Quantifying spatial patterns of coral reef fish assemblages to inform marine management actions in Hawaii

Lisa Wedding [a,b], Alan Friedlander [b,c]

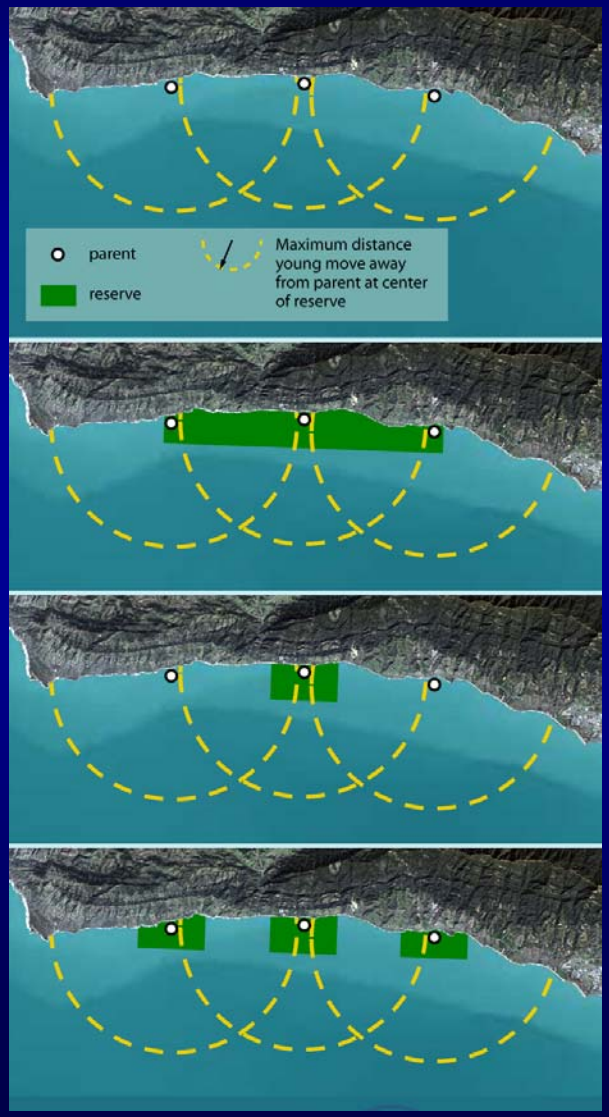
a *University of Hawaii at Manoa, Department of Geography*
b *NOAA/NCCOS/CCMA/NOS Biogeography Branch*
c *The Oceanic Institute*

Introduction

- Fishes are ecologically & economically important components of reef ecosystems
- Sustainability of reef fishes has becoming an increasing concern
- Paradigm shift towards EBM
  - changes management focus from target sp. to entire ecosystem

Marine spatial management

- MPAs allow for EBM principles to be applied to conserve EFH & protect entire ecosystem within boundary
  - a spatial approach to marine management
- Understanding spatial patterns of fish across the seascape impt. to support management



Spatial analysis

- Several distinct theoretical approaches used for spatial analysis of environmental data

1. Landscape ecology
2. Biogeographic
3. Geostatistical

- Common thread quantification of spatial patterns

Quantifying spatial patterns of fish assemblages

1. Introduction

2. Research projects

Landscape ecology

- Pupukea MPA boundary expansion

Biogeographic

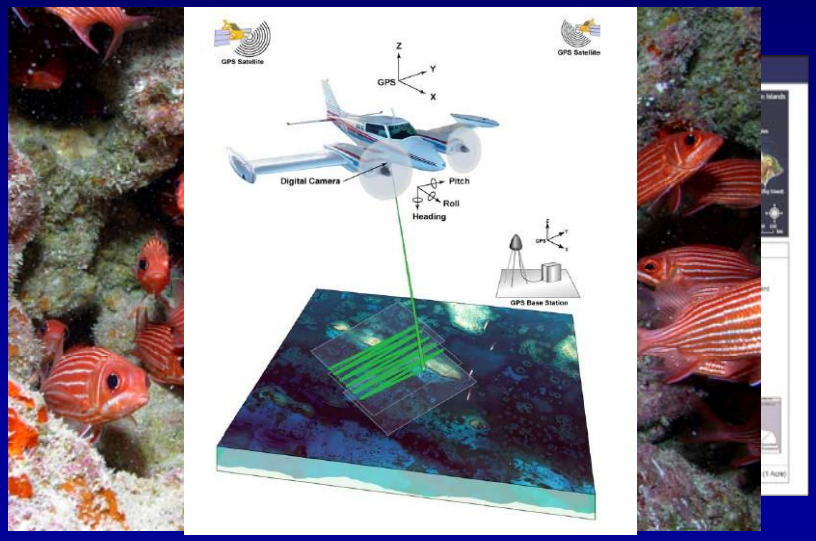
- NWHI fish spatial patterns

Geostatistical

- Relating remotely sensed measures of the seascape to fish assemblage structure

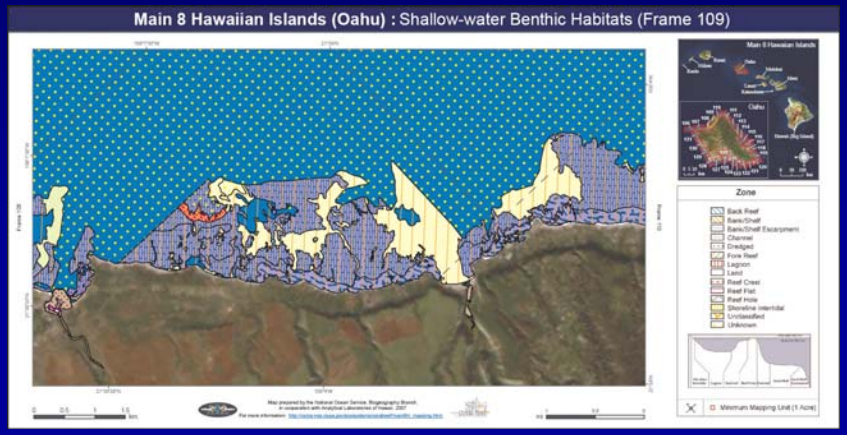
3. Integration & Discussion

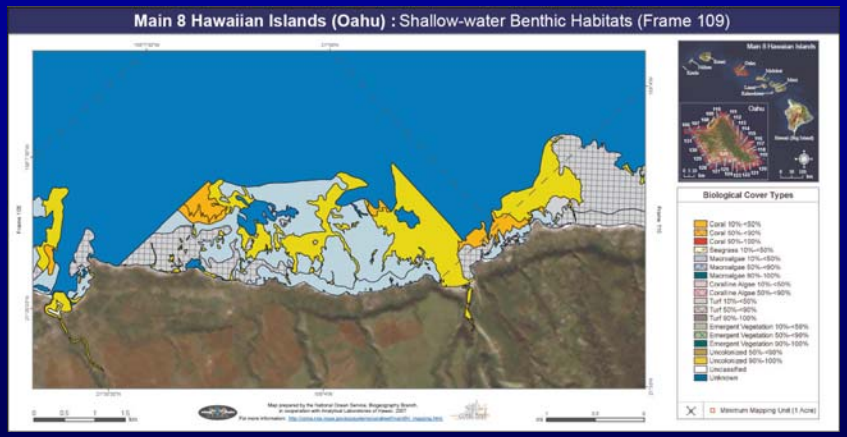
4. Future work



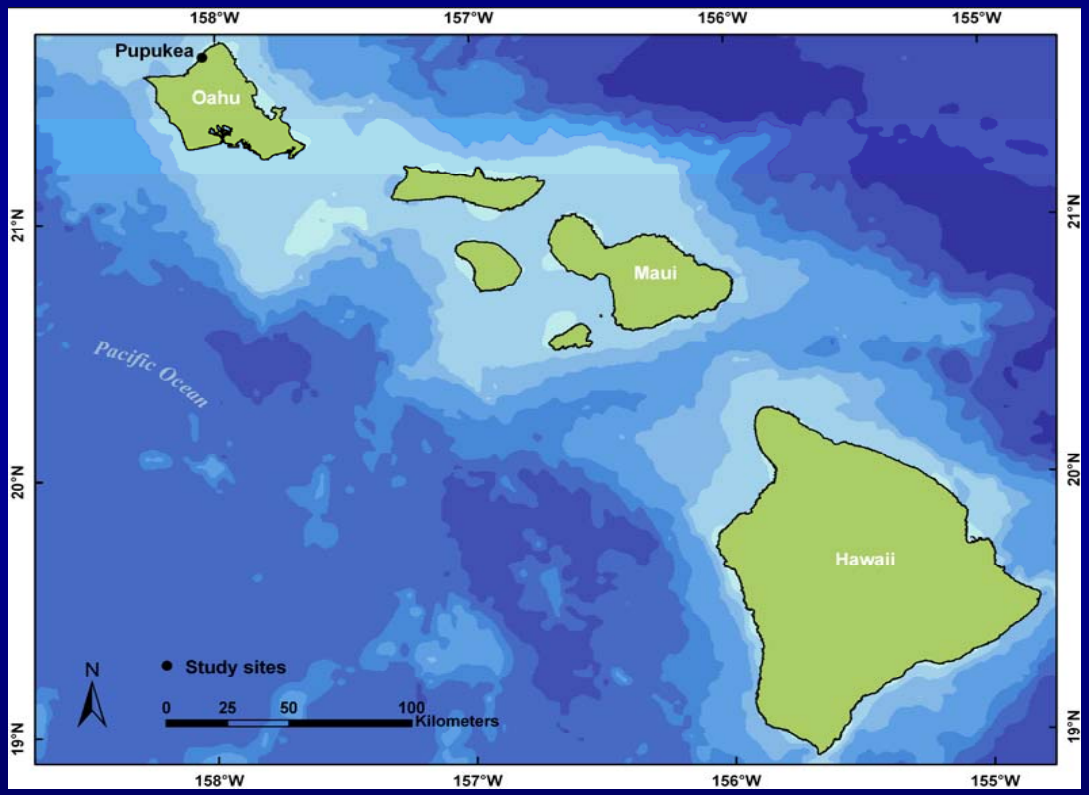
Case study 1: Landscape ecology

- Objective: Evaluate the expansion of the Pupukea MPA using the new NOAA benthic habitat maps
- Does the new 2003 MPA boundary include:
  - a more representative amount of structure & cover types?
  - habitat corridors?
  - a broader range in depth and structural complexity?





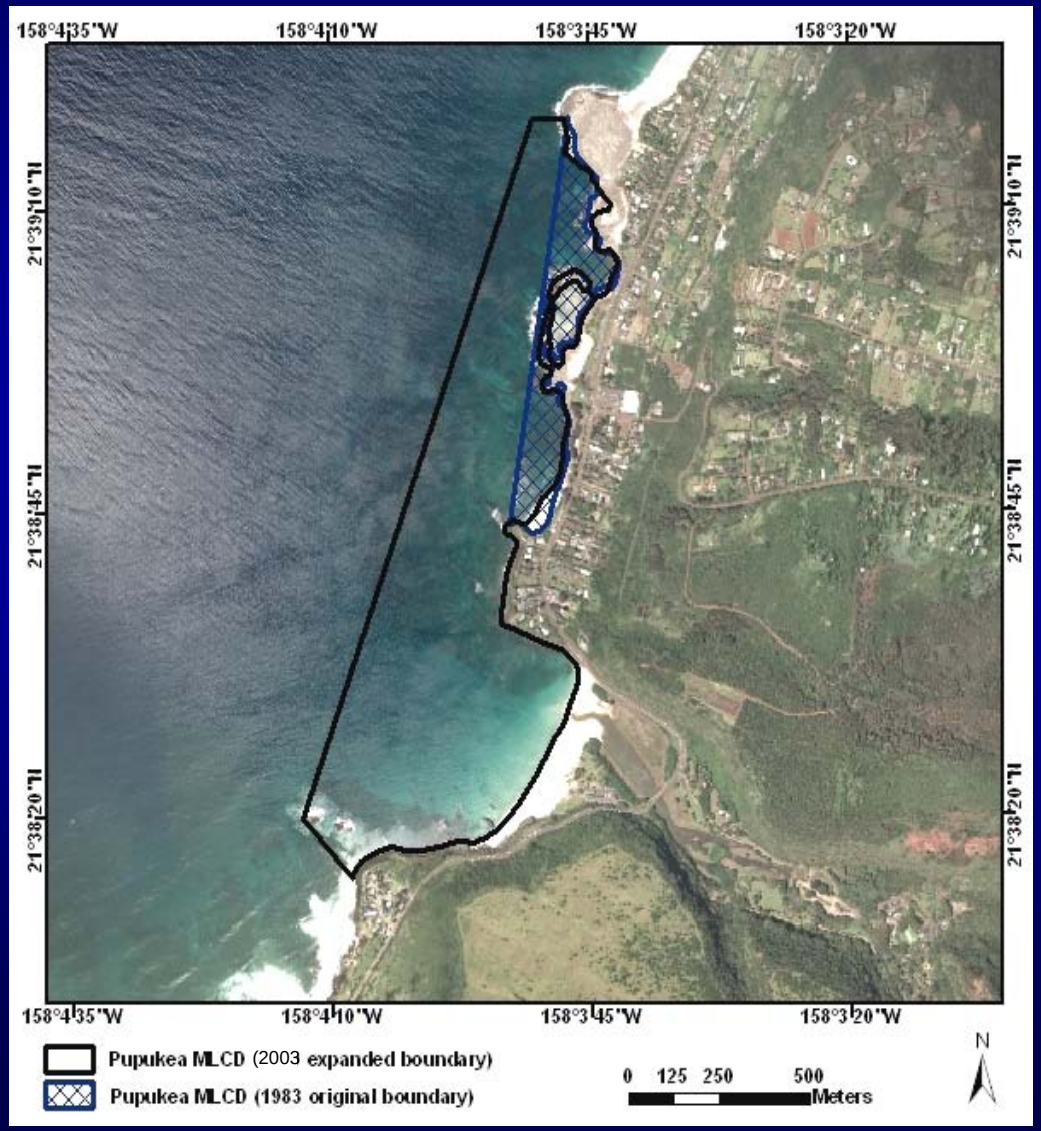
Pupukea MLCD, Oahu



Pupukea MLCD boundary expansion

- 1983 MLCD established, 2003 expanded
- Community was concerned for the resources (overuse, poaching, tourism)

