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

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

Data Acquisition
- Population Dynamics
- Habitats
- Bioeconomics

Model Building
- Physical ↔ Biological
- Humans ↔ Habitats

Fishery Resource Risk Assessment

Human-Fishery Sector

Coral Reef Ecosystem

Larval Dispersal
“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
Humston, Olson and Ault. 2004. Trans. Amer. Fish. Soc. 133
"Observable" Assessment Indicator Variables

Fishing Mortality Rate

Average Size (TL, mm)

Minimum Legal Size (24 inches)

Unexploited

40.6", 42.8 lbs
SPR = 100%

MSY Exploitation

36.4", 30.1 lbs
SPR = 35.1%

Current Exploitation

27.9", 12.6 lbs
SPR = < 6%

\[
\bar{L}(t) = \frac{\int_{a_c}^{a_z} F(t) \int N(a,t) L(a,t) \, da}{a_c}
\]

\[
F(t) \int N(a,t) \, da
\]
Model Cross-Validations

Fishery-Dependent “Observables”

Fishery-Independent “Observables”

FI Recruitment “Observables”

Fishery-Dependent “Observables”

- Rec Observed
- Rec Predicted
- Comm Observed

Fishery-Independent “Observables”

- Headboats
- RVC

FI Recruitment “Observables”

- Crec Obs
- C comm Obs
- CpredRec
- CpredComm

0.00 0.10 0.20 0.30 0.40
Index value (fish/177m²)

0 20000 40000 60000
Catch (kg)

0 100000 200000 300000 400000
Average Length (mm)

0 500 1000 1500 2000

0 500 1000 1500 2000

Year

Year


Bigger is (Biologically) Better!

Black Grouper

Individual

Population

Length (cm)

Weight (kg)

Biomass (mt)

Fecundity

Eggs (millions)

Age (years)
But, ... BIGGER is Better!!
Fishery Sustainability Decision Metrics

Most likely estimate for 1985-2002

MSY

YPR

SPR

F_{msy} = 0.13025

F_{0.1} = 0.1040

F_{2002} = 0.5039

SPR_{2002} = 9.0%

Overfishing (30% SPR)
Management Benchmarks: FL Keys Reef Fish Community

Exploited Coral Reef Fishes

(Best Publication Award 1998, NOAA NMFS Scientific Publication Office)

Florida Keys Reef Fish Community
Limit Control Rule

Overfished

- Hogfish
- Scamp
- Nassau
- Yellowfin
- Black
- Graysby
- Yellowtail
- Red Dog
- Mutton
- Schoolmaster
- Bluestriped
- White
- Margate
- Cottonwick
- Schoolmaster
- Goliath
- French Tomtate
- Red Hind
- Lane
- Rock Hind
- Goliath
- French Tomtate

Unexploited

Overfishing, but stock not overfished

Stock overfished, no overfishing (recovering)

No overfishing, not overfished

Unexploited

Grouper

Snapper

Grunt

Yield-per-Recruit

Traditional Fishery Management Benchmarks & Controls

Yw/R:
\[ 4.77 \rightarrow 9.14 \text{ kg} \]
92% increase

SPR-per-Recruit

SPR:
\[ 0.022 \rightarrow 0.305 \]
1286% increase
Transitional Productivity Dynamics of Florida Keys Black Grouper Stock

Yield in Numbers

Yield in Weight

Years Post Management Intervention
Designing the Tortugas No-Take Marine Reserves

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 km²
Florida Keys: 500 km²
Tortugas: 325 km²

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)
Stratified Random Sampling Design

Single Stage Design

Two Stage Design

Survey Domain

Stratum Domain

Primary Unit Domain

Secondary Unit Domain

\[ A \] (reef tract)

\[ A_h \] (Habitat Class, Depth, Zone)

\[ a_{hi} \] (200 x 200 m)

\[ T_{hij} \] (177 m^2)
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

- Patchy hard-bottom
- Patch reefs
- Pinnacles
- Low-relief spur & groove
- Rocky outcrops
- High-relief spur & groove
- Low-relief hard-bottom
- Medium-profile reef
- Reef terrace

