Coral Reef Restoration

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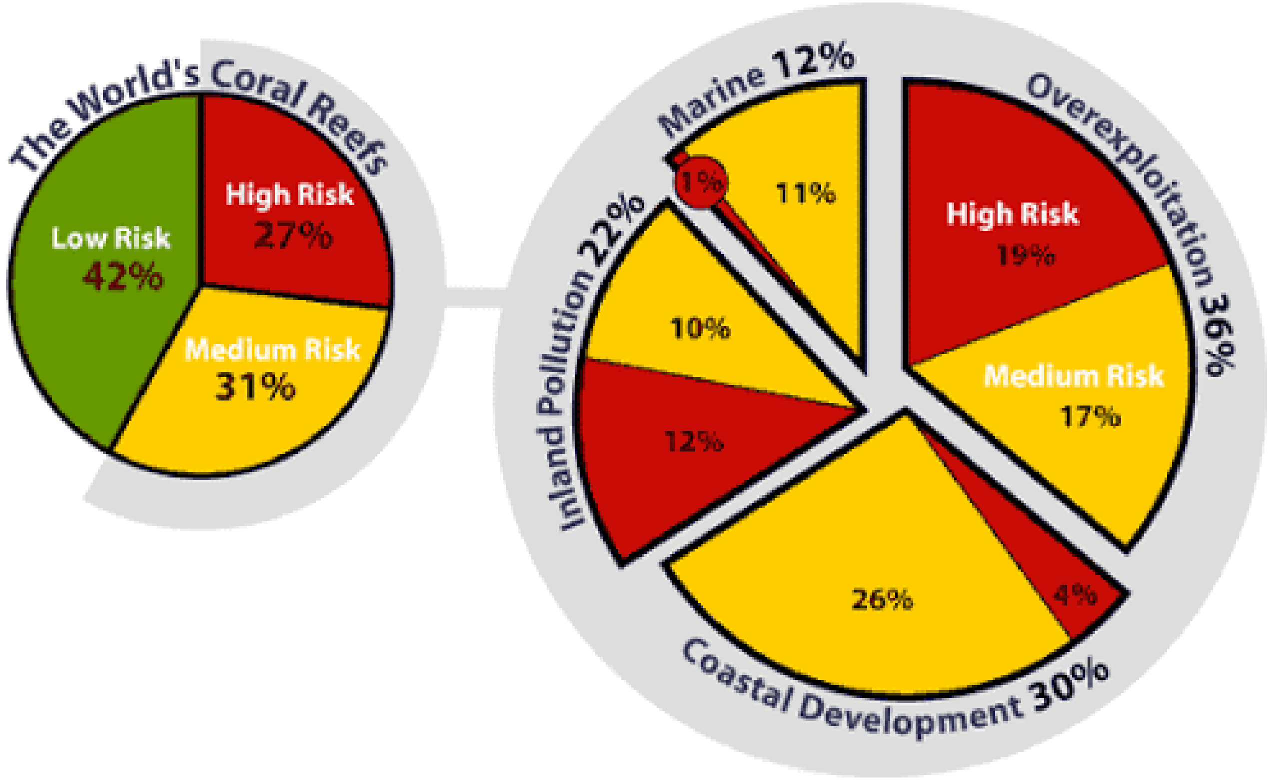
https://storymaps.arcgis.com/stories/8274639a09ed449ab4433d304b83271a

Introduction

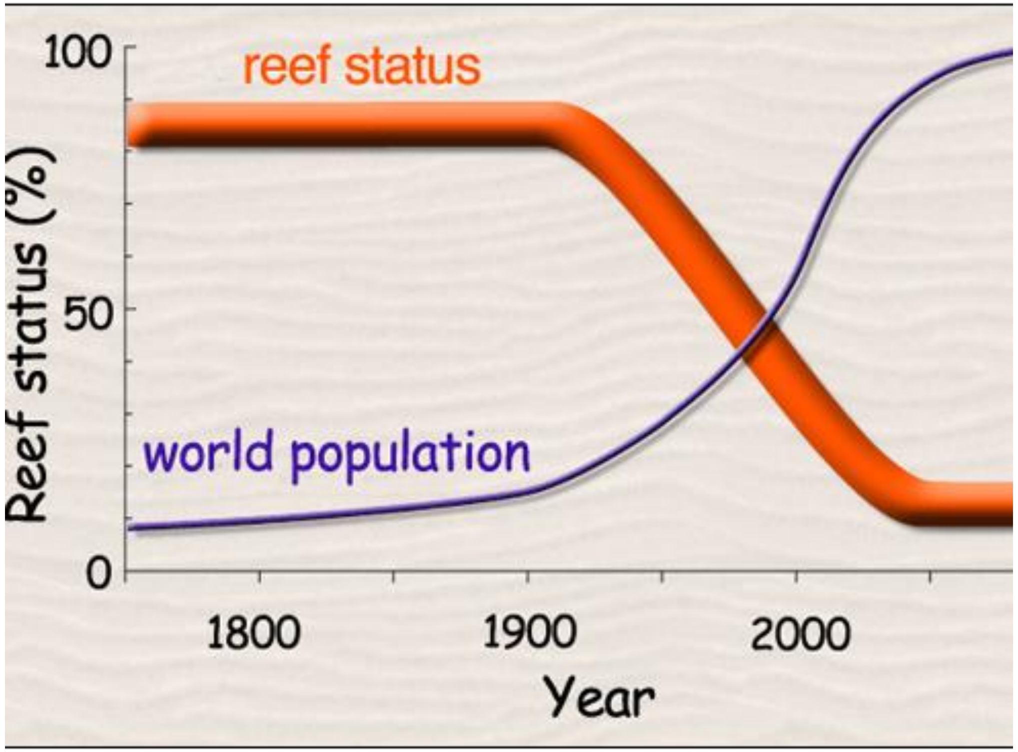
- Decrease in coral reef health
  - Hoegh-Guldberg et al. 2007; Hughes et al. 2017
- 0.1% of Earth's surface, over 30% marine biodiversity
  - Reaka-Kudla 2005



http://www.cotf.edu/ete/modules/coralreef/CRanthro.html

Introduction

- Provide various crucial ecological services:
  - Protein and shoreline protection
    - Burke & Maidens 2004; de Groot et al. 20; Ferrario et al. 2014
- Past 50 years, world's coral reefs have been decimated
  - Caribbean reefs lost about 80% of coral cover
    - Jackson et al. 2014



http://www.virtualcoralreefdive.com/peril.php

Introduction

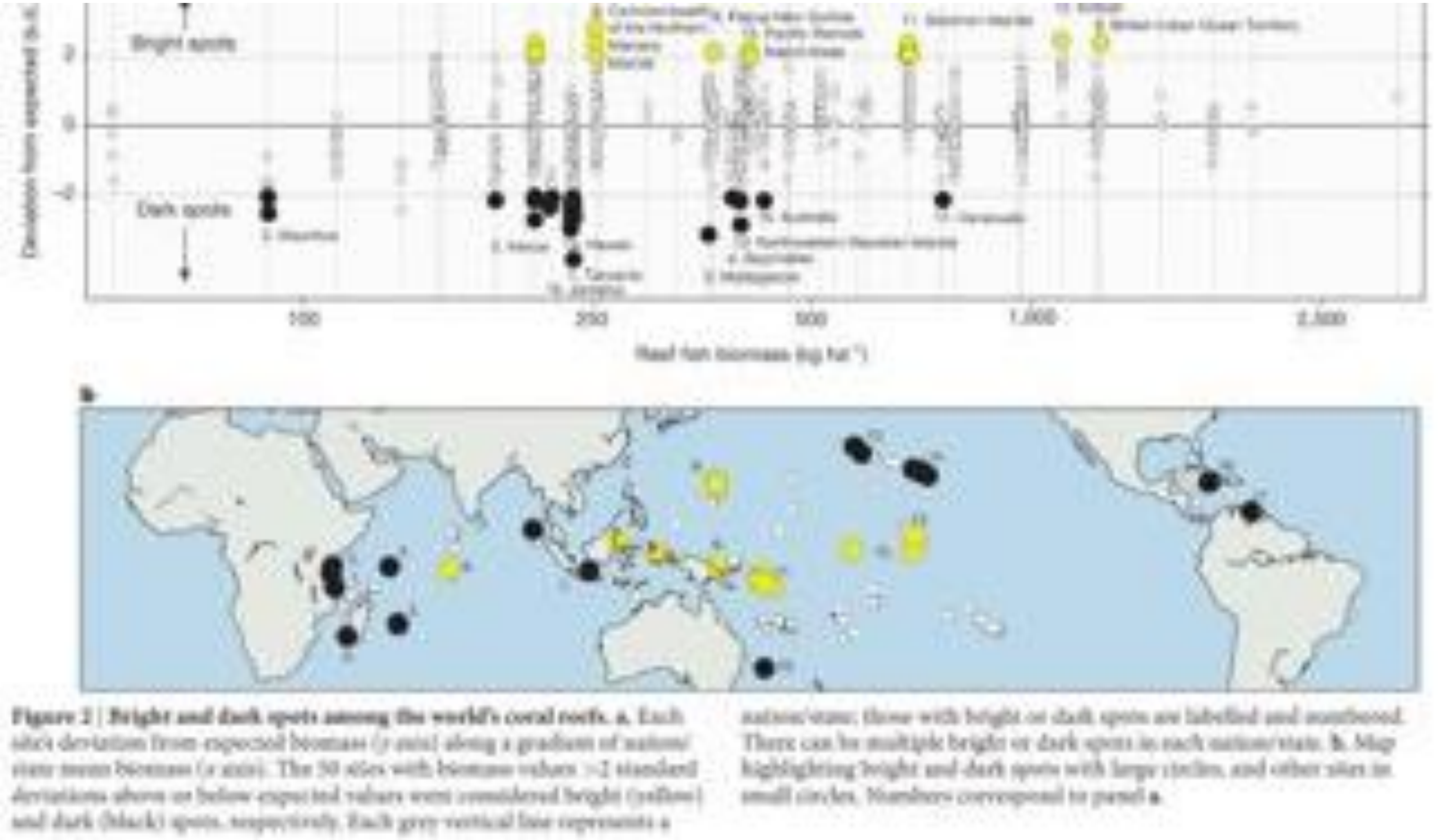
- <u>Local Threats:</u>
- Overfishing
  - Smith et. al, 2016
- Deforestation, sedimentation
  - Smith et. al, 2016
- Coastal development
- Pollution
  - Zaneveld et al. 2016; Hughes et al. 2018

https://www.independent.co.uk/environment/plastic-pollution-coral-reefs-disease-damage-seas-oceans-cornell-university-a8178156.html

