Studying coral reef ecosystems with NASA tools in an age of climate change and coral bleaching: the role of spectroscopy

Juan L. Torres-Pérez, PhD, Liane S. Guild and Roy Armstrong

Bay Area Environmental Research Institute

NASA Ames Research Center

Univ of PR-Mayagüez

Advancing the knowledge of coral reef spectroscopy and human impacts in coastal and marine ecosystems in the Caribbean

Juan L. Torres-Pérez, PhD, Liane S. Guild and Roy Armstrong

Bay Area Environmental Research Institute

NASA Ames Research Center

Univ of PR-Mayagüez

Coral reefs – an endangered ecosystem

- **Coral reefs are among the most biodiverse marine ecosystems in the World**
- **While they only cover less than 1% of the ocean floor, they provide for the sustenance of millions of people worldwide**
- **Many of these ecosystems are threatened by human-related activities and climate change**
- **This will potentially lead to a phase-shift in the predominant species or groups**

NASA National Aeronautics and Space Administration

Ames

Discovery · Innovations · Solutions

sign in | subscribe | search | jobs | US edition

theguardian

election 2016 | US | world | opinion | sports | soccer | tech | arts | lifestyle | fashion | business | travel | environment | browse all sections

home › environment › climate change | wildlife | energy | pollution

Great Barrier Reef

Great Barrier Reef: 93% of reefs hit by coral bleaching

Comprehensive aerial survey reveals full extent of the devastation caused by abnormally warm ocean temperatures

Michael Slezak

@MikeySlezak

email

Tuesday 19 April 2016 16.00 EDT

This article is 1 month old

Shares 10,554 | Comments 418

Save for later

Science AAAS

Home | News | Journals | Topics | Careers

Latest News | ScienceInsider | ScienceShots | Sifter | From the Magazine | About News | Quizzes

SHARE

3K

Coral bleaching in March at Lizard Island on the Great Barrier Reef.

Survey confirms worst-ever coral bleaching at Great Barrier Reef

By **Dennis Normile** | Apr. 19, 2016 , 6:00 PM

NOAA HOME | WEATHER | OCEANS | FISHERIES | CHARTING | SATELLITES | CLIMATE | RESEARCH | COASTS | CAREERS

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

UNITED STATES DEPARTMENT OF COMMERCE

» About NOAA | » Contacts | » Staff Directory | » Help | » SEARCH

Weather.gov Forecast

City, ST » GO

» Active Weather Alerts

» NOAA Organizations

» Working With NOAA

» Media & Constituents

» NOAA In Your State

» Emergency Information for NOAA Employees

Media Contact:

» Keeley Belva
301-643-6463

Tweet

Like 1.3K

Share

Email

Print

Facebook

Google

StumbleUpon

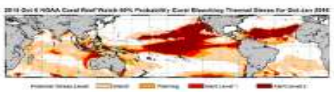
Digg

NOAA declares third ever global coral bleaching event

Bleaching intensifies in Hawaii, high ocean temperatures threaten Caribbean corals

October 8, 2015

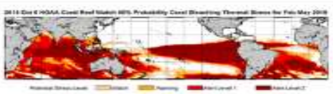
As record ocean temperatures cause widespread coral bleaching across Hawaii, NOAA scientists confirm the same stressful conditions are expanding to the Caribbean and may last into the new year, prompting the declaration of the third global coral bleaching event ever on record.



October 2015–January 2016: NOAA's standard 4-month bleaching outlook shows a threat of bleaching continuing in the Caribbean, Hawaii and Kiribati, and potentially expanding into the Republic of the Marshall Islands. (Credit: NOAA)

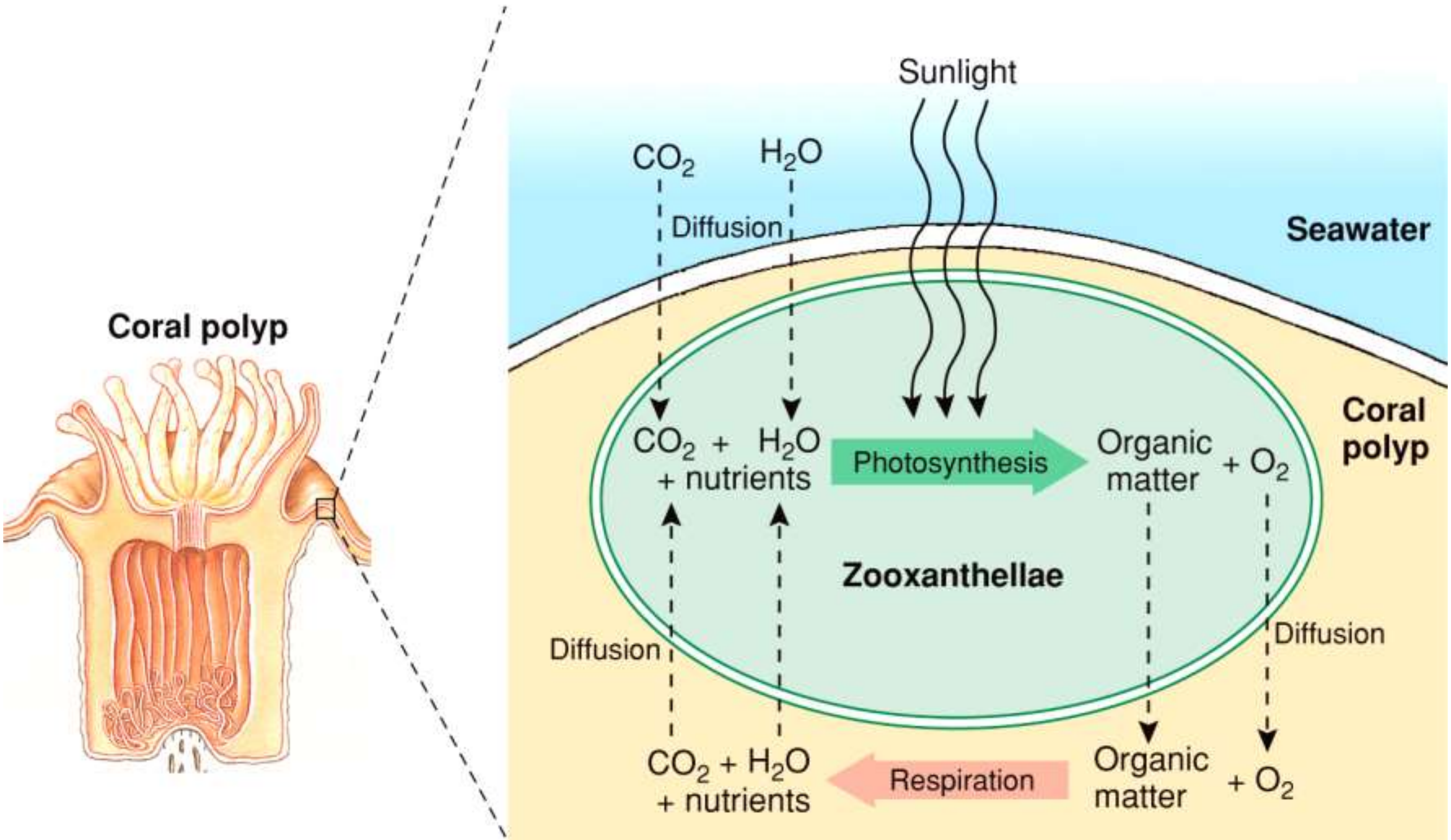
Waters are warming in the Caribbean, threatening coral in Puerto Rico and the U.S. Virgin Islands, NOAA scientists said. Coral bleaching began in the Florida Keys and South Florida in August, but now scientists expect bleaching conditions there to diminish.

"The coral bleaching and disease, brought on by climate change and coupled with events like the current El Niño, are the largest and most pervasive threats to coral reefs around the world," said Mark Eakin, NOAA's Coral Reef Watch coordinator. "As a result, we are losing huge areas of coral across the U.S., as well as internationally. What really has us concerned is this event has been going on for more than a year and our preliminary model projections indicate it's likely to last well into 2016."



February–May 2016: An extended bleaching outlook showing the threat of bleaching expected in Kiribati, Galapagos Islands, the South Pacific, especially east of the dateline and perhaps affecting Polynesia, and most coral reef regions in the Indian Ocean. (Credit: NOAA)

