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Coral Reef Watch

Remote Sensing Coastal Areas

Carl Nim
2010 Knauss Fellow
Coral Reef Watch (CRW)

Outline

- Personal Introduction
  - Academic Background and Interests
  - Relevant Experience to the Fellowship
- Examples of Remote Sensing in Coastal Areas
  - Cozumel, Mexico
  - Curaçao, Netherlands Antilles
- My Role as a Knauss Fellow
  - Australia CRW Workshop
  - CRW Project

Personal Introduction

- Academic Background and Interests

- Relevant Experience to the Fellowship

Background and Interests

- Undergraduate Degrees: Indiana University of Pennsylvania
  - Social Studies Education (Geography and History)
  - Environmental Geography
    - Introduction to GIS / Remote Sensing
- Graduate Work: Miami University (Ohio)
  - M.A. Geography: Nature – Society Interactions
    - GIS TA, Remote Sensing
  - M.En. Environmental Science: Coastal Management
    - Tropical Marine Ecology, Coral Reef Ecology, GIS in Landscape Ecology, Limnology

Experience

- Remote Sensing
  - ERDAS Imagine
    - Geography M.A.
      - Landsat: LULC Change of Cozumel, Mexico
    - Environmental Science M.En.
      - Quickbird: Classification of Benthic Features, Curaçao N.A.
- Marine Ecology
  - Tropical Marine Ecology
  - Coral Reef Ecology

Examples of Remote Sensing in Coastal Areas

- Cozumel, Mexico
  - LULC Change
- Curaçao, Netherlands Antilles
  - Benthic Mapping

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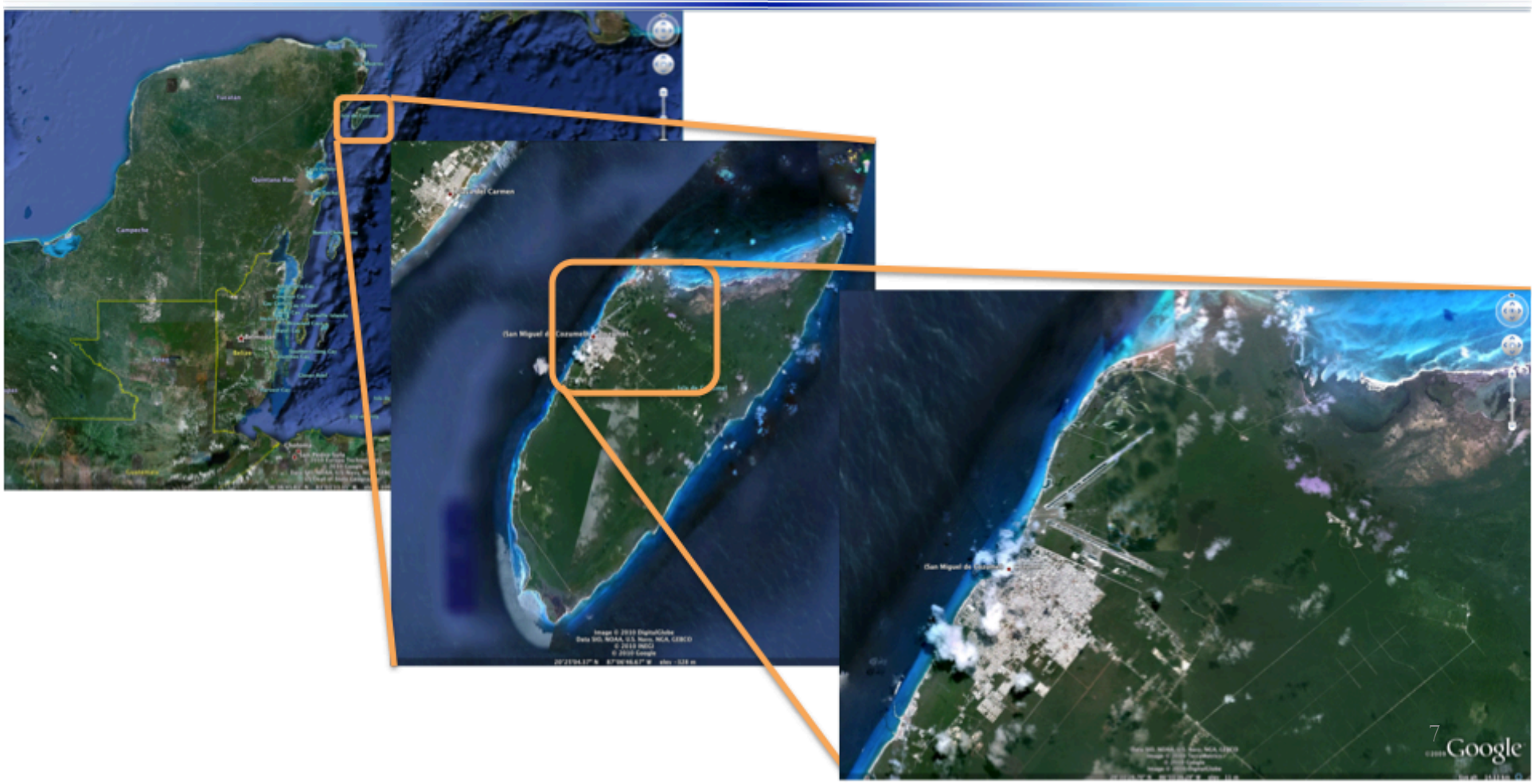
Cozumel, Mexico



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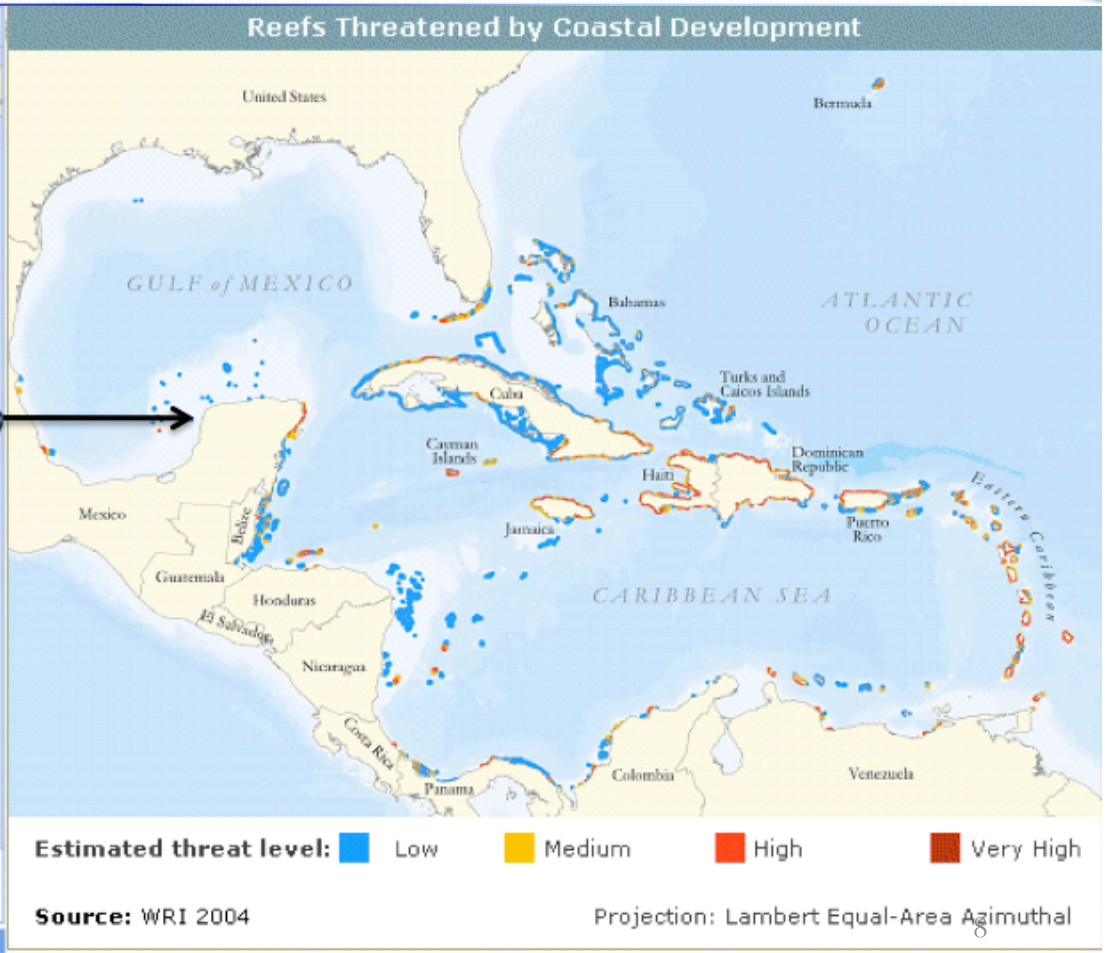
Cozumel

MESOAMERICAN REEF ECOREGION



Dudenhoefer 2004 and http://earthtrends.wri.org/features/view_feature.php?theme=3&fid=55

Biological Significance of Cozumel

- In this region, the island of Cozumel represents a key ecological reserve because of the high species richness and the complexity of the ecosystem (Jordán- Dahlgren and Rodríguez-Martínez 2003; Fig. 1).

- Within the Gulf of Mexico and the Mexican Caribbean "Species richness suggests that the highest coral biodiversity is located around Cozumel on the Caribbean with 33 species."

Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 14

INDIRECT EVIDENCES ON THE CONNECTIVITY OF CORAL REEFS OF THE GULF OF MEXICO AND THE MEXICAN CARIBBEAN

A. Chávez-Hidalgo*, G. De la Cruz-Agüero & E.A. Chávez

Centro Interdisciplinario de Ciencias Marinas. Instituto Politécnico Nacional. Av. IPN s/n
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Abstract. Coral reef connectivity results from the export and import of species or reproductive product between localities. Possible exchange pathways between the reef ecosystems in the country are not known; such knowledge about coral reef connectivity could contribute to its management and conservation. The connectivity between reefs of the Gulf of Mexico and Mexican Caribbean was evaluated based on patterns of similarity. Information for 48 stony coral species in 19 localities was compiled from different sources. Species richness suggests that the highest coral biodiversity is located around Cozumel on the Caribbean with 33 species. Cluster analysis based on biological similarity between localities shows that the Veracruz Reef System (VRS) is more similar to the reefs of the Mexican Caribbean than those on the Campeche Bank. Correlation (Mantel test) of biological similarity with geographical distance, days of transport by currents and environment variables, was negative and highly significant, corroborating that biological similarity decreases with increasing distances. The hypothesis that the reefs of the VRS and the Caribbean are more similar because these areas are less affected by hurricanes is proposed. This environmental stability would lead to an accumulation of Caribbean coral species that makes VRS more similar to the Caribbean than to those reefs in the Northern Veracruz or those in the Yucatan shelf.

