Drivers of Macroalgal Dynamics within Halodule Seagrass Beds

MSc Thesis Defense
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Thesis Committee:
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Dr. Ryan Okano (outside member)

Outline

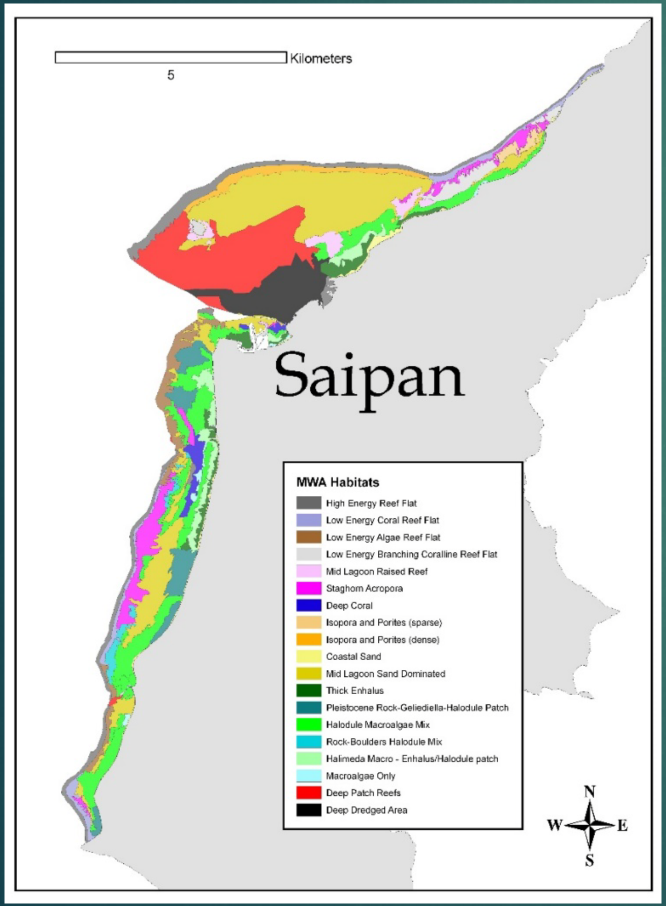
- Study site – Saipan lagoon
  - Challenges and Key Questions
- Seagrass habitats
  - Global trends and key functions
- History of studies in the Saipan Lagoon
- Thesis objectives
- Methods
- Results
- Summary and Discussion
  - Evidence for similar seasonal trends
    - Elsewhere and in Saipan
  - Management

Saipan Lagoon





Habitat-forming seagrasses in the Saipan lagoon



Halodule uninervis

Enhalus acoroides

Saipan Lagoon

Filters land-based pollution




Challenges and Key Questions

- Seasonal cycles?
- Change over time?

- Are current land-use patterns ?
- Can temporal trends and seasonal cycles be reconciled?

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Seagrass habitats globally in decline (spatial coverage and integrity)

- What is going on with seagrass globally and why?
  - **Eutrophication**
  - Direct exploitation
- Meta-analysis examining global trends in seagrass

Table 1. Percentage rate of change for seagrass meadows globally

Trajectory*	Median % rate of change, μ (*N*)	Proportion in category, %	Mean % rate of change, μ (±SE, *N*)	Net maximum measured area, km^2	Net change in study areas, km^2 (% of maximum)	Mean study length, yr
Declining	−3.7 (126)	58	−6.9 (±0.9, 116)	9,147	−3,662 (40)	25
Increasing	5.4 (53)	25	11.8 (±3.6, 43)	879	314 (36)	20
No detectable change	−0.06 (36)	17	−0.2 (±0.2, 36)	1,565	−19 (1)	14
Overall	−0.9 (215)	100	−1.5 (±1.1, 196)	11,592	−3,367 (29)	22

Rate of change expressed as μ, % yr^{-1}.
*Meadows were categorized as declining (<90% of initial area), increasing (final area >110% of initial area), or having no detectable change (final area within ±10% of initial area).

Between 1879 and 2006, there was a 29% loss of seagrass habitat.