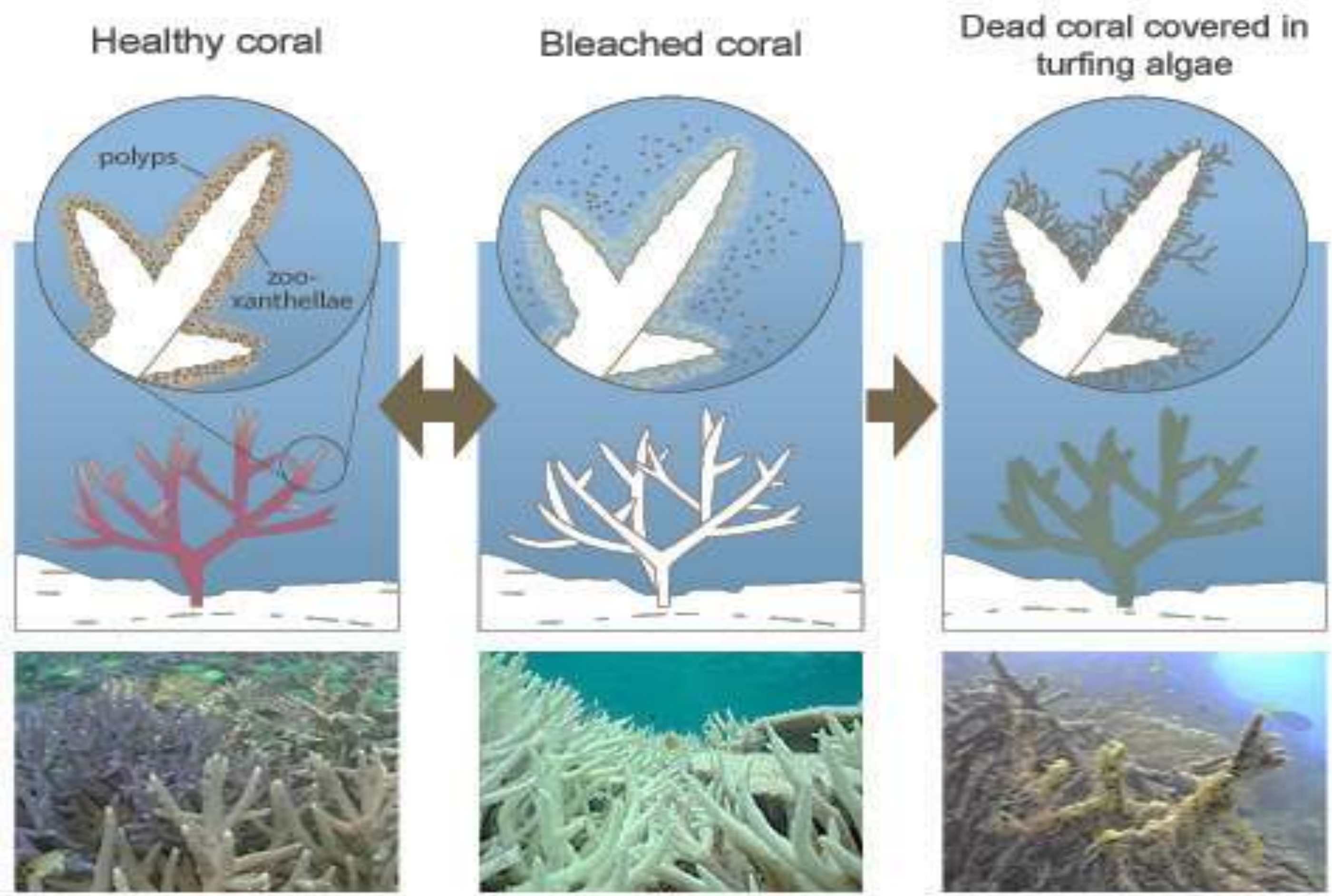
While corals can recover from mild bleaching, severe or long-term bleaching is often lethal. After corals die, reefs quickly degrade and the structures corals build erode. This provides less shoreline protection from storms and fewer habitats for fish and other marine life, including ecologically and economically important species.


Coral polyp
Sunlight
CO2
H2O
Diffusion
Seawater
Coral polyp
CO2 + H2O
+ nutrients
Photosynthesis
Organic matter
+ O2
Zooxanthellae
Diffusion
Diffusion
CO2 + H2O
+ nutrients
Respiration
Organic matter
+ O2

Coral Bleaching

- **Due to environmental factors:**
  - Dramatic ocean temperature increase/decrease
  - Sedimentation
  - UV radiation
- **Effects:**
  - Zooxanthellae lose their pigments
  - Expulsion of zooxanthellae from the coral host
  - Combination of both
- **Consequences:**
  - Decrease in coral's resistance to other diseases
  - Reduced competitiveness of corals against other benthic components (algae, encrusting sponges)
  - Coral colony death
  - Reduced resilience of the coral reef ecosystem as a whole

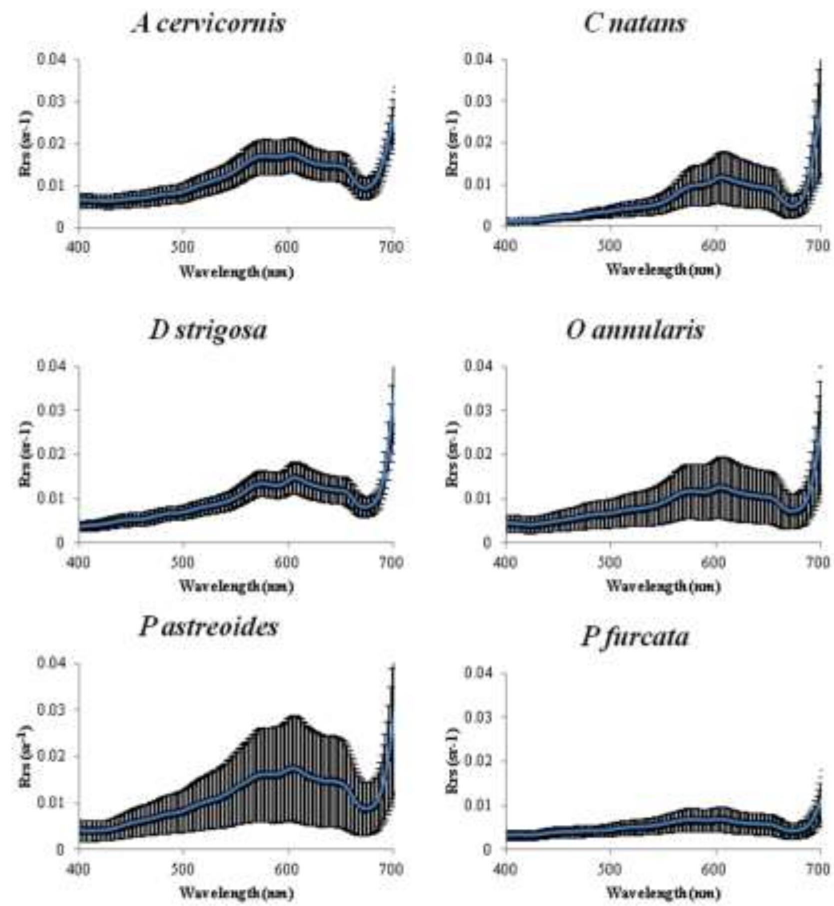
What is coral bleaching?

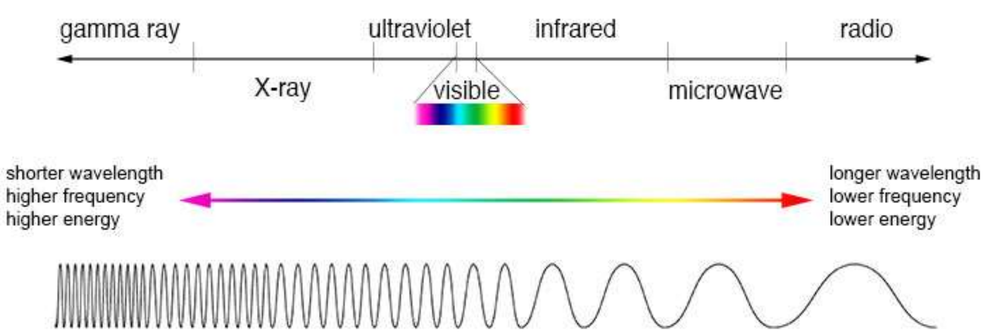


From: www.gbrmpa.gov.au

What is spectroscopy?

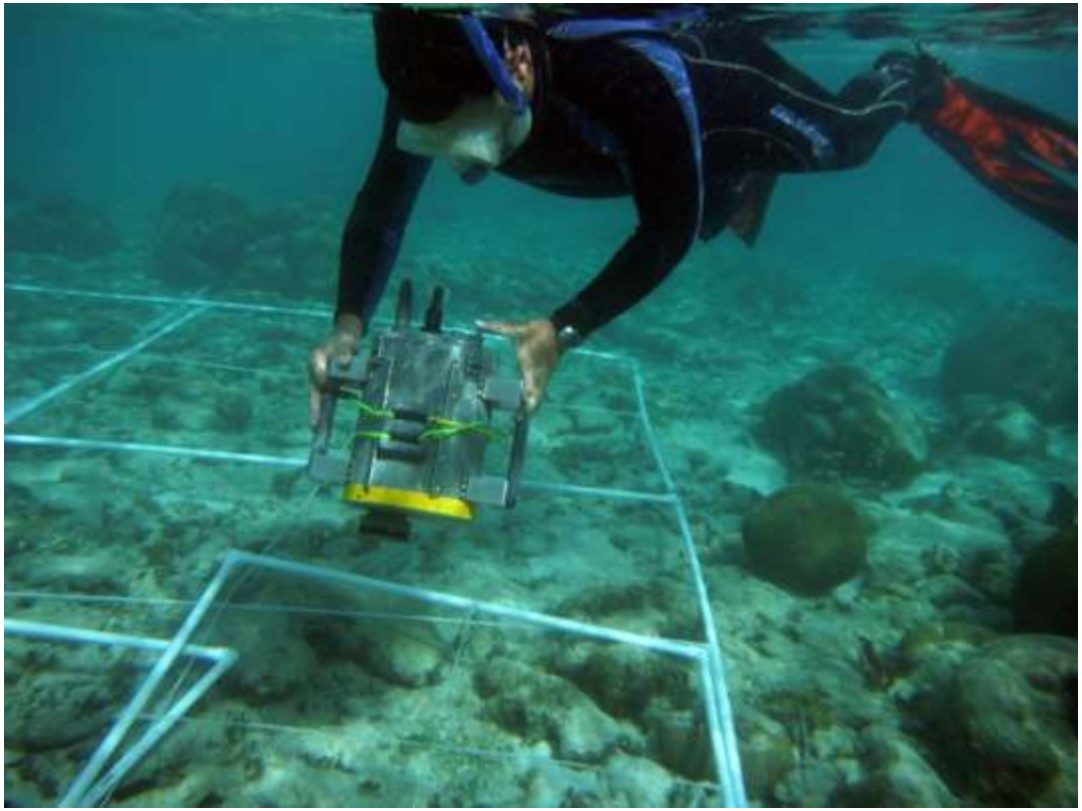
- Is the study of the interaction between matter and electromagnetic radiation.
- It is often represented by the spectrum and a response of the medium as a function of wavelength (nm).
- In our case, we use the response in the visible range (400-700nm).





What can spectroscopy help with?