  - boundary expansion was a result of the community efforts



Community support for MPA expansion

Hui Malama o Pupukea-Waimea

(partners: CCN, DLNR, DOCAR)

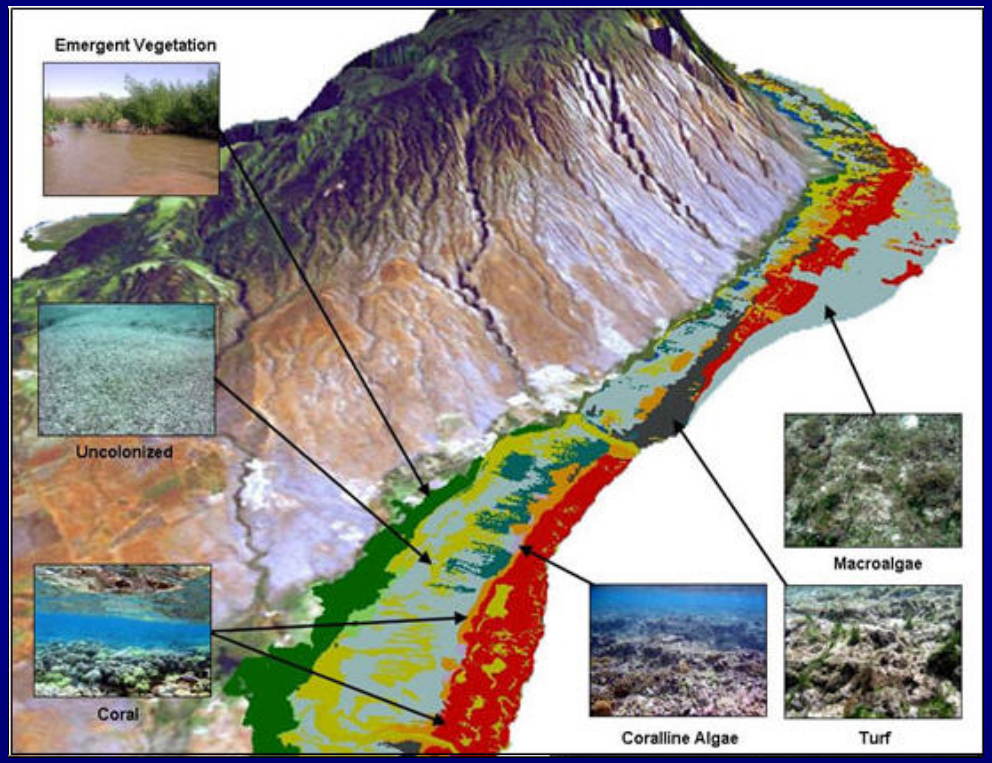
- **Awareness-raising and Outreach**
- **Biological and Human-use Monitoring**
- **Observation and Compliance**

New NOAA Benthic Habitat Maps for Hawaii

- NOAA Biogeography Branch created benthic habitat classification scheme & habitat maps for Hawaii

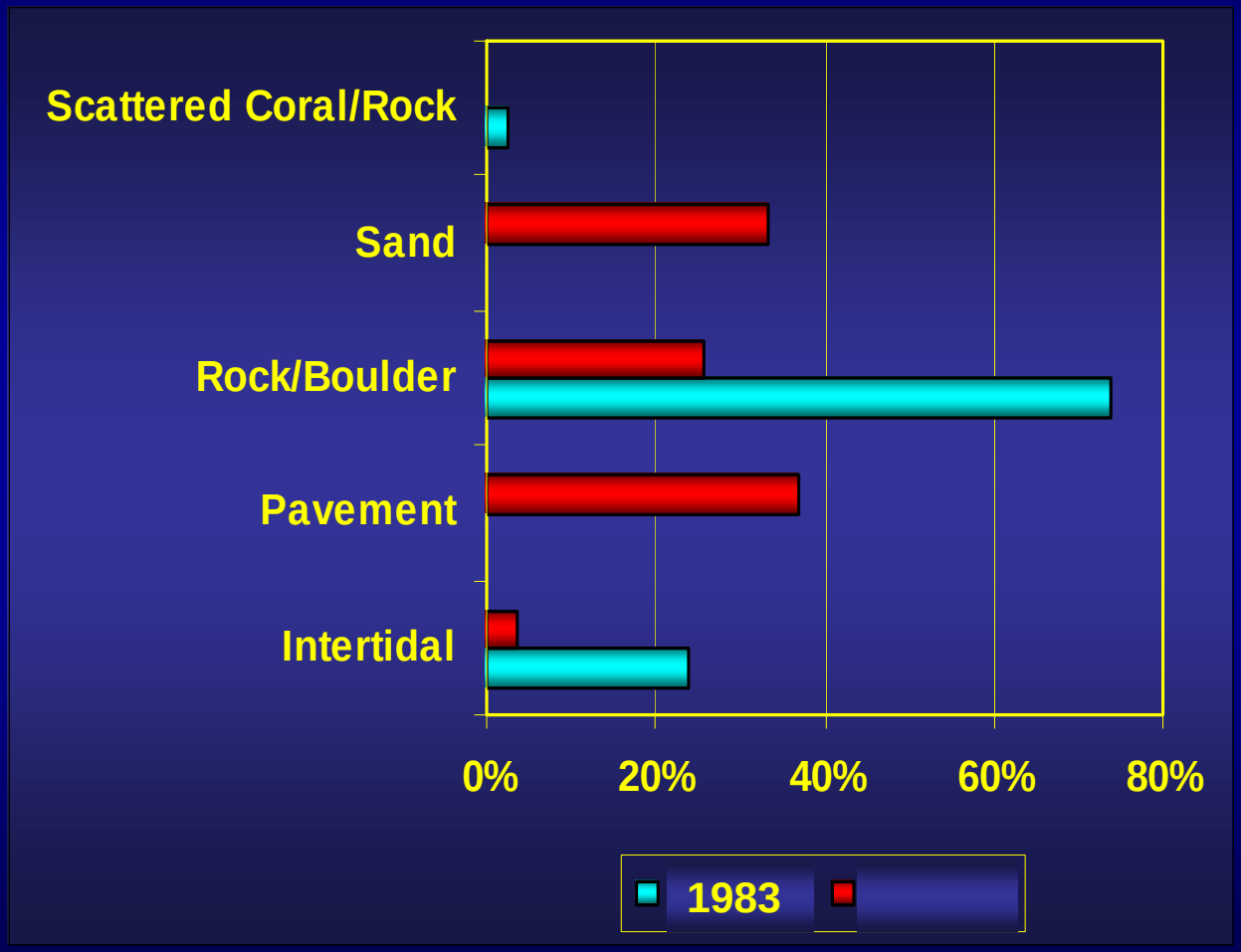
- Zone
- Geomorphic structure
- Biological cover

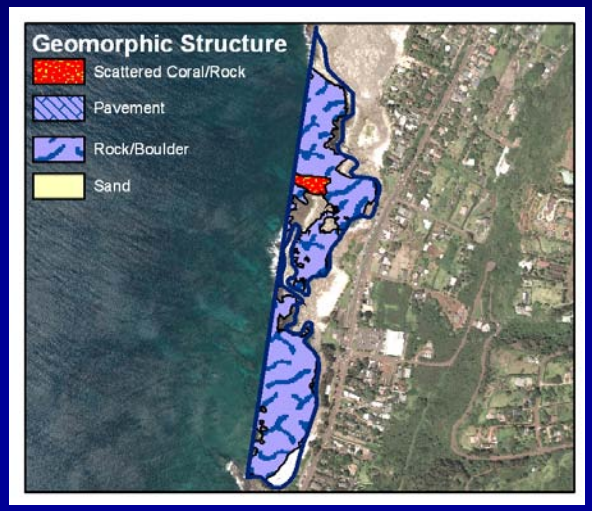
- MMU 1 acre

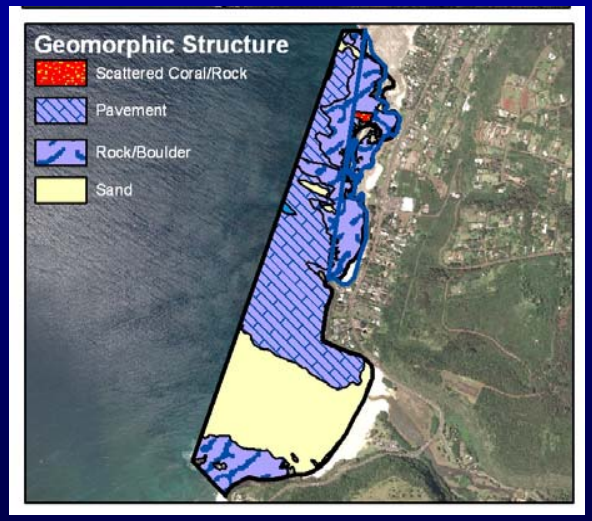


Battista et al. (2007)