Key words: Connectivity, Dispersion, Coral reefs, Similarity

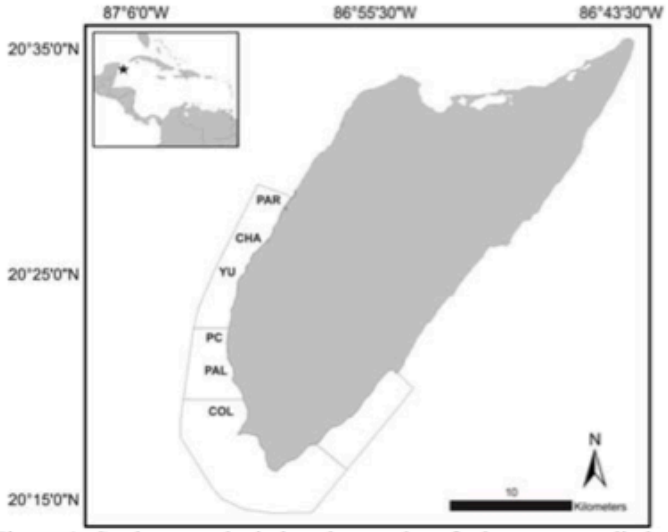
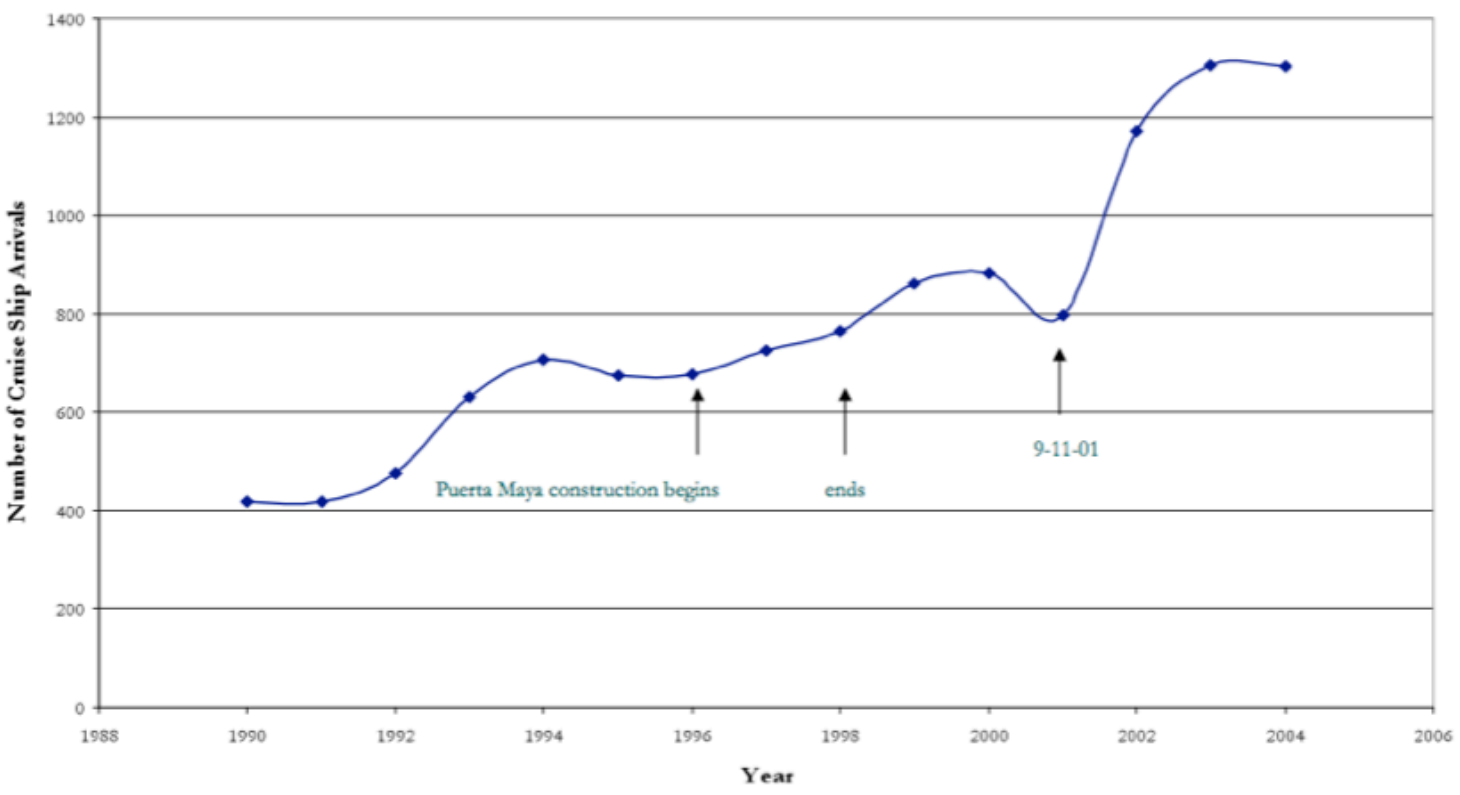


Figure 1: Study area, depicting the coral reefs that were studied at Cozumel Island. PA= Paraiso, CHA= Chanlana´ab, YU= Yucab, PC= Paso del Cedral, PAL= Palancar, COL= Colombia. Continuous line delimits the polygon of the Parque Nacional Arrecifes de Cozumel.

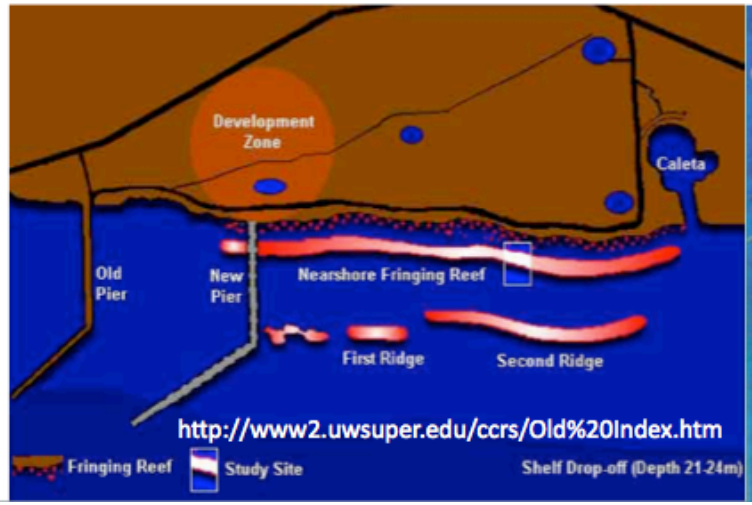
Cozumel Cruise Ship Arrivals

Cruise Ship Arrivals to Cozumel
(1990-1994 Carabias Lillo *et al.* 1998) : (1995-2005 Data Tur)



Tourism Development

- Construction of additional cruise ship pier (Puerta Maya) over Paradise Reef (3 piers total).
- Public opposition to construction.
- EIA permitted transplantation of Paradise Reef, a typically unsuccessful operation.



Methodologies

- Qualitative
  - Semi-structured interviews with 21 participants in July of 2005.
- Quantitative
  - LULC 1998-2001

Interview Results

- Perception of residents indicated:
  - Politicians disregarded local requests.
  - Cruise ship visitation stresses local resources (e.g. water supply, sanitation)
    - Cozumel population estimate as of 2005: 75,000 – 2010: 90,000
      - http://www.travelyucatan.com/cozumel_mexico.php
    - Cruise Ship Tourist arrivals for 2003: 2,708,913
      (World Travel and Tourism Council 2004)
  - Concern for coastal water quality from dolphin enclosures, ship discharges and inadequate sewage treatment at tourist locations.
  - No real economic "trickle down" to residents

LULC 1988 - 2001

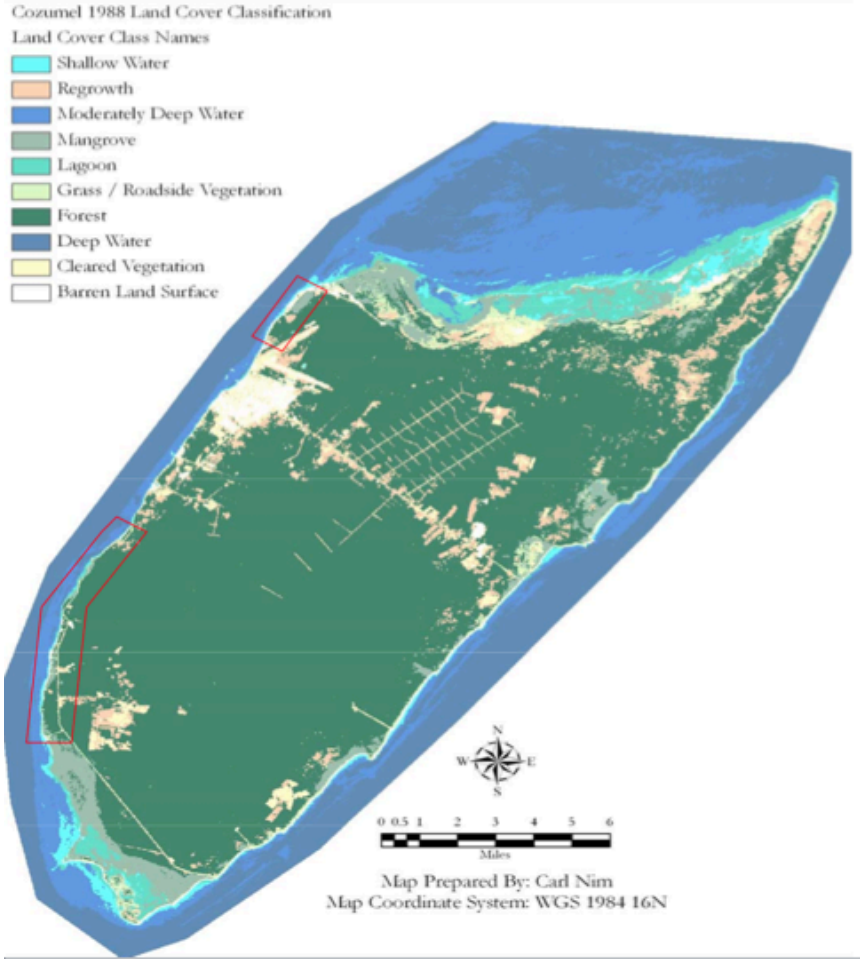
Landsat TM: 13 April 1988
Path 18 – Row 46