Waycott et al. 2009 PNAS

Global concerns about seagrass habitat decline

- Functional roles of seagrass habitats
  - **Filtering nutrients and driving the rates of nutrient releases to ecosystem**
  - Stabilization of substrates and shorelines
  - Habitat provisioning for fish and macro-invertebrates

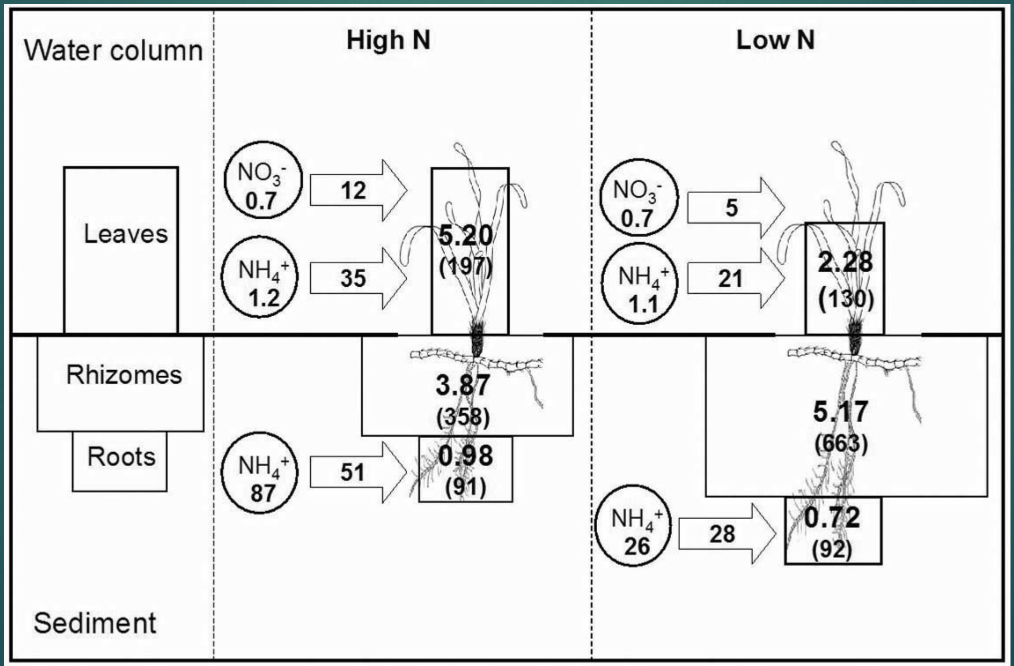
Simplified view of seagrass and nutrients

