Coral Reef Colour:
In Situ and Remote Hyperspectral Sensing of
Reef Structure and Function

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Coral Reef Background

Importance

- Traditional Culture & Food
- Shoreline Protection
- $Multibillion Recreation Industry
- Major Locus of Global Biodiversity

Coral reefs do not influence the short-term global carbon cycle, but...

Concern

...they are among the first ecosystems to respond critically and dramatically to climate change.

Climate change may exacerbate local impacts, leading to reef degradation worldwide.
All reef assessments are based on extremely sparse in situ data, collected using non-uniform methods.

The primary metric for reef condition is proportional cover of benthic types, especially coral, but values have not been standardized across reefs.
Global Coral Reef Distribution

- 9,000 reefs in the world, covering 500,000 km²
- Spread across 200,000,000 km² of ocean
- Quantitative in situ surveys cover only 10s to 100s of km² worldwide
- Only 0.01–0.1% of the world’s reef area

Remote sensing is the only available tool to acquire synoptic, uniform data on reef condition at regional to global scales
In-Water Spectral Measurements

1990s: 30-m-long fiber, spectrometer on boat

2000s: Spectrometer in underwater housing

Hochberg et al. (2003)
Spectral Discrimination

The coral reflectance spectrum is driven by zooxanthellae pigments.

It is possible to invert coral reflectance to derive pigment concentrations.

Hochberg et al. (2003)

Hochberg et al. (2006)
Coral Pigment Phenology

- Temperature increases from winter through summer
- Insolation increases from winter through summer
- Chlorophyll $a$ generally decreases from winter through summer
- No very obvious relationships

- Changes in chl $a$ occur both after and before changes in the environmental variables.
- The strength, direction, and lag of the correlations all vary with season.
• Coral species cannot be spectrally discriminated
• Diversity of optical types may be correlated to diversity of species types
Near Spectral Imaging

Brandon Russell & Heidi Dierssen

Caras & Karnieli (2015)
Remote Spectral Imaging

Leiper et al. (2014)

Goodman & Ustin (2007)
Gao et al. (2007): Combined wavebands across NIR/SWIR (0.865, 1.04, 1.24, 1.64, and 2.25 µm) provide very good atmosphere correction.

Lee & Carder (2002), Lee et al. (2007): Contiguous, 10-nm-wide wavebands over range 400–800 nm is excellent band set for retrieval of shallow water bathymetry.
Primary production is a function of light absorption

$$P = \text{LUE} \times A \times \text{PAR}$$

Light-use efficiency is primary production normalized by light absorption

$$\text{LUE} = \frac{P}{A \times \text{PAR}}$$

• Functional Convergence Hypothesis: Natural selection should produce plants that optimize resource allocation relative to photosynthetic capacity, thus maximizing carbon gain
  ➔ With the same resource limitations, different plants should have the same LUE

• LUE should scale with $A$, making it possible to estimate LUE with optical measurements ➔ remote sensing
Existing survey data (US Caribbean, Hawaii, Great Barrier Reef) do not follow expected trends with respect to biogeophysical forcing parameters.

Either our understanding of reefs is incorrect, or our data have insufficient density and/or (more likely) scale.
CORAL: COral Reef Airborne Laboratory  
Eric J Hochberg

**PRISM L1, L3 and L4 Products for Reef Condition**

**Benthic Reflectance Cal/Val**

- coral
- phaeophyte
- chlorophyte
- rhodophyte
- coralline algae
- turf algae

**Water IOP/AOP Cal/Val**

- Reflectance vs. Wavelength (nm)
- Absorption coefficient ($a$) vs. Wavelength (nm)
- Scattering coefficient ($K_d$) vs. Wavelength (nm)

**Threshold and Baseline Investigation Regions**

- Map of coral reef regions with threshold and baseline investigation sites marked.
• Satellite remote sensing of coral reefs actually predates CZCS
• As of early 2015, coral reef remote sensing remains developmental: only a long series of one-off studies, no standard algorithms, no large-scale programs
• June 2015 marks the pivot to operational: CORAL
• High-spatial-resolution spectral imaging satellites are coming: Sentinel-2, EnMAP, PRISMA, HyspIRI
• Standard algorithms are now a requirement
• Spectral imagery is a fundamental requirement
• Reef change is slow (except with major acute disturbances), so seasonal to yearly observations
• Algorithms will not be perfect, and they may initially provide a limited set of products (benthic cover, bathymetry)
• Algorithms will improve and include more products (e.g., pigments) over time
• This is the “CZCS phase” of coral reef remote sensing — fortunately ocean colour provides an excellent model to follow
• Regional to global data products will open new science inquiries and will become a major asset to resource management