Introduction

- <u>Global Threats:</u>
- Ocean acidification
- Climate change
  - Zaneveld et al. 2016; Hughes et al. 2018

https://www.iucn.org/theme/marine-and-polar/our-work/climate-change-and-ocean/ocean-acidification https://twitter.com/trevorabranch/status/743320235655102464



Introduction

- Various factors affect reef health:
  - Reef location
  - Human and environmental impacts
- Health determined through multiple methods:
  - Bright spots (healthy)
  - Dark spots (unhealthy)
    - Cinner et. al, 2016

https://listverse.com/2007/08/30/top-10-densely-populated-nations/

Introduction

- Distinguish healthy vs. unhealthy - compare human activity and impact:
  - Highly populated areas = unhealthy reef
  - Low population areas = healthy reef
    - Smith et. al, 2016

https://www.worldatlas.com/articles/the-10-least-densely-populated-places-in-the-world-2015.html https://www.climatechangenews.com/2015/10/08/warming-seas-devastate-coral-reefs-in-global-bleaching-event/

Introduction

- Climate change: major threat
  - Hughes et. al, 2018
- Higher temperatures = higher mortality rates
- Heatwaves inflict irreversible damage
  - Hughes et. al, 2018
- Millions of people rely on coral for livelihood
  - Foo et. al, 2019

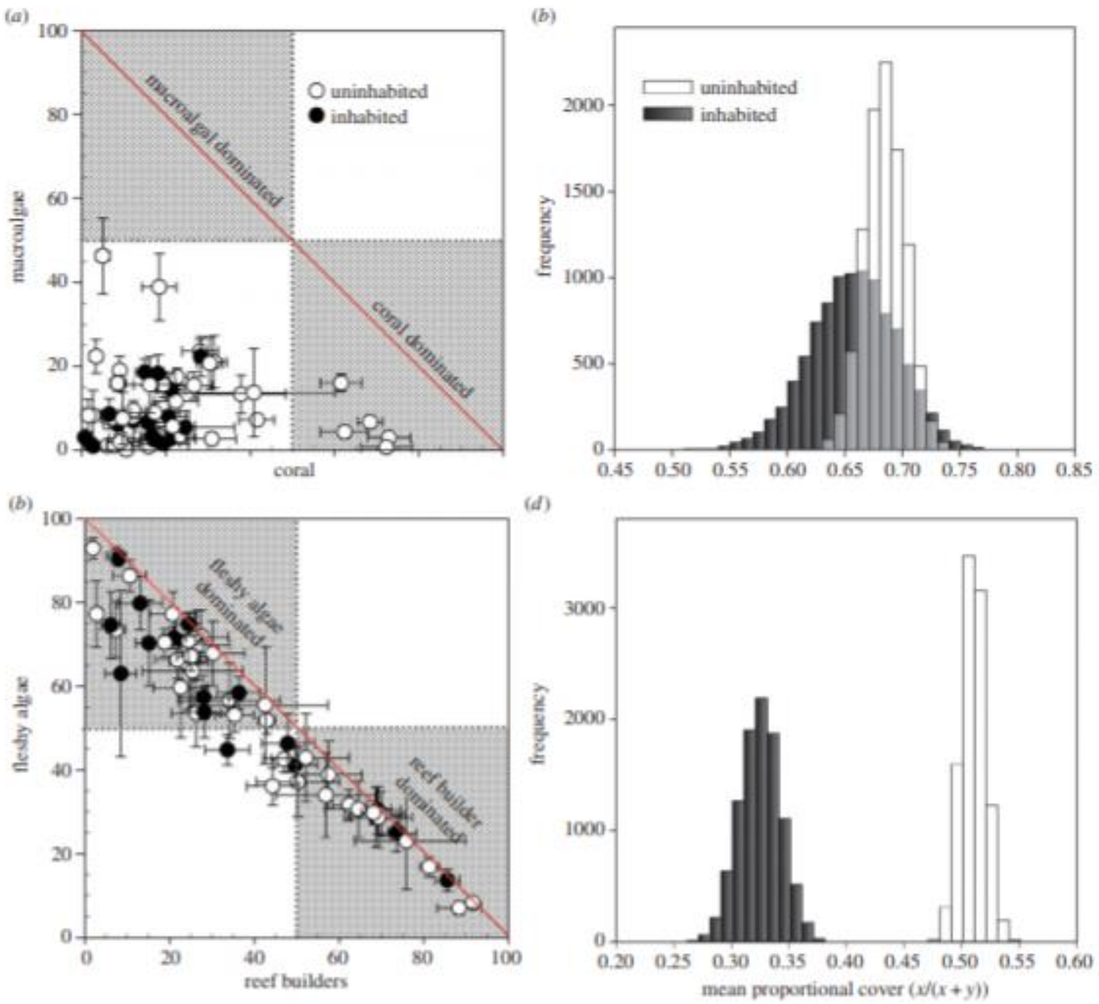
Introduction

http://www.globalcoral.org/biorock-electric-reef-restoration-projects-to-start-in-india/

- Restoration successful in rehabilitating populations
  - Foo et. al, 2019
- Methods: plant nursery corals on weakened reefs
  - Young et al. 2012
- Improve species crucial to reef health and maintenance
  - Ladd et. al, 2019
- Recovery by helping communities that provide important ecological services:
  - Herbivory
- Mixture of various methods (steel frames, concrete reef balls, transplantation, etc.) could be most effective
  - Hein et. al

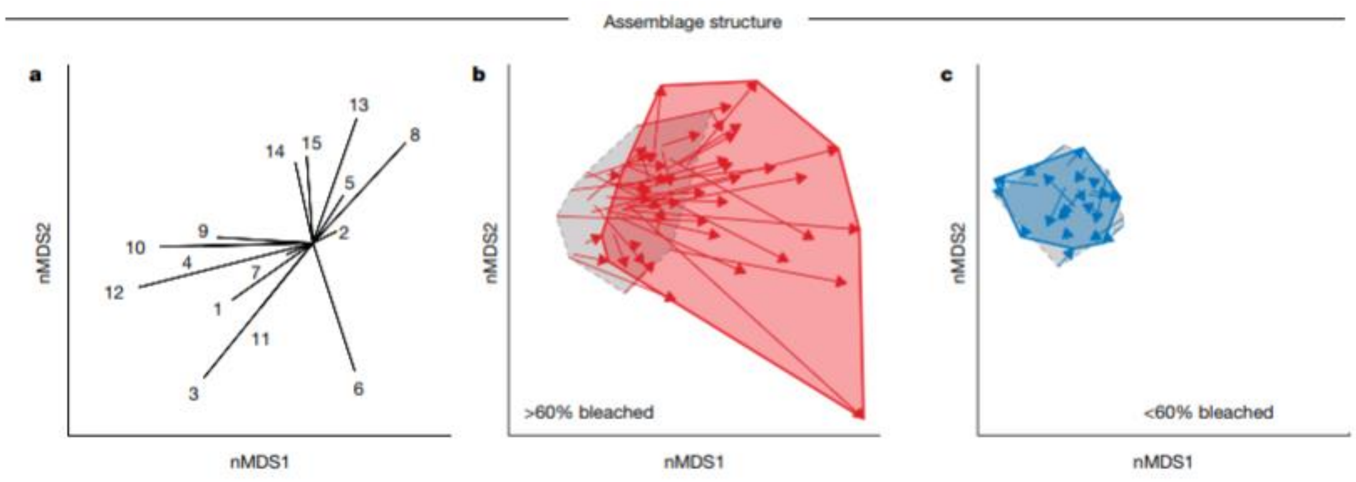
Literature Review

- Smith et. al, 2016
  - **Evaluating the health of coral reefs and how human impacts affect them**
    - **Findings:**
      - Majority of reefs on inhabited islands dominated by fleshy, non reef-building organisms
        - Turf algae
        - Fleshy macroalgae
        - Non-calcifying invertebrates
      - Benthic communities from uninhabited islands more variable and supported more calcifying organisms and active reef builders
        - Stony corals
        - Crustose coralline algae
      - Results suggest cumulative human impacts across the central Pacific causing reduction in abundance of reef builders, resulting in phase shifts to dominance by fleshy organisms