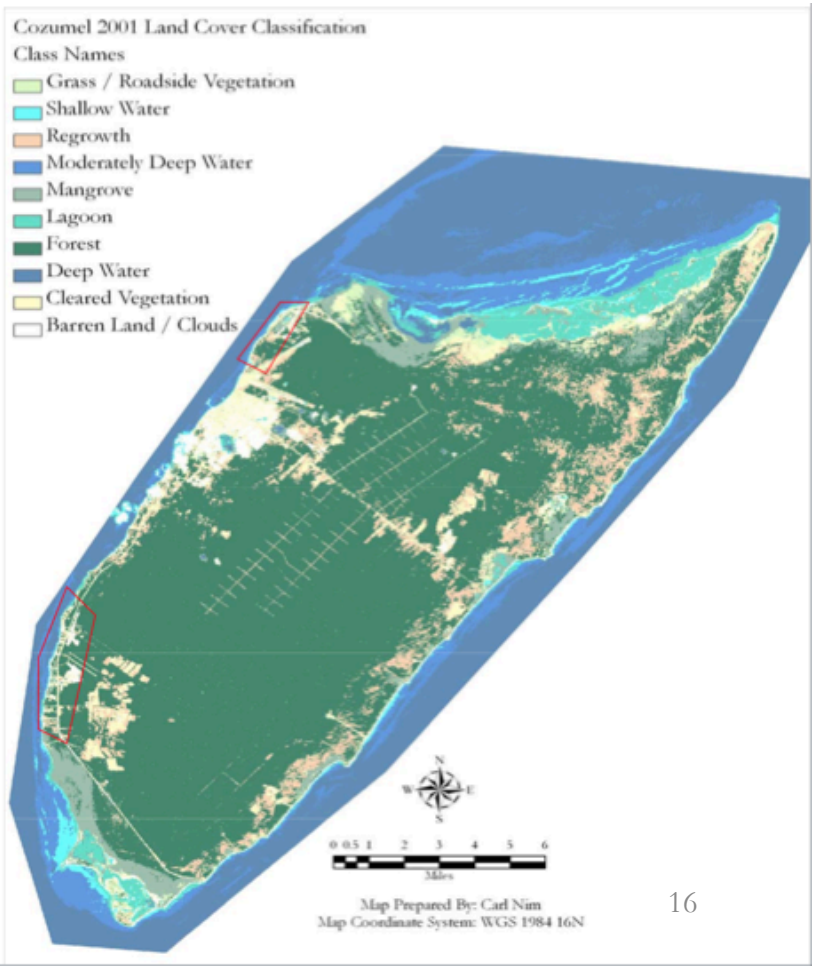
Landsat ETM: 17 April 2001
Path 18 – Row 46

Image Processing

- Conversion of Landsat TM Digital Numbers (DN) to ETM DNs.
- Created AOI of Cozumel Island
- Dark object subtraction for atmospheric correction.
- Subset of bands 5,3,1 for vegetation comparison.
- Unsupervised classification of 20 classes.
- Using ground reference points, I merged the 20 classes to 10.

LULC Change 1998 - 2001





LULC Summary

- Additional Cruise Ship Piers
  - 1-3 Piers: Sediment from concrete mixing, Paraiso reef damage.
- Increased Urban Areas
  - Change in San Miguel's urban area from 2.09 miles^2 to 3.25 miles^2.
- Increased Coastal Construction
  - Sediment from concrete mixing, removal of mangroves, sewage runoff.
- Increased Water Well Pipelines
  - Aquifer reduction and salt water intrusion

Hurricanes Emily / Wilma (2005)

21 DEC 2003

Punta Langosta Pier

International Pier

Puerta Maya Pier

5 JUN 2006

Biological effects of Hurricanes Emily and Wilma

- Wilma 4 times more damaging than Emily.
- Coral cover 24% to 10% and back to 16% in May 2007.

Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 18

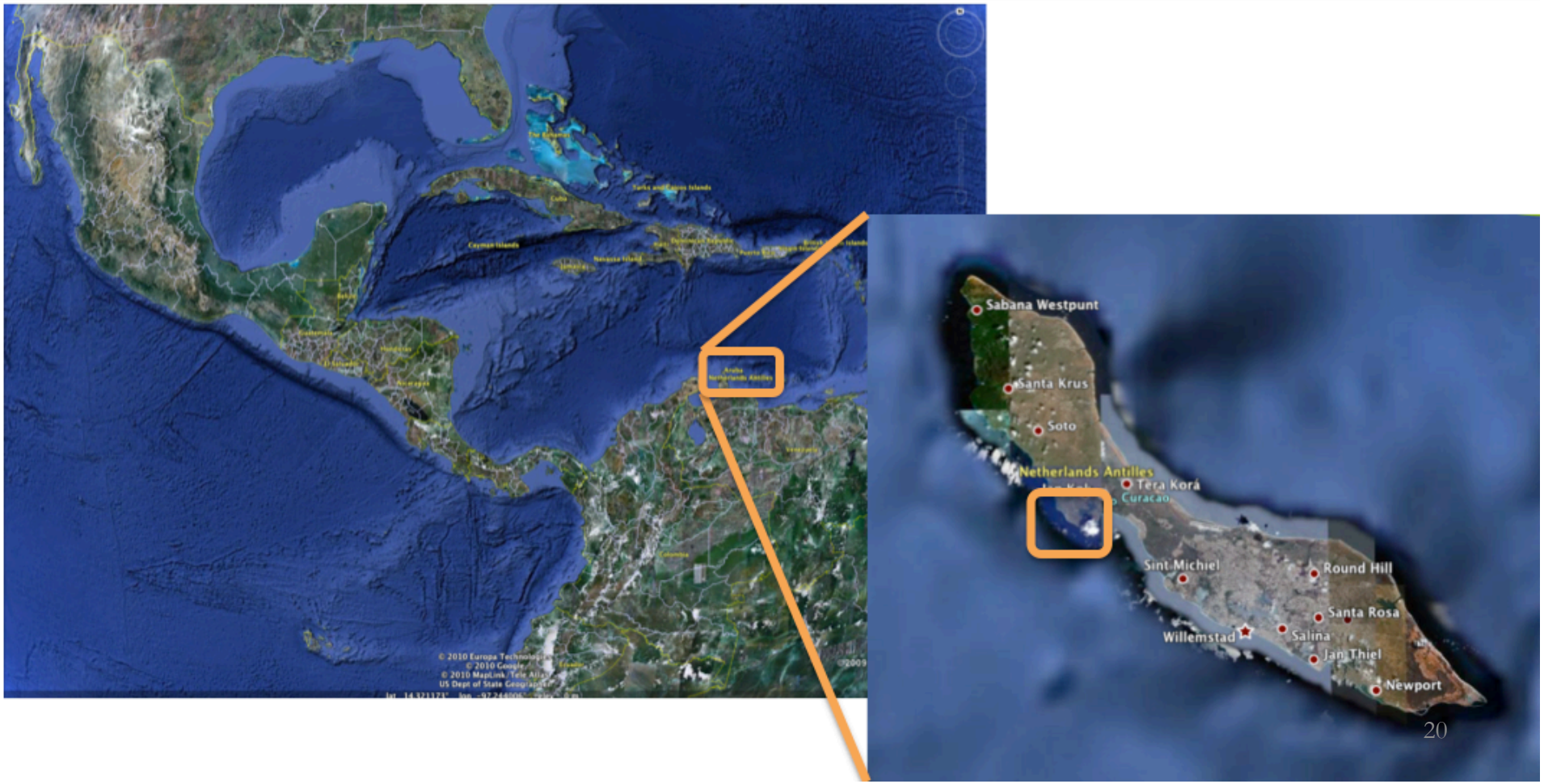
Cozumel Island, México: A disturbance history

P.A. Álvarez del Castillo-Cárdenas[1*], H. Reyes-Bonilla[1], L. Álvarez-Filip[2], M. Millet-Encalada[3], L.E. Escobosa-González[1]

1) Departamento de Biología Marina. UABCS. Carretera al Sur km 5.5, CP 23080. La Paz, BCS, México. *strellada@gmail.com
2) Centre for Ecology, Evolution and Conservation. University of East Anglia. Norwich, NR4 7TJ. United Kingdom.
3) Departamento de Monitoreo y Vinculación Científica. Parque Nacional Arrecifes de Cozumel. Oficinas de la CONANP. Altos Plaza Sol S/N. Col. Centro. C.P. 77600 tel. (987)-8724689. Cozumel Quintana Roo, México.

Abstract. This study aims to determine the damage caused by the 2005 hurricanes "Emily" and "Wilma" on the landscape structure of the Parque Nacional Arrecifes de Cozumel (PNAC), México. We conducted samplings at six reefs located in the PNAC during May 2005 and May 2007. At each reef, six 30-m point-intercept transects were run parallel to the coast. The bottom elements that were quantified were coral, sponges, macro algae, coral with recent death, rock and sand. Landscape structure was quantified with the Pielou´s evenness index (J´), and changes were evaluated with non-metric multi-dimensional scaling (NMDS) and the Bray-Curtis similarity coefficient. The results show a significant decrease in the percentage of live cover, and an increase in the percentage of sand and rock. Corals were the most affected group decreasing from 24% to 10% in cover after the two hurricanes; fortunately, cover has increased to 16% by May 2007. Significant differences were found in the landscape evenness, being lower in July 2005($F_{5,210}$= 14.94, P=0.00),; the high similarity of J´ between May 2005 and May 2007 indicates a clear trend of recovery in the reefs. The NMDS show that the two hurricanes affected Cozumel reefs with varying intensity, with "Wilma" having an impact four times higher than "Emily".

Curaçao N.A.