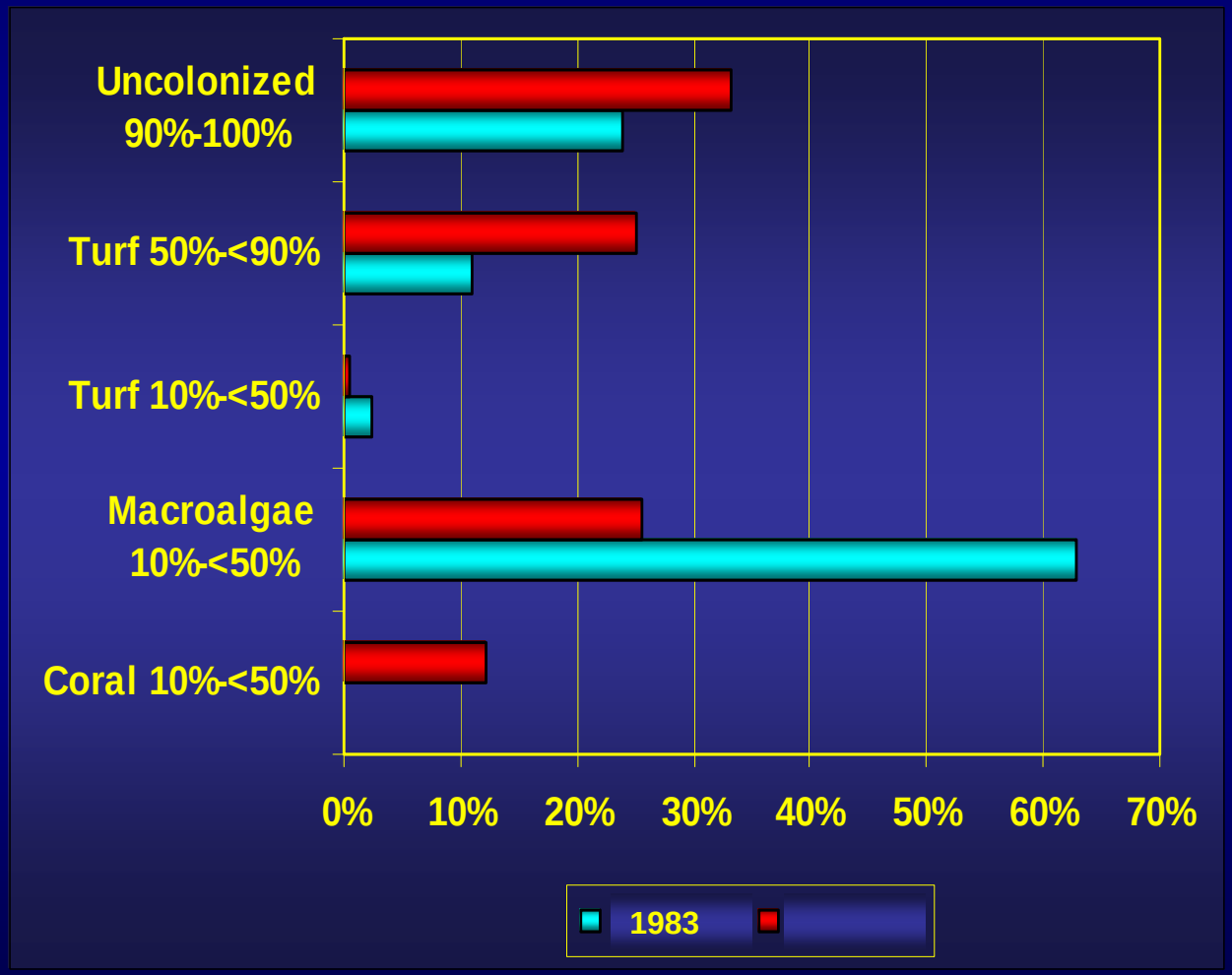
Geomorphic structure

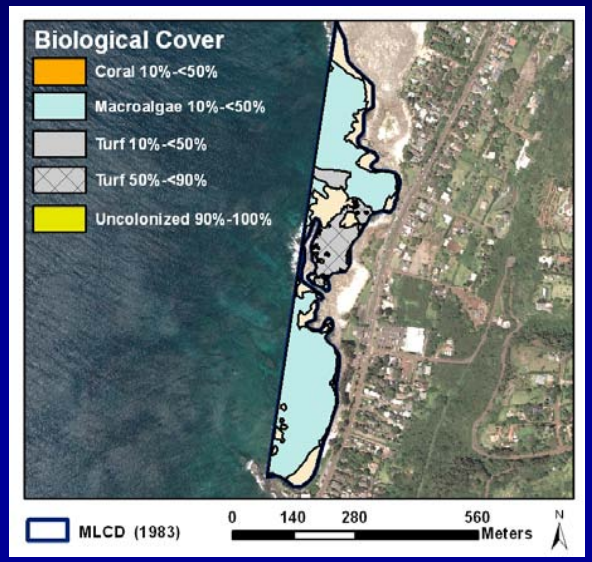


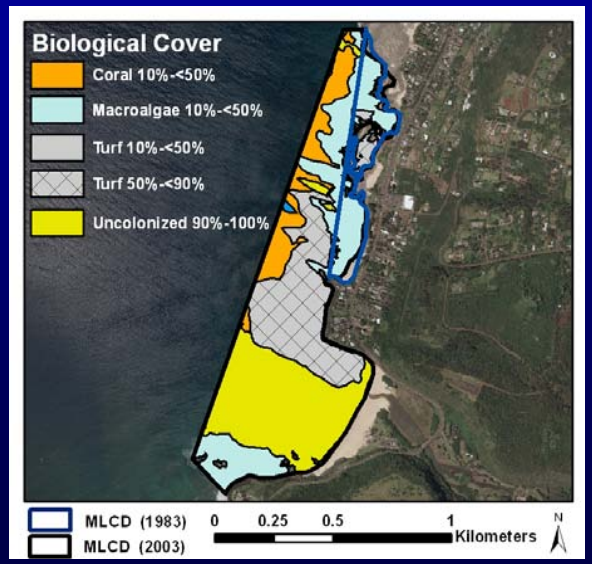




Biological cover



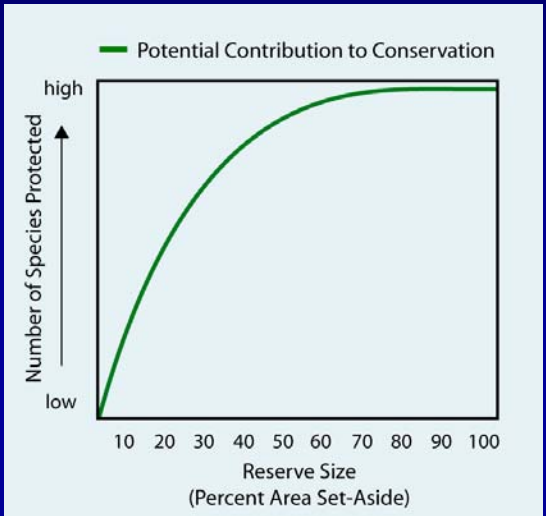


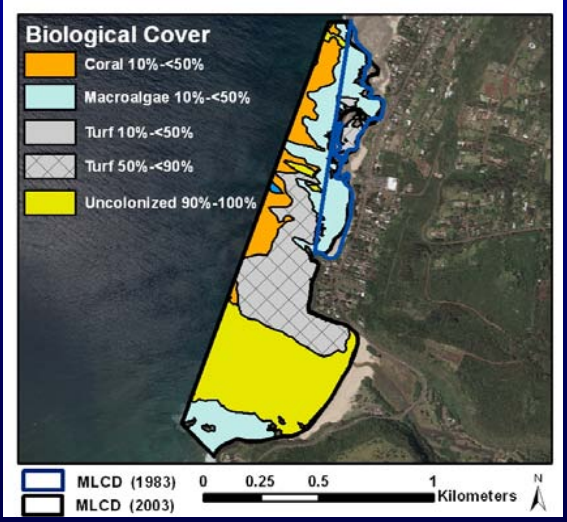


Summary of seascape metrics derived from NOAA benthic habitat maps (ha)

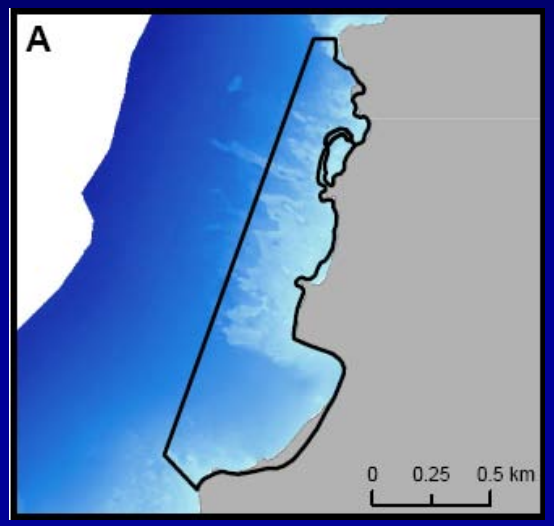
	1983 MLCD	2003 MLCD
Reserve		
Total seascape area	10.65	71.00
Reserve perimeter	2.97	5.21
Reserve P/A ratio	3	1
Biological cover		
Shannon's diversity	0.91	1.45
Shannon's evenness	0.65	0.81

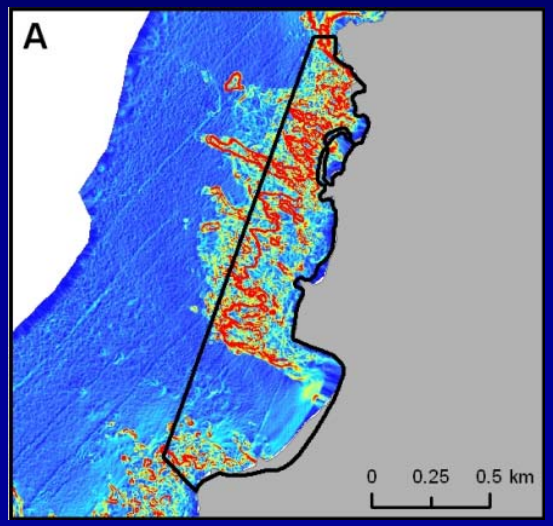
(2003

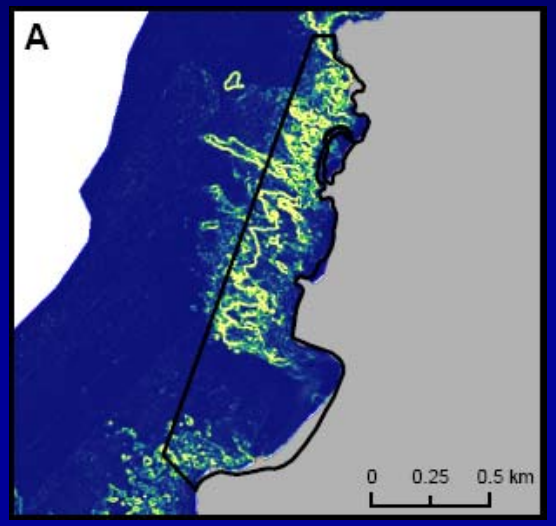




LIDAR-derived depth & habitat complexity







	1983 MLCD	2003 MLCD
Depth range (m)	0 – 12.1	0 – 17.0
Average rugosity	1.016	1.018
Average % slope	8.55 %	9.28 %
Variance in depth	6.85	17.89

Spatial patterns of reef fish at Pupukea MPA

- May 08 re-sampling
  - Fish data currently being analyzed (before 03 expansion)

- Qualitatively seen a dramatic increase in size & abundance of key resource species
  - Parrotfish, goatfish

Implications for MPA design

- Larger P/A ratio
  - > area relative to boundary
  - fish daily movements w/in MPA, more effective
- A broader depth range
  - a greater range of habitat types
  - Includes, deeper coral-rich areas
- reef complexity provides refuge from predation
- More representative habitat types shown from maps
  - Sand, corridors

Case Study 2: Papahanamokuakea Marine National Monument

- Objectives: Determine spatial patterns of reef fish assemblages in the NWHI
  - Patterns of species richness
  - Endemism
  - Gradient of latitudinal bias
  - Trophic structure

MARINE NATIONAL MONUMENT

Contact Information
6600 Kalaniana'ole Hwy
#300
Honolulu, HI 96825
808-397-2660
hawaiireef.noaa.gov

Habitats
- Reef
- Pelagic
- Abyssal
- Seamount
- Slope
- Bank
- Islands
- Atolls
- Hypersaline lake
- Lagoon

Key Species
- Hawaiian Monk seal
- Green sea turtle
- Sharks and jacks
- Corals
- Endemic reef fishes
- Calcareous algae
- Spinner dolphins
- Laysan Albatross

Topography & Bathymetry
-5000 0 274
Contours in meters

- Marine National Monument
- Ecological Reserve
- Special Preservation Area
- Special Management Area
- Marine National Monument Office
- Monument Visitor Information

Location
Located approximately 140 miles northwest of the Main Hawaiian Islands and covering an area roughly 1,200 miles long by 100 miles wide. It is the largest protected marine area in the world and is co-managed by NOAA, USFW and the State of Hawai'i.

Protected Area
139,797 square miles

Designation
June 2006

175°00'W 165°00'W 30°00'N 25°00'N 20°00'N

Papahānaumokuākea Marine National Monument

PACIFIC OCEAN

HAWAIIAN ARCHIPELAGO

Kure Atoll
Midway Atoll
Pearl and Hermes Atoll
Lisianski Island
Laysan Island
Maro Reef
Gardner Pinnacles
French Frigate Shoals
Necker Island
Nihoa Island
Middle Bank
Neckar ridge
HAWAIIAN RIDGE

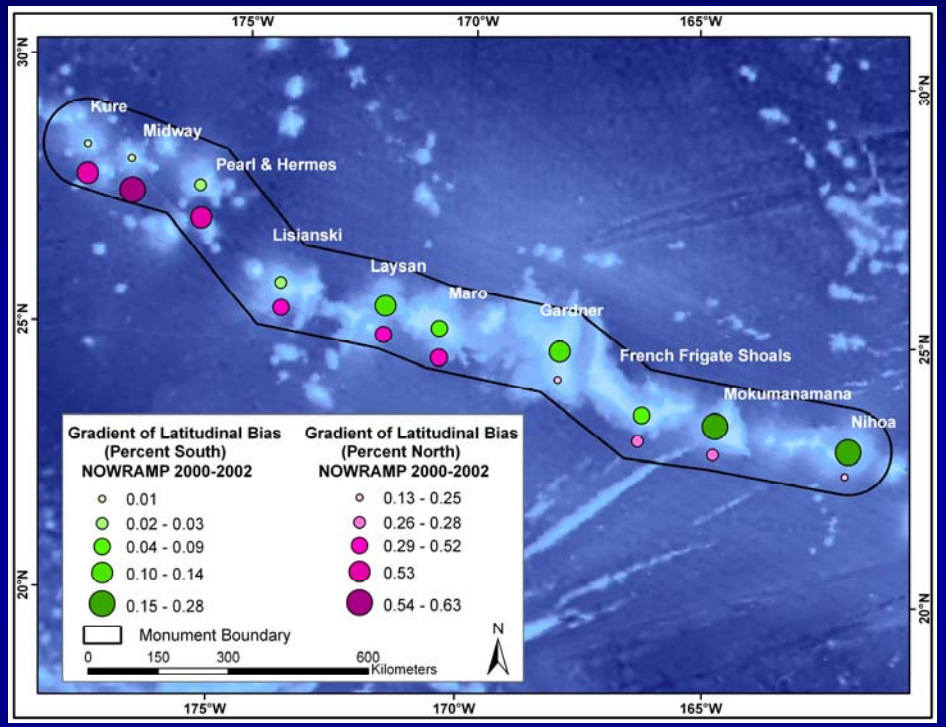
N W E S

Mercator Projection
Scale at 25° North is 1:4,080,000
0 50 100 miles
0 50 100 kilometers

RUSSIA
CANADA
CHINA
JAPAN
UNITED STATES
MEXICO
AUSTRALIA
NEW ZEALAND
Olympic Coast National Marine Sanctuary
Cordell Bank National Marine Sanctuary
Gulf of the Farallones National Marine Sanctuary
Monterey Bay National Marine Sanctuary
Channel Islands National Marine Sanctuary
Papahānaumokuākea Marine National Monument
HI
Equator
Orthographic Projection
1:86,900,000
0 1000 2000 miles
0 1000 2000 kilometers
Flower Garden Banks National Marine Sanctuary

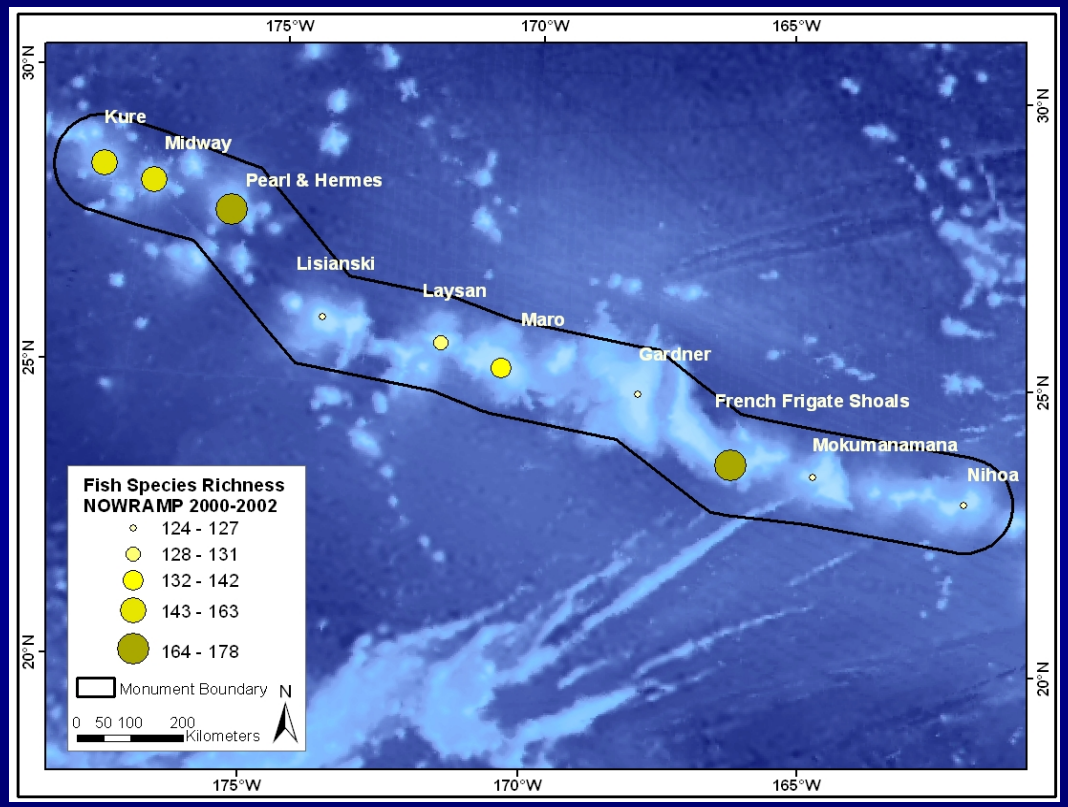
Gradient of latitudinal bias

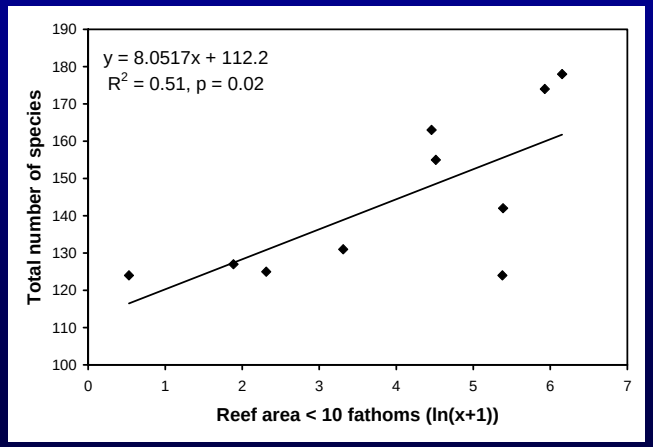
- At N end of chain more subtropical species and S end more tropical associated species
- Biogeographic break occurs about midchain
- Large lat. gradient leads to broad biogeographic distribution of species