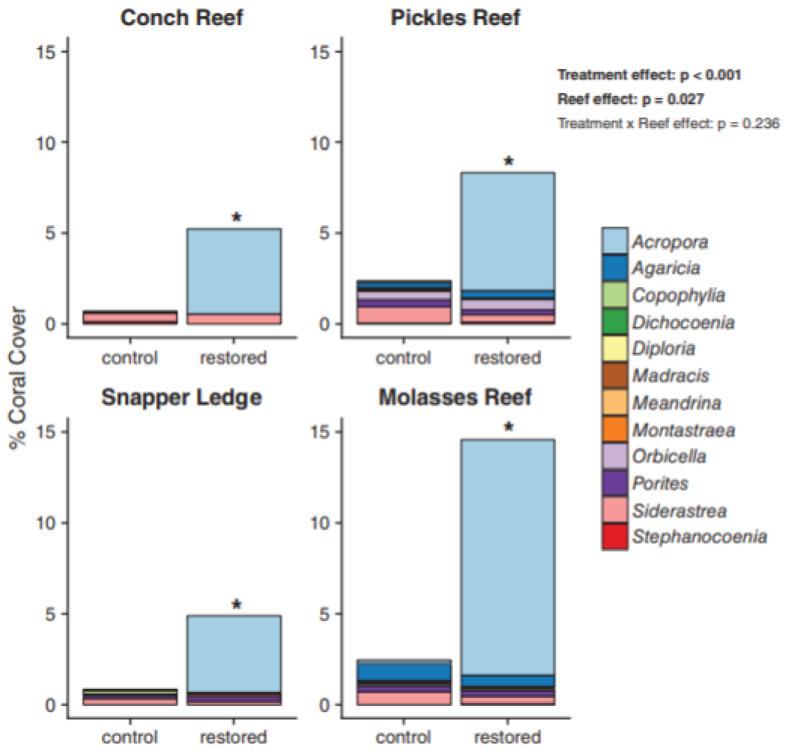


Literature Review

- ➢ Hughes et. al, 2018
  - ➢ **Global warming transforms groups of coral reefs**
    - ➢ **Leads to increased bleaching**

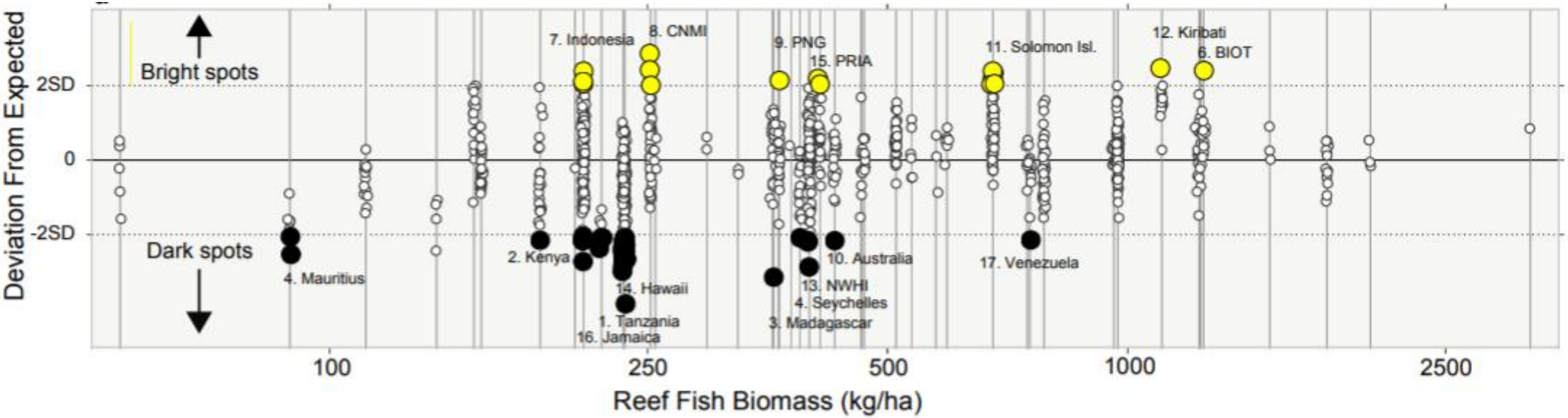


- Ø Ladd et. al, 2019
  - Ø **Impacts of coral restoration on ecological and community structure in reefs**
    - Ø **Diversity**
    - Ø **Community Structure**
    - Ø **Ecological Processes**