Sabana Westpunt
Santa Krus
Soto
Netherlands Antilles
Tera Kora
Curacao
Sint Michiel
Round Hill
Santa Rosa
Willemstad
Salina
Jan Thiel
Newport

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Curaçao Reefs

Coral Reefs (2005) 24: 475–479
DOI 10.1007/s00338-005-0009-1

REPORT

Rolf P. M. Bak · Gerard Nieuwland · Erik H. Meesters

Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire

Received: 17 June 2004 / Accepted: 16 June 2005 / Published online: 9 November 2005

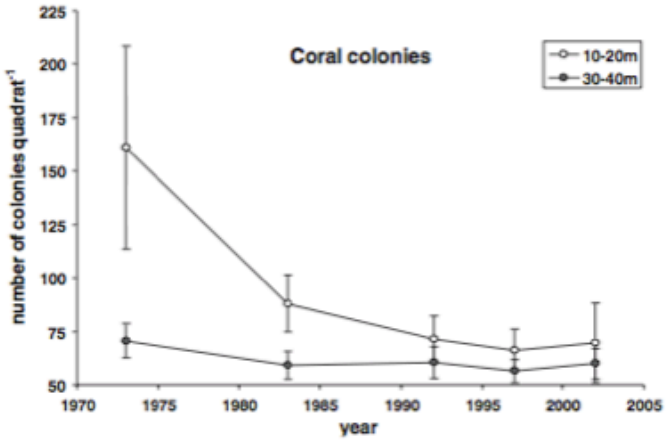


Fig. 1 Number of coral colonies (mean ± 1SE) from 1973 to 2003 at two depths, 10–20 and 30–40 m

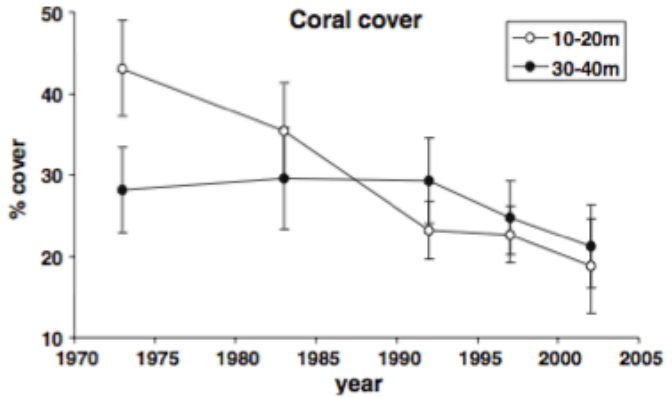


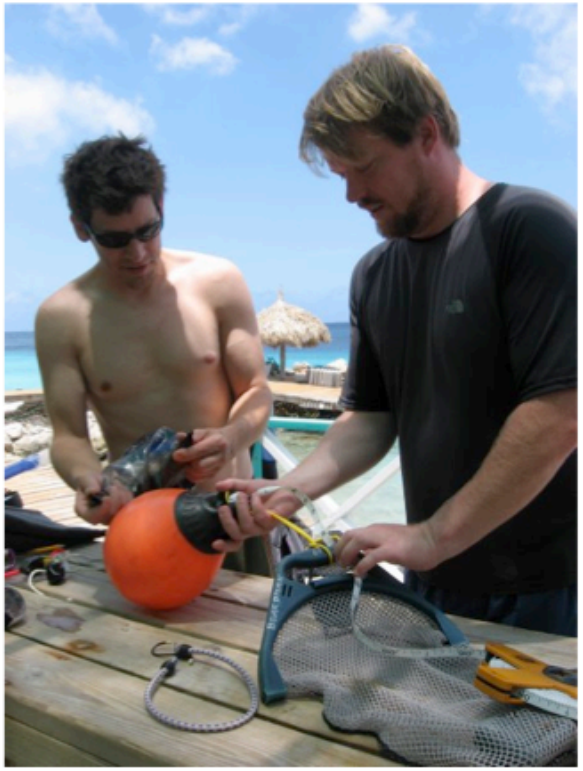
Fig. 2 Coral cover (mean ± 1SE) from 1973 to 2003 at two depths, 10–20 and 30–40 m

Mapping Procedures

- Create Bathymetric Map of Study Site
  - Using Depth Data Loggers, GPS and ArcGIS

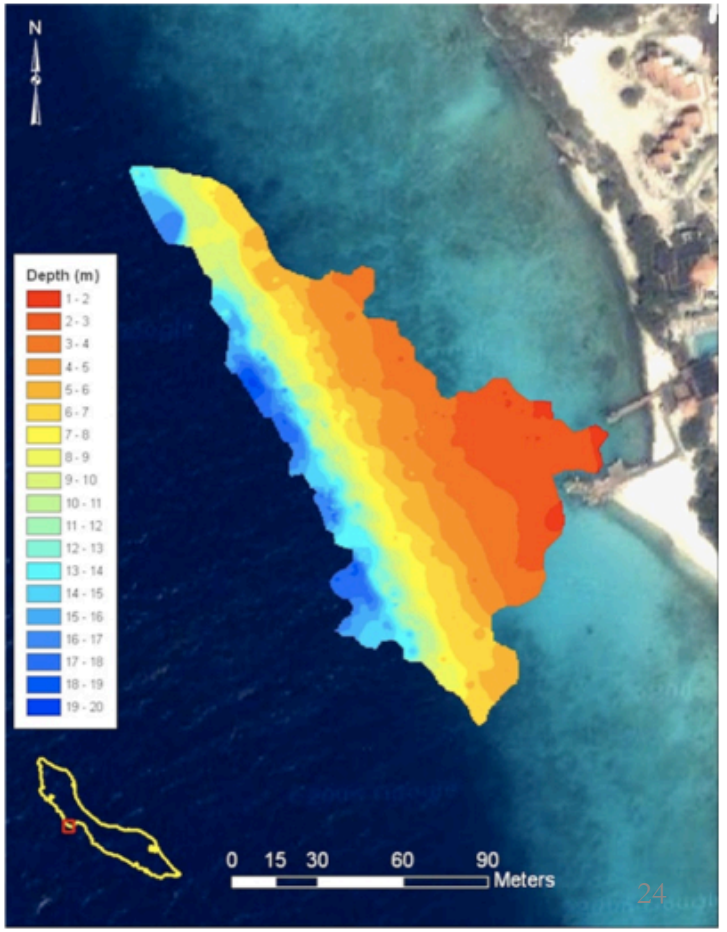
- Create Benthic Classification Map of Study Site
  - Using Remote Sensing Data

Transect Data Collection



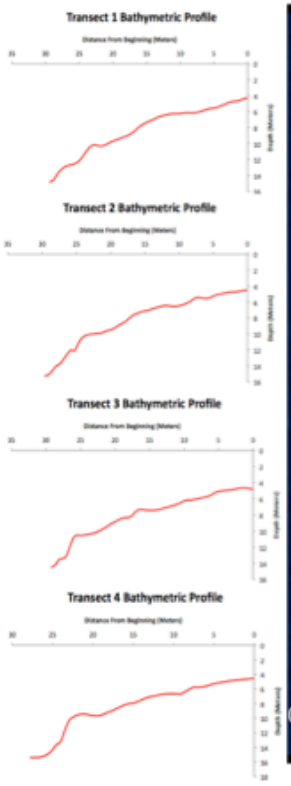
Benthic Mapping

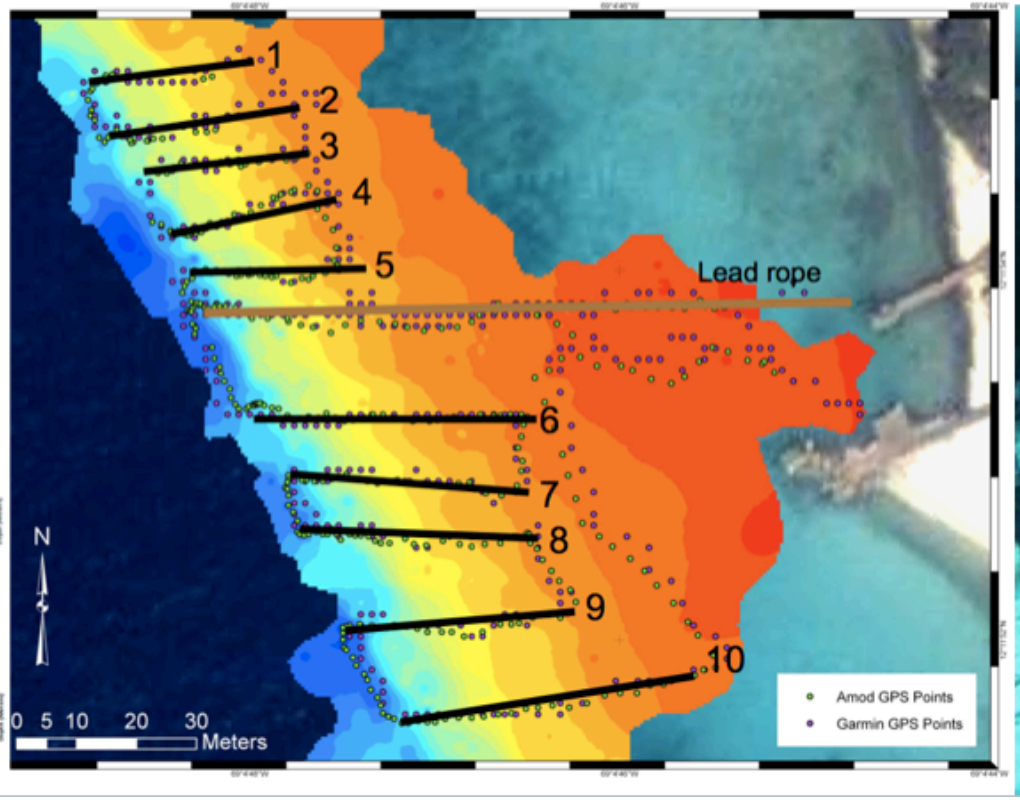
- 10, 50 meter transects at varied intervals; started at a depth of 50 feet.
- Used Triangular Irregular Networks (TIN) Creation Tool in ArcGIS 3D Analyst to make map.



Transect Video

- HD Video of all Transects to be analyzed later





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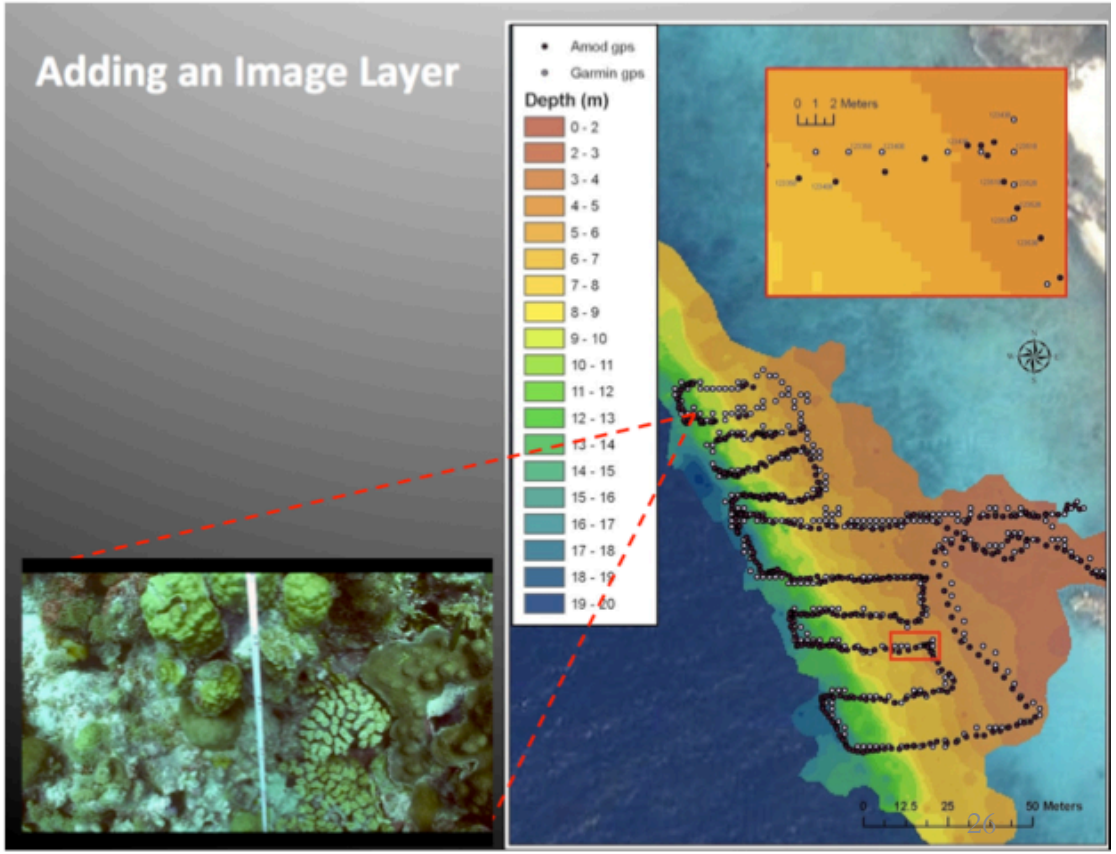
Incorporating Coral Cover with Habitat Maps

- Provides baseline
- Monitors trends
- Still frames and coral cover quantification (and other data) from video can be placed in DB for GPS points in ArcGIS.