Degree of Patchiness

Vertical Relief

Low
High

Low
High
Reef Terrace
Low-Relief Hardbottom
Rocky Outcrops
Pinnacles
Low-Relief Spur & Groove
Medium Profile Reef
Patchy Hardbottom in Sand
Reef Terrace
Patch Reefs
Low-Relief Spur & Groove
High-Relief Spur & Groove
Figure 2
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

\[ CV[\bar{D}] = \frac{SE[\bar{D}]}{\bar{D}} \]

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

\[ n^* = \sum_h w_h s_{uh} \left( \sum_h w_h s_{uh} + \sum_h \frac{w_h^2 s_{2h}^2}{m^*_h w_h s_{uh}} \right) \]

\[ V[D_{st}] + \sum_h \frac{w_h^2 s_{1h}^2}{N_h} \]

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

Neyman Optimal Sampling Allocation

CV

n*
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
<table>
<thead>
<tr>
<th>Species</th>
<th>Bank Fished</th>
<th>Bank MPA</th>
<th>National Park</th>
<th>Total Domain</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Grouper</td>
<td>+ 84%</td>
<td>+ 120%</td>
<td>+ 128%</td>
<td>+ 124%</td>
<td>***</td>
</tr>
<tr>
<td>Red Grouper</td>
<td>- 41%</td>
<td>+ 38%</td>
<td>- 9%</td>
<td>- 2%</td>
<td>ns</td>
</tr>
<tr>
<td>Hogfish</td>
<td>- 27%</td>
<td>+ 6%</td>
<td>+ 50%</td>
<td>- 19%</td>
<td>ns</td>
</tr>
<tr>
<td>Mutton Snapper</td>
<td>- 45%</td>
<td>+ 303%</td>
<td>+ 142%</td>
<td>+ 109%</td>
<td>***</td>
</tr>
<tr>
<td>Yellowtail Snapper</td>
<td>- 19%</td>
<td>+ 367%</td>
<td>+ 132%</td>
<td>+ 181%</td>
<td>*</td>
</tr>
<tr>
<td>Gray Snapper</td>
<td>- 96%</td>
<td>- 51%</td>
<td>+ 270%</td>
<td>+ 39%</td>
<td>ns</td>
</tr>
<tr>
<td>White Grunt</td>
<td>+ 7%</td>
<td>+ 24%</td>
<td>+ 2%</td>
<td>+ 4%</td>
<td>ns</td>
</tr>
<tr>
<td>Bluestriped Grunt</td>
<td>+ 50%</td>
<td>+ 13%</td>
<td>+ 242%</td>
<td>+ 159%</td>
<td>ns</td>
</tr>
<tr>
<td>Spotted Goatfish</td>
<td>+ 133%</td>
<td>+ 326%</td>
<td>+ 175%</td>
<td>+ 198%</td>
<td>***</td>
</tr>
<tr>
<td>Redband Parrotfish</td>
<td>+ 121%</td>
<td>+ 26%</td>
<td>+ 26%</td>
<td>+ 56%</td>
<td>ns</td>
</tr>
<tr>
<td>Foureye Butterfly</td>
<td>+ 86%</td>
<td>- 18%</td>
<td>+ 32%</td>
<td>+ 13%</td>
<td>ns</td>
</tr>
<tr>
<td>Purple Reeffish</td>
<td>+ 31%</td>
<td>+ 42%</td>
<td>+ 263%</td>
<td>+ 76%</td>
<td>***</td>
</tr>
</tbody>
</table>
Baseline 1999-2000
N = 209
Abundance = 277,455

2004
N = 558
Abundance = 621,662
Tortugas Bank, Fished
n = 7

18.8%

Tortugas Bank, NTMR
n = 71

64.0%

Dry Tortugas NP
n = 207

37.3%

2004
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!