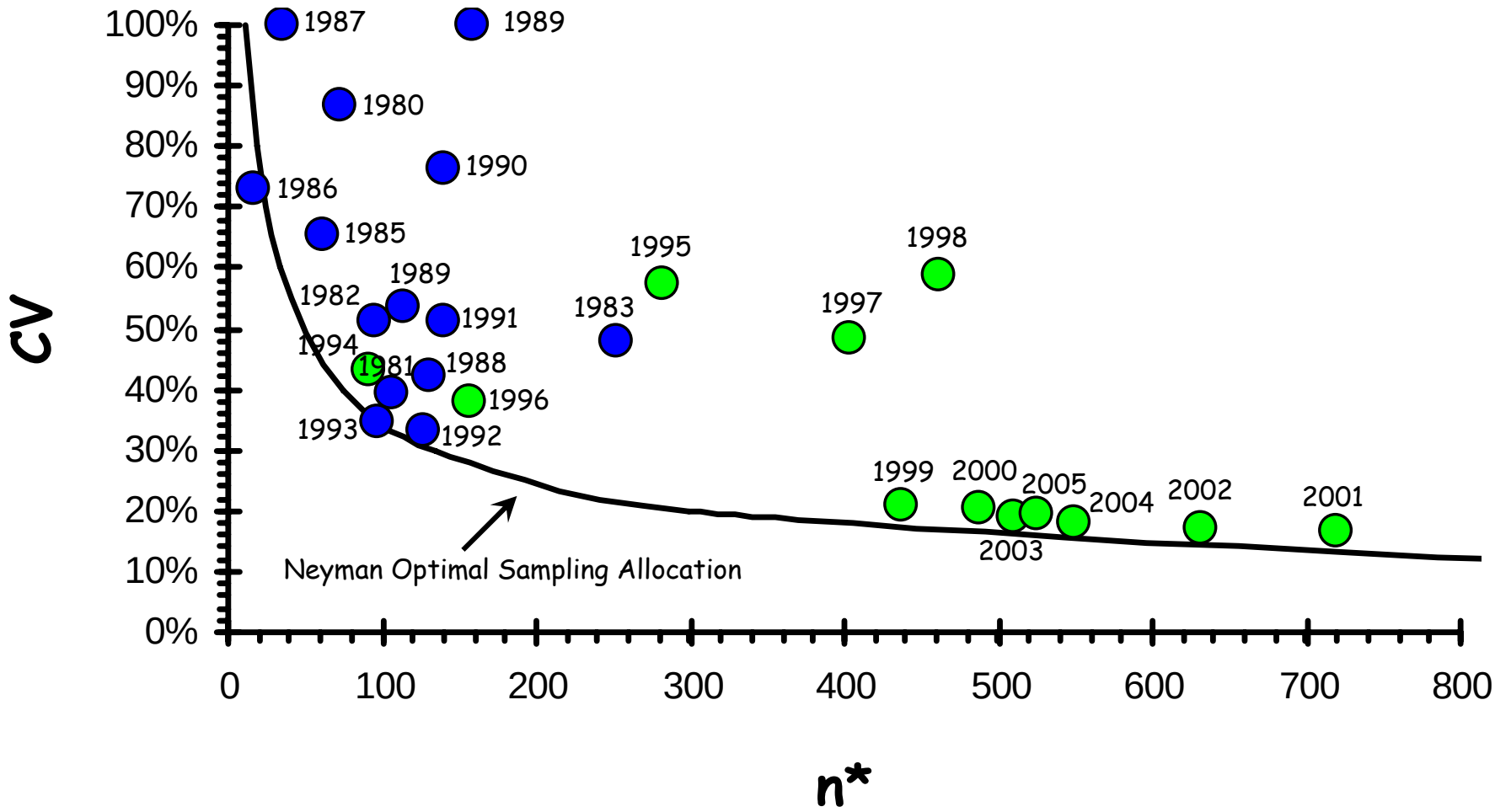
Primary units to achieve specified CV

$$n^* = \frac{\sum_h w_h s_{uh} \left(\sum_h w_h s_{uh} + \sum_h \frac{w_h^2 s_{2h}^2}{m^*_h \, w_h s_{uh}} \right)}{V\left[\overline{\overline{D}}_{st}\right] + \sum_h \frac{w_h^2 s_{1h}^2}{N_h}}$$