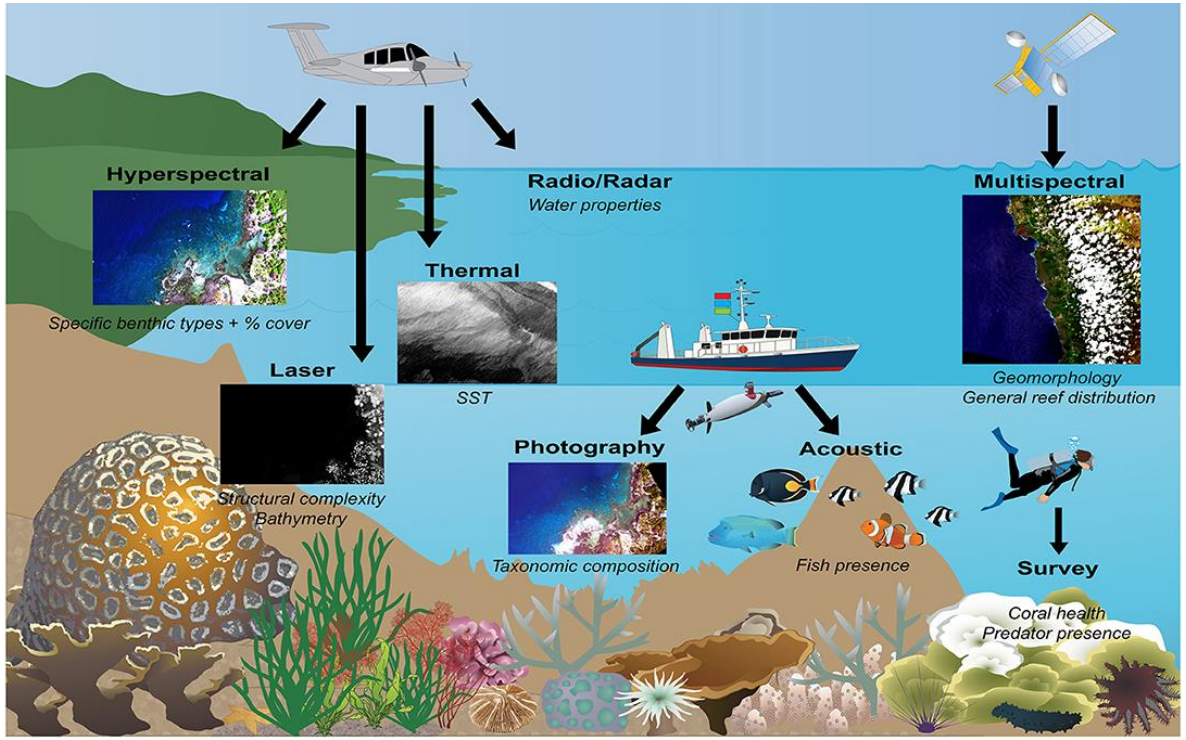
Literature Review

- Ø Cinner et. al, 2016
  - Ø**Bright spots can determine reef health**



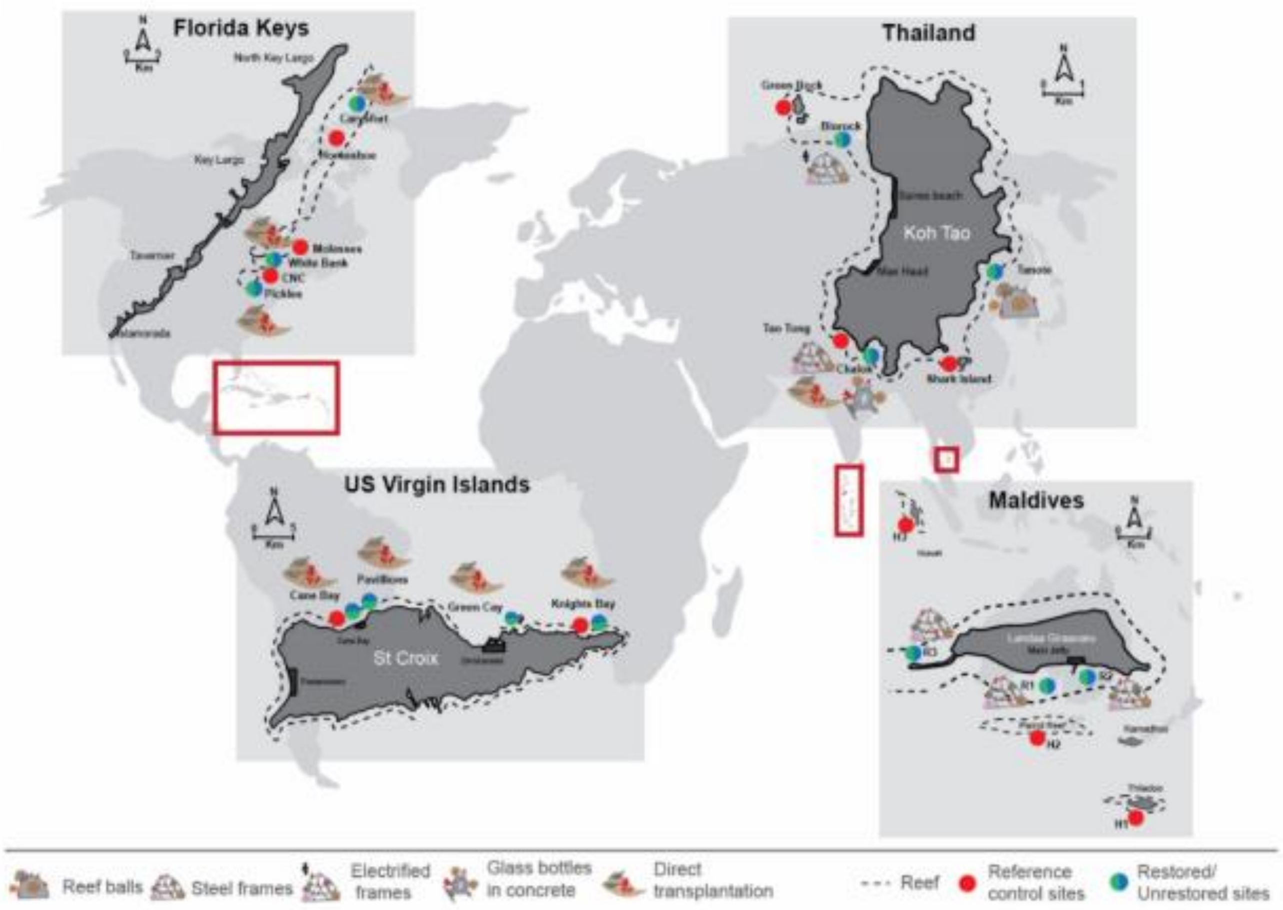
Literature Review

- ØFoo et. al, 2019
  - Ø **Improving coral reef restoration through remote sensing technology**
    - Ø is a need for baseline data on
      - Ø Need for baseline data on global reef
      - Ø Distribution,
        - Ø Composition
        - Ø Condition
      - Ø Provide targets for conservation and restoration



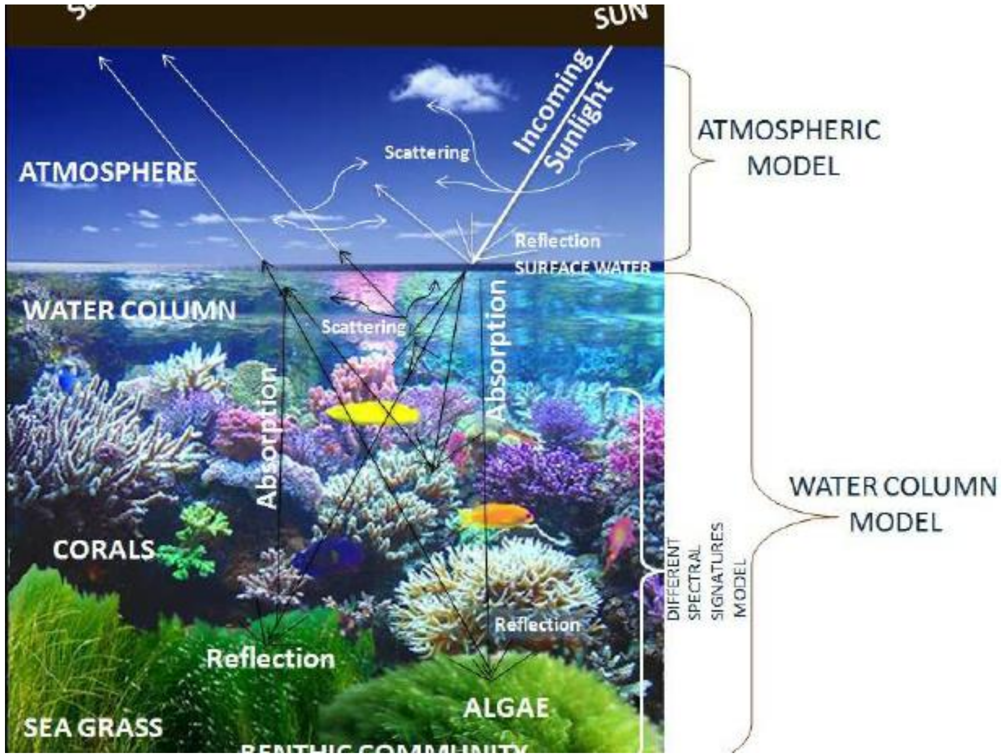
Literature Review

- Hein et. Al, 2020
  - **Coral restoration effectiveness on a long-term scale**
    - **Mixed-methods coral restoration techniques most effective based on site analysis**



Gap in the Research

- No research has utilized remote sensing data to track
  - Coral health
  - Coral species identification
  - Regional ecosystem health
  - Predator abundance
  - Design mitigation strategies uniquely based on data analysis

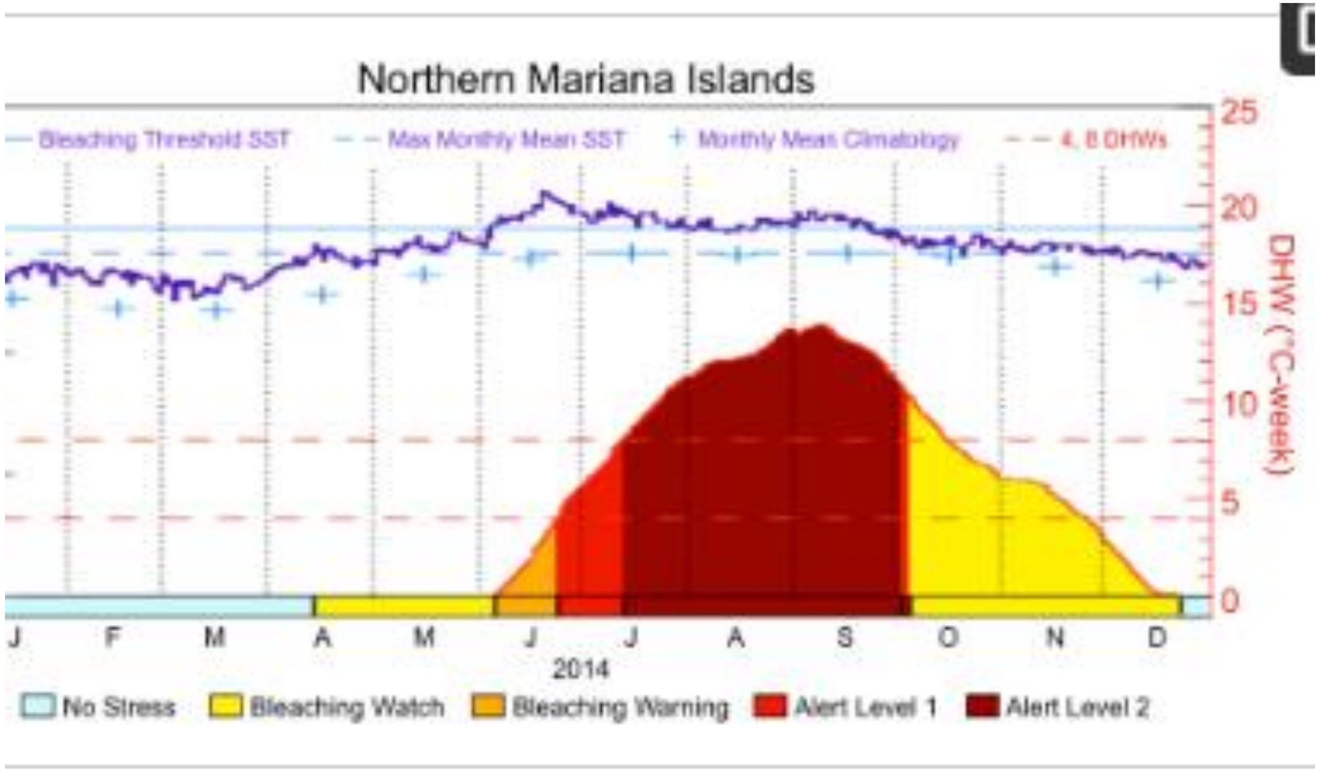


https://www.researchgate.net/figure/Components-of-Remote-Sensing-in-mapping-coral-reefs_fig1_272293192

Statement of Purpose

- To design global database that uses remote sensing (RS) data to track
  - Coral health
  - Coral species identification
  - Regional ecosystem health
  - Predator abundance
- Utilize data analysis to design mitigation strategies for unique restoration techniques