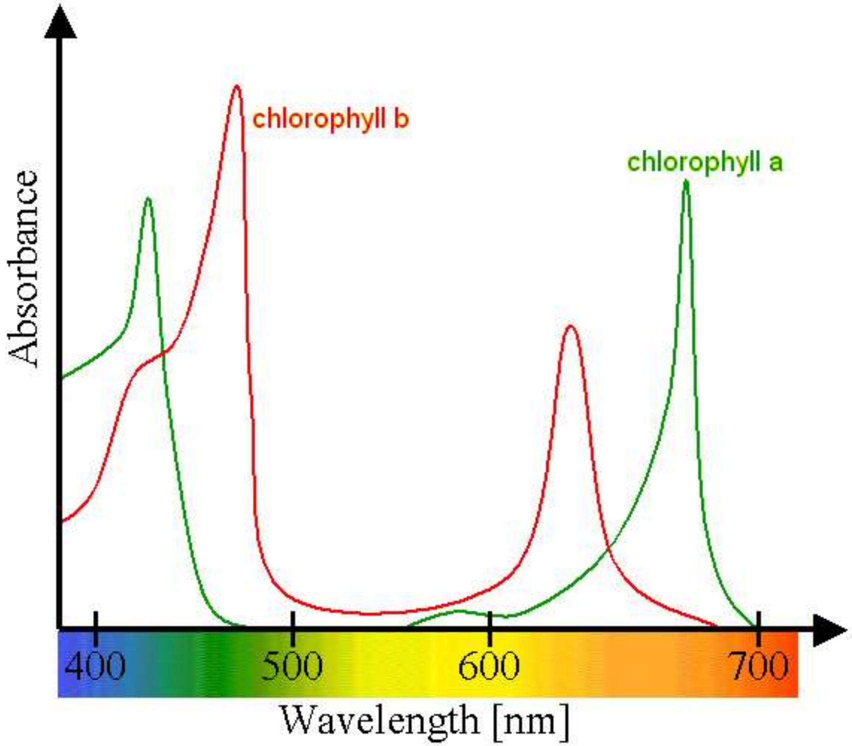
- There is a need for better spectral discrimination of reefs benthic components
- Aid in the cal/val of satellite or airborne images
- Provides for a non-invasive tool to assess the health of reef corals
- Can be used in physiological studies to follow the development of a potentially devastating event such as bleaching or disease outbreaks

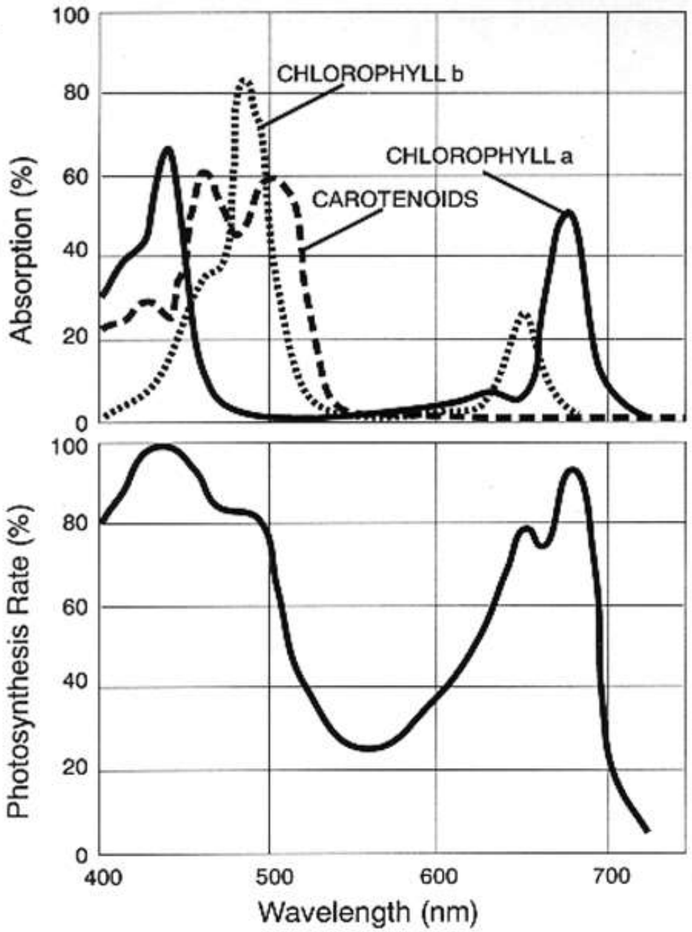


Many pigments/compounds absorb in the visible range

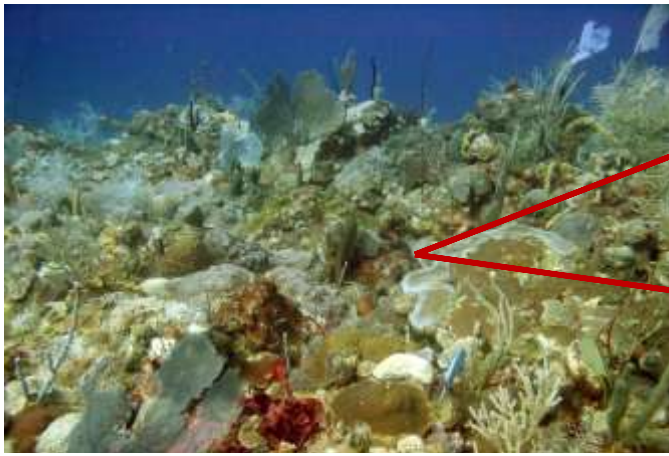
- **Chlorophylls – Chl *a*, *b*, c_1, c_2, etc.**
  - Main components of the photosynthetic apparatus
- **Phycobilisomes – phycoerythrin, phycocyanin**
  - Work as light-harvesting antennas of PSII
  - Capture photons between 500-650nm
- **Carotenes – photoprotection; absorb energy from ROS, help dissipate excess energy through NPQ**
  - Carotenoids (i.e. Peridinin, β-carotene)
  - Xanthophylls (i.e. Diadinoxanthin, Zeaxanthin, etc.)
- **Green Fluorescent Proteins (GFPs) – found in Cnidarians, bacteria and others.**
  - Possible photoprotective function?

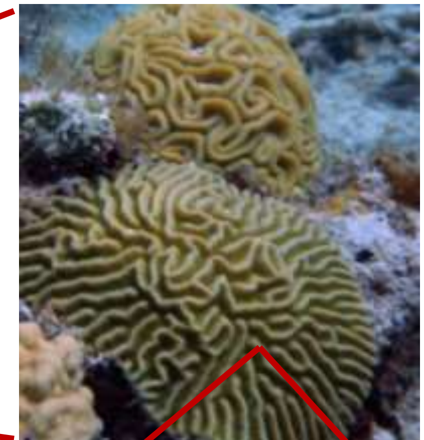
Chlorophylls and carotenoids absorption

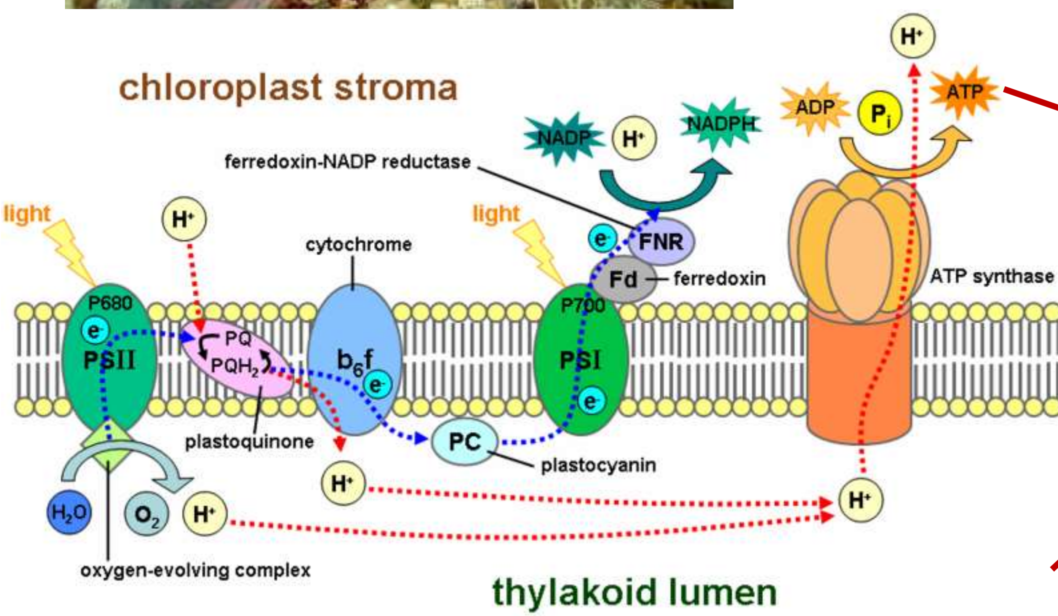


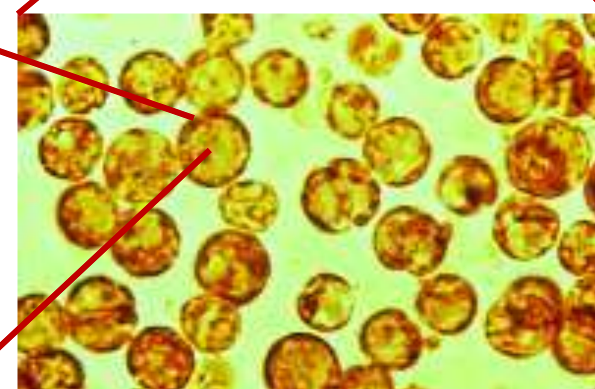


How deep do we need to go?