Optimal (Neyman) Sample Allocation

$$n_h = \frac{n^* w_h s_{uh}}{\sum_h w_h s_{uh}}$$

Florida Keys Reef Fish: Sampling Allocations 1979-2005



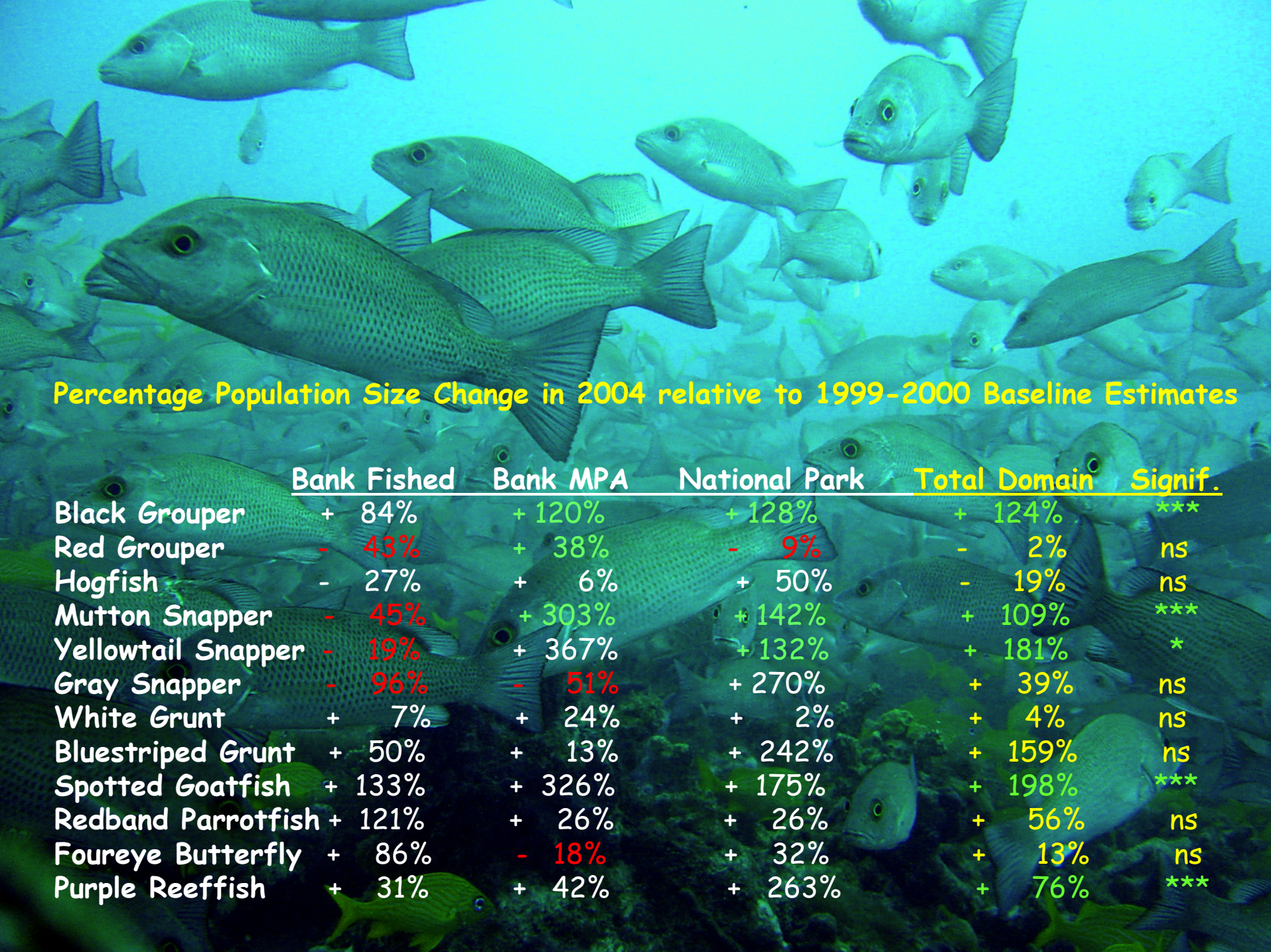
Survey Design Estimation of MPA Effects

Accounts for:

- Different ‘mix’ of habitats inside & outside MPAs
- Disparity in survey area inside & outside MPAs