- Seagrass habitats change nearshore nutrient dynamics

- From pulsed nutrients… to slow and continuous release

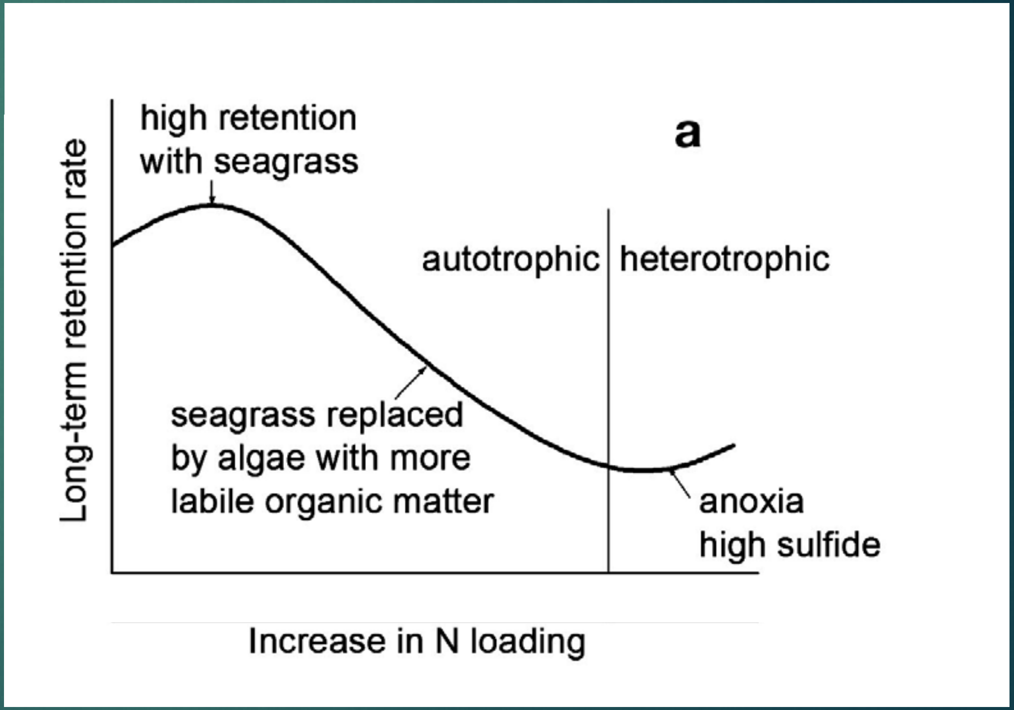
Evidence of nutrient uptake

Accumulation above and below ground, key difference from most macroalgae



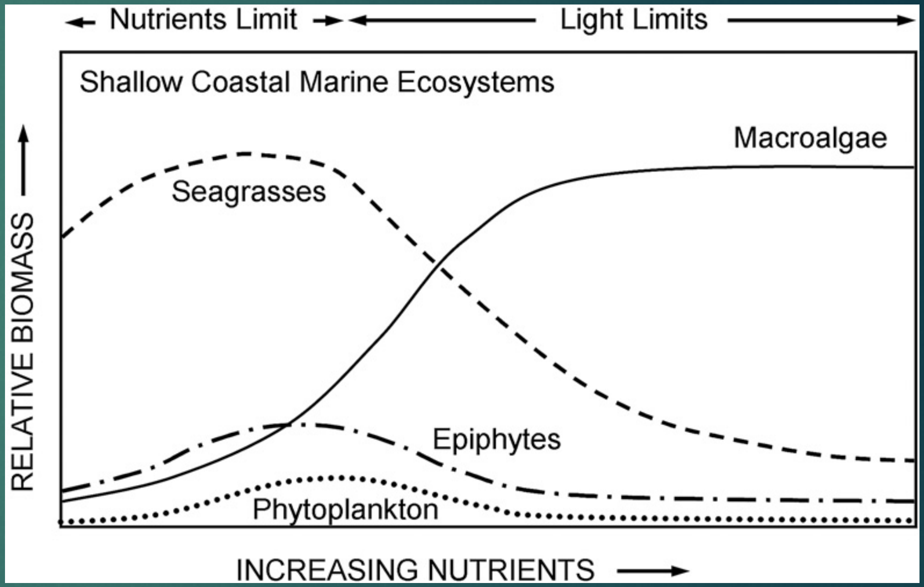
Romero et al 2006

Nutrient dynamics, in turn, can control assemblage dynamics



McGlathery et al. 2007 MEPS

So, water quality represents an influential driver

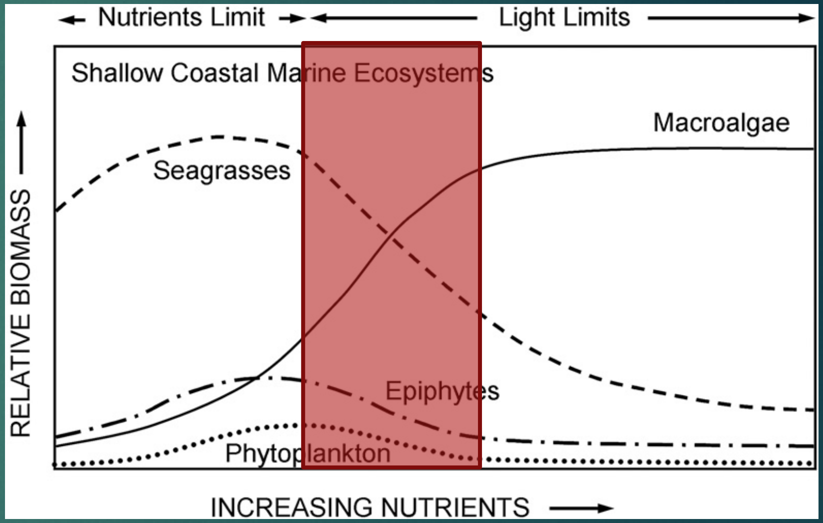


Starts with nutrient uptake,
Ends with community dynamics

Burkholder et al 2007

But, nutrients are pulsed events and assemblages shift over time

- In reality, the transition is not smooth
- Environmental ‘noise’ can emerge from seasonal cycles (rainfall, etc.)
- True temporal change can take years