Fish species richness

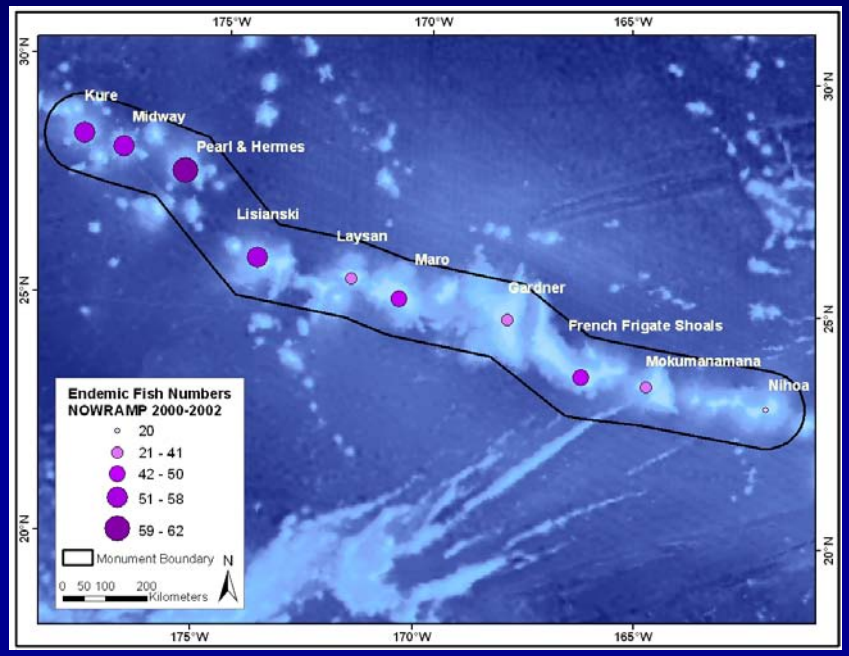
- Overall lower richness in NWHI relative to MHI
  - subtropical
  - small basalt islands, less reef area
- Positive relationship w/ reef area (island biogeography theory)





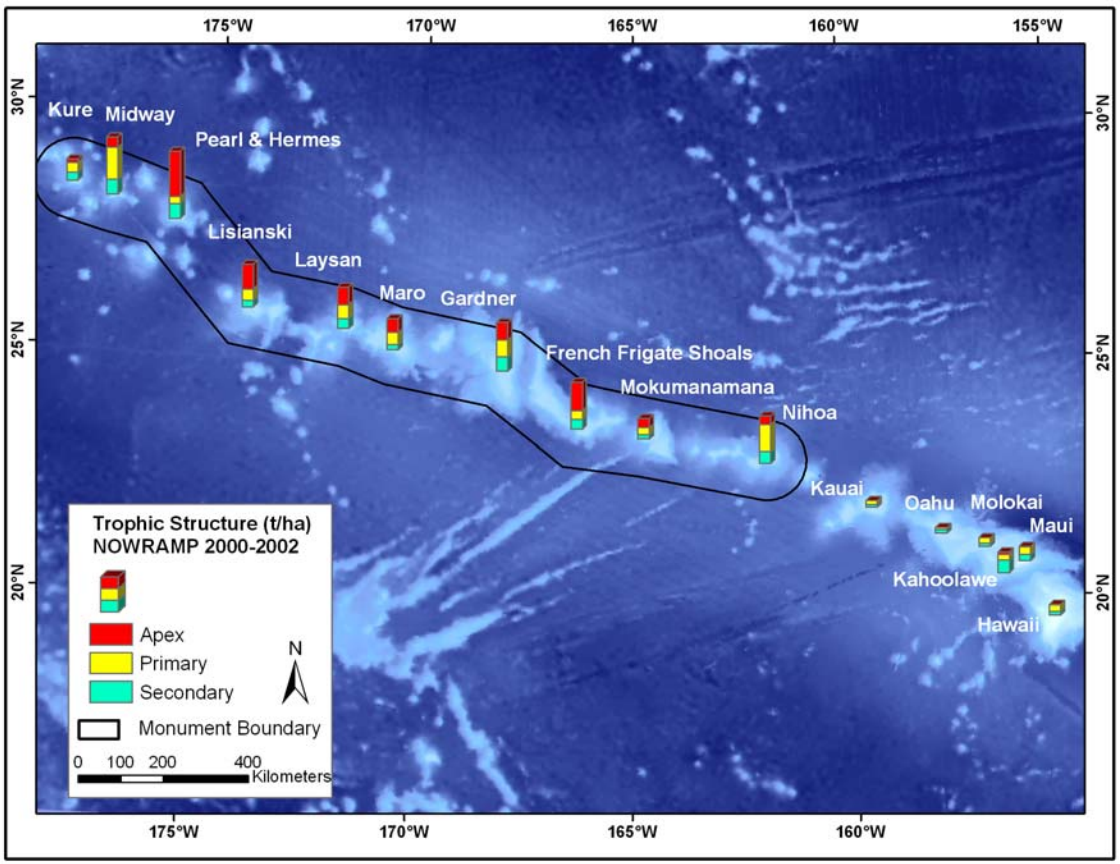
Fish endemism

- Higher endemism at the N end of chain
- Global biodiversity hotspot (30% fish endemic NWHI)
- Numerical endemism is 52%



Trophic structure (NWHI – MHI) Biomass (t ha^{-1})

- Total biomass is 3.5 x higher in NWHI
- Apex predators account for 54% of biomass in NWHI (3% in MHI)
- Highest apex predator biomass at PHR, LIS, FFS



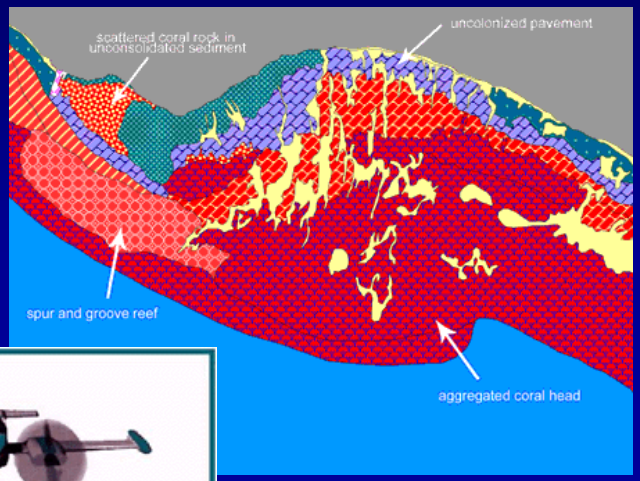
- High biomass at Kahoolawe

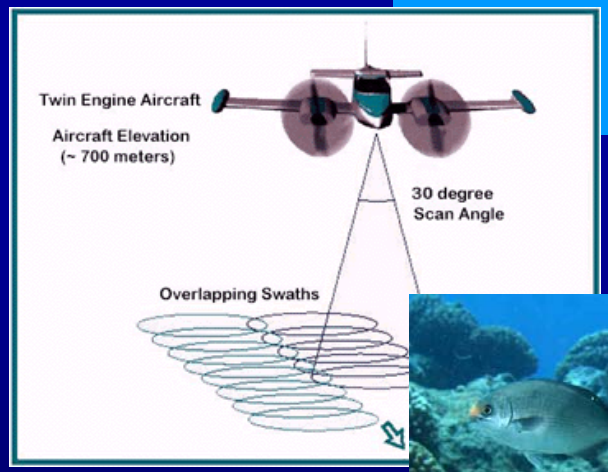
NWHI spatial patterns summary

- Latitudinal gradient, biogeographic break in species composition occurring mid-chain
- Overall lower richness in NWHI relative to MHI
- Higher endemism at Northern end of chain
- Apex predators account >% biomass in NWHI relative to MHI

Case study 3: Remote sensing seascape metrics

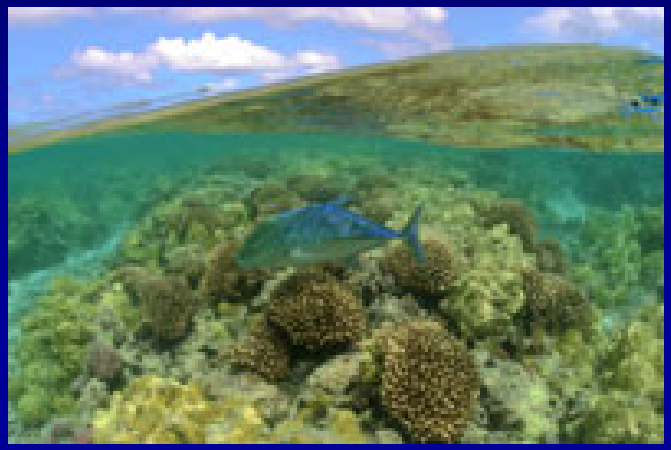
- Overall objective: Determine the influence of seascape structure on coral reef fishes
- What remotely sensed data provides seascape metrics relevant to reef fishes?
  - relevant to MPA design?





Research objectives

- <u>Objective 1</u>: What remotely sensed measures of the seascape demonstrate significant relationships w/ reef fishes
  - Ultimately serve as best ecological criteria to guide MPA design