Methodology



https://www.mdpi.com/2072-4292/8/1/59/htm

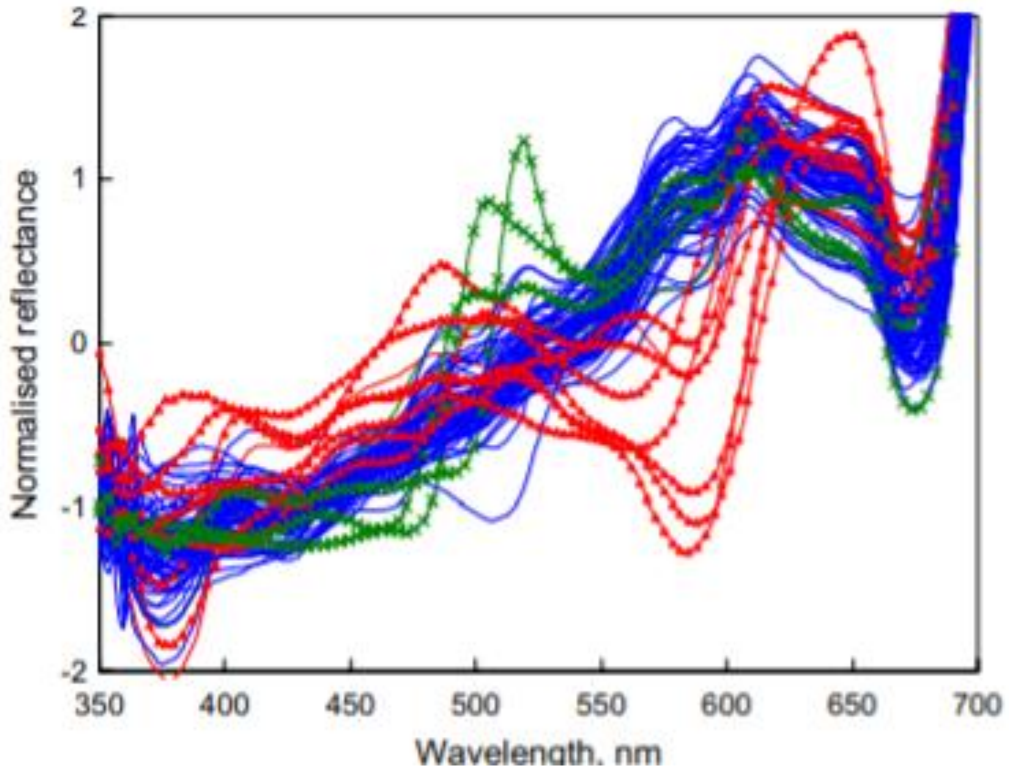
Remote Sensing (RS) Data - Coral Health:

- Thermal stress satellites monitor coral bleaching
- Two new monitoring products: Regional Virtual Stations and Seven-day Sea Surface Temperature (SST) Trend
- Regional Virtual Stations consists of a regional synthesis of thermal stress conditions
- SST Trend describes recent changes in temperature at each observed location

Methodology

Remote Sensing (RS) Data - Coral Species Identification:

- Spectral Angle Mapper mixed with an *in situ* spectral library can recognize corals correctly
- Still uncommon to identify hard corals at species level
- Hyperspectral sensing can be used to identify specific species
- Visual observation of coral spectra and clustering analyses suggest it's possible to separate 3 main coral colors: blue, green, and brown
- Could create an optical foundation for RS rather than traditional taxonomy

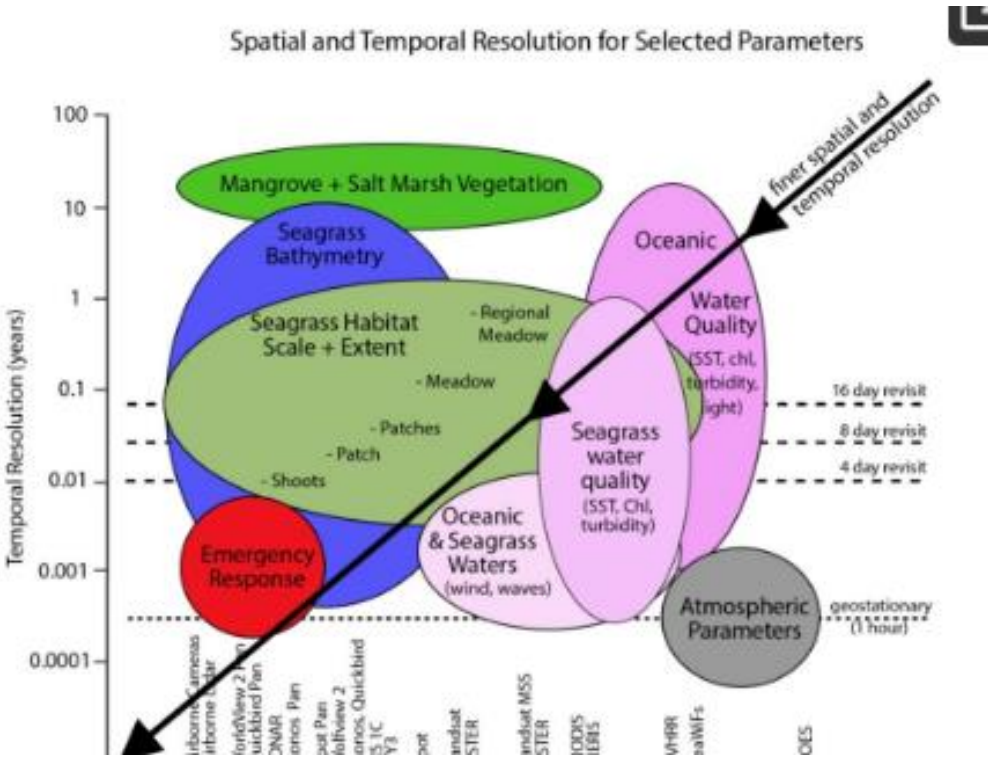


https://www.sciencedirect.com/science/article/abs/pii/S0272771406002289

Methodology

Remote Sensing (RS) Data - Regional Ecosystem Health:

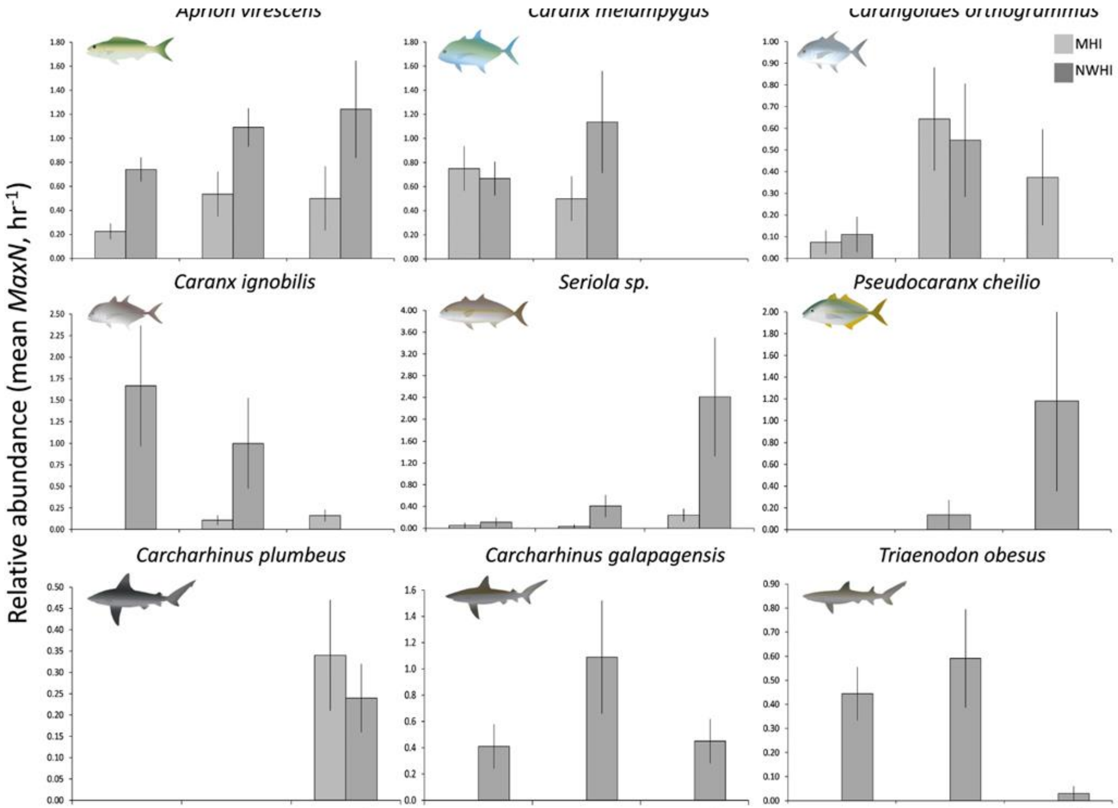
- Optical passive RS maps habitats
- Habitat/benthic type mapping requires highest level of data and technology
- RS most cost effective for reef mapping
- Satellite RS can assess reef environment and map locations, but still difficult to determine reef health



Methodology

Remote Sensing (RS) Data-Predator Abundance:

- Match appropriate RS observations to species distribution with a multi-scale approach
- Aerial and/or ship surveys, GPS tagging, and RS data can help identify species and possible feeding habits
- Use higher sampling frequencies and spatial resolutions to observe benthic communities, harmful algal blooms, feeding/spawning events, etc.
- Sea turtles, sharks, and marine mammals directly observed with very high resolution images

