Coupling Ecology and GIS Technology to Evaluate the Efficacy of Marine Protected Areas in Hawaii

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Objective: Conduct integrative coral reef ecosystem mapping and monitoring to evaluate MPA effectiveness, define essential fish habitat, and identify biologically relevant MPA boundaries.

I) Background - Integrated Benthic Habitat Mapping and Monitoring
II) Define Reef Fish Habitat Utilization Patterns
III) Evaluate MPA Effectiveness
IV) Design principles for reserves in Hawaii
Imagery for Developing Benthic Habitat Maps

IKONOS – true-color; 4 m pixel

AERIAL PHOTOGRAPHY – true-color; 1.2 m pixel

HYPERSPECTRAL – 72 bands between 350 and 1000 nm; 3 m pixel
South Molokai, Hawaii Coral Reef Ecosystem Habitats

Habitat Types

- Sand
- Mud
- Seagrass/90%-100%
- Seagrass/60%-90%
- Seagrass/10%-50%
- Macaoalga/90%-100%
- Macaoalga/50%-90%
- Macaoalga/10%-50%
- Enrusting Coraline Algae/90%-100%
- Enrusting Coraline Algae/50%-90%
- Enrusting Coraline Algae/0%-50%
- Linear Reef
- Spur and Groove Reef
- Patch Reef/Individual
- Patch Reef/Aggregated
- Coral Head/Individual
- Coral Head/Aggregated
- Scattered Coral/Rock in Unconsolidated Sediments
- Colonized Pavement
- Colonized Volcanic Rock/Boulder
- Colonized Pavement with Sand Channels
- Uncolonized Pavement
- Reef Rubble
- Uncolonized Volcanic Rock/Boulders
- Uncolonized Pavement with Sand Channels
- Emergent Vegetation
- Artificial
- Artificial Fishpond
- Unknown

MMU = 0.4 ha (1 acre)
South Molokai Study Area

1. Draw Boundary
2. Delineate Habitats
3. Generate Random Points
4. Map Accuracy Analysis
5. Assessment Transects- Fish/benthic Community
6. Identify Essential Fish Habitat
7. Evaluation of Marine Protected Areas
Locations of Hawaii Marine Life Conservation Districts and the University Marine Laboratory Refuge (Moku o Loe)
## Marine Life Conservation Districts in Hawaii

<table>
<thead>
<tr>
<th>Island</th>
<th>Protected area</th>
<th>Acres</th>
<th>Year estab.</th>
<th>Use</th>
<th>Protection from fishing</th>
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</thead>
<tbody>
<tr>
<td>Oahu</td>
<td>Hanauma Bay</td>
<td>101</td>
<td>1967</td>
<td>High</td>
<td>High</td>
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<tr>
<td></td>
<td>Pupukea</td>
<td>179</td>
<td>1983*</td>
<td>Mod</td>
<td>Mod</td>
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<tr>
<td></td>
<td>Waikiki</td>
<td>76</td>
<td>1988</td>
<td>High</td>
<td>High</td>
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<tr>
<td></td>
<td>Moku o Loe</td>
<td>73</td>
<td>1967</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Hawaii</td>
<td>Kealakekua Bay</td>
<td>315</td>
<td>1969</td>
<td>High</td>
<td>Mod</td>
</tr>
<tr>
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<td>Lapakahi</td>
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<td>1979</td>
<td>Low</td>
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<tr>
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<td>Waialea Bay</td>
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<td>1985</td>
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<td>Old Kona Airport</td>
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<tr>
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<td>Wai Opae</td>
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<td>2000</td>
<td>Mod</td>
<td>High</td>
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<tr>
<td>Lanai</td>
<td>Manele-Hulopoe</td>
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<td>1976</td>
<td>Mod</td>
<td>Mod</td>
</tr>
<tr>
<td>Maui</td>
<td>Molokini Shoal</td>
<td>211</td>
<td>1977</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Honolua-Mokuleia Bay</td>
<td>45</td>
<td>1978</td>
<td>Mod</td>
<td>High</td>
</tr>
</tbody>
</table>

Friedlander and Brown 2003

* Modified 2003
Using Maps to Support Field Activities

Random stratified design
- inside vs. outside MPAs
- coral, other hard bottom, macroalgae, sand

Fish Censuses
- 25m x 5m transects

Corresponding habitat metrics
- biotic cover
- abiotic cover
- habitat complexity
Waikiki Benthic Habitats, MPAs, and Sampling Locations (N = 99)