- <u>Objective 2</u>: Examine degree that

  (1) physical protection

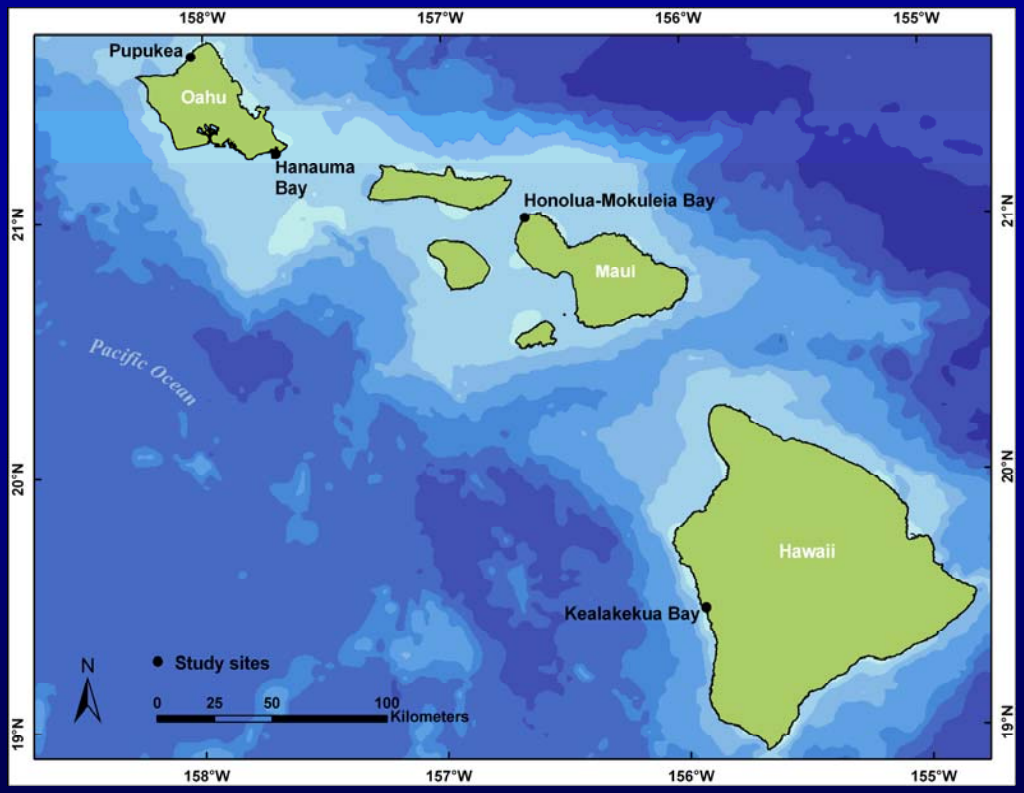
  (2) protection from fishing

  influence fish assemblages

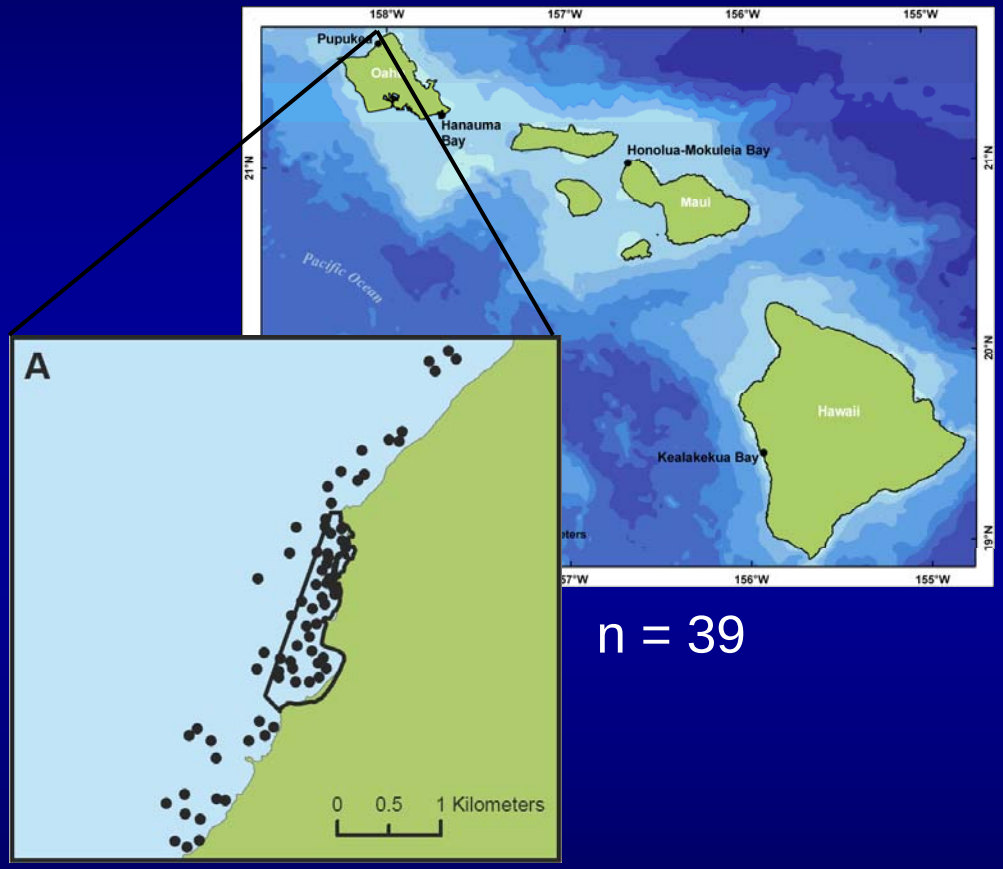
Research approach

- We assessed four current MPAs in order to evaluate the seascape structure, reserve configuration & fish assemblage

- Resource protection
- Human use
- Human population
- Wave exposure
- Full range of habitat types
- Structural complexity



Study sites: Pupukea MLCD



n = 39

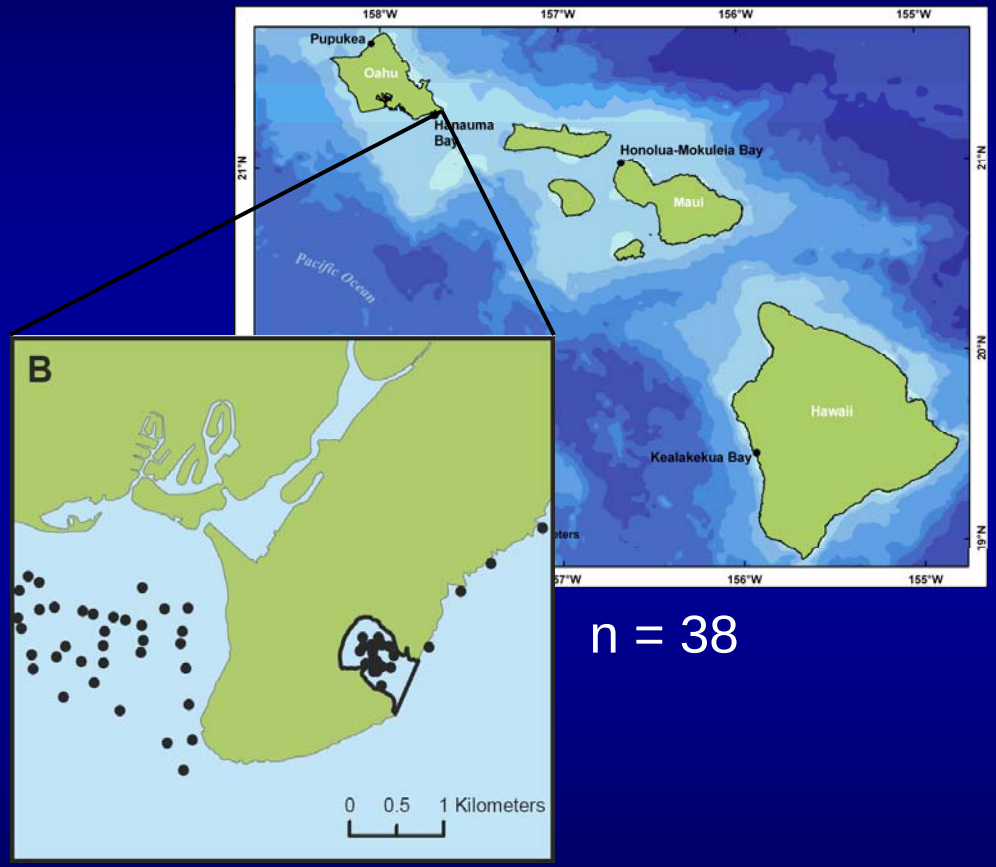
- Protection level: Pole & line, seaweed (seasonal)*

-MLCD est. 1983 (2003*)