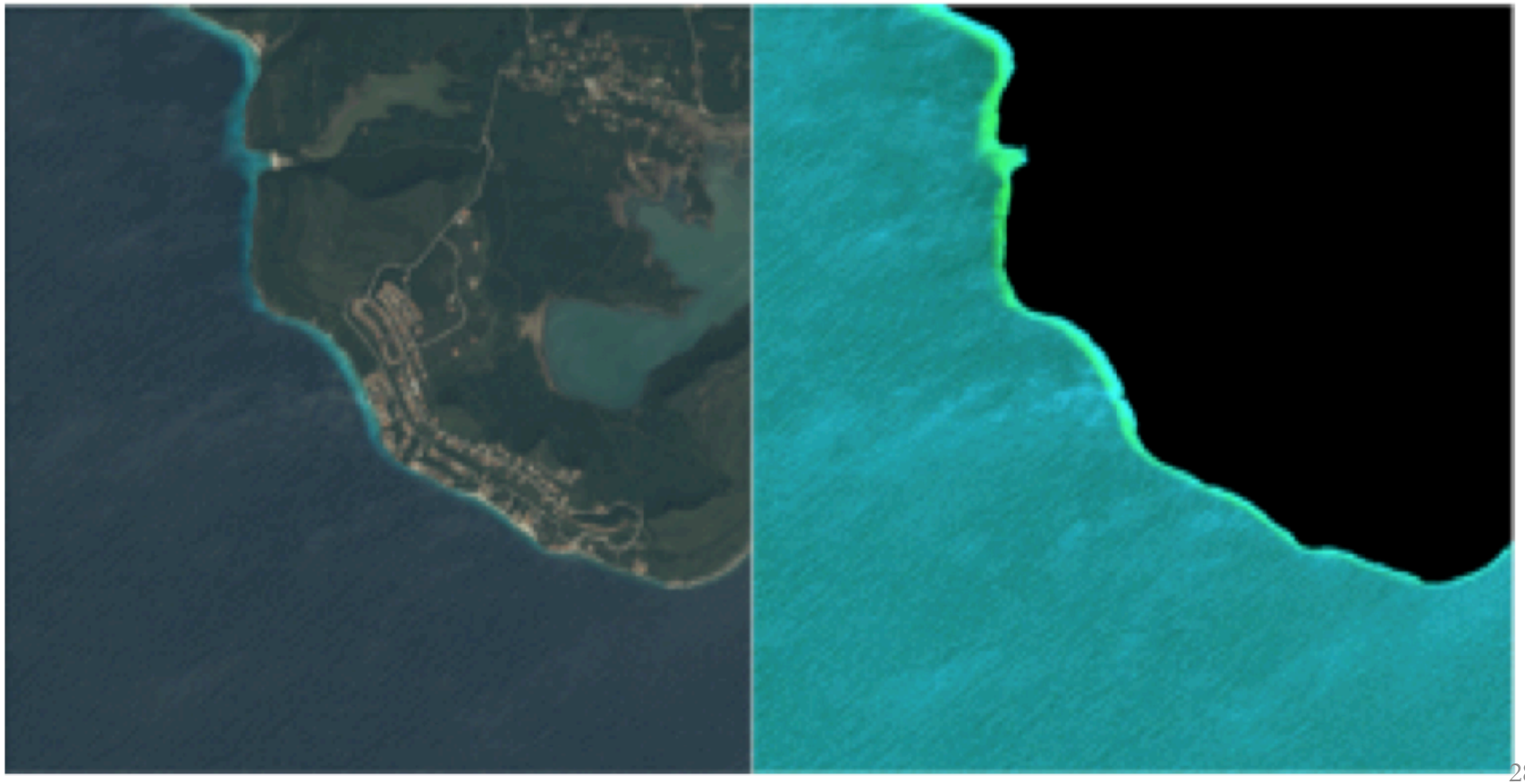


Benthic Classification

Learning Experience (Course Project: Landscape Ecology)

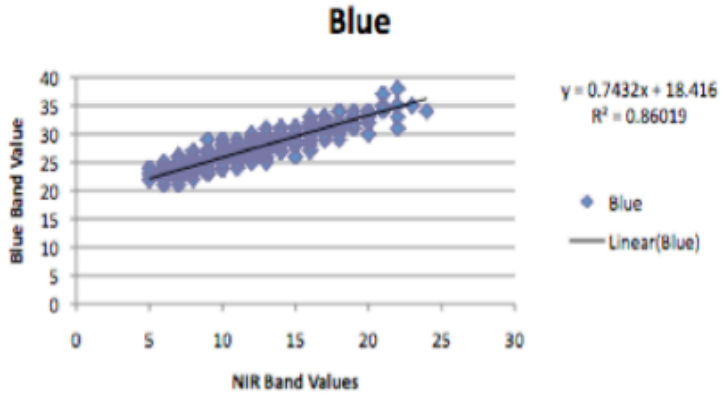
- QuickBird 2.4 meter pixel from 28 December 2008.
- Mask
- Deglinting
- Supervised Classification
- Atmospheric Correction
- Water Column Correction

Land Mask



Deglinting

$$R'_i = R_i - b_i(R_{NIR} - Min_{NIR})$$

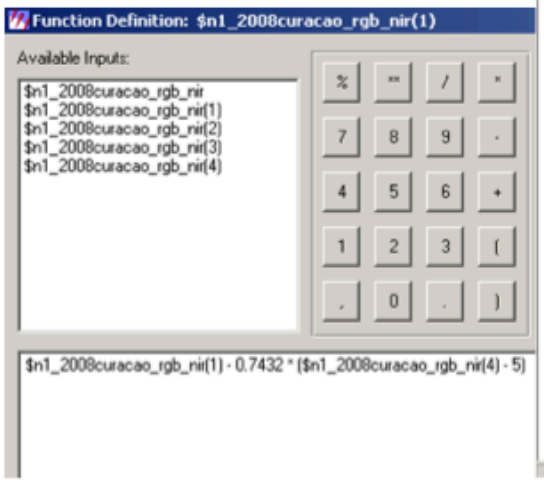


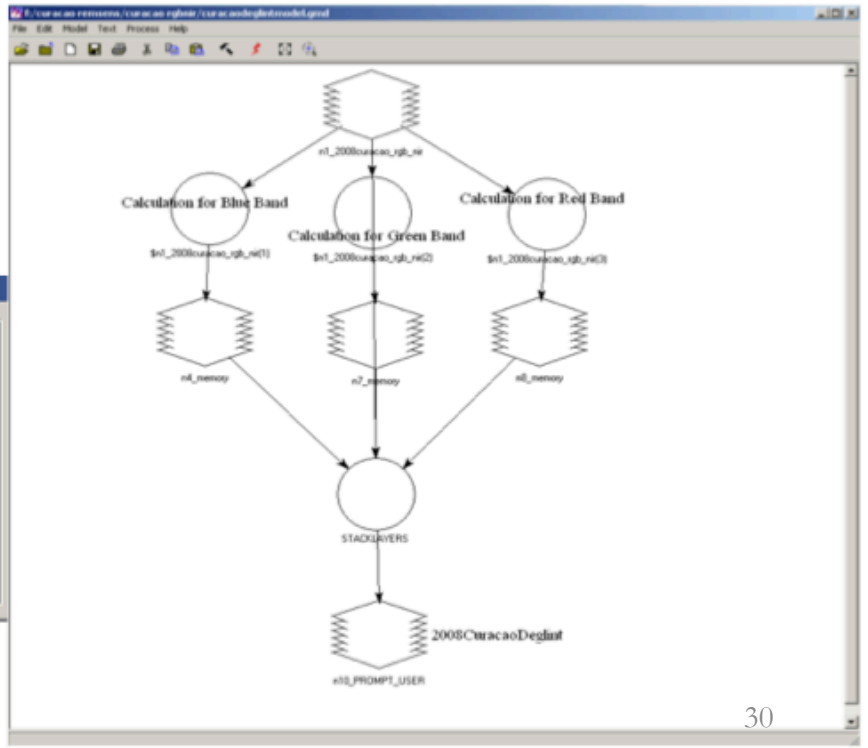
Hedley, J.D., Harborne, A.R., and Mumby, P.J. 2005. Simple and robust removal of sun glint for mapping shallow-water benthos. *International Journal of Remote Sensing* 26(10): 2107-2112.

- Select AOI of open water at varying degrees of reflectance.
- Convert pixel to ASCII
- Plot R,G, B bands against NIR band.
- R'_i =Deglinted Band
- R_i = Band to be corrected
- b_i = slope of band plotted against NIR band
- R_{NIR} = NIR band
- Min_{NIR} = lowest NIR pixel value from sample.