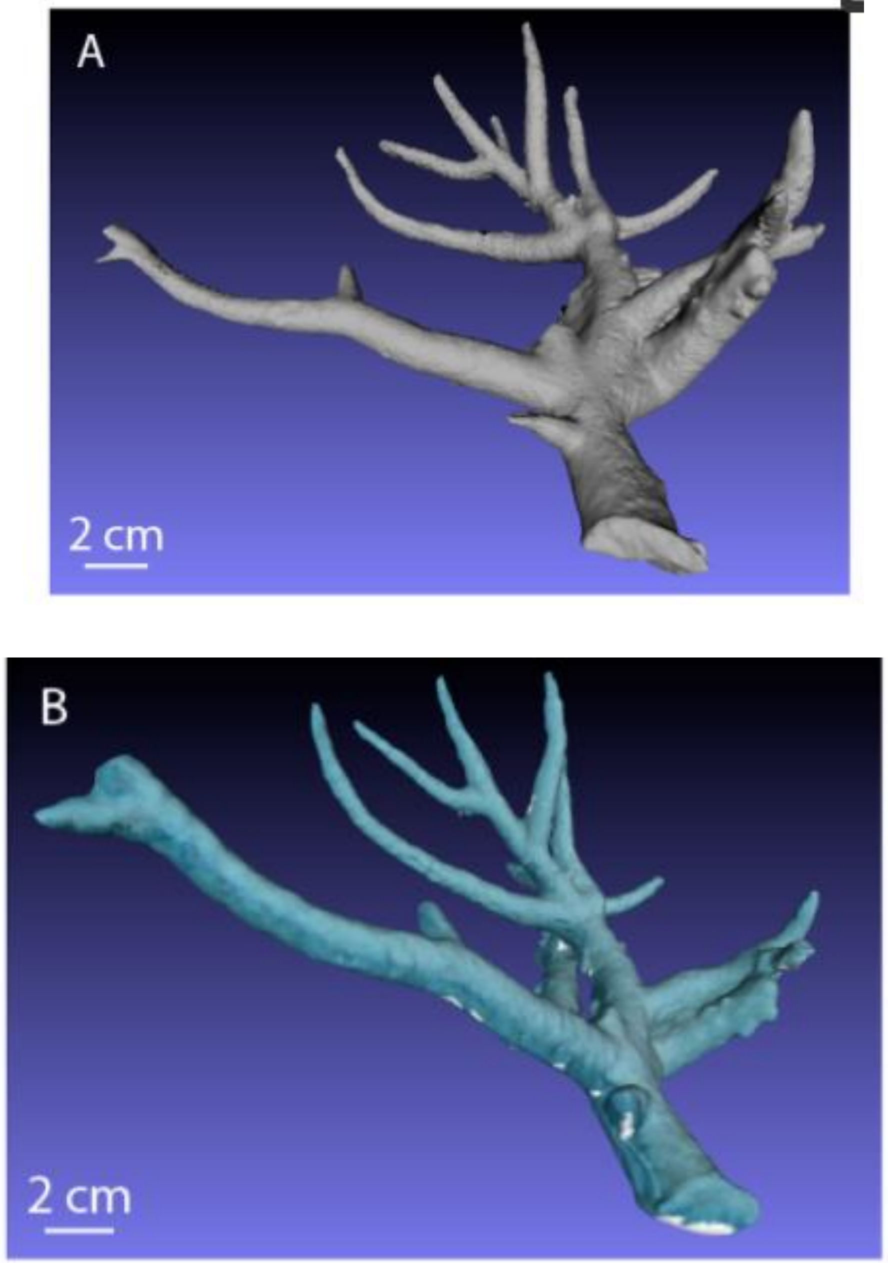


https://origin-apps-pifsc.fisheries.noaa.gov/news/where_the_wild_things_are-camera_fishing_for_predators_in_hard-to-reach-places.php

Methodology

Data Analysis of Remote Sensing Data:

- LiDAR is highly accurate for mapping reef bathymetry
- Process the RS images using an implicit surface reconstruction algorithm
- Take images from various viewpoints and fuse them together to create a 3D model



Methodology

Mitigation Strategies for Coral Restoration:

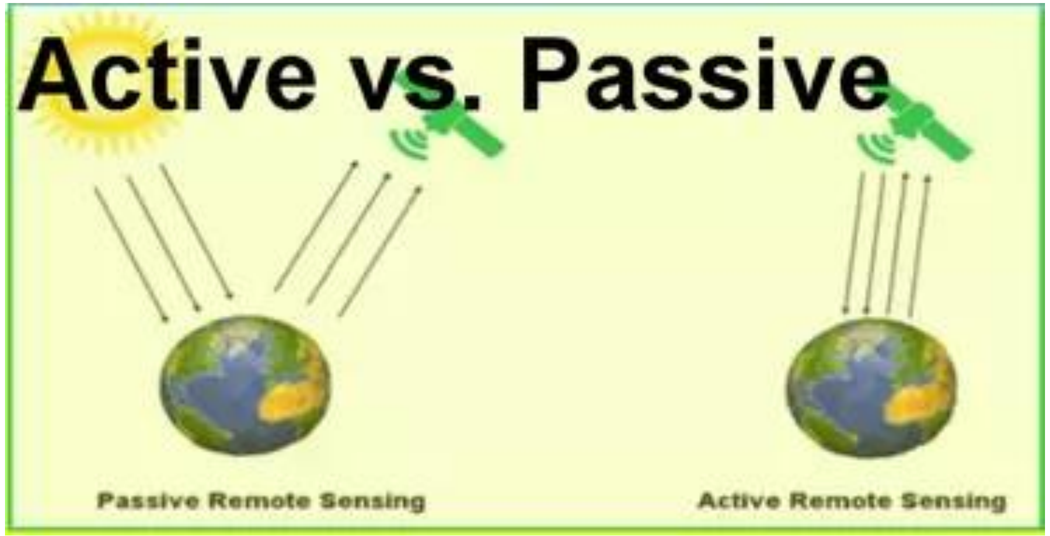
- Coral restoration aims to reduce severity of local and global threats to reefs
- Providing compensatory mitigation for environmental impacts is vital in restoring species and overall ecosystems
- Most restoration programs take direct intervention to rehabilitate coral species
- Transplantation, fragmentation, use of coral nurseries, reef mapping, etc. all crucial aspects of restoration efforts

https://dlnr.hawaii.gov/coralreefs/mitigation-bank/

Methodology

Mixed methods:

- Two types: Passive and Active
- Passive: Relies on reflected sunlight or emitted heat, includes photographic, multispectral, hyperspectral, and infrared imaging
- Active: Records a return signal from an emitted source, includes lasar-, radar-, radio-based settings, and scanning approaches
- Best time to acquire data is the summer (months w/ highest sun angles and longest days)



https://grindgis.com/remote-sensing/active-and-passive-remote-sensing

Methodology

Reef restoration criteria paired with the most appropriate remote sensing technology								
Platform	**Satellite**	**Airborne**				**Boat or ROV**		**Diver operated**
Sensor	Multispectral	Hyperspectral	Laser	Thermal	Radio/Radar	Acoustic	Photography	Photography or visual survey
General outplanting parameter	Geomorphology; General reef distribution	Specific benthic types	Structural complexity; Bathymetry	Sea surface temperature	Water properties	Fish presence	Taxonomic composition	Coral health; Predator presence
Outplanting criteria addressed	Protection status; Reef site selection	Site selection; Existing wild populations; Size of the area; Bottom/substrate type and stability; Human activity and impact; Far from land-based pollution; How much to outplant/space to expand; Site accessibility; Reef connectivity; Macroalgal cover; Sufficient light for species and its productivity	Depth; Spurs and grooves to reduce predator migration	Sea surface temperature; Temperature and fluctuations	Water quality; Sedimentation loads; Flow regime/wave exposure	Fish presence; Predator presence	Space competitors such as encrusting sponges; Crustose coralline algae cover	Coral bleaching; Coral disease; Origin of parent colonies; Presence of *diadema*

Criteria considered by restoration practitioners are assigned to general outplanting categories and paired with the platform and sensing technology best suited and developed, or needed, to measure that criterium at the appropriate resolution required. The information from this table is visualized in ***Figure 1****.*

Previous Results

- Last 20 years, RS has become much more advanced and developed
- Past results indicate ability of RS to map reef structure and habitat composition
- Previous studies have neglected to consider physical environment of reefs
- Few studies have tried to directly map reef health or status
- Remote sensing has been modeled to determine bleaching events

Previous Results

Status of remote sensing coral reefs

Platform	Boat		Aircraft			Satellite				
Sensor type	Acoustic	Laser	Laser	Hyperspectral	Photographic film	Hyperspectral	Multispsectral (high resol.)	Multispectral (med resol.)	Radiometer	Multispectral (low resol.)
Example of sensor	RoxAnn	FILLS	Lidar, LADS	AVIRIS, CASI, ATM	SLR camera	Hyperion	Ikonos, Quickbird	Landsat TM, SPOT, IRS	AVHRR, ATSR, GOES	SeaWiFS, MODIS, OCM
Coral species										
Coral & algal cover		?	?	? ✓		?				
Reef community (>5 classes)	? ✓	?	? ✓	✓	✓	?	? ✓			
Occurrence of bleaching		?	?	?	? ✓	?	?			
Structural complexity (rugosity)	✓		?	?	?		?			
Reef geomorphology	✓		✓	✓	✓	?	✓	✓		
Location of shallow reefal areas	✓		✓	✓	✓	?	✓	✓	?	? ✓
Reef community (<5 classes)	✓	✓	✓	✓	✓	?	✓	✓		
Bathymetry	✓		✓	✓	? ✓	?	✓	✓		? ✓
Coastal land use (& change)			✓	✓	✓	✓	✓	✓	✓	