- 0.72 km^2

- human use: moderate

Study sites: Hanauma Bay MLCD

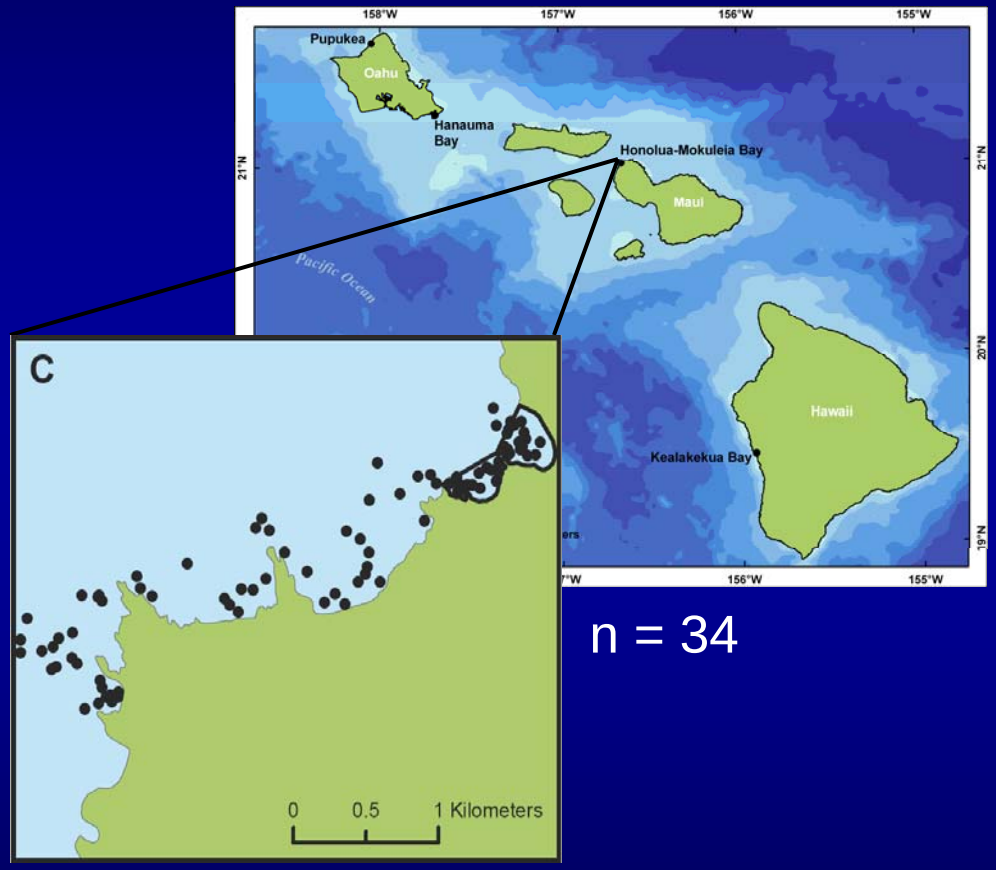


n = 38

Complete no-take

- MLCD est. 1967
- 0.41 km^2
- human use: high

Study sites: Honolua-Mokuleia Bay MLCD



n = 34

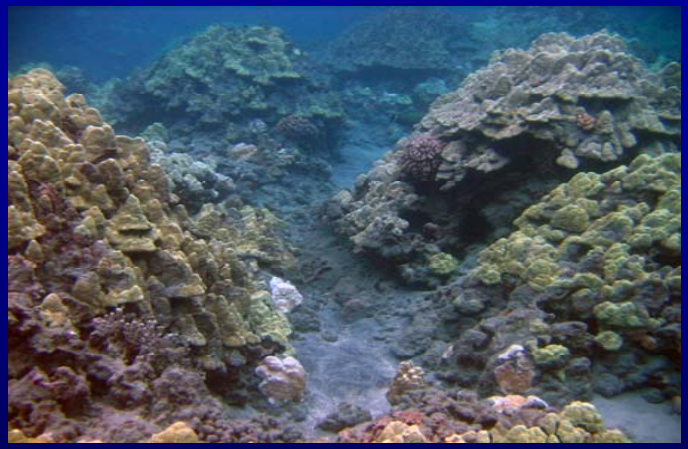
- Complete no-take

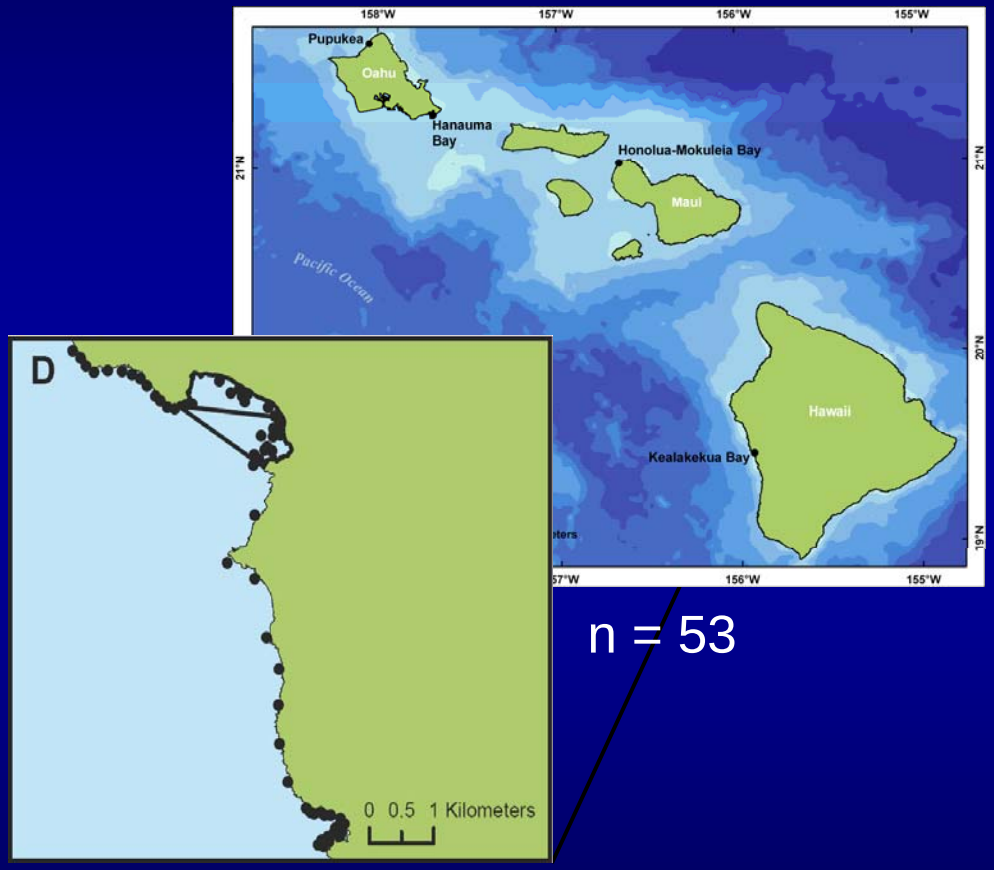
MLCD est. 1978

- 0.18 km^2

- human use: high

Study sites: Kealakekua Bay MLCD





n = 53

- (subzone B) pole & line, throw net

-MLCD est. 1969 - 1.24 km^2 - human use: moderate

Data & methods

- Stratified random sampling design

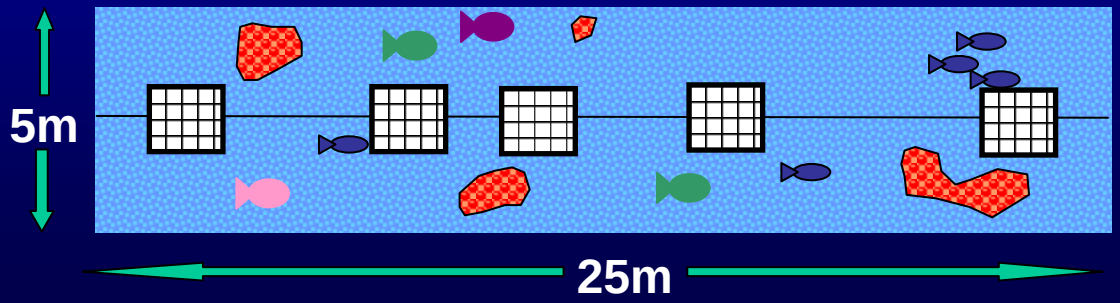
Fish censuses

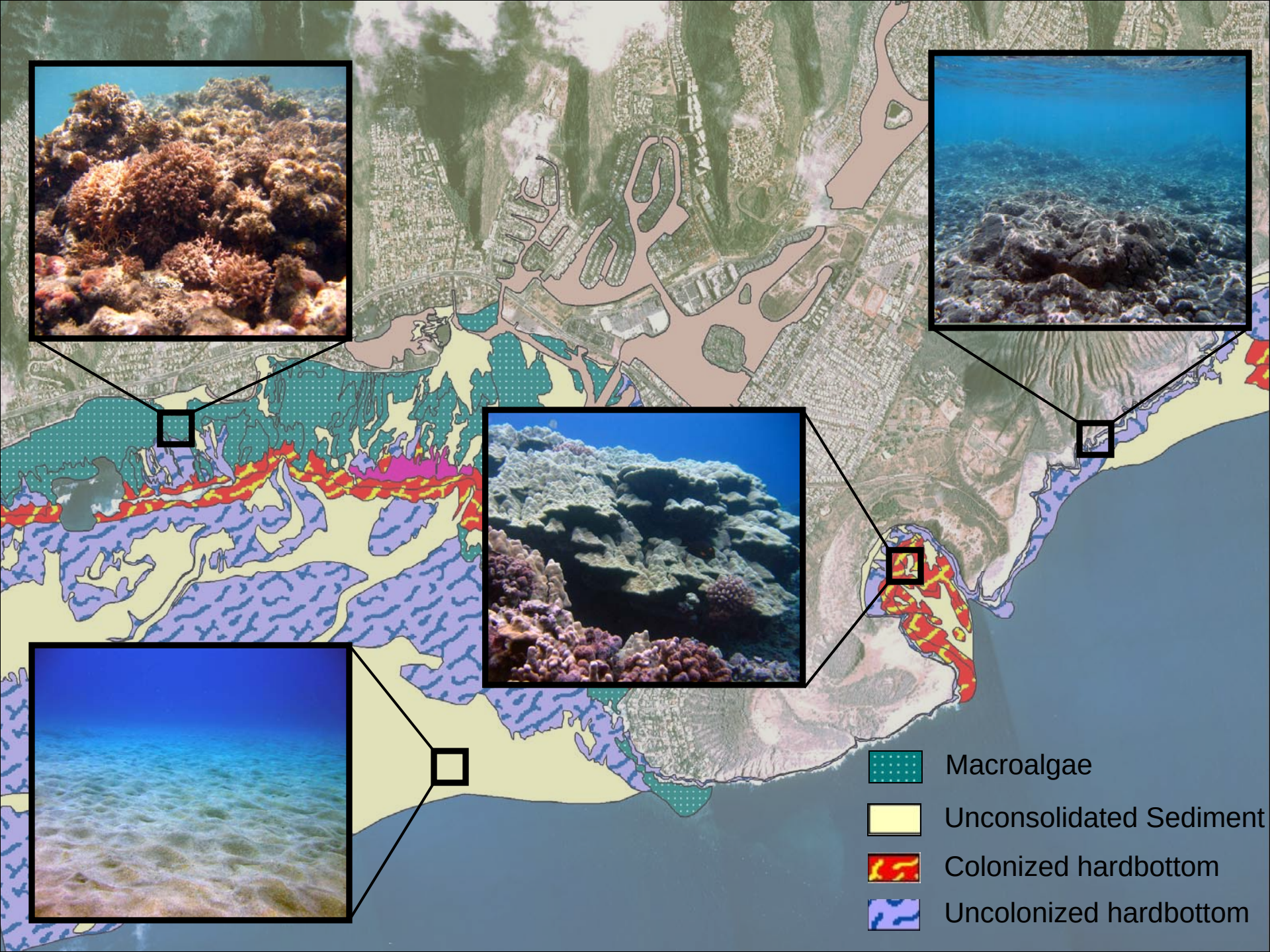
– 25 x 5 m transects

Habitat metrics

– Biotic cover
(coral, algae, inverts)

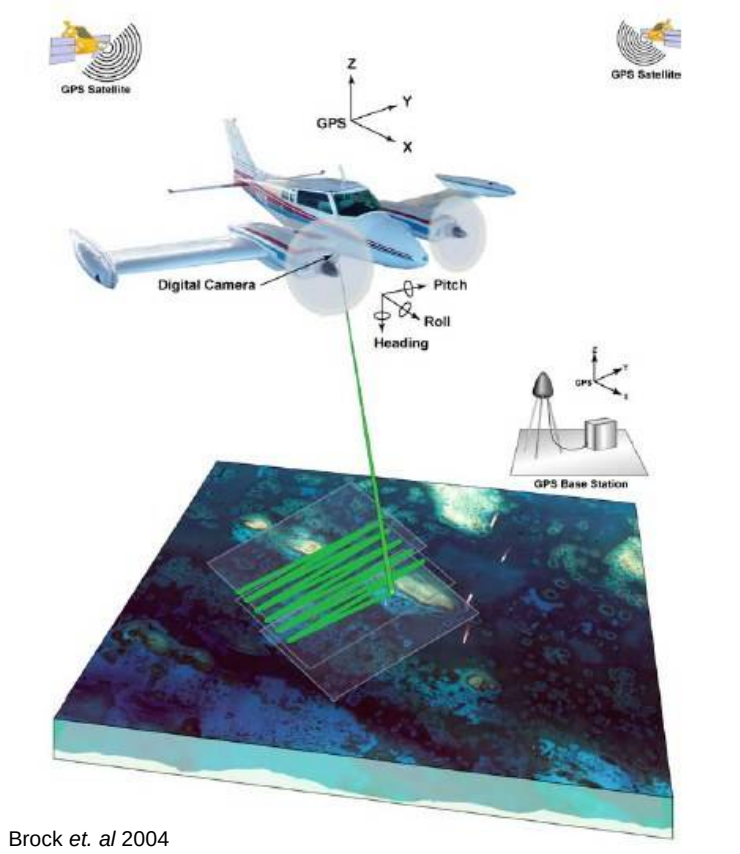
– Abiotic
(depth, rugosity)




Macroalgae
Unconsolidated Sediment
Colonized hardbottom
Uncolonized hardbottom

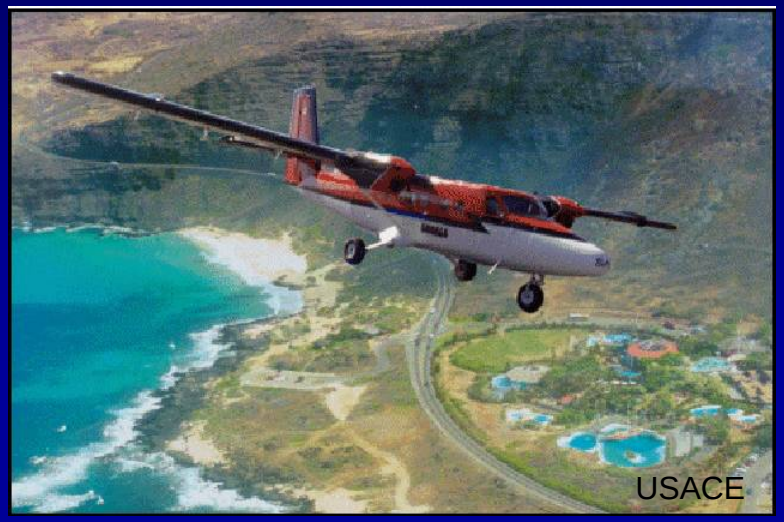
Remotely sensed LIDAR

- Light detection and ranging (LIDAR)
  - Active remote sensor
- The Shoals LIDAR system emits a 1064 nm (infrared) & a 532 nm (green) wavelength
- Depth derived from time difference between ocean surface return & bottom return



Brock *et. al* 2004

USACE Shoals LIDAR data

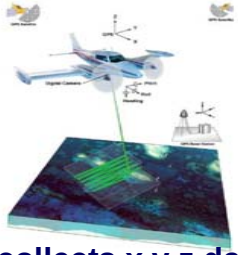


- US Army Corps of Engineers (USACE) Shoals LIDAR surveys in Hawaii (1999-2000)

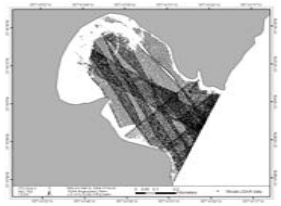
- Irregularly spaced, need to interpolate data for DEM

Horizontal Accuracy	± 1.5 m
Vertical Accuracy	± 20 cm
Min. Depth Range	0-1 m
Max Depth Range	40 m
Sounding Density	4 x 4 m

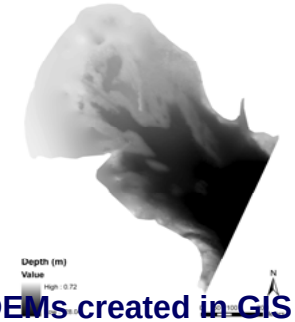
Work flow: LIDAR-derived seascape metrics



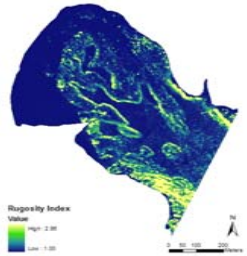
LIDAR collects x,y,z data



Data processing **(QA/QC, project, clip to AOI)**



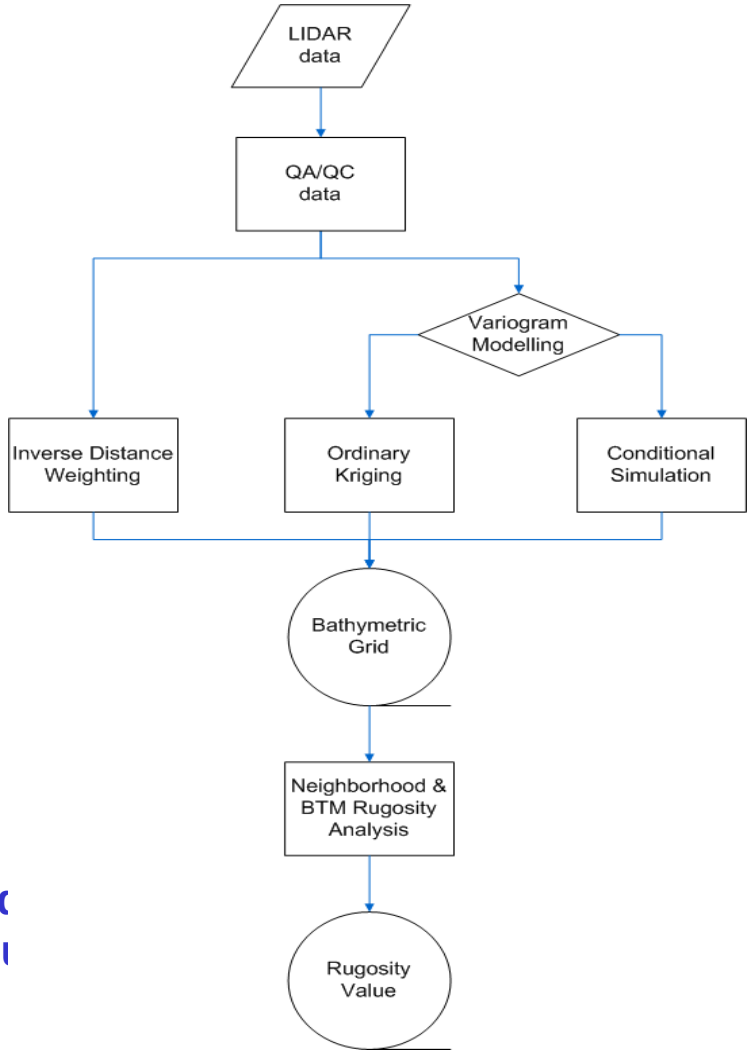
DEMs created in GIS **(4, 10, 15, 25 m)**