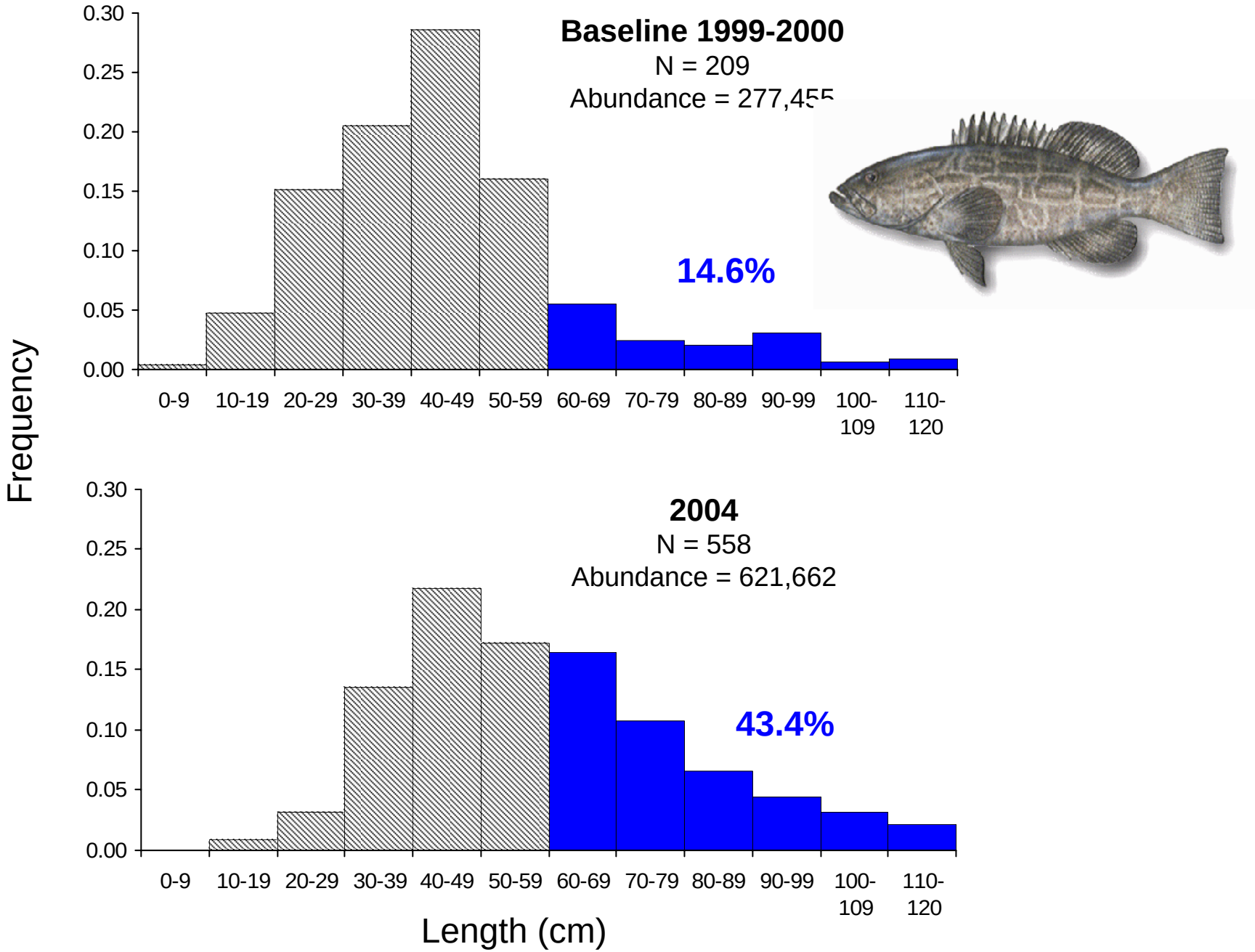
Enables analysis of:

- Population-level impacts
- Inside vs. outside comparisons

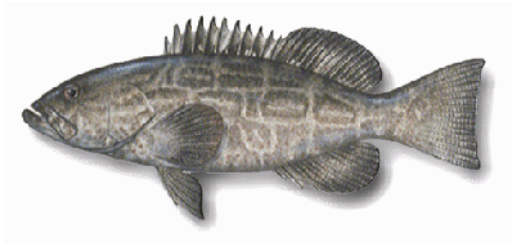


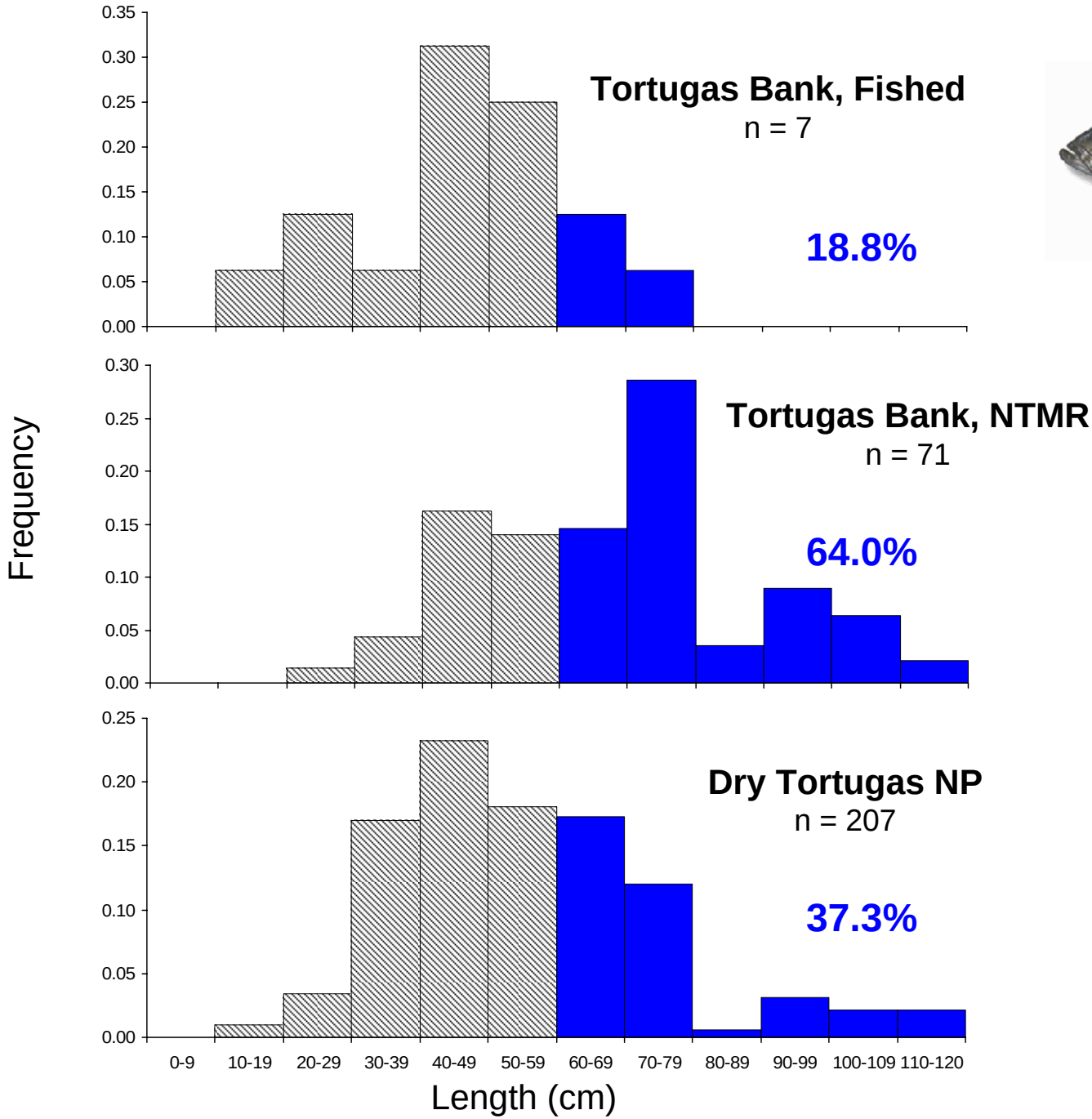
Percentage Population Size Change in 2004 relative to 1999-2000 Baseline Estimates