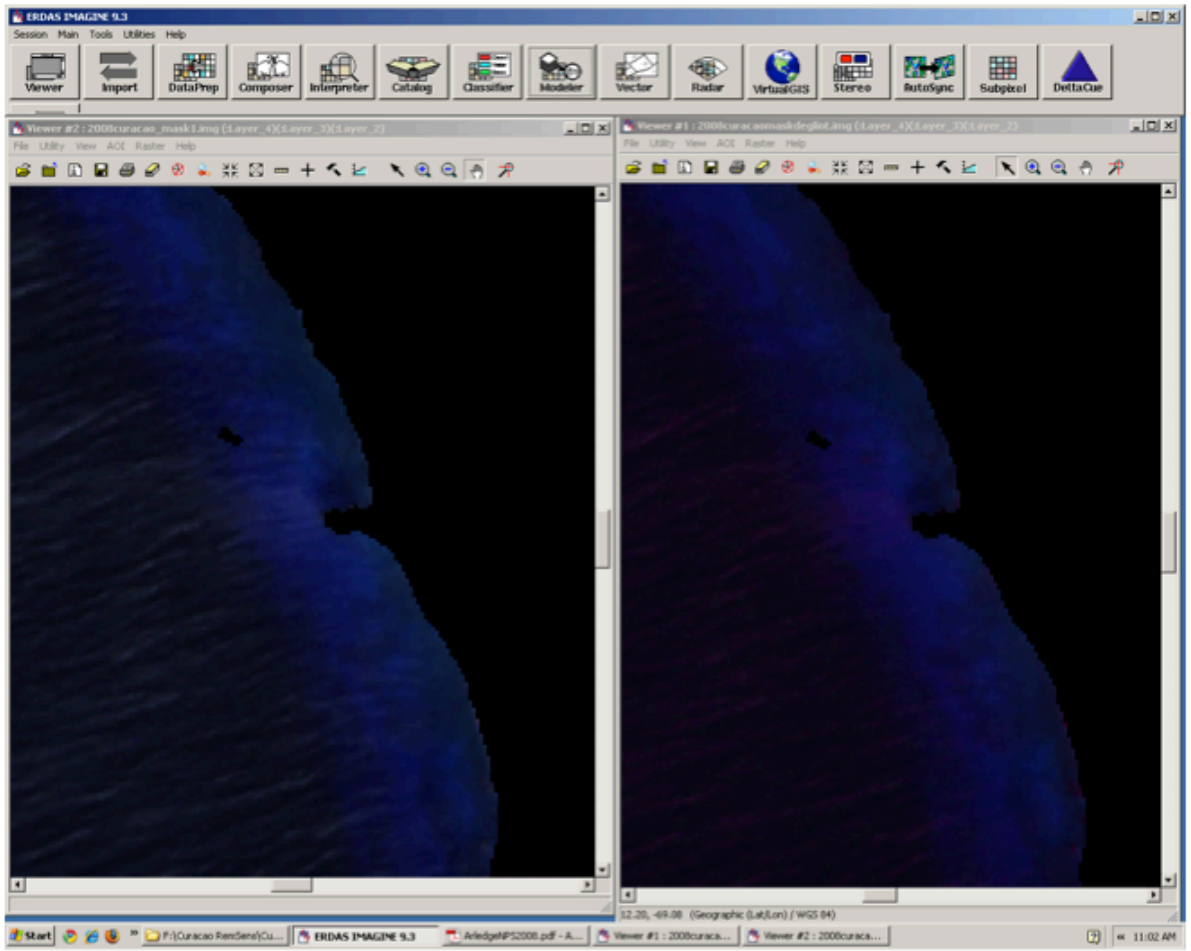
Deglinting Equations and Model

ERDAS Imagine



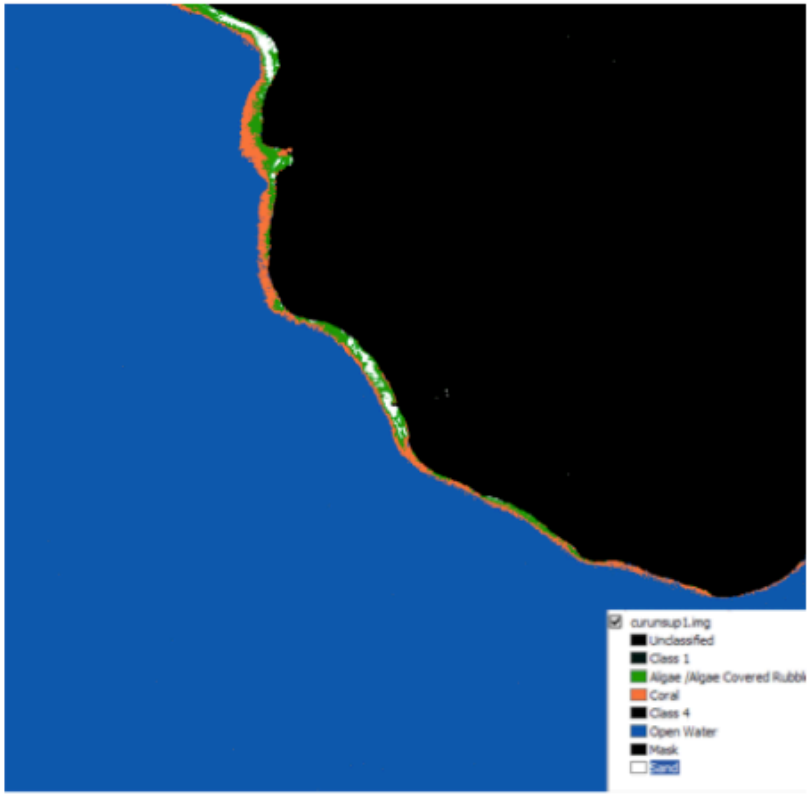


Deglinting Results

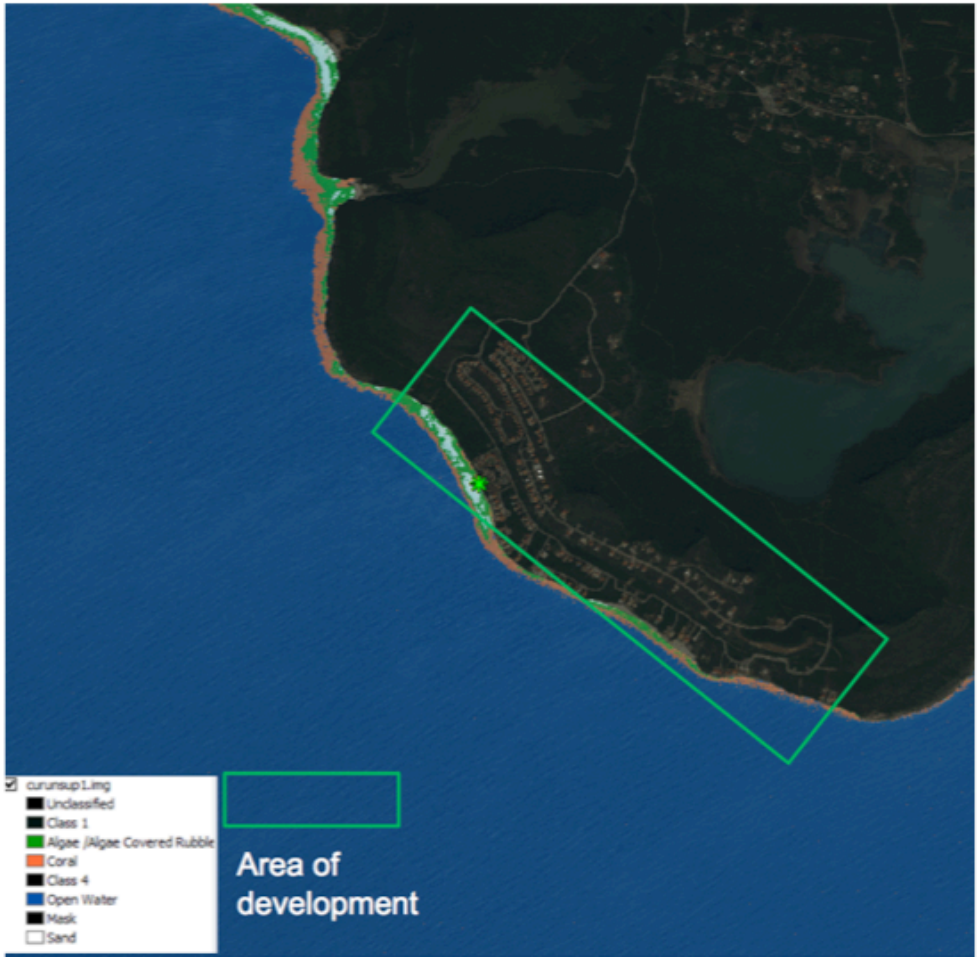


Benthic Classification

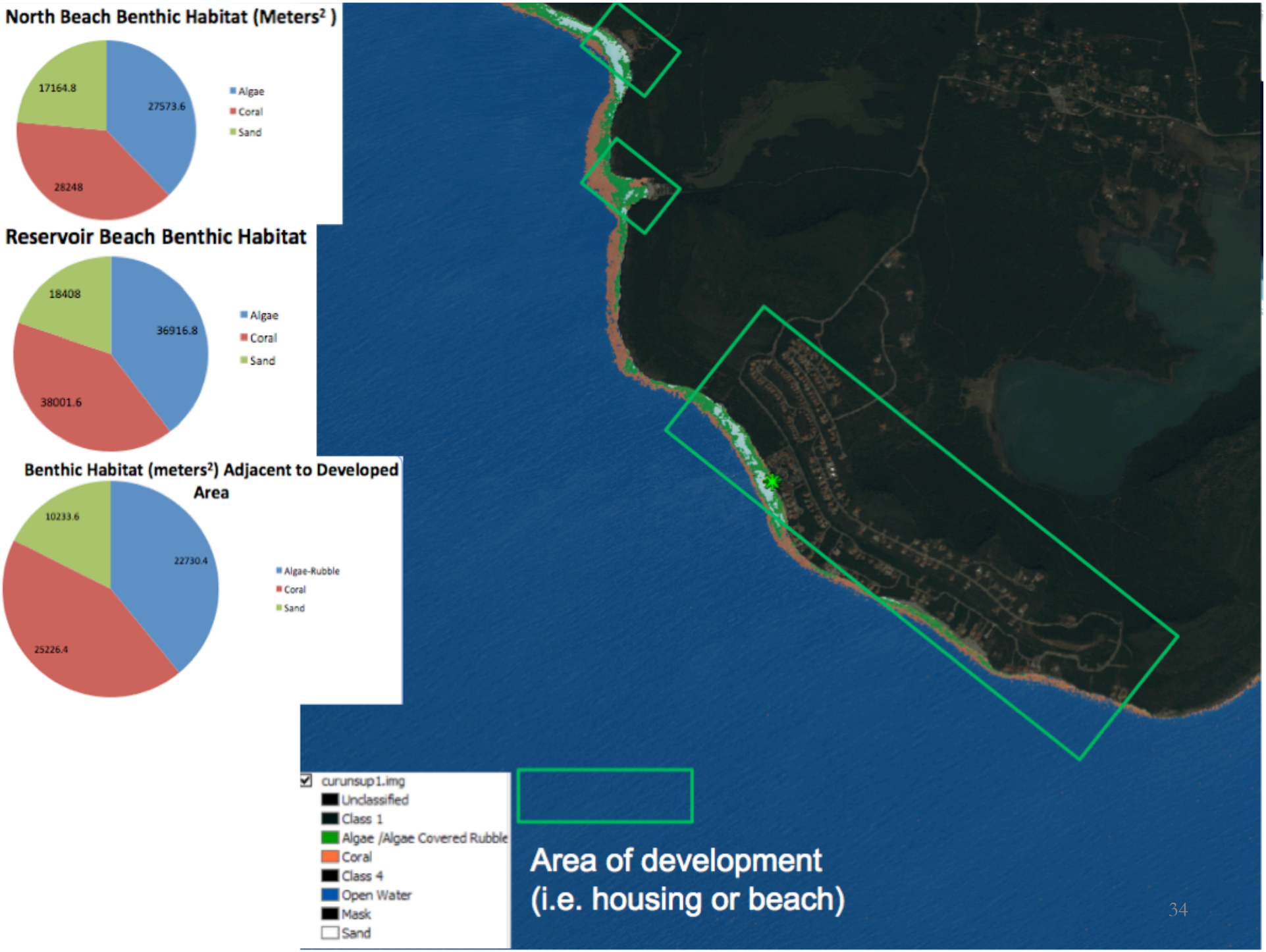
- Unsupervised Classification (20 classes)
- Supervised Classification (3 classes)
  - Coral
  - Algae / Algae covered rubble
  - Sand