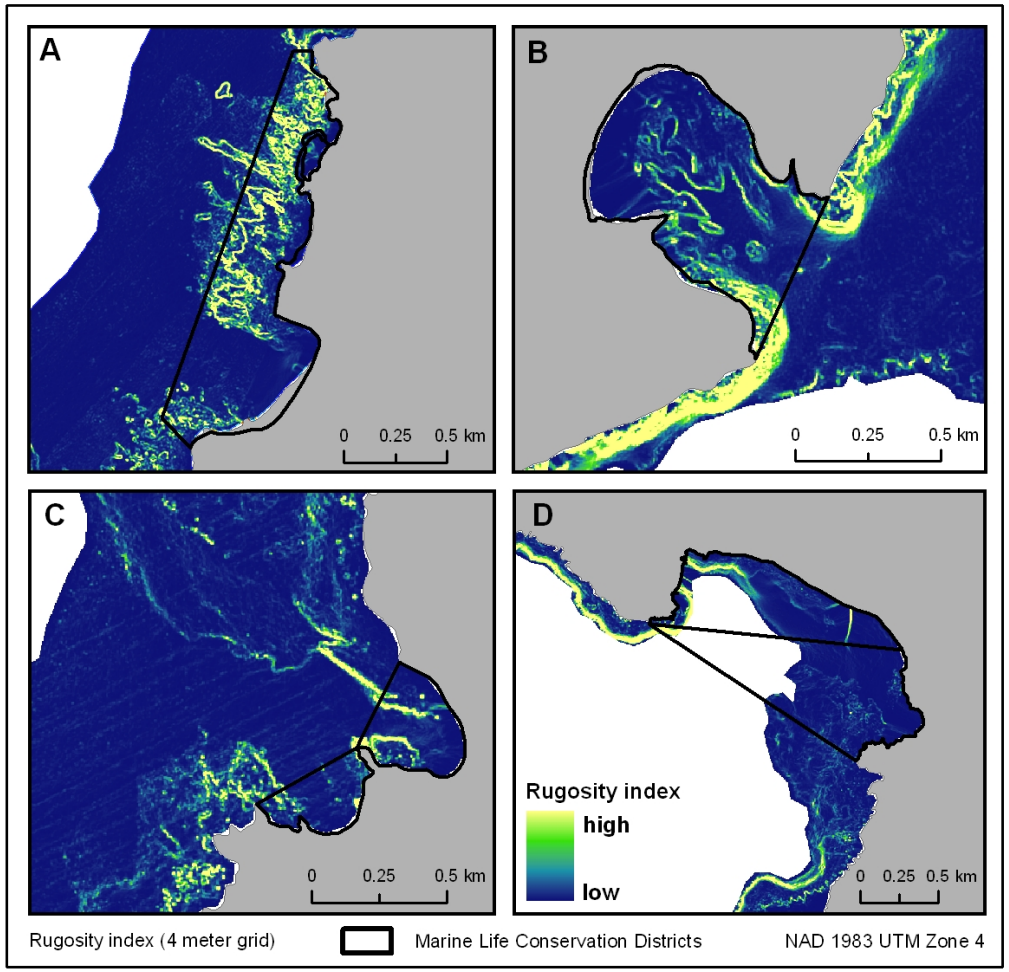
Rugosity grid created from DEM

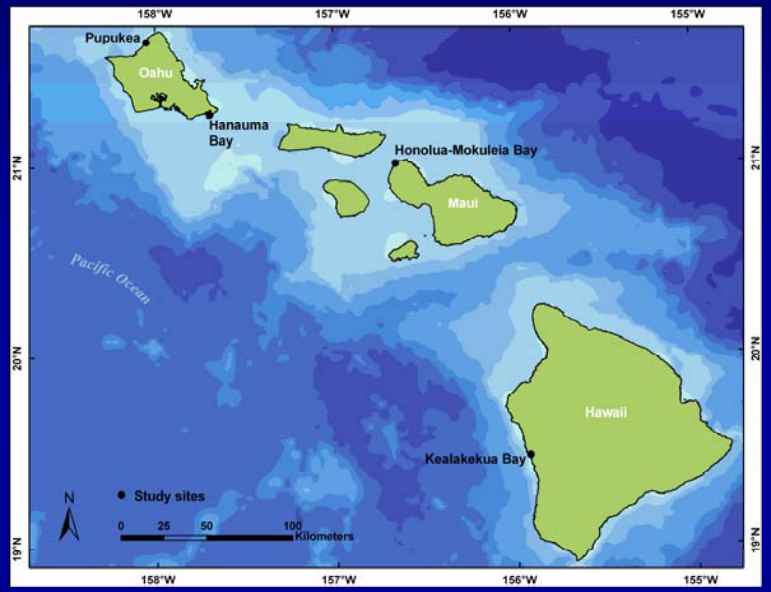
LIDAR data acquisition

LIDAR-derivec seascape produ



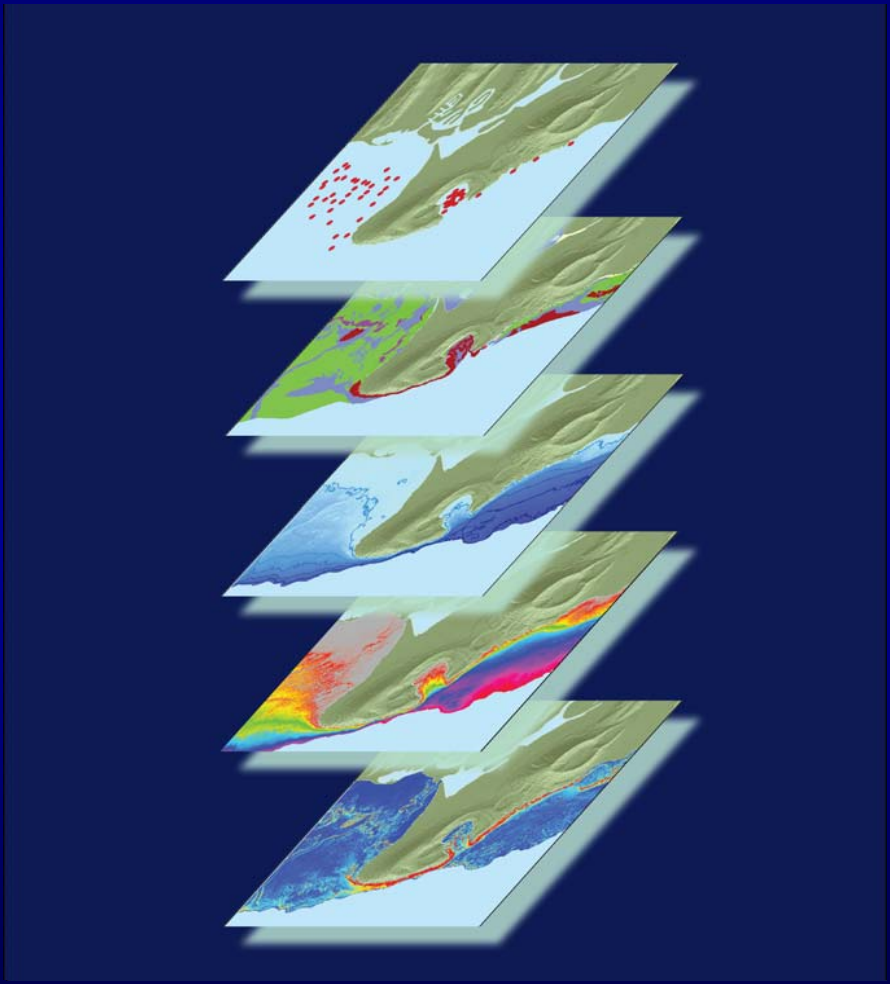
LIDAR-derived seascape metrics





- Bathymetry
- Percent slope
- Rugosity

GIS layers for analysis



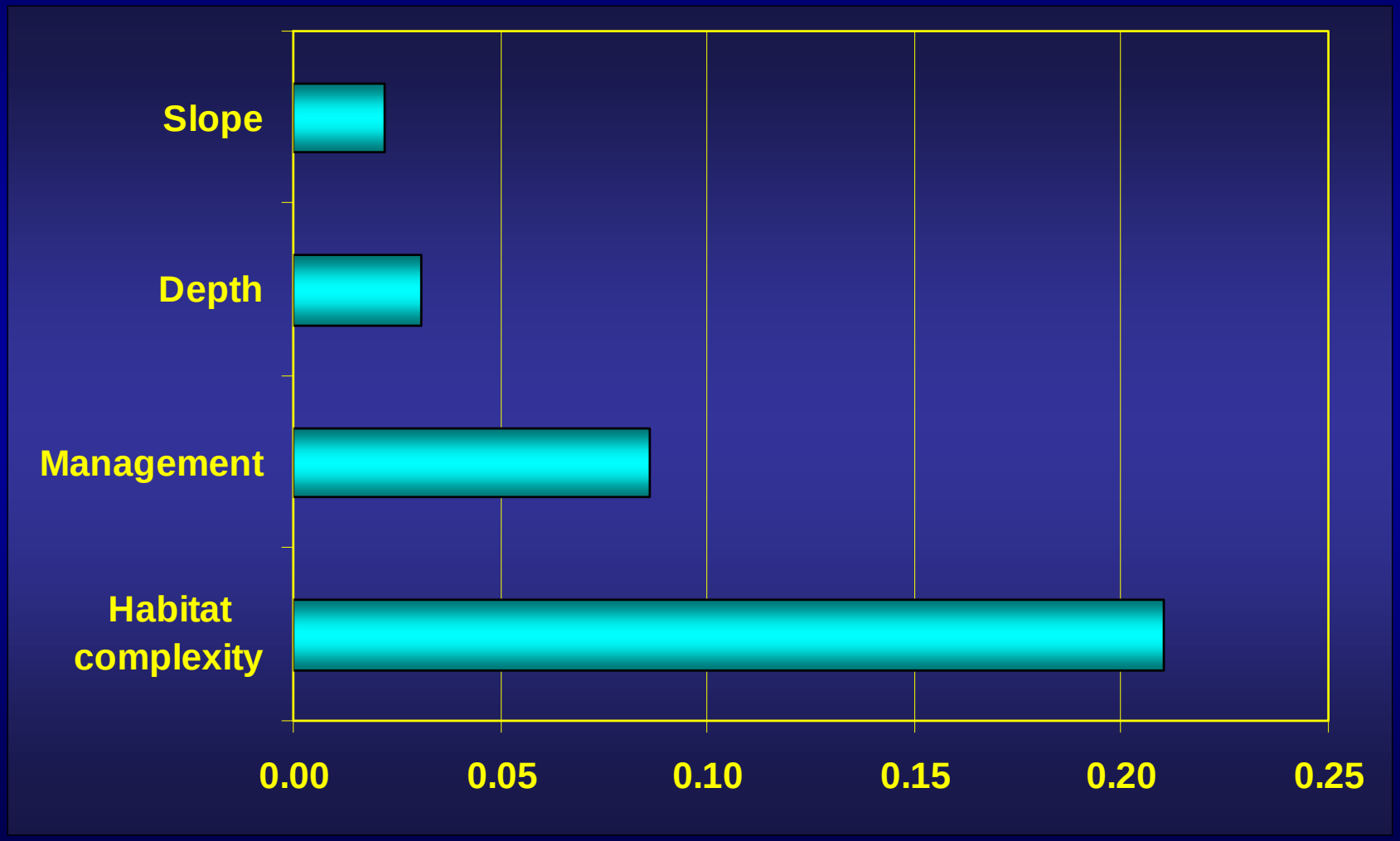
- GIS layers provided data on independent variables at each location for a stepwise multiple regression analysis

- Sampling locations
- Geomorphic structure
- Depth
- Percent Slope
- Habitat complexity
- Management

Factors Influencing Numerical abundance among all Locations

Stepwise multiple regression analysis (hardbottom only)

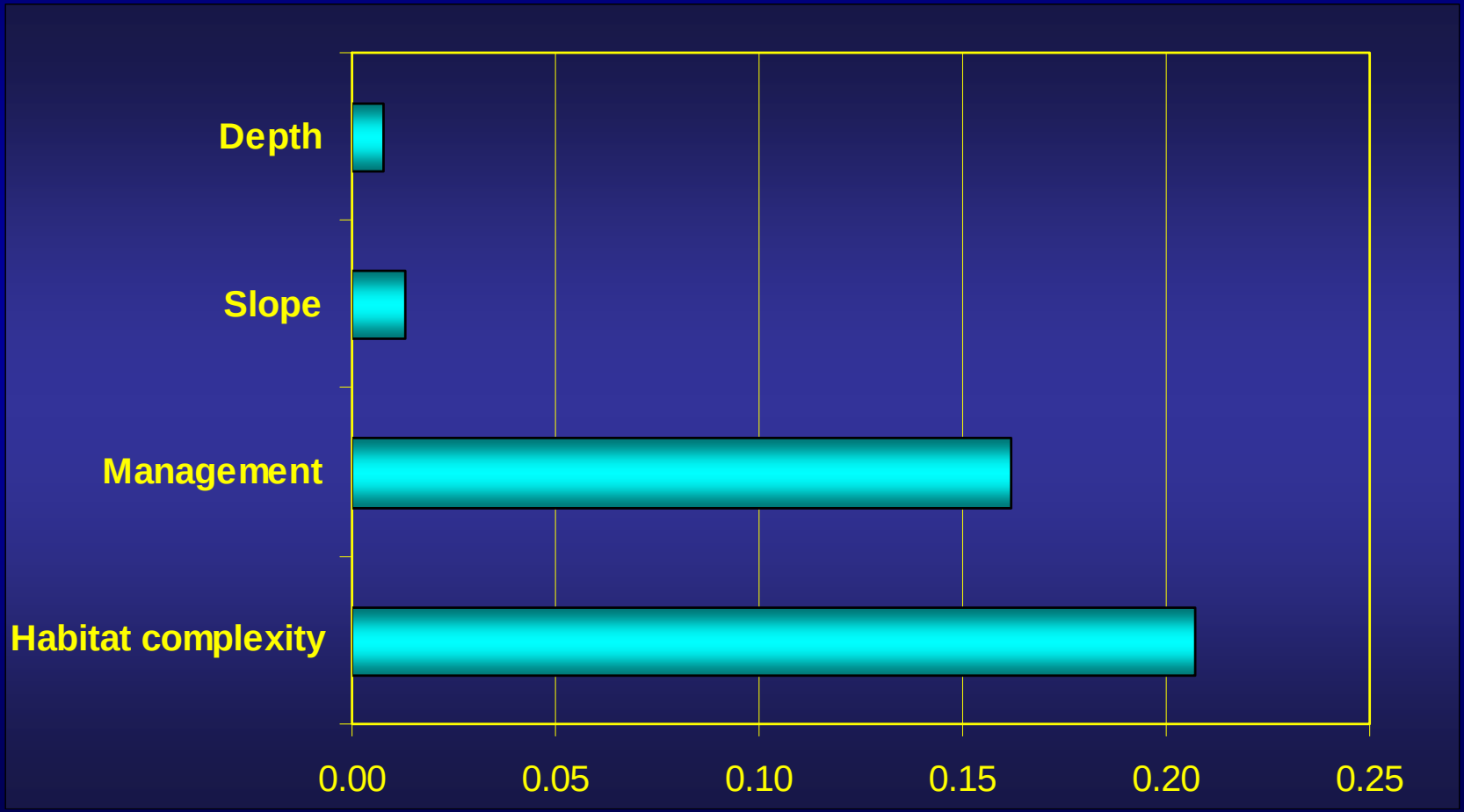
Probability to enter model 0.25, probability to leave 0.10, $R^2 = 0.35$



Factors Influencing Species Richness among all Locations

Stepwise multiple regression analysis (hardbottom only)