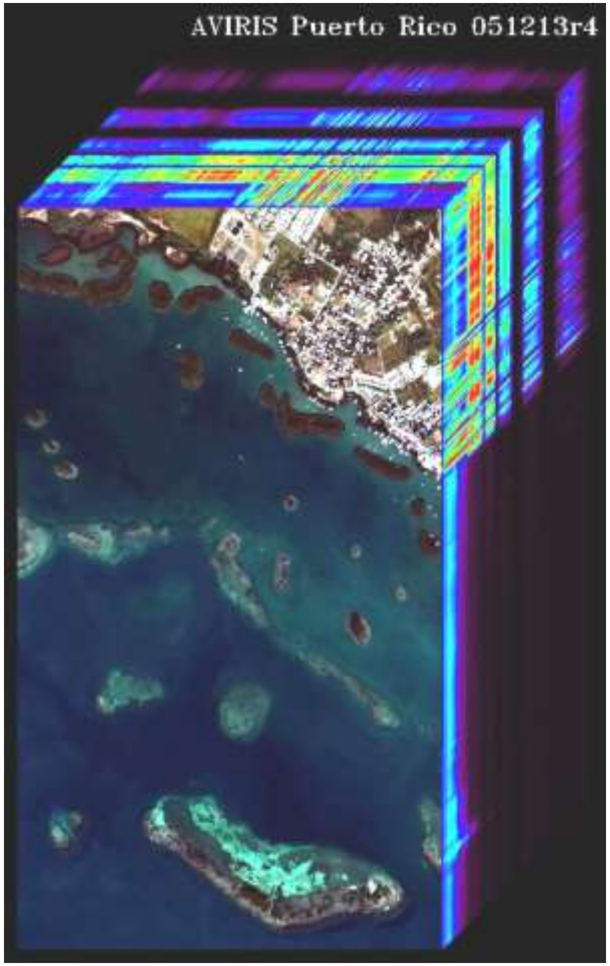


Other components …

<u>All</u> have pigments (photosynthetic, photoprotective or both).

_	Groups							Peaks
Pigments	**Green Algae**	**Red Algae**	**Brown Algae**	**Dinoflag. (Zoox.)**	**Mangrove**	**Seagrass**	**Cyanobact.**	**Max Abs**
Chl a	+			+	+	+	+	430, 580, 616, 663
Chl b	+				+	+		453, 597, 645
Chl c1			+					445, 578, 627
Chl c2			+	+				450, 581, 630
Peridinin				++				(428),474
Zeaxanthin	+	+			+	+	+	455, 478
Lutein	+	+						448, 477
Fucoxanthin			+	+				449, 468
Violaxanthin	+				+	+		441, 471
Anteraxanthin	+				+	+		444, 471
Neoxanthin	+	+			+			439, 468
Diadinoxanthin				+				448, 477
Diatoxanthin				+				454, 482
Dinoxanthin				+				443, 473
Diadinochrome				+				430, 458
Phycoerythrin		+					+	495, 545, 566
Phycocyanin					+?	+?	+	620
Alophycocya.		+					+	650
P-457				+				457
α-carotene	+	+						449, 476
β-carotene	+	+	+	+	+	+	+	455, 482

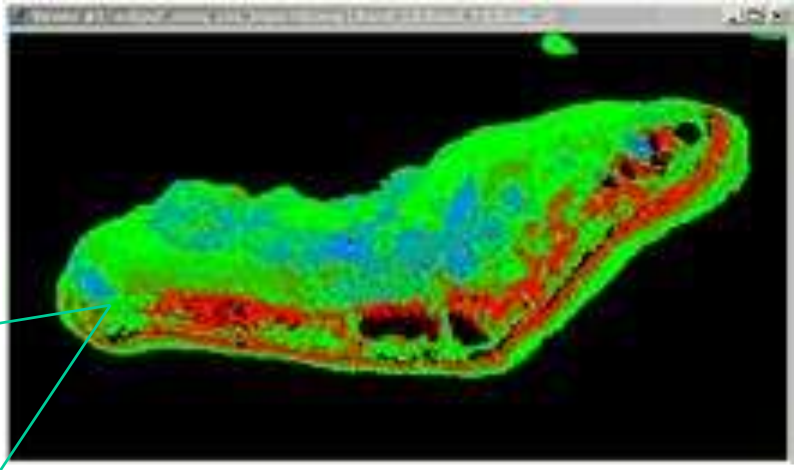
Now, How can we connect pigments with remotely sensed images?

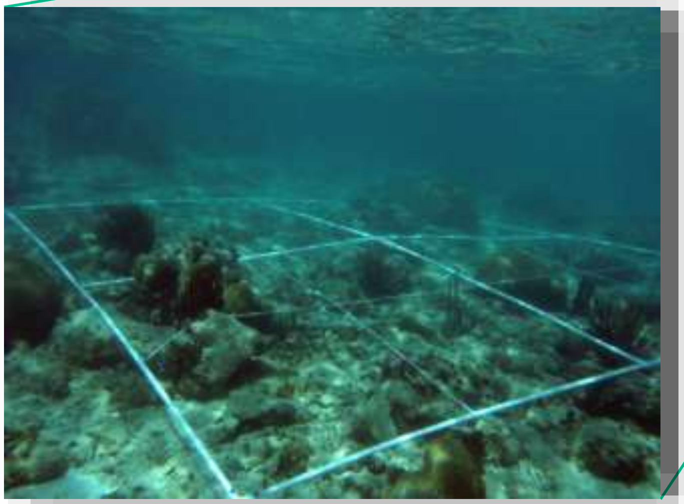


We need:

1. **To know the pigments (identification and quantification)**
2. **A signal related to these pigments**
3. **Association of particular absorption peaks from pigments, if possible**
4. **Algorithms**

Multiple benthic features in 1 pixel

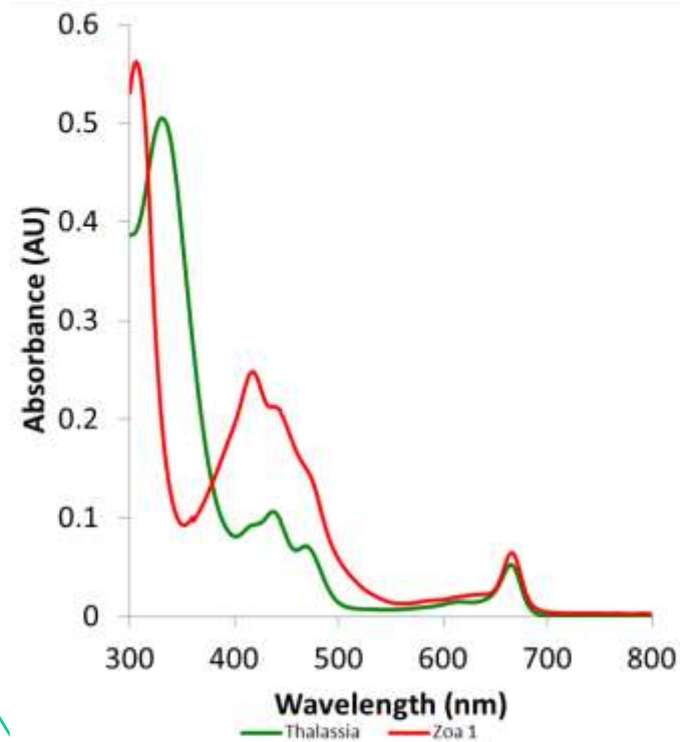


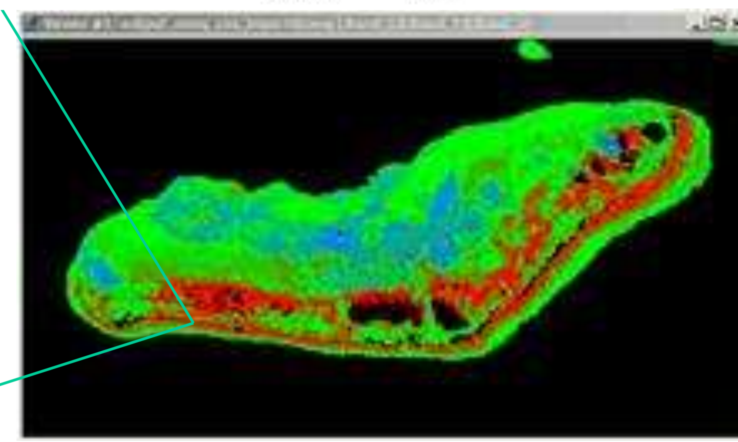


1. Hard Corals (1 to X # of Spp.)
2. *Thalassia*
3. Gorgonians
4. Green Calcareous Algae
5. Brown Algae
6. Dead coral rubble
7. Etc.

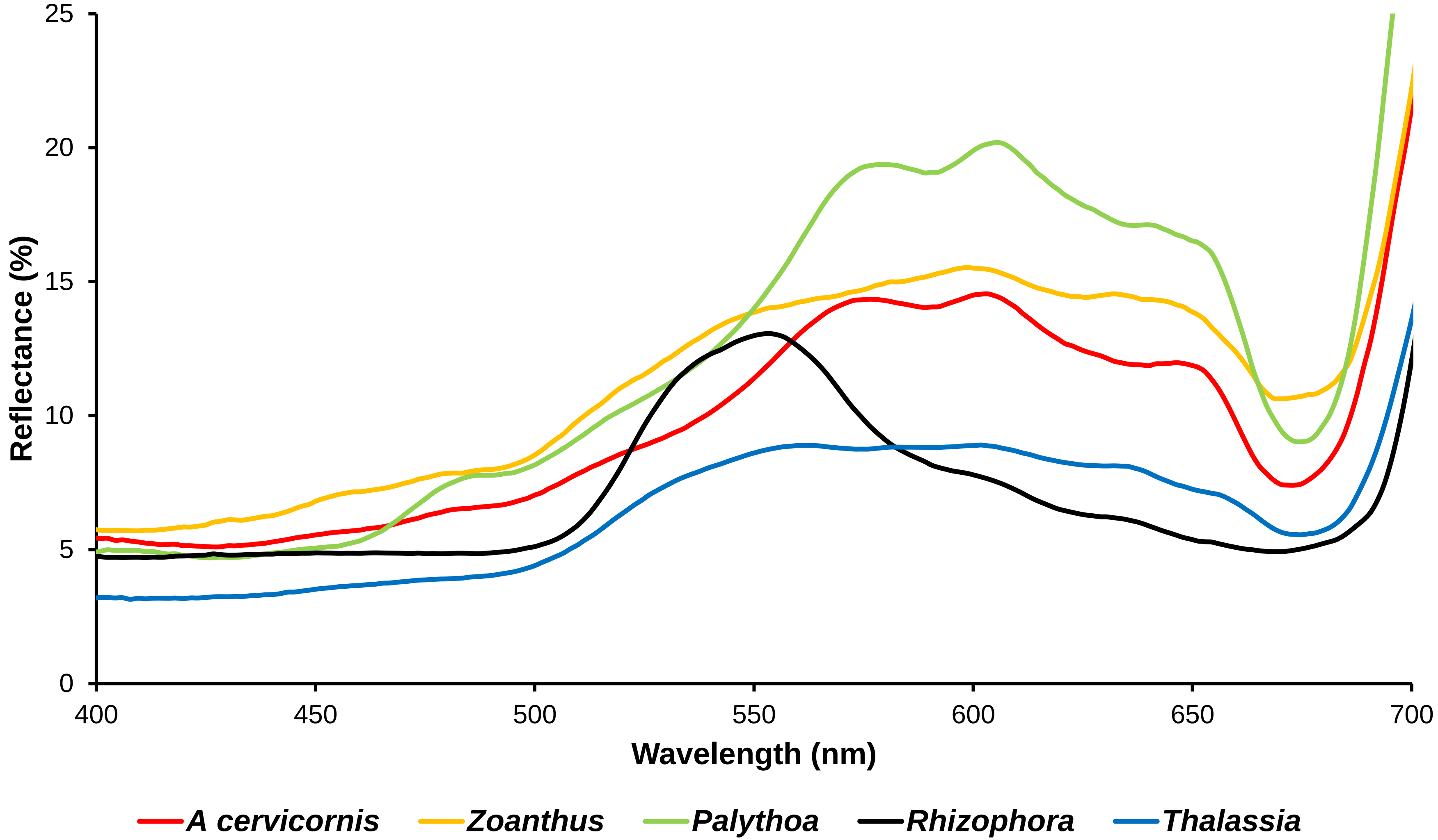
The contents of 1 pixel:

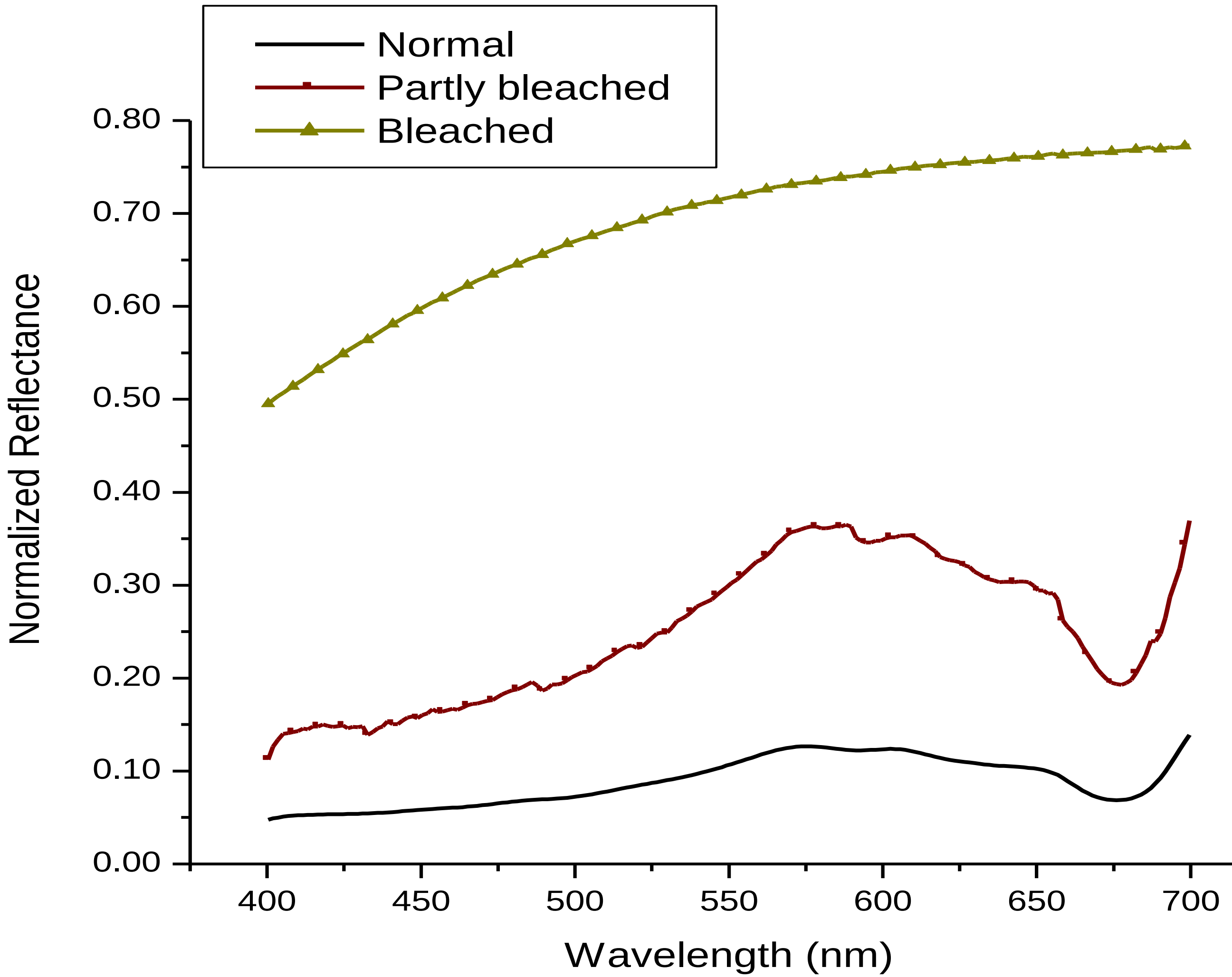
Benthic components may have similar colors but be spectrally different.

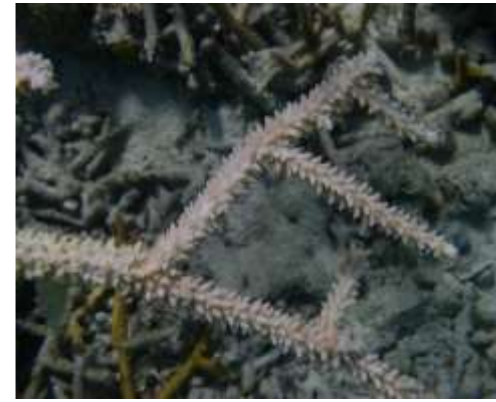


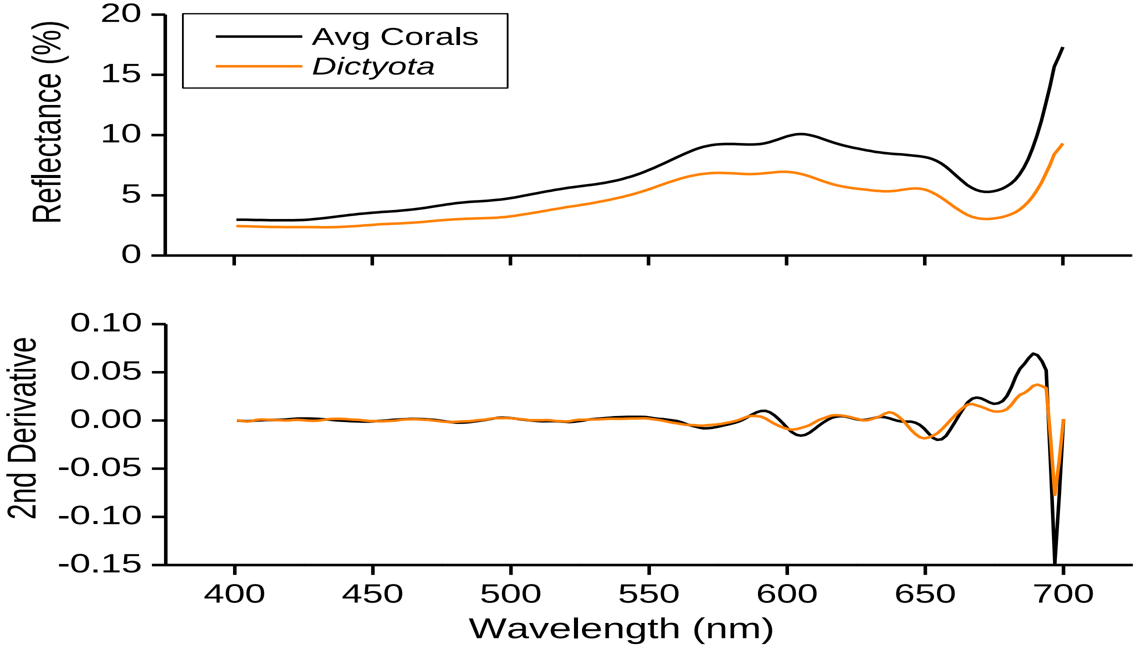


Comparison of different benthic components

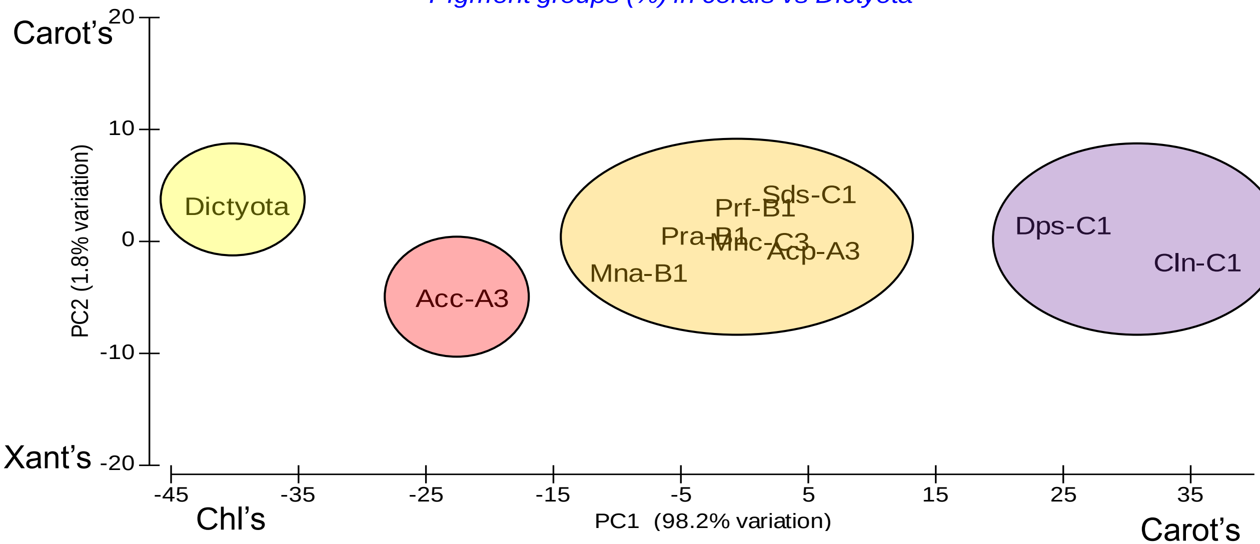



Normal
Partly bleached
Bleached
Normalized Reflectance
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
400
450
500
550
600
650
700
Wavelength (nm)