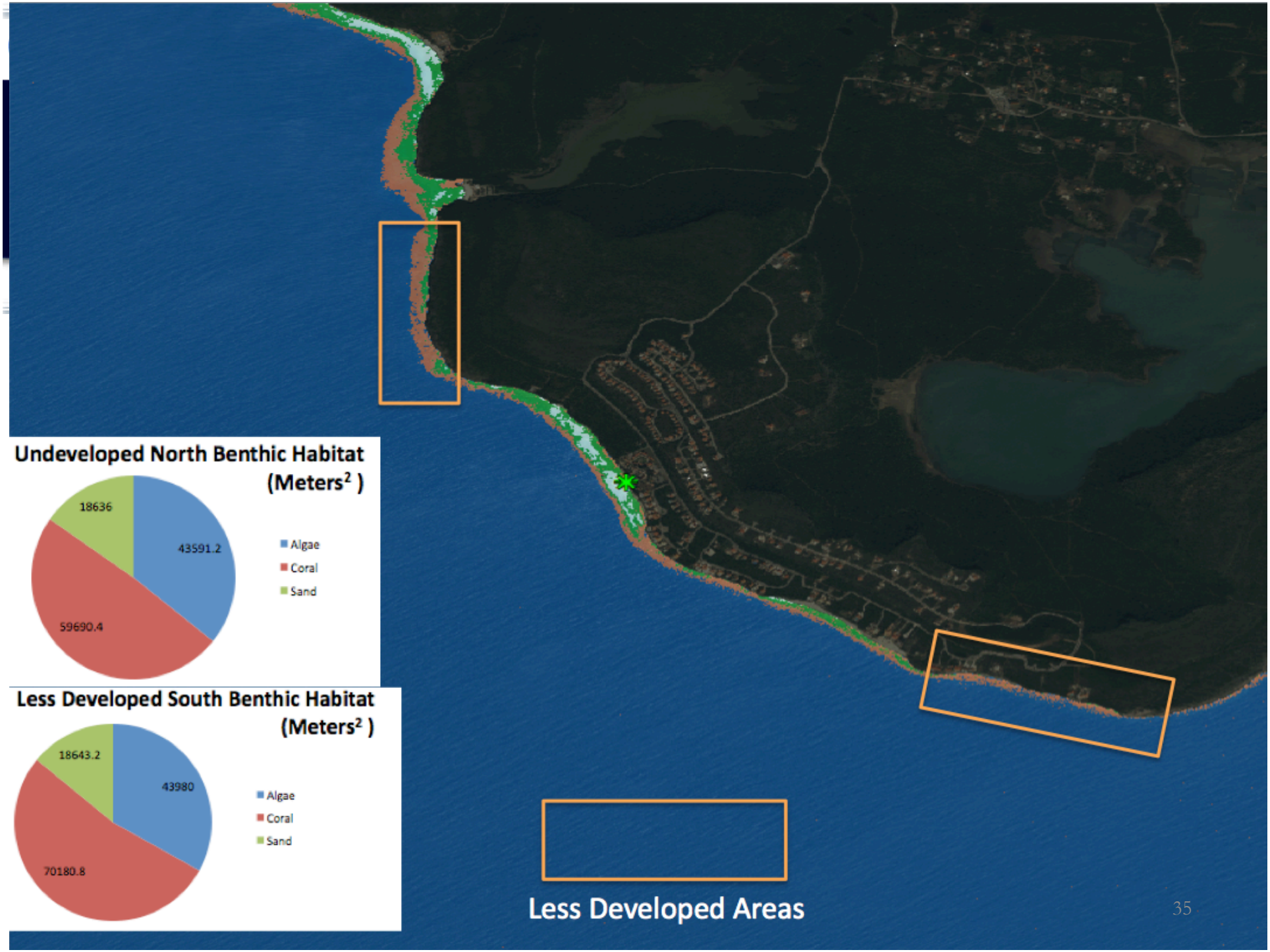


Spatial Survey of Benthic/Terrestrial Relationships



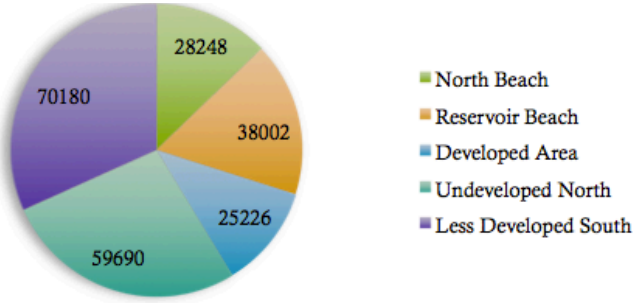
- Import classified image into ArcGIS and overlay transparent pan-sharpened image of study site.


North Beach Benthic Habitat (Meters²)
17164.8
27573.6
28248
Algae
Coral
Sand
Reservoir Beach Benthic Habitat
18408
36916.8
38001.6
Algae
Coral
Sand
Benthic Habitat (meters²) Adjacent to Developed Area
10233.6
22730.4
25226.4
Algae-Rubble
Coral
Sand
curunsup1.img
Unclassified
Class 1
Algae /Algae Covered Rubble
Coral
Class 4
Open Water
Mask
Sand
Area of development
(i.e. housing or beach)

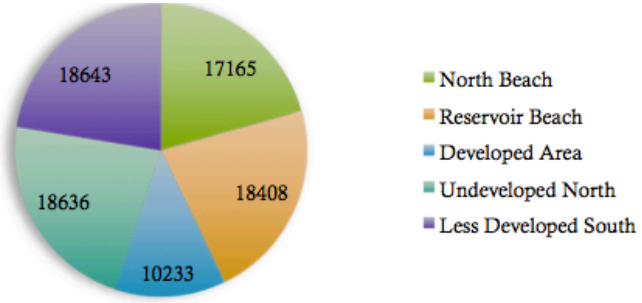

Undeveloped North Benthic Habitat (Meters²)
18636
43591.2
59690.4
Algae
Coral
Sand
Less Developed South Benthic Habitat (Meters²)
18643.2
43980
70180.8
Algae
Coral
Sand
Less Developed Areas

Benthic Composition by Location (Meters^2)

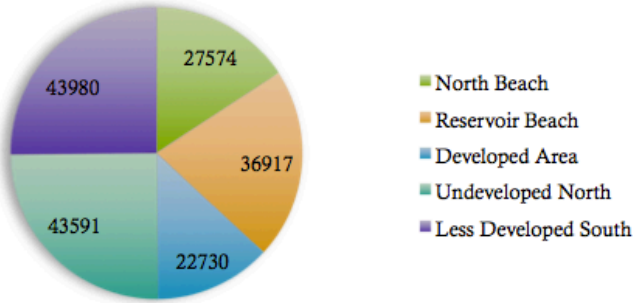
Coral

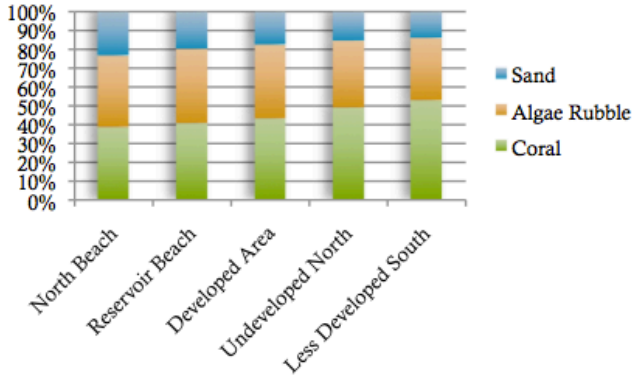


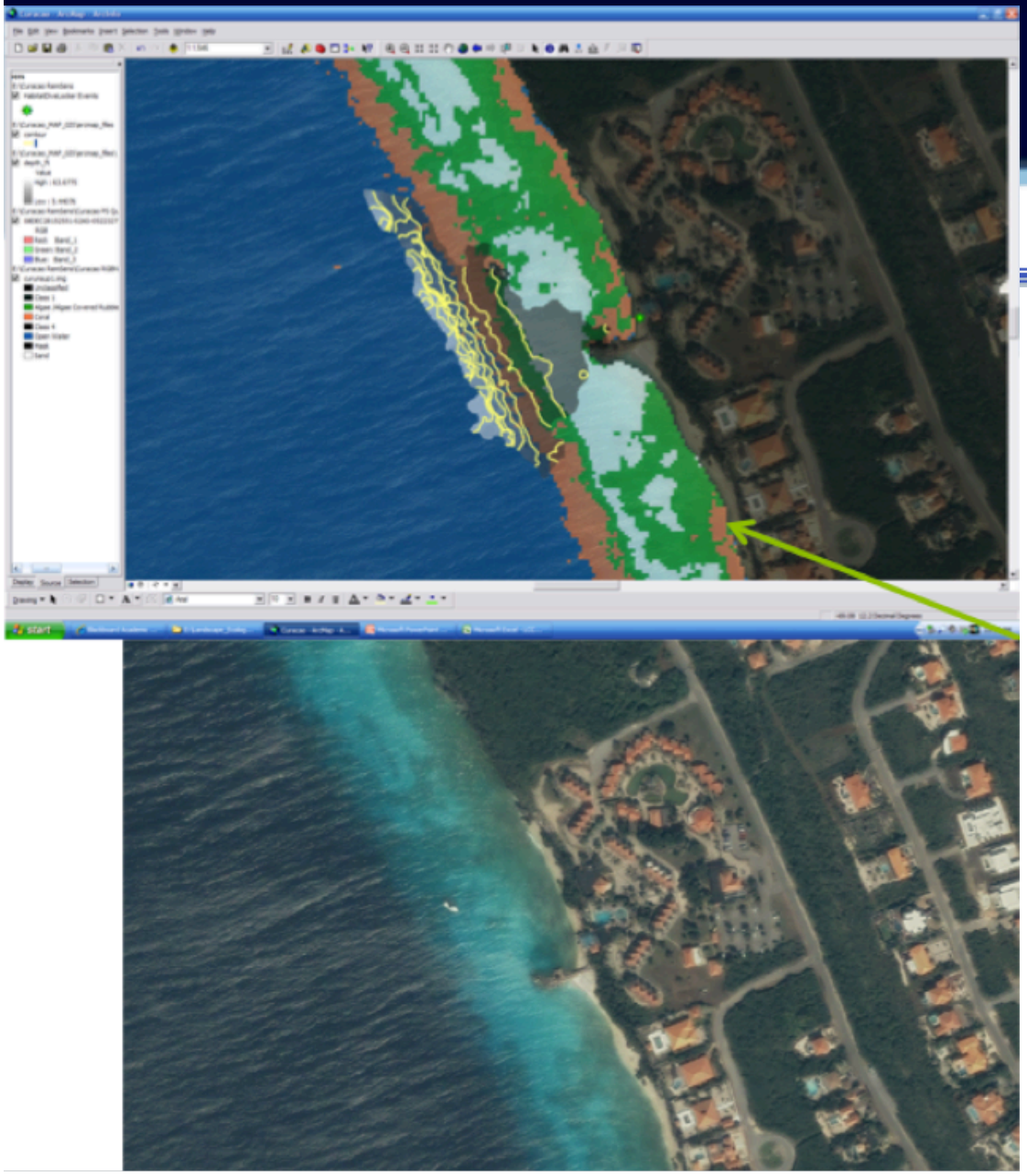
Sand



Algae Rubble







Discussion

- Additional preprocessing procedures would enhance classification by minimizing the similarities in the spectral reflectance signatures.
- Some classification errors
- Important to understand limits of tools, coral reef areas that look like they have less coral may just be oriented differently, and sensors can't observe coral deeper than 24'.
- Further research needed to see if development is influencing reef organization.