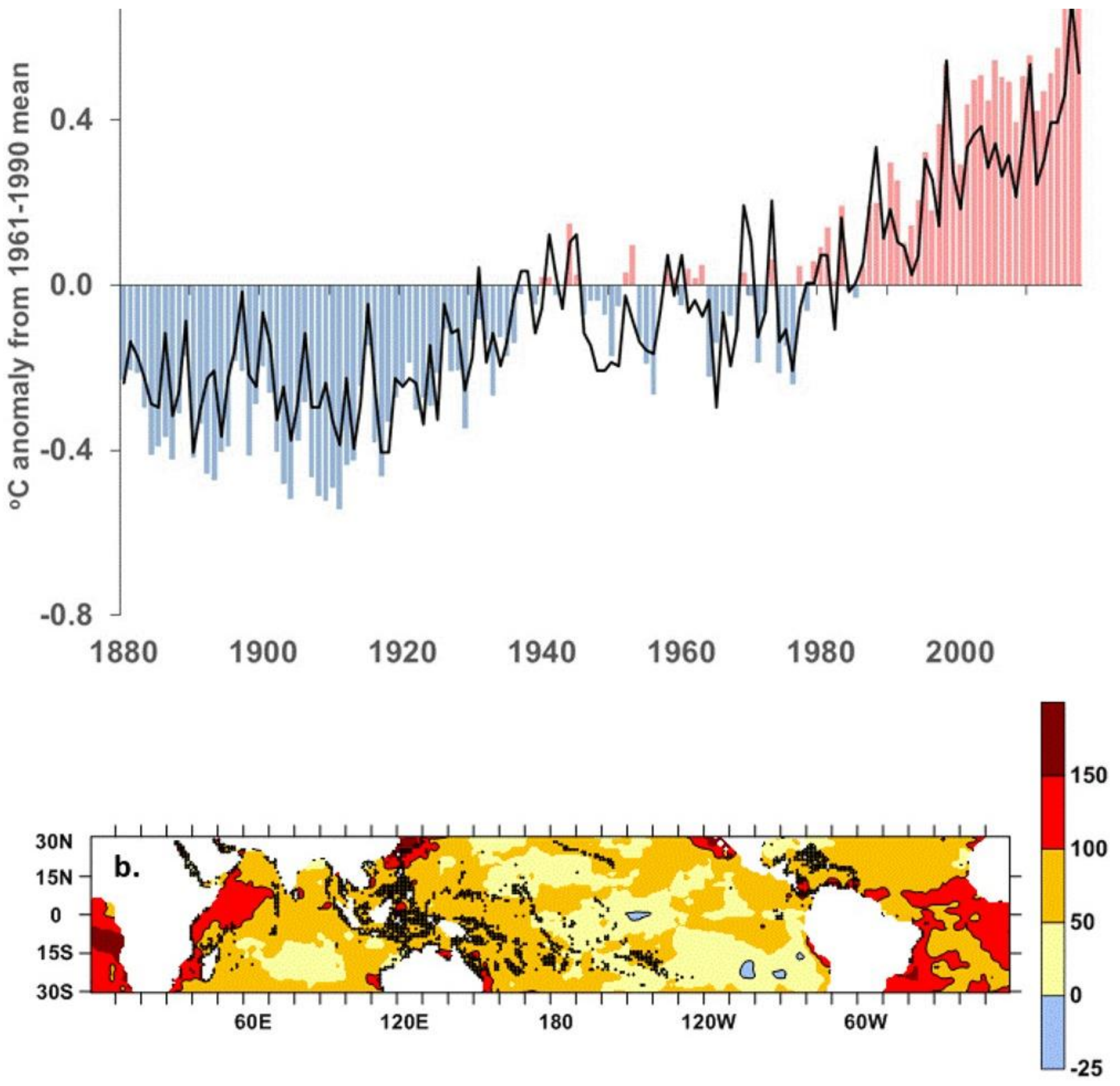
✓ indicates routinely possible; ? ✓ indicates demonstrated in limited cases only; ? indicates untested but we believe it to be possible; blank indicates not possible (at this time).
LADS = Laser Airborne Depth Sounder, AVIRIS = Airborne Visible/Infrared Imaging Spectrometer, CASI = Compact Airborne Spectrographic Imager, ATM = Airborne Thematic Mapper, SLR = Single Lens Reflex, TM = Thematic Mapper, SPOT = Systeme Probatoire de l'Observations de la Terre, IRS = Indian Remote Sensing Satellite, AVHRR = Advanced Very High Resolution Radiometer, GOES = Geostationary Operational Environmental Satellite, SeaWiFS = Sea Wide Field-of-view Sensor, MODIS = Moderate Resolution Imaging Spectroradiometer, OCM = Ocean Colour Monitoring.

P.J. Mumby et al. / Marine Pollution Bulletin 48 (2004) 219–228

https://www.nature.com/articles/s41598-018-24530-9

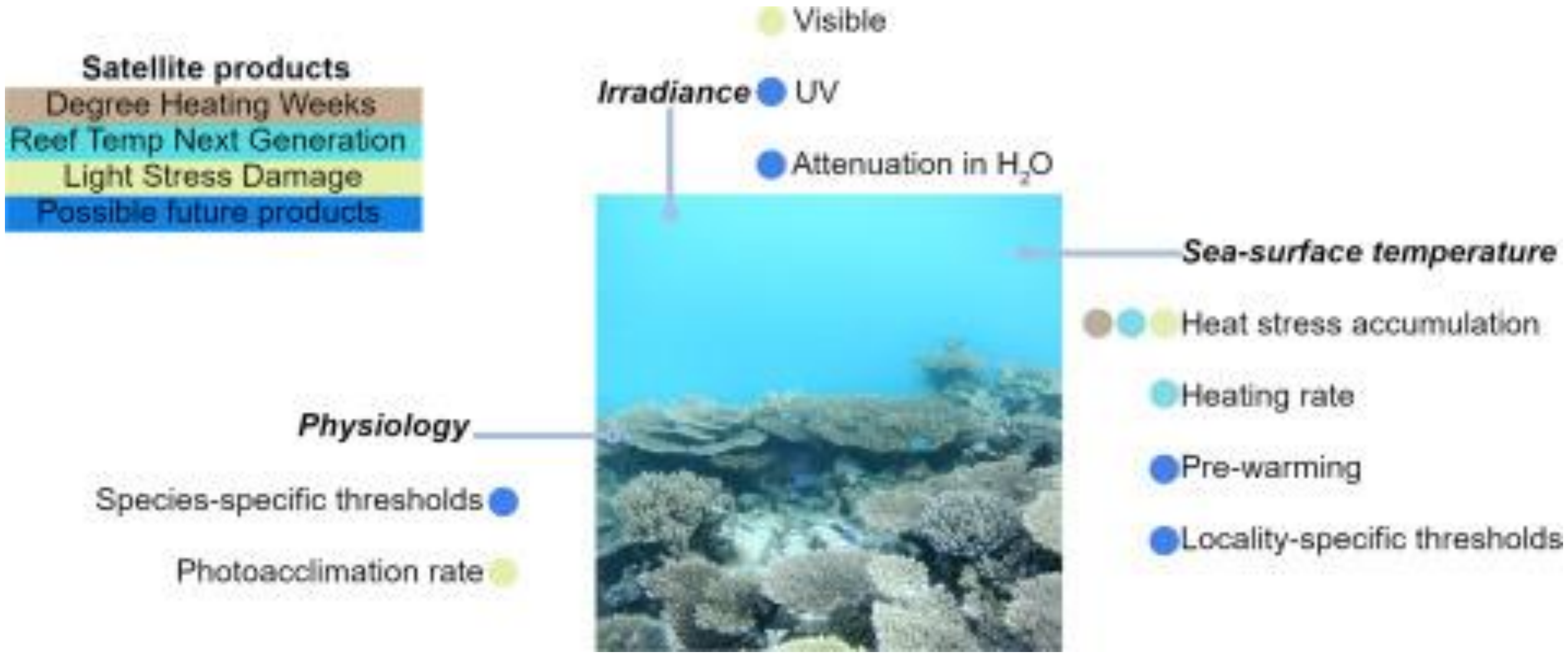
Anticipated Results

- Wide variation of coral health expected due to varying threats and level of severity in various regions
- Reefs in locations like the Gulf will be more impacted due to frequent changes in water temperature