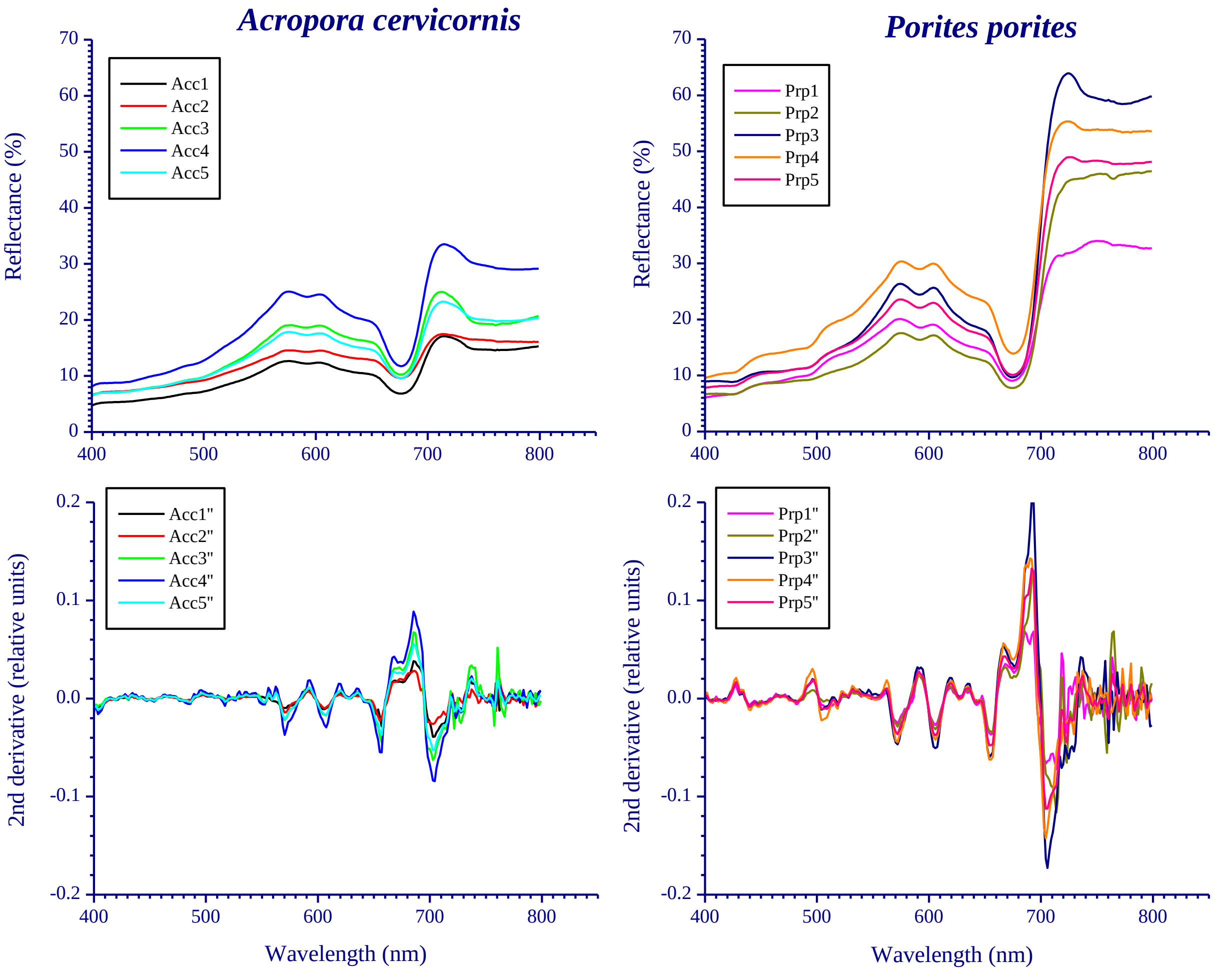


Pigment groups (%) in corals vs Dictyota



Acropora cervicornis

Porites porites



(Torres-Pérez et al. 2012 Rem. Sens.)

Acropora cervicornis

Colpophyllia natans

Siderastrea siderea

Pseudodiploria strigosa

Orbicella annularis

Porites astreoides

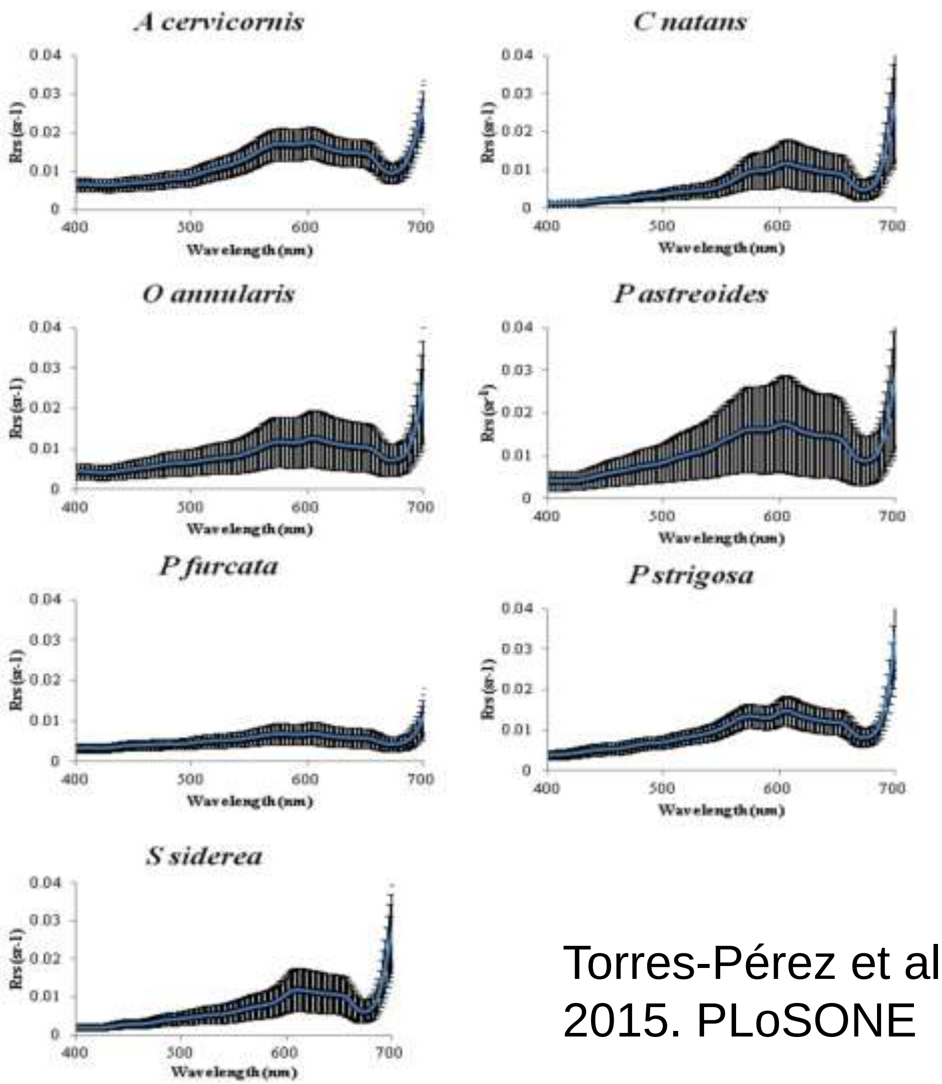
Porites furcata

Pigments identified in 7 Scleractinian species:

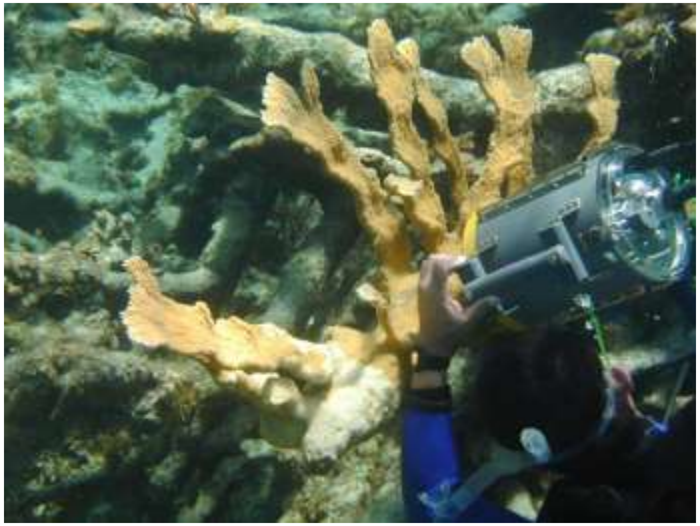
Pigment Name	***Absorption range (nm)***
Siphonaxanthin	441-464
Sipho-do	448-463
Monovynil Chl C3	447-456, 580-588, 624-630
MgDVP	437-440, 574-580, 624-632
Peridinin	465-483
Chl c1	442-445, 577-580, 626-634
Chl c2	448-454, 580-587, 629-635
P-457	450-458
P-468	468
Diadinoxanthin	424-476
Diadinochrome I	402-458
Diadinochrome II	402-458
Fucoxanthin	446-475
Gyro-de	444-472
Lutein	421-475
Zeaxanthin	428-481
Neochrome	398-450
9-cis-neochrome	398-450