Burkholder et al. 2007 JEMBE

Natural factors that influence the growth dynamics of macroalgae/seagrass

- Seasonal
  - Rainfall and sea-surface temperature
  - Extreme tidal cycles (also linked with temperature)
- Storms and disturbance events
- Nature of watershed discharge
  - Groundwater
  - Surface runoff

All of these can potentially limit our ability to detect temporal trends

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Historical studies in the Saipan lagoon

- Starting in 1950's after WWII
  - US Geological survey commissioned habitat mapping
- UOGML two key technical reports looking at fish and sea cucumber abundances
- Work comparing habitat maps between 1950's and present
- Recent work examining seasonal dynamics at small spatial scales

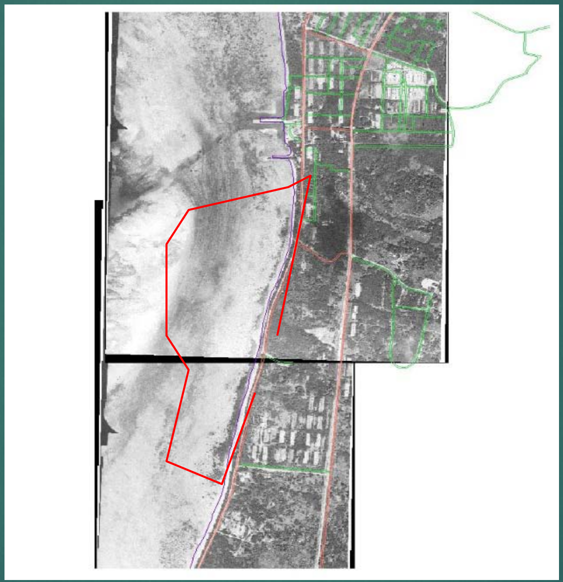
Evidence from the past

Prior to historical maps

1945

Heavy watershed development, extensive submerged aquatic vegetation evident

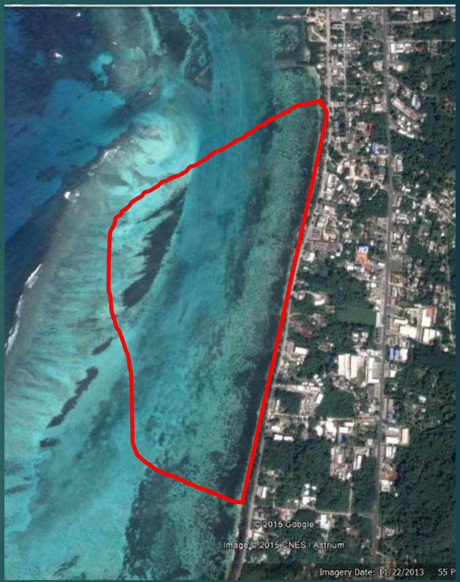
Historical maps



1956

Lower watershed development after WWII, lagoon returned to mostly sand

Contemporary maps



2013

Growing watershed development, lagoon once again becoming dominated by submerged vegetation

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Thesis goals

- Examine if seasonal dynamics suggested by smaller-scale seagrass plots are consistent across a larger scale of investigation
- Use the improved understanding of seasonal dynamics to evaluate trends in macroalgal canopy cover with respect to watershed characteristics and environmental factors