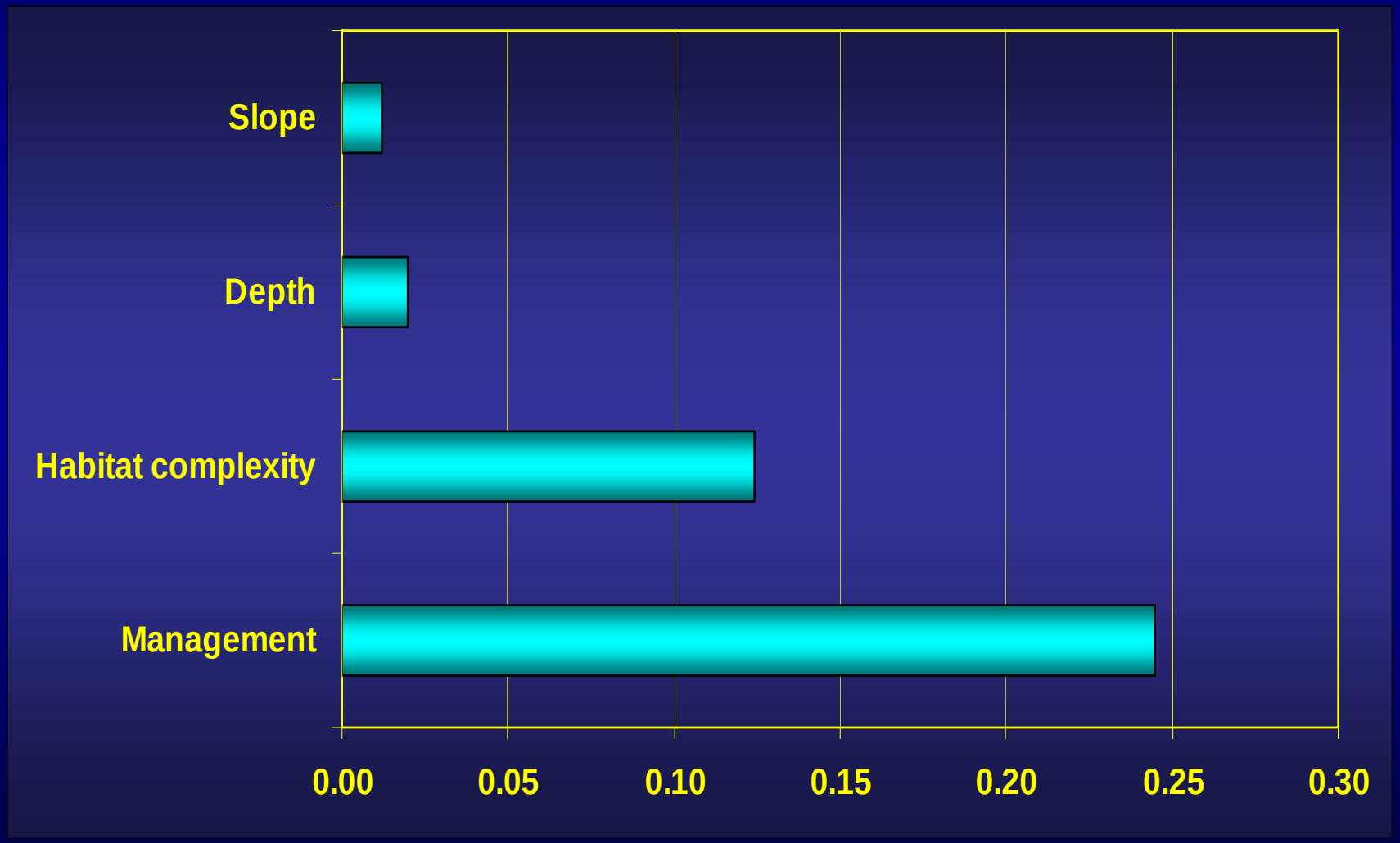
Probability to enter model 0.25, probability to leave 0.10, $R^2 = 0.39$



Factors Influencing Fish Biomass (t ha^{-1}) among all Locations

Stepwise multiple regression analysis (hardbottom only)

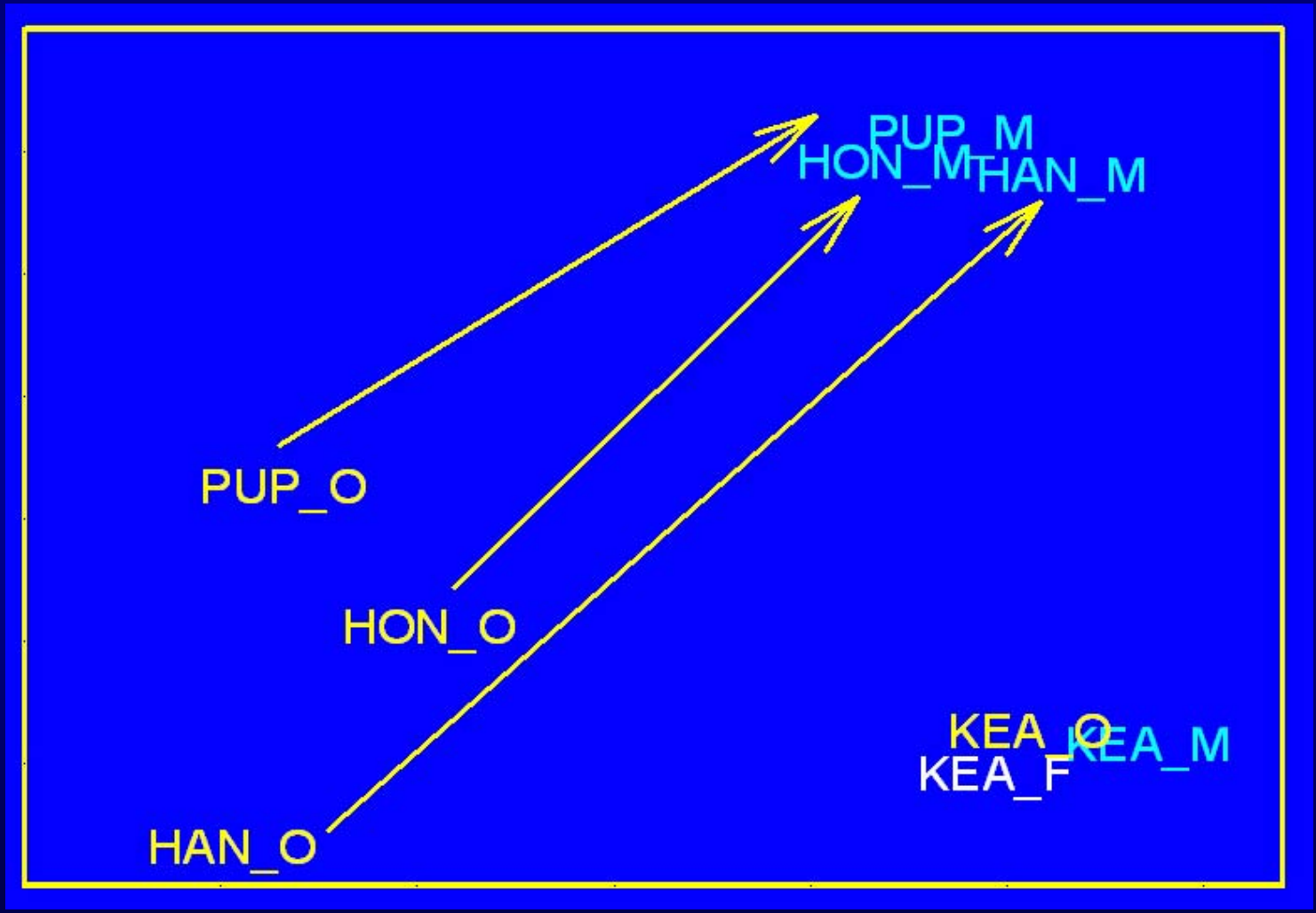
Probability to enter model 0.25, probability to leave 0.10, $R^2 = 0.40$



Factors Influencing Biomass for each Locations

Stepwise multiple regression analysis (hardbottom only)
Probability to enter model 0.25, probability to leave 0.10

MDS plot of fish biomass (t ha^{-1}) :Inside & outside MPA sites



Summary

- Habitat complexity was the <u>remotely sensed</u> measure of the seascape that demonstrated strongest relationship w/ reef fishes
  - abundance, richness & biomass

- Protection from fishing (MPA) was more impt. than physical protection (complex habitat) in explaining variability in biomass

- Despite proven success, no-take MPAs account for < 1% of nearshore areas in MHI

Implications for MPA design & function

- LIDAR data provides information on seascape metrics in a min. amount of time at broad geographic scales (~100km^2/day) relevant to regional-level management actions

- LIDAR id specific areas that offer greater natural protection to fish through habitat complexity

Design Criteria for Effective MPAs in Hawaii

- Range of habitat complexities
- Shoreline to deep habitats
- Mosaic of habitats (sand corridors, etc.)
- Representative wave exposures
- Full protection from fishing

Quantifying spatial patterns supports marine management

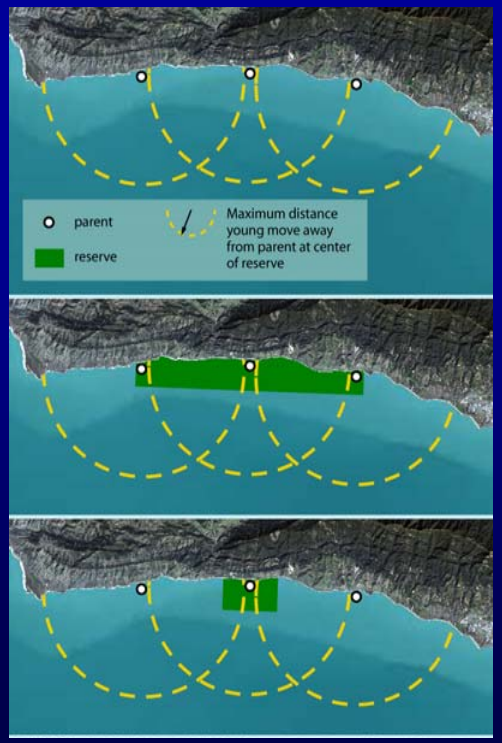
- Research demonstrated different approaches to spatial analysis of the marine environment

  Landscape ecology

  Biogeographic

  Geostatistical

Common thread quantification of spatial patterns



- approach can support spatial management actions (MPAs)

- Advances in technology allow quantification of spatial patterns
  - Next step predictive modeling and mapping

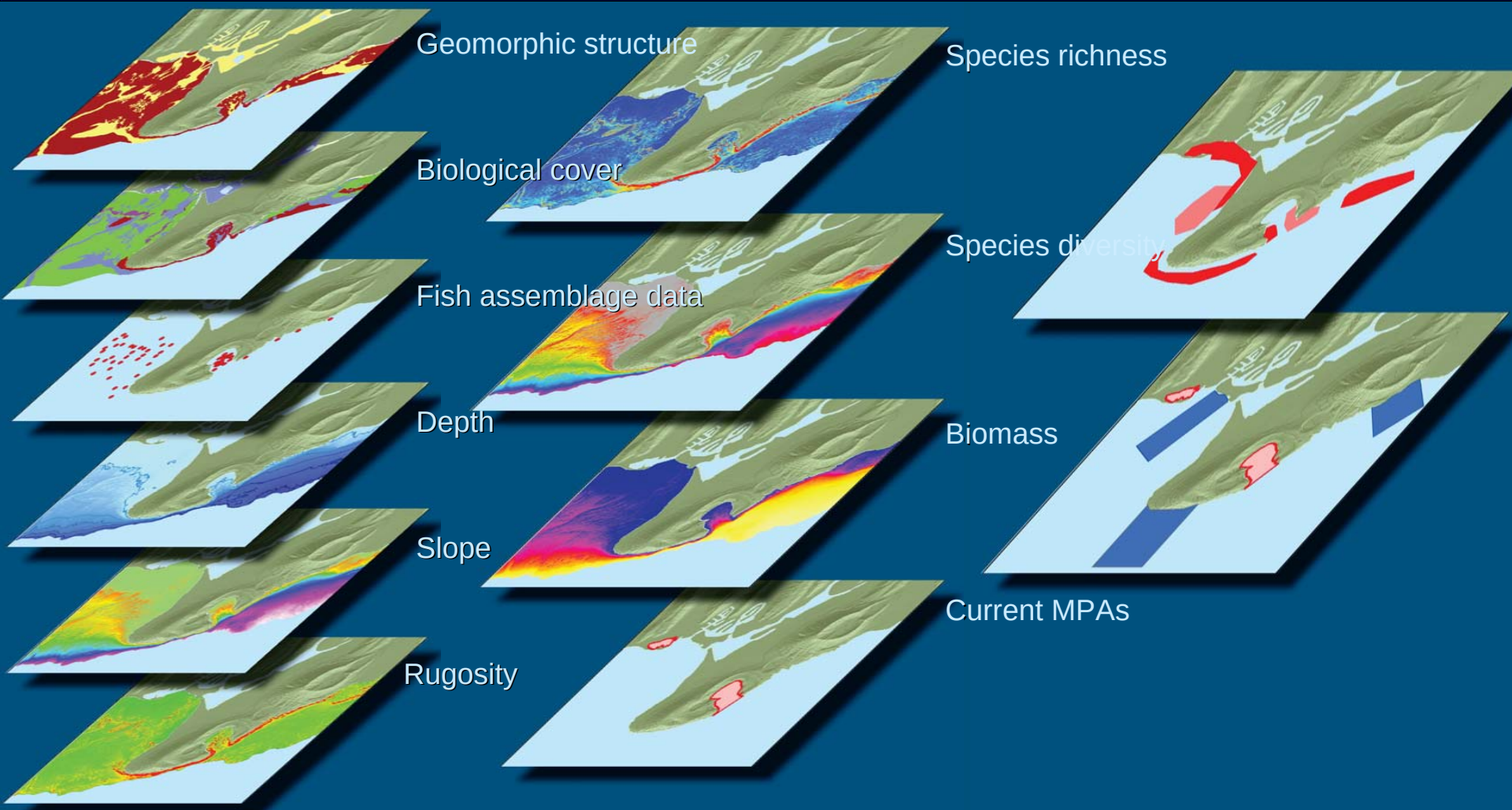
Future work

- Continue to examine the relationships between habitat complexity (seascape metrics) & fish assemblages
  - Trophic & mobility guilds

- Explore various measures of complexity (e.g. texture measures, fractals)
- Predictive mapping of fish communities to inform MPA design and management actions

Predictive mapping

GIS data layers | Modeled Distribution | Future MPA design



Acknowledgements

- Eric Brown, Alan Hong, Brian Hauk, Tommy Ogawa, Brent Carmen, Russell Sparks, Skippy Hau, Ariel Rivera-Vicente
- NOAA NOS NCCOS CCMA Biogeography Branch
- NOAA Coral Reef Conservation Program
- State of Hawaii, Division of Aquatic Resources
- Hawaii Geographic Information Coordinating Council
- UH, Department of Geography & Ecology, Evolution & Conservation Biology