Waikiki MLCD
Est. 1988, 31 Ha

Waikiki-DH FMA
Rotational closure since 1978
97 Ha

Colonized Hardbottom
Macroalgae
Sand
Uncolonized Hardbottom
Unknown

1  0  1  2 Kilometers
Fish biomass (t ha⁻¹) by individual transects (N=99) for Waikiki including Waikiki MLCD and Waikiki-Diamondhead FMA.
Mean biomass (t ha$^{-1}$) by habitat type and management regime for Waikiki

Error bars are standard error of the mean

$F_{5,68} = 5.10$

$P < 0.001$

MLCD > FMA = Open
Fish Biomass (t ha$^{-1}$) by Habitat among Management Regimes

![Graph showing fish biomass by habitat and management regime]

- **Open**
- **FMA**
- **MLCD**

Habitats: CHB, UCH, MAC, SAND
Factors Influencing Fish Biomass (t ha\(^{-1}\)) among all Locations
Stepwise multiple regression analysis (hardbottom only)
Probability to enter model 0.25, probability to leave 0.10, \(R^2 = 0.41\)

![Graph showing factors influencing fish biomass](image-url)
Comparison of Fish Biomass between MPAs and Open Areas Across Range of Habitat Complexities

![Graph showing the comparison of fish biomass between MPAs and open areas across different habitat complexities. The graph includes a linear regression line with the equation F_{3,21} = 20.93, p < 0.001, R^2 = 0.78. The LS Means Intercept for MPA is 0.59 and for Open is 0.37.](image)

F_{3,21} = 20.93  
\( P < 0.001, R^2 = 0.78 \)  
LS Means Intercept (p < 0.05)  
MPA - 0.59  
Open - 0.37
Ratio of biomass (t ha\(^{-1}\)) inside MPAs vs. outside areas open to fishing

Hardbottom habitats only.

<table>
<thead>
<tr>
<th>Location</th>
<th>Ratio of biomass (t ha(^{-1})) inside/outside protected area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waialae</td>
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<tr>
<td>Kealakekua</td>
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<td>Manele</td>
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<td>Old Kona Airport</td>
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</tr>
<tr>
<td>Moku o Loe</td>
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<tr>
<td>Waiopae</td>
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<td>Waikiki</td>
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<td>Pupukea</td>
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<tr>
<td>Honolua</td>
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</tr>
<tr>
<td>Molokini</td>
<td></td>
</tr>
<tr>
<td>Hanauma</td>
<td></td>
</tr>
</tbody>
</table>

- **Partial protection**
- **No-take**
Size spectra of $\log_{10}$ number ha$^{-1}$ by standardized size class (TL in cm) for all fishes on hardbottom habitats.

$F_{2,26} = 10.21$
$P < 0.001$

**LS Means Intercept**
- MLCD = 2.08  A
- FMA = 1.71   B
- Open = 1.54  C
Mean biomass per transect (t ha$^{-1}$) by trophic guild and management regime on hardbottom habitats
Trophic composition among major habitat types pooled across all locations

- Highest biomass of apex on colonized hardbottom
- Highest proportion on sand
- Sand important corridor
- Lowest on macroalgae and uncolonized hardbottom
Habitat Variables Affecting Fish Assemblage Characteristics in MLCDs

Results of General Linear Models

- Fish Species Richness
  - Depth: Partial $R^2$
  - Sand: Partial $R^2$ (-)

- Fish Biomass
  - Rugosity: Partial $R^2$

hardbottom only
Major Conclusions

- Habitat complexity explained much of the variability in fish species richness, biomass, and diversity
- Overall fish biomass was 2.6 times greater in reserves
- Apex predators showed the greatest difference between open and protected areas
- Depth explained most variability in richness and diversity among reserves
- Overall size of the adult fish assemblage larger in the protected areas & larger size classes had greater number of individuals compared with the other management regimes
- Despite their proven success, no-take reserves account for less than 1% of nearshore areas in the main Hawaiian Islands
Design Criteria for Effective MPAs in Hawaii

- Range of habitat complexities
- Full protection from fishing
- Shoreline to deep habitats
- Mosaic of habitats
- Sand corridors
- Low macroalgae cover
- Representative wave exposures
Spatial Management is the Best Solution for Fisheries and Biodiversity in Hawaii

- Conventional fisheries management not well suited for Hawaii or other tropical insular areas
  - Catch/effort restrictions not effective in non-commercial fisheries
  - Closed seasons not effective with non-selective gear
  - Gear restrictions difficult to enforce
  - Size limits (little enforcement, lack of compliance, non-selective gear)
    - Large fish contribute more and higher quality offspring

- High endemism = biodiversity hotspot

- Ecosystem management = spatial management