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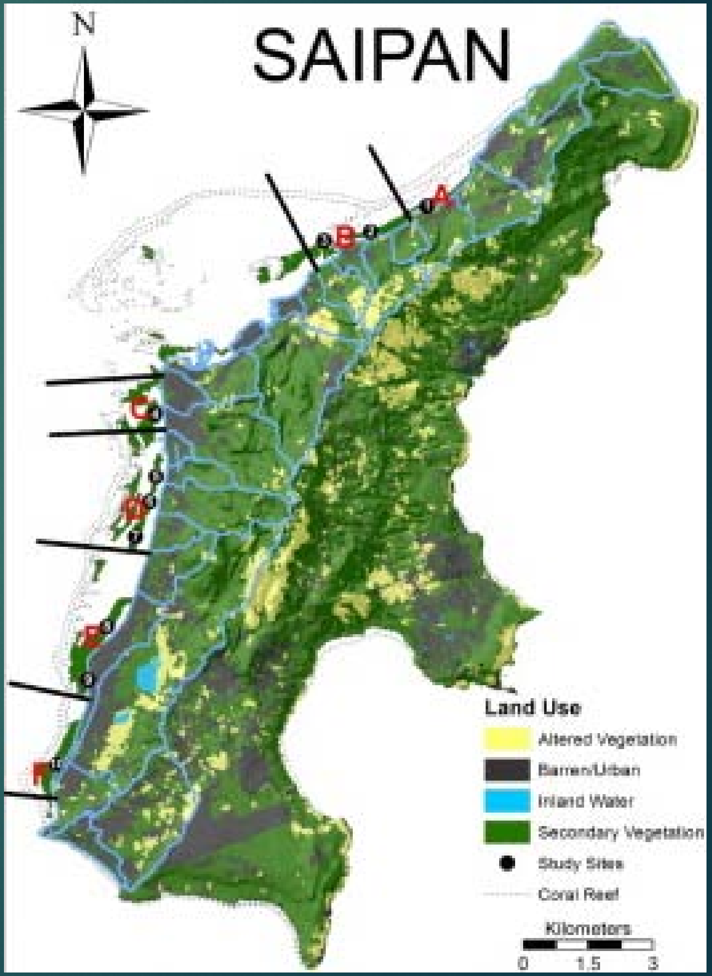
Data Collection

- Benthic Substrate
  - 5 x 50m transects
  - Photo quadrats
    - Canopy cover
  - 250 points per transect
  - Similar methods over 13 years



Data Analyses

Raw Data

↓

Transform Data

↓

Distance based similarity matrix (e.g. Bray-Curtis)