Things I would have done differently…

… if I had more time!

- Atmospheric correction
- Water column correction

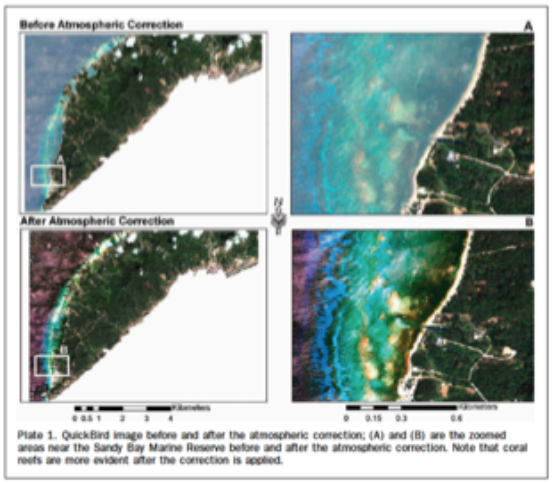


Plate 1. QuickBird image before and after the atmospheric correction; (A) and (B) are the zoomed areas near the Sandy Bay Marine Reserve before and after the atmospheric correction. Note that coral reefs are more evident after the correction is applied.

Mishra, D., Narumalani, S., Rundquist, D., and Lawson, M. 2006. Benthic Habitat Mapping in Tropical Marine Environments Using QuickBird Multispectral Data. *Photogrammetric Engineering & Remote Sensing*. 72(9): 1037-1048.

Mumby, P., Clark, C. D., Green, E. P. and Edwards, A. J. 1998. Benefits of water column correction and contextual editing for mapping coral reefs. *International Journal of Remote Sensing* 19: 203-210.

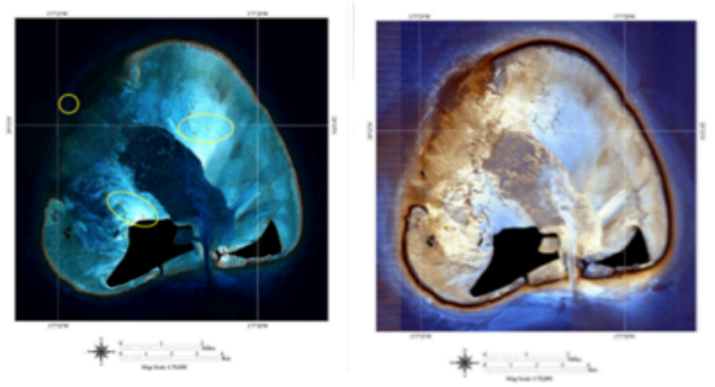


Figure 31. QuickBird water column corrected image

$$DII_{ij} = \ln(L_i) - \left[\ln\left(\frac{k_i}{k_j}\right)\ln(L_j)\right] \quad (8)$$

Where i and j represent image bands, L is the pixel reflectance value and the ratio of attenuation coefficients (k_i/k_j) is defined by:

$$\frac{k_i}{k_j} = a + \sqrt{a^2 + 1} \quad (9)$$

Where a is the difference in the variances of bands i and j divided by twice their covariance, as shown below:

$$a = \frac{\sigma_{ii} - \sigma_{jj}}{2\sigma_{ij}} \quad (10)$$

The covariance σ_{ij} is the mean of the products of X_i and X_j minus the product of the means of X_i and X_j:

$$\sigma_{ij} = \overline{X_i X_j} - \overline{X_i} \bullet \overline{X_j} \quad (11)$$

Where X is the natural log of pixel reflectance (L).

$$X_i = \ln(L_i) \quad (12)$$

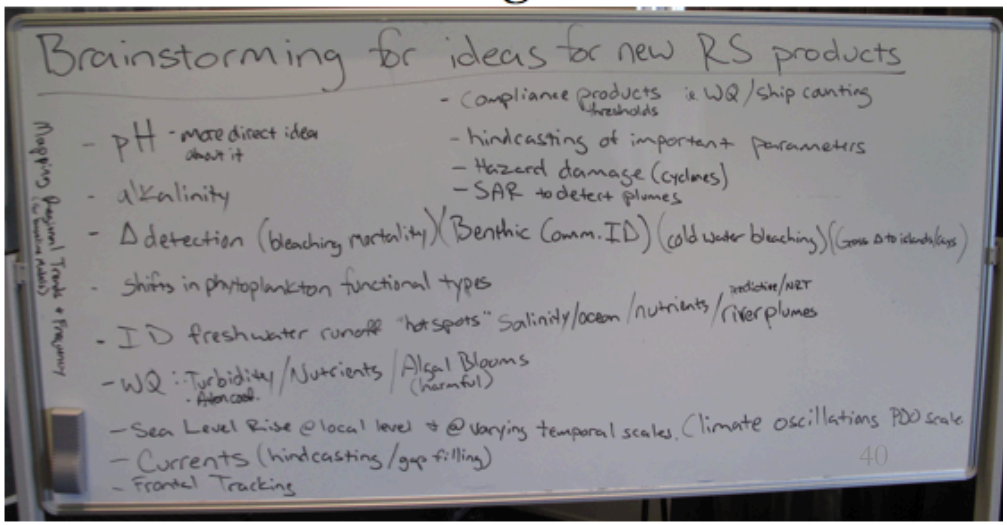
Arledge, R.K. and Hatcher E.B. 2008. Investigating the effects of higher spatial resolution on benthic classification accuracy at Midway atoll. Naval Postgraduate School Thesis. Monterey, California.

Role as a Fellow

- Facilitate the development of a land-based source of pollution product for Coral Reef Watch
- Collaborate with STAR Remote Sensing Scientists and CRCP managers to ascertain components of an effective product for detecting sediment plumes in coastal waters.

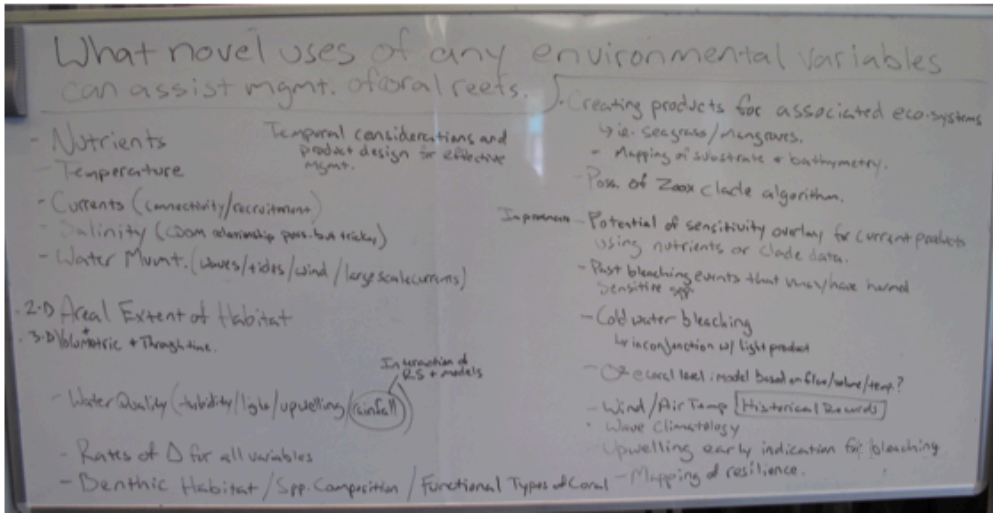
Australia Workshop

- Interest in developing robust ocean color products.
  - Examples include:
    - Chlorophyll *a*
    - Colored Dissolved Organic Matter
    - Transparency/Turbidity/Vertical Attenuation of Light
    - Total Suspended Matter
    - Seagrass / Macro-algae
    - Compliance maps
    - Bleaching



Australia Workshop

- Information products useful for Managers.
  - Examples include:
    - Eutrophication / Compliance
    - Sediment Loads / Compliance
    - Primary Productivity
    - Flood Plume and Algal Bloom Monitoring



Australia Workshop

- Perceived obstacles to developing these.
  - Atmospheric corrections applicable to locations throughout the world (Wang).
  - Correction for backscattering from substrate surface in shallow coastal areas.
  - Water column correction.

Needs Identification

(As they relate to CRW)

- CRCP Goals and Objectives (2010-2015)
  - Impacts
    - Fishing (NMFS)
    - Climate Change (CRW – SST etc.)
    - Land-based sources of pollution

Needs Identification

(As they relate to CRW)

- STAR Mission Statement:
  - To accelerate the transfer satellite observations of the land, atmosphere, ocean, and climate from scientific research and development into routine operations, and offer state-of-the-art data, products, and services to decision makers.

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

Coral Reef Watch

Crosswalk between CRW, STAR and CRCP Goals and Objectives

Role:

Provide land-based pollution product:

Sediment Plumes

Chlorophyll a concentrations

Mission:

Provide managers with tools needed to monitor threats to coral reefs.

Role:

Algorithms for operational products:

Atmospheric corrections (Wang)

Backscattering corrections

Mission:

Provide CRW with operational products that will fulfill STAR mission objectives.

Role:

Facilitate input from managers to identify the best possible LBSP product and provide opportunities for developing LBSP products by obtaining access to validation and verification data.

Mission:

To reduce and prevent the impacts of land-based sources of pollution on coral reef ecosystems

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