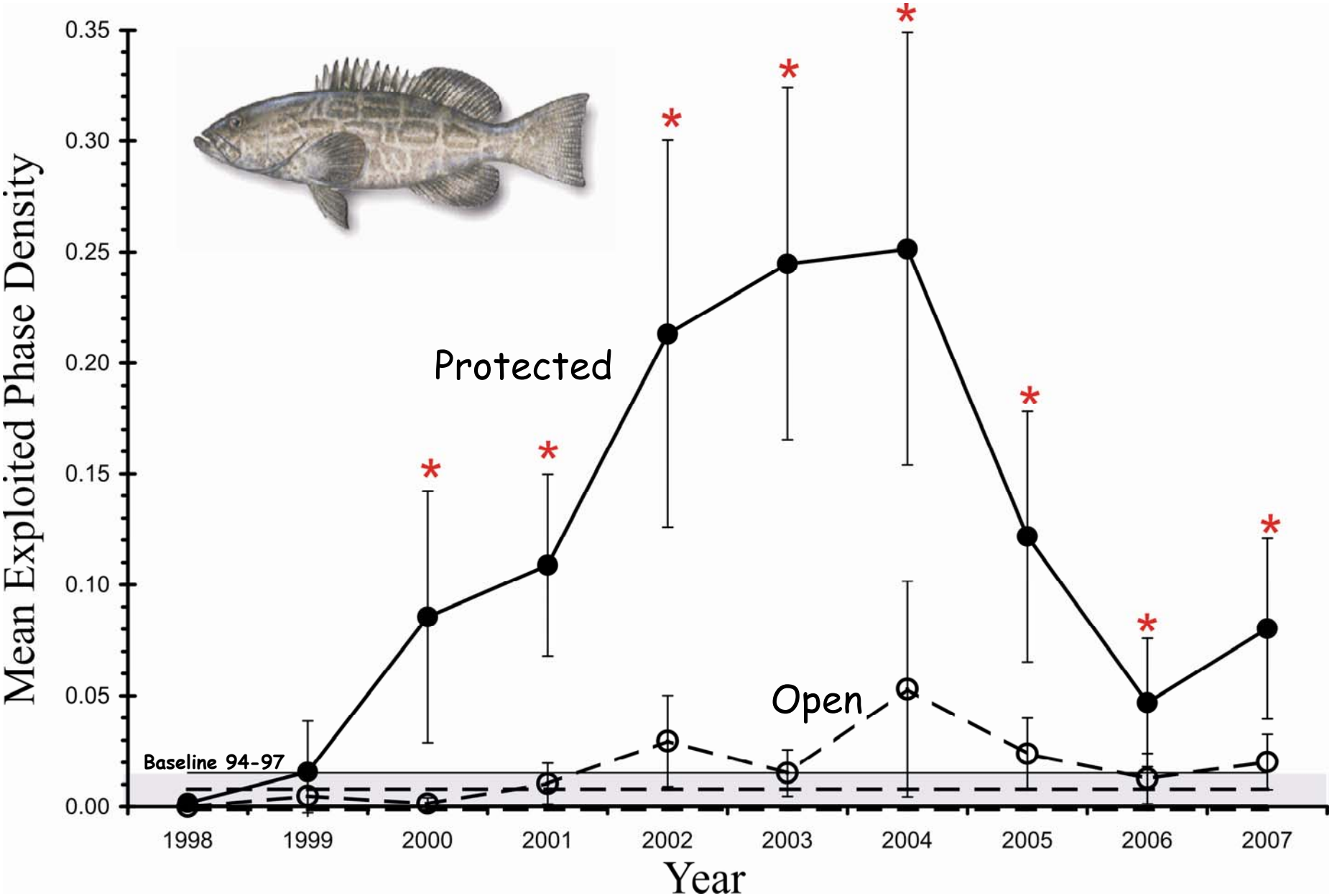
	Bank Fished	Bank MPA	National Park	Total Domain	Signif.
Black Grouper	+ 84%	+ 120%	+ 128%	+ 124%	***
Red Grouper	- 43%	+ 38%	- 9%	- 2%	ns
Hogfish	- 27%	+ 6%	+ 50%	- 19%	ns
Mutton Snapper	- 45%	+ 303%	+ 142%	+ 109%	***
Yellowtail Snapper	- 19%	+ 367%	+ 132%	+ 181%	*
Gray Snapper	- 96%	- 51%	+ 270%	+ 39%	ns
White Grunt	+ 7%	+ 24%	+ 2%	+ 4%	ns
Bluestriped Grunt	+ 50%	+ 13%	+ 242%	+ 159%	ns
Spotted Goatfish	+ 133%	+ 326%	+ 175%	+ 198%	***
Redband Parrotfish	+ 121%	+ 26%	+ 26%	+ 56%	ns
Foureye Butterfly	+ 86%	- 18%	+ 32%	+ 13%	ns
Purple Reeffish	+ 31%	+ 42%	+ 263%	+ 76%	***


Baseline 1999-2000
N = 209
Abundance = 277,455
14.6%
2004
N = 558
Abundance = 621,662
43.4%
Frequency
Length (cm)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-120

2004




Frequency
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Tortugas Bank, Fished
n = 7
18.8%
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Tortugas Bank, NTMR
n = 71
64.0%
0.25
0.20
0.15
0.10
0.05
0.00
Dry Tortugas NP
n = 207
37.3%
0-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-120
Length (cm)


Mean Exploited Phase Density
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Protected
Open
Baseline 94-97
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year

Summary

Strive for "strategic balance" in Florida reef resource management. Necessary tactics involve a combination of reserves and traditional management, while mitigating environment and chance.

With more people is our management strategy sufficient?

Optimum management strategy involves multiple control methods with closed areas to buffer uncertainty.

Maps & consistent sampling resources to detect changes.

Good for fish, ecosystem, fishermen and Florida's economy!