↓

PERMDISP Analysis

= → PCO

Visualize Bray-Curtis

↓

PERMANOVA

Nested PERMANOVA

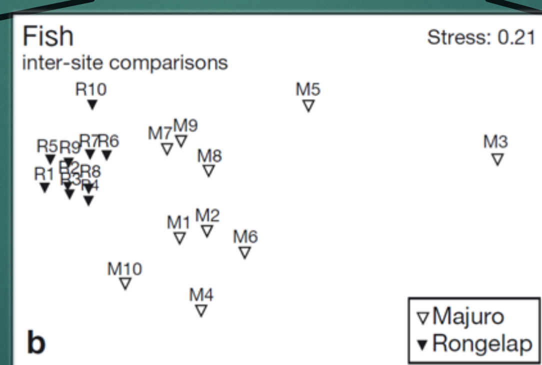
≠ → nMDS

Visualize Bray-Curtis

↓

ANOSIM

Nested ANOSIM



PERMANOVA → Vectors ← ANOSIM

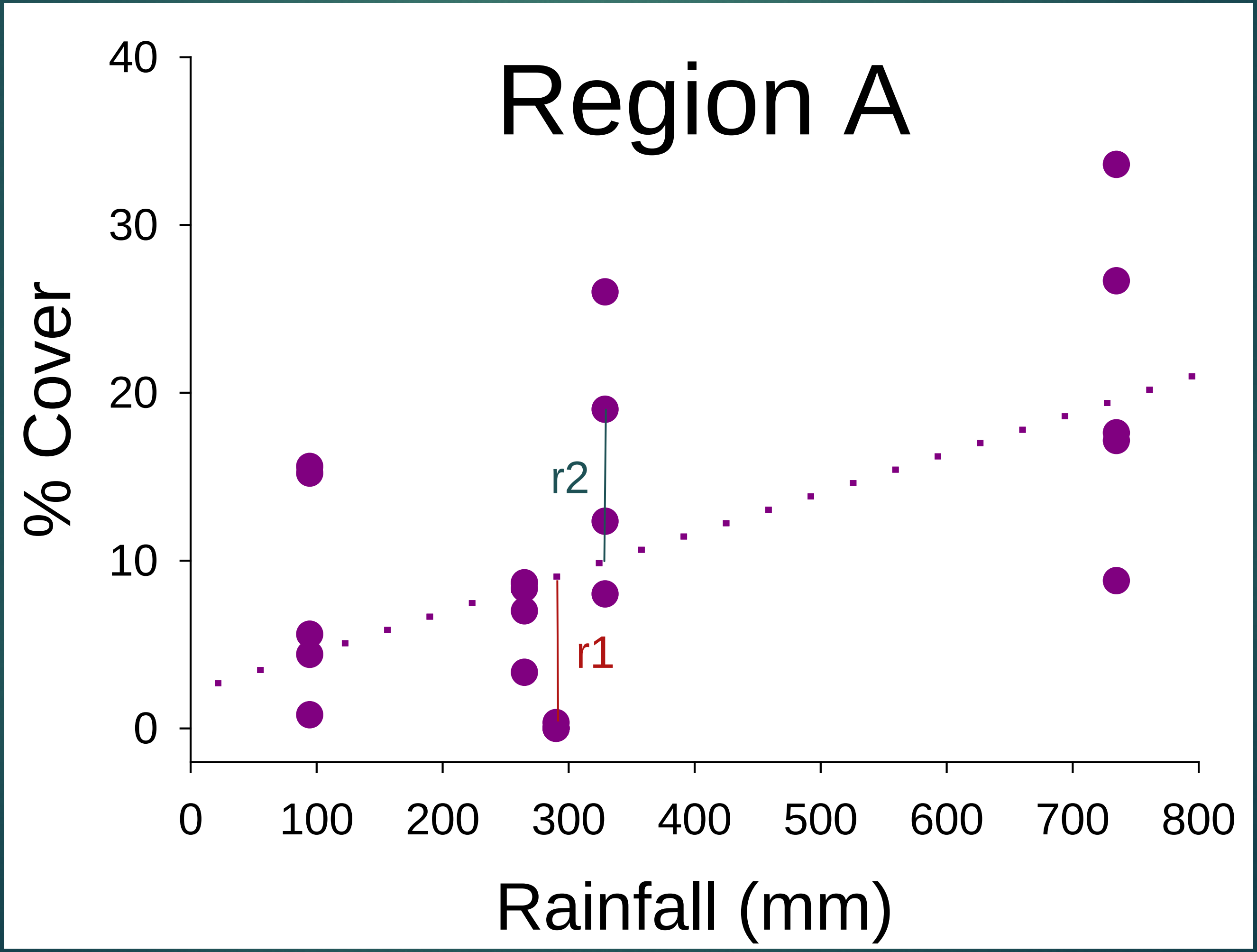
Vectors

What species driving trends?

(Lirman et al., 2008, Hydrobiologia)

Forward Stepwise Models

lm(red algae~rainfall) example



Other Models/Tests

- ANOVA/post-hoc tests for time series
- Binomial Models
  - Logistic regression

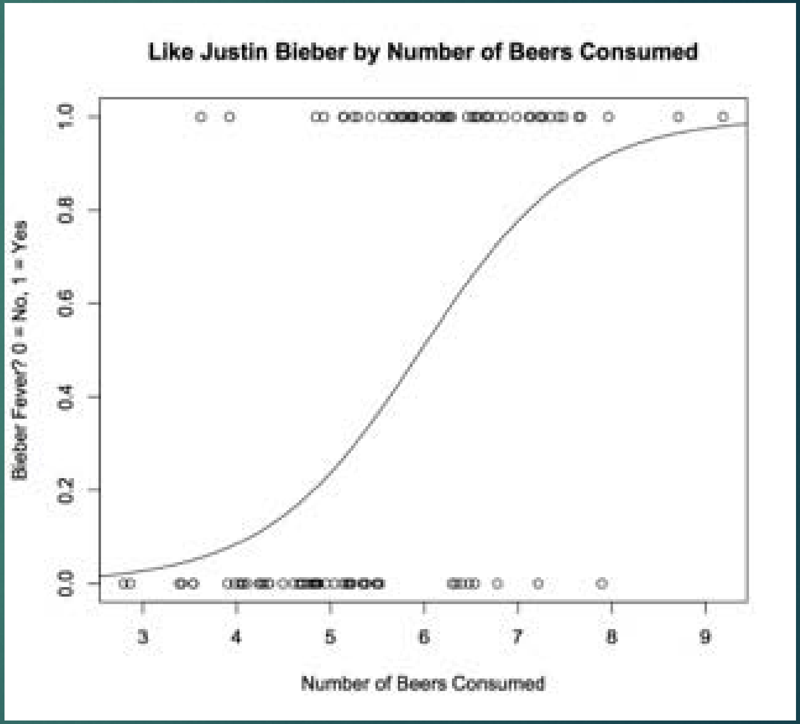


Image: Jeremy Albright (https://www.methodsconsultants.com/tutorial/what-is-the-difference-between-logit-and-probit-models/