Discussion

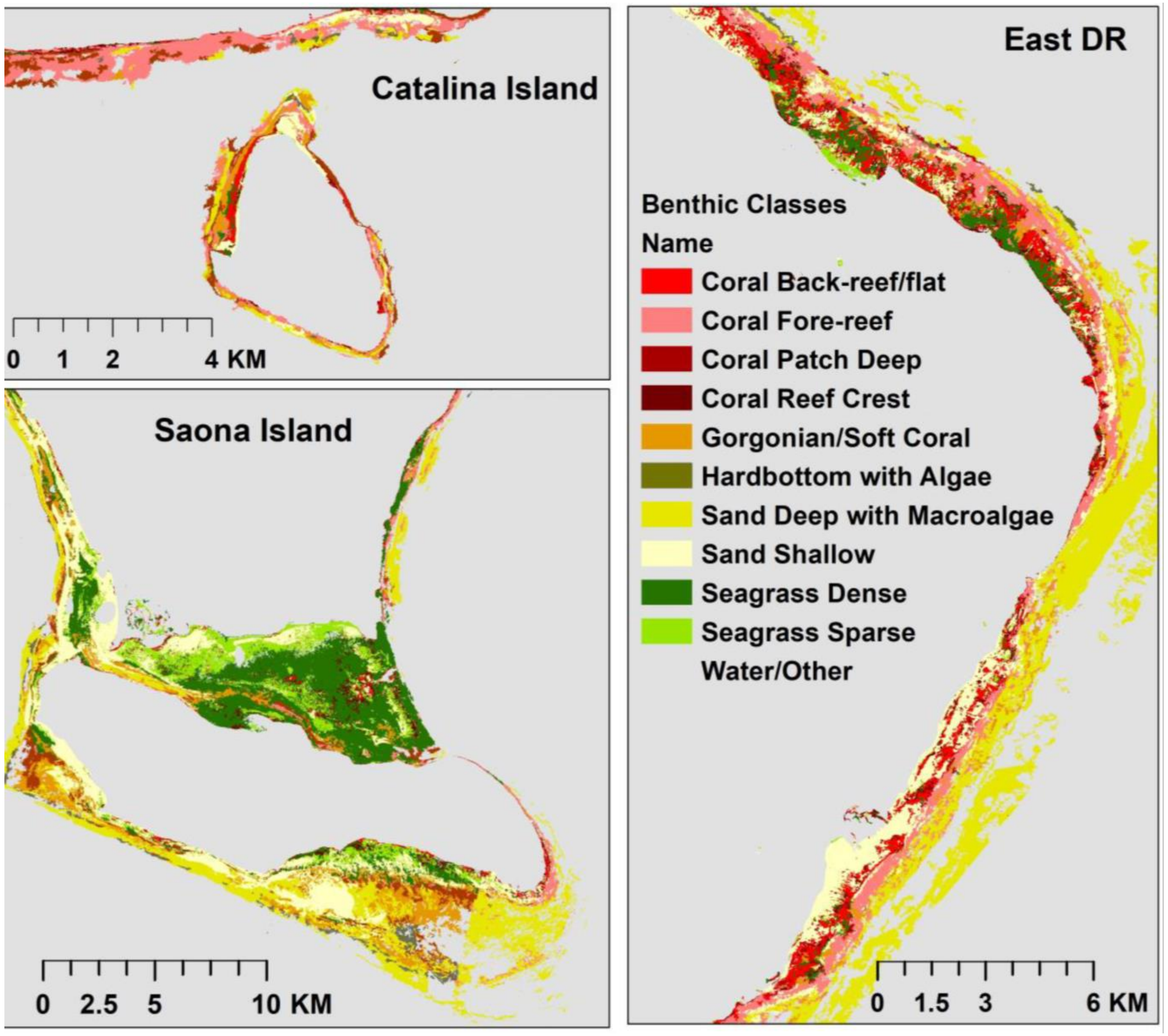
- Database needs to be created before it can be implemented
- Results will provide data for restoration strategies



https://www.sciencedirect.com/science/article/abs/pii/S0034425720301644

Discussion

- Research will contribute to reef rehabilitation and identify species that need to be restored more than others
- RS analyses can also determine thermal stress levels that contribute to bleaching events
- Application:
  - RS can supply data on environmental parameters and marine habitats to help establish Marine Protected Areas (MPAs)



https://www.mdpi.com/2072-4292/11/12/1445

Discussion

- Limitations:
  - Inaccurate coverage/data estimations of benthic types
  - Spectral mixing can sometimes limit benthic cover quantification
  - Depth and turbidity affects optical data accuracy
  - Spectral sensors unable to target specific habitats with high accuracy
  - Species should not be grouped together to ensure accurate estimations
  - Sensors can fail to show the complexity of habitats, thus making it harder to identify issues

Limitations of Remote Sensing

- Some of the drawbacks of remote sensing are
  - The interpretation of imagery requires a certain skill level
  - Needs cross verification with ground (field) survey data
  - Data from multiple sources may create confusion
  - Objects can be misclassified or confused
  - Distortions may occur in an image due to the relative motion of sensor and source

https://www.slideshare.net/thiruvengadamnaveen/groundtruth-collection-for-remotesensing-support

Conclusion

Purpose: Gather RS data to establish a database that will be used to design unique restoration strategies

Anticipated Methodology: Use various RS technologies and sensors to produce an array of information (thermal stress satellites, 3D modeling, surveys, etc.)

Anticipated Results: Broad variation of results due to regional differences in health, conservation efforts, and frequent temperature changes

Significance: Research will help determine future restoration strategies to rehabilitate coral reefs

Future Research

Use remote sensing data to create site specific mitigation strategies unique to issues at particular location

Track coral health over long periods of time

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- My Science Research Peers

- My Science Research Teacher

https://scripps.ucsd.edu/labs/coralreefecology/people/

References

- Kachelriess, D., Wegmann, M., Gollock, M., & Pettorelli, N. (2013, August 15). The application of remote sensing for marine protected area management. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S1470160X13002653
- Heron, S. F., Skirving, W. J., Strong, A. E., & Eakin, C. M. (2016, February 6). Remote Sensing of Coral Reefs for Monitoring and Management: A Review. Retrieved from https://www.mdpi.com/2072-4292/8/2/118/htm
- Geller, G. N., Halpin, P. N., Helmuth, B., Hestir, E. L., Skidmore, A., Abrams, M. J., … Williams, K. (1970, January 1). Remote Sensing for Biodiversity. Retrieved from https://link.springer.com/chapter/10.1007/978-3-319-27288-7_8
- A., S., Asner, & P., G. (2019, February 11). Scaling Up Coral Reef Restoration Using Remote Sensing Technology. Retrieved from https://www.frontiersin.org/articles/10.3389/fmars.2019.00079/full
- Renata, McKinnon, David, Smith, N., R., Corke, … Ferrari. (2016, February 4). Quantifying Multiscale Habitat Structural Complexity: A Cost-Effective Framework for Underwater 3D Modelling. Retrieved from https://www.mdpi.com/2072-4292/8/2/113/htm
- Coral Reef Mitigation. (n.d.). Retrieved from https://dlnr.hawaii.gov/coralreefs/mitigation-bank/
- (n.d.). Retrieved from https://ieeexplore.ieee.org/abstract/document/968743
- Remote Sensing Techniques. (n.d.). Retrieved from https://openei.org/wiki/Remote_Sensing_Techniques
- Goodman, J. A., Purkis, S. J., & Phinn, S. R. (n.d.). Coral Reef Remote Sensing: A Guide for Mapping, Monitoring and Management. Retrieved from https://nsuworks.nova.edu/occ_facbooks/27/
- Smith, J. E., Brainard, R., Carter, A., Grillo, S., Edwards, C., Clinton, … Stuart Sandin Scripps Institution of Oceanography. (2016, January 13). Re-evaluating the health of coral reef communities: baselines and evidence for human impacts across the central Pacific. Retrieved from https://royalsocietypublishing.org/doi/full/10.1098/rspb.2015.1985.
- Mumby, P. J., Skirving, W., Strong, A. E., Hardy, J. T., LeDrew, E. F., Hochberg, E. J., … David, L. T. (2003, December 3). Remote sensing of coral reefs and their physical environment. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0025326X03004600

References

- Hughes, T. P., Kerry, J. T., Baird, A. H., Connolly, S. R., Dietzel, A., Eakin, C. M., ... Torda, G. (2018). Global warming transforms coral reef assemblages. *Nature*, *556*(7702), 492–496. doi: 10.1038/s41586-018-0041-2
- Ladd, M. C., Burkepile, D. E., & Shantz, A. A. (2019). Near-term impacts of coral restoration on target species, coral reef community structure, and ecological processes. *Restoration Ecology*, *27*(5), 1166–1176. doi: 10.1111/rec.12939
- Cinner, J. E., Huchery, C., MacNeil, M. A., Graham, N. A. J., McClanahan, T. R., Maina, J., ... Mouillot, D. (2016, June 15). Bright spots among the world's coral reefs. Retrieved from https://www.nature.com/articles/nature18607.
- Hein, M. Y., Beeden, R., Birtles, A., Gardiner, N. M., Berre, T. L., Levy, J., ... Willis, B. L. (2020). Coral Restoration Effectiveness: Multiregional Snapshots of the Long-Term Responses of Coral Assemblages to Restoration. *Diversity*, *12*(4), 153. doi: 10.3390/d12040153
- Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, et al. (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737–1742
- Reaka-Kudla ML (2005) Biodiversity of Caribbean coral reefs. DesTech Publishers, Lancaster, Pennsylvania
- de Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, et al. (2012) Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services 1:50–61
- Ferrario F, Beck MW, Storlazzi CD, Micheli F, Shepard CC, Airoldi L (2014) The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nature Communications 5:3794
- Burke L, Maidens J (2004) Reefs at risk in the Caribbean, World Resources Institute, Washington D.C.
- Jackson JBC, Donovan M, Cramer K, Lam V (2014) Pages 1970–2012. Status and trends of Caribbean coral reefs. Global Coral Reeef Monitoring Network, IUCN, Gland, Switzerland
- Young C, Schopmeyer S, Lirman D (2012) A review of reef restoration and coral propagation using the threatened genus Acropora in the Caribbean and Western Atlantic. Bulletin of Marine Science 88:1075–1098
- Zaneveld JR, Burkpepile DE, Shantz AA, Pritchard CE, McMinds R, Payet JP, et al. (2016) Overfishing and nutrient pollution interact with temperature to disrupt coral reefs down to microbial scales. Nature Communications 7:11833