Pigment Name	***Absorption range (nm)***
Dinoxanthin	416-472
Diatoxanthin	426-483
Violaxanthin	415-472
Antheraxanthin	420-475
19-hexanoloxyfucoxanthin	443-472
9-cis-neoxanthin	411-467
Chl a allomer	382-432, 617-618, 652-665
Chl a	382-432, 617-618, 652-665
Chl a epimer	382-432, 617-618, 652-665
Pheophytin a	417, 533, 567, 602, 654
Pyropheophytin a	412, 504, 536, 608, 666
Chlorophyllide a	432, 619, 664
Pheophorbide a	411, 467, 507, 538, 609, 666
Chl b	459-465, 599-603, 646-652
B,B-carotene	451-480
B,e-carotene	444-477
Unknown λmax 442nm	442
Unknown λmax 421, 446nm	421, 446
Unknown λmax 456, 477nm	456, 477

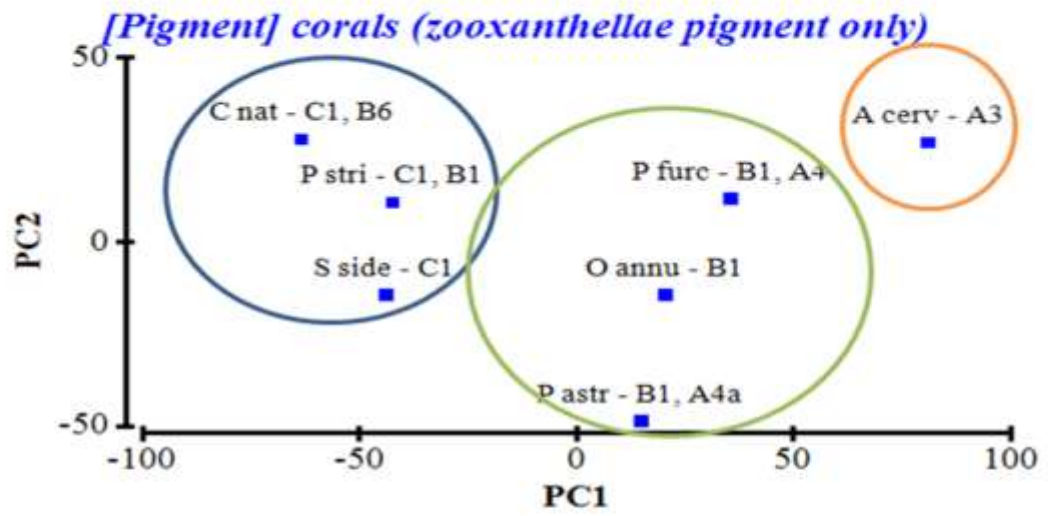
Field measurements in La Parguera



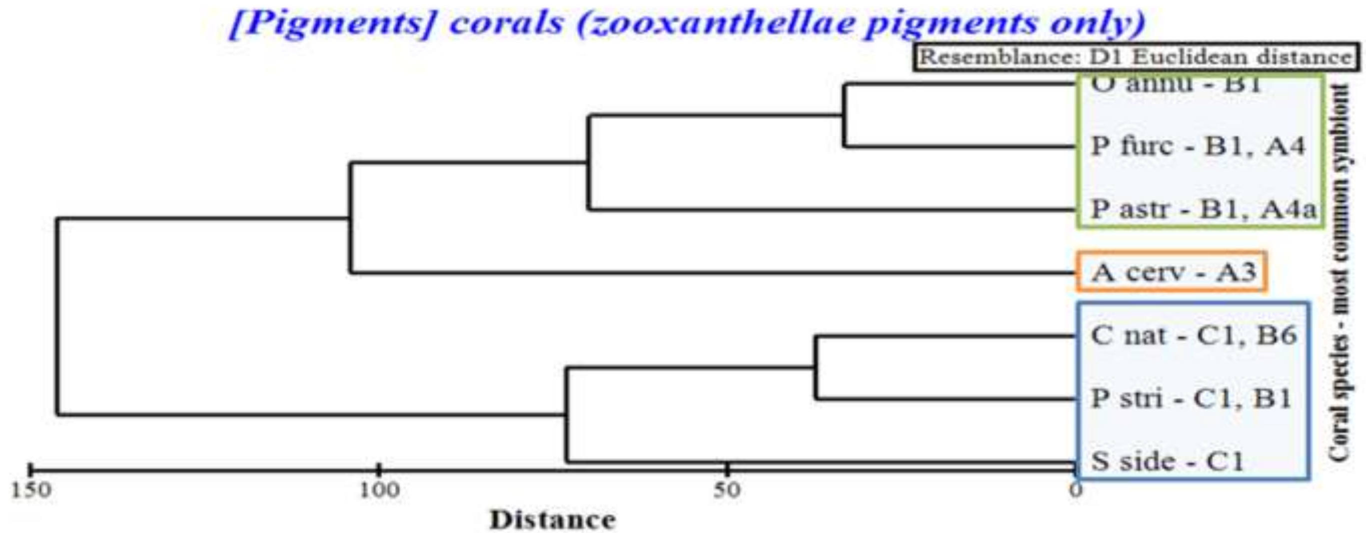
Torres-Pérez et al.
2015. PLoSONE



A)



B)



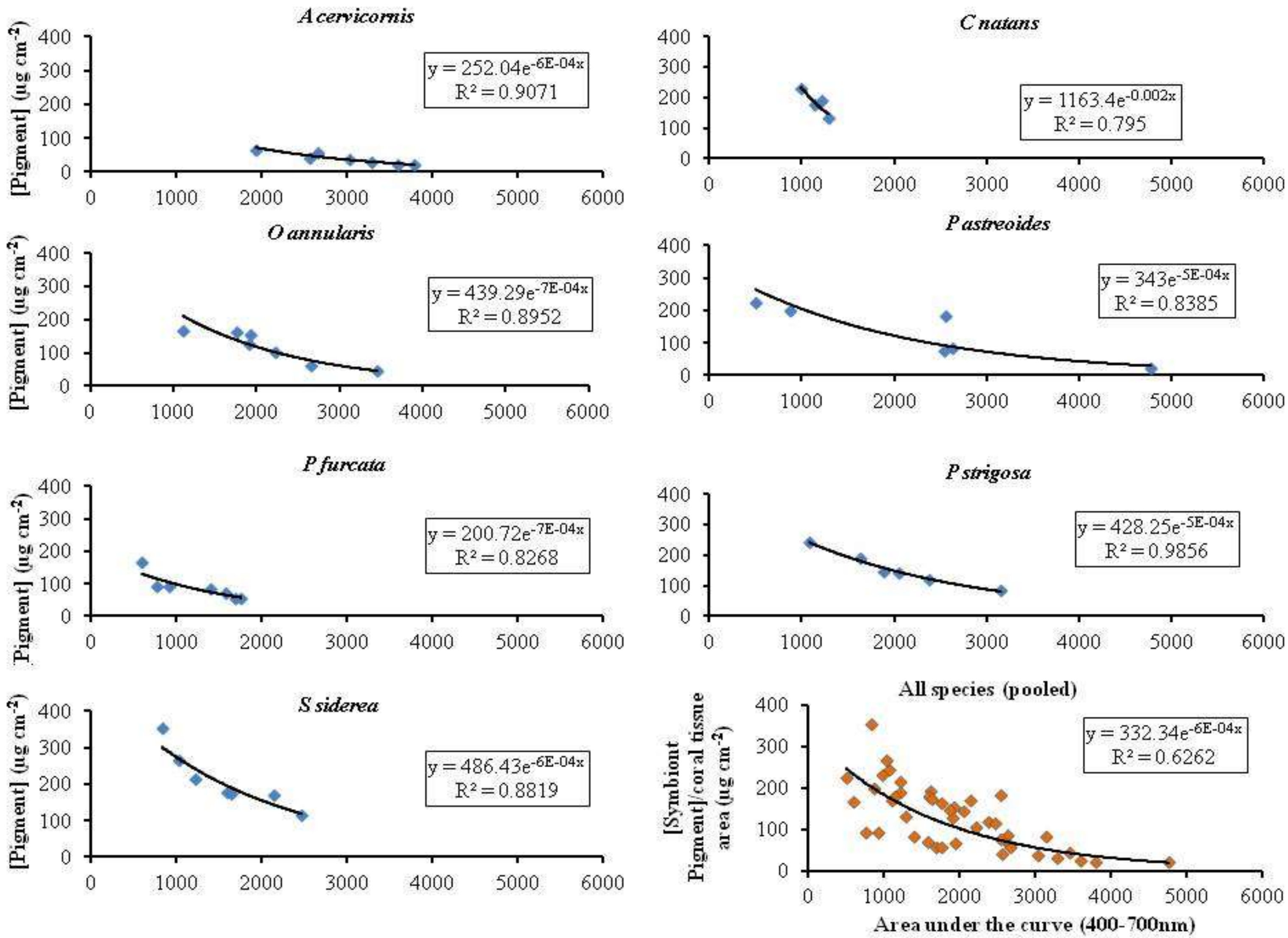
Torres-Pérez et al. 2015. PLoSONE

National Aeronautics and Space Administration

Ames

Discovery · Innovations · Solutions

Can we predict pigments concentration using the reflectance of the colony?



In summary…

- **Benthic components can be distinguished with their reflectance or absorption values; but to what extent, especially b/n coral species?**
- **In corals, zooxanthellae clades seem to rely on diff. pigment composition despite living at the same depth.**
  - Coral skeletal structure may influence the light regime available for the photosynthetic symbionts.
- **Area under the reflectance curve can be used to estimate the total concentration of pigments in corals.**
  - Provides an additional tool for studying bleaching conditions without the use of invasive techniques.
- **High spatial (images) & spectral (images & field data including chemical ID) resolution needed.**
  - Keep in mind that within an image pixel there might be X amounts of species from different taxa and other abiotic components.