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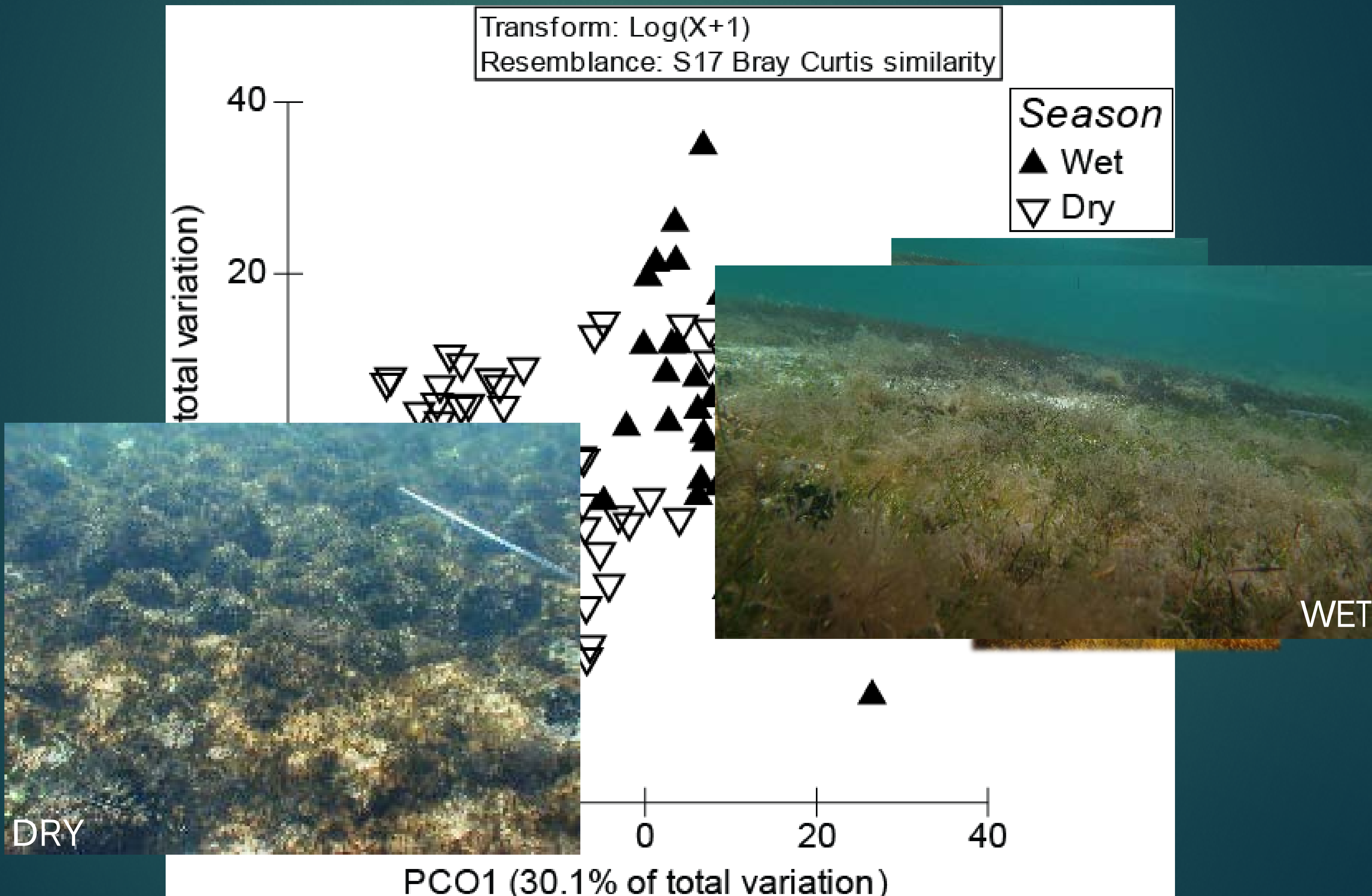
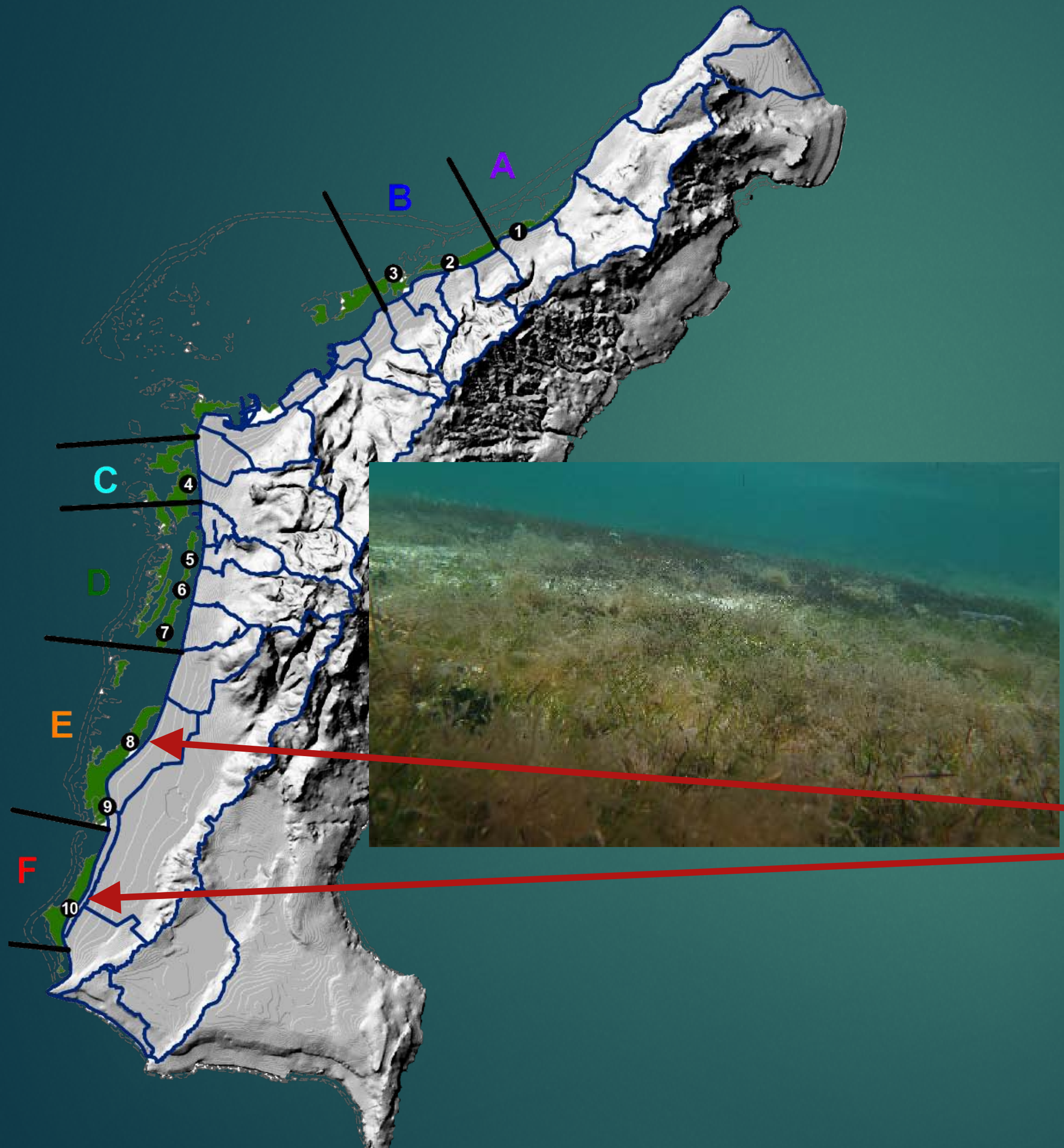