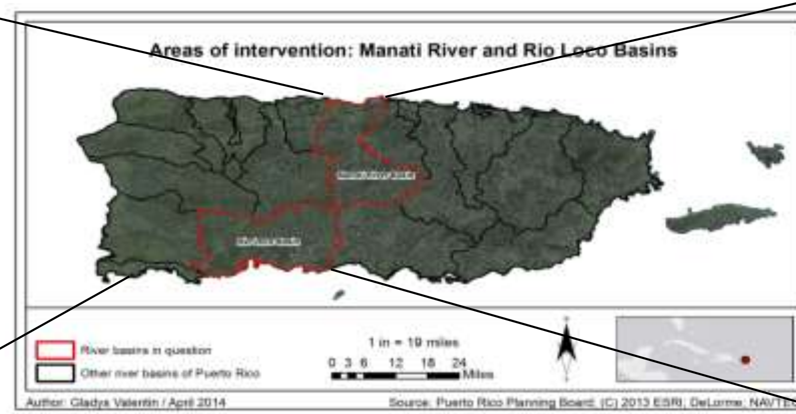
Human Impacts to Coastal Ecosystems in Puerto Rico (HICE-PR)

- **Interdisciplinary assessment of land use land cover changes (LULCC) in two priority watersheds in PR and the effects to associated ecosystems (coral reefs, beaches, mangroves, seagrass beds)**
  - Remote Sensing
  - Hydrological modeling
  - Ecological modeling
  - Socio-economic (ecosystem attributes valuation)
- **3-years (2014-2017)**
- **Involves the use of multiple remote sensing platforms/products including orthophotos, MODIS, VIIRS, Landsat imagery**
- **LCLUC analysis from 1930's to present**
- **Beach changes in north coast of PR**
- **Coral cover analysis to establish temporal changes at selected sites**

National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions



LCLUC in southwest PR (La Parguera)

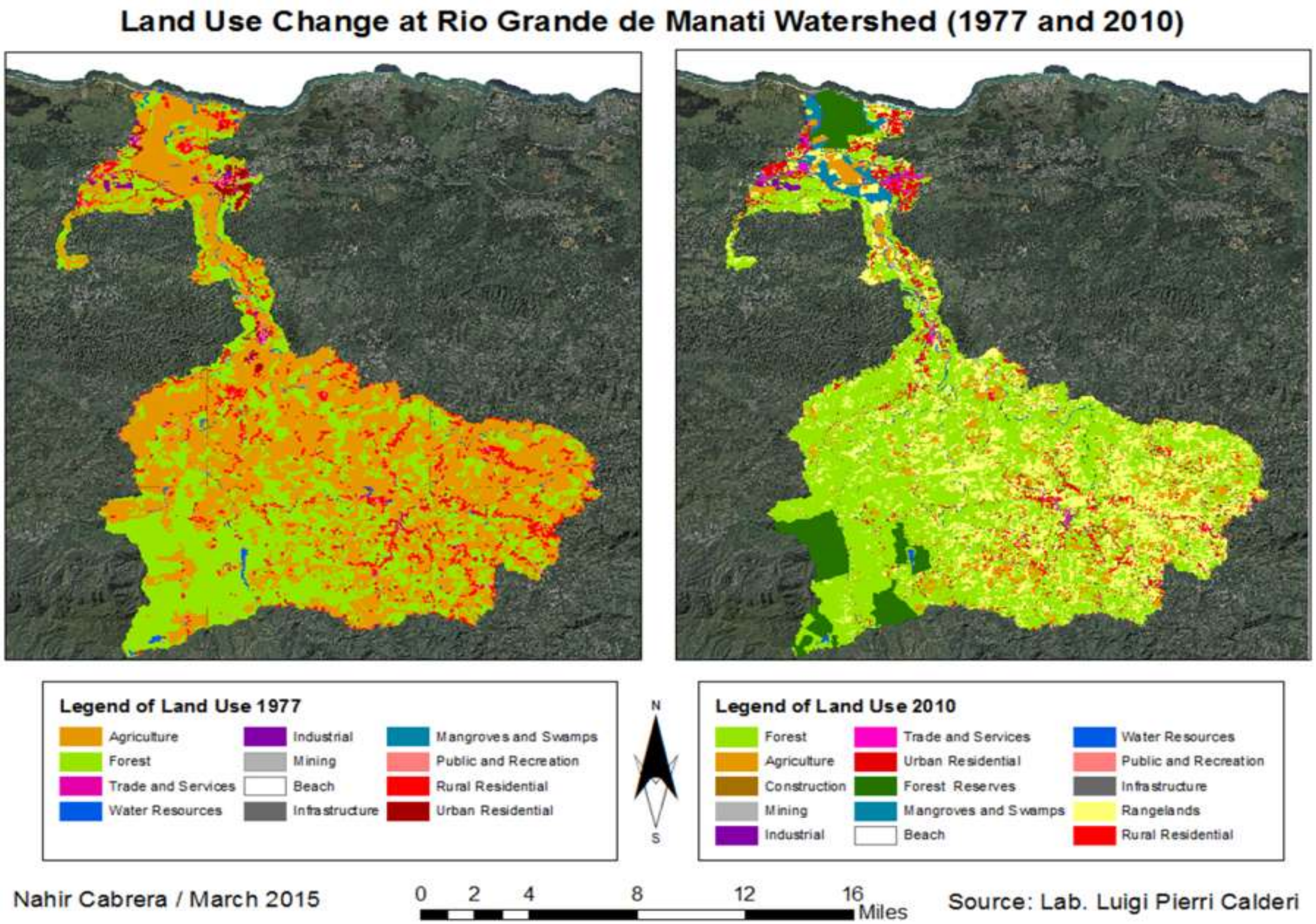

10/2004
Arrecife coral
Corona La Laja
Turrumote II

Present condition at La Parguera-Guánica

For back-reef areas (La Parguera and Guánica):

- Dominated by gorgonian plains
- Average hard coral cover: 0.02-30%, with most sites ~11% cover
- Significant cover of the encrusting sponge *Cliona*
- Some reef zones show ~40% macroalgal cover, mostly *Dyctiota*
- Dead coral colonies covered by turf or other algae: ~40% in most areas
- Ongoing 2nd Yr of reef characterization show minor coverage of bleached colonies, mostly Acroporids

LCLUC in the north coast (Manatí)

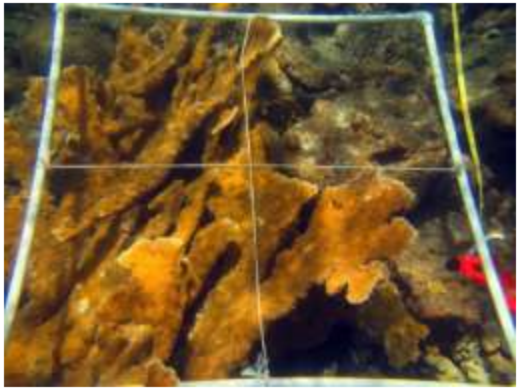
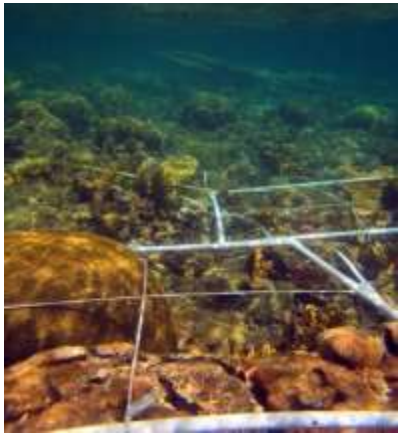



Machuca Beach
Tombolo Beach

Present condition at Tombolo Beach (Manatí)

Summary:

- **Relatively shallow depth (0-4m); high waves most of the year**
- **High hard coral cover: 28-60%; average = 35%**
- **Mostly dominated by *Acropora palmata* and *Pseudodiploria* sp. (*P. clivosa* and *P. strigosa*)**
- **Other species include *Orbicella annularis*, *Porites astreoides*, fire corals (*Millepora* sp.), and sea fans (*Gorgonia* sp.)**
- **High cover of turf algae on dead coral surfaces**
- **Extremely low % of diseased colonies, mostly gorgonians**

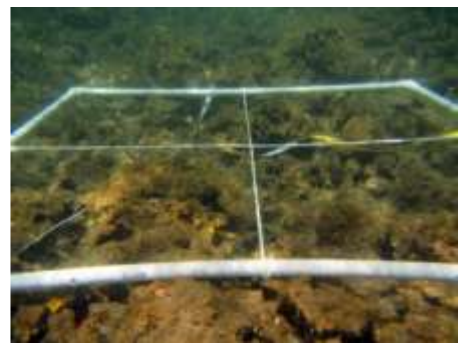



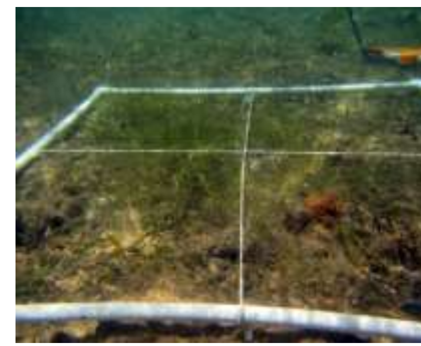


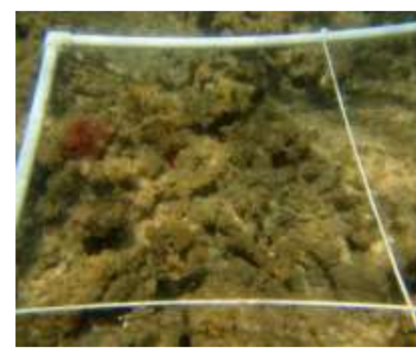
Present condition at Machuca Beach (Manatí)

Summary:

- **Very shallow site (<2m depth); high waves most of the year**
- **Close to the Río Grande de Manatí mouth**
- **Coral cover: <5%**
- **Site shows the structure of a relict or old reef (bioeroded dead coral colonies now covered by algae)**
- **Dominant algae: *Dictyota*, *Padina* and turf**







Contact Information

Dr. Juan Torres-Pérez
Telephone 650-604-0915
Building 245 Room 120
Mail Stop 245-4
Juan.l.torresperez@nasa.gov

Thank you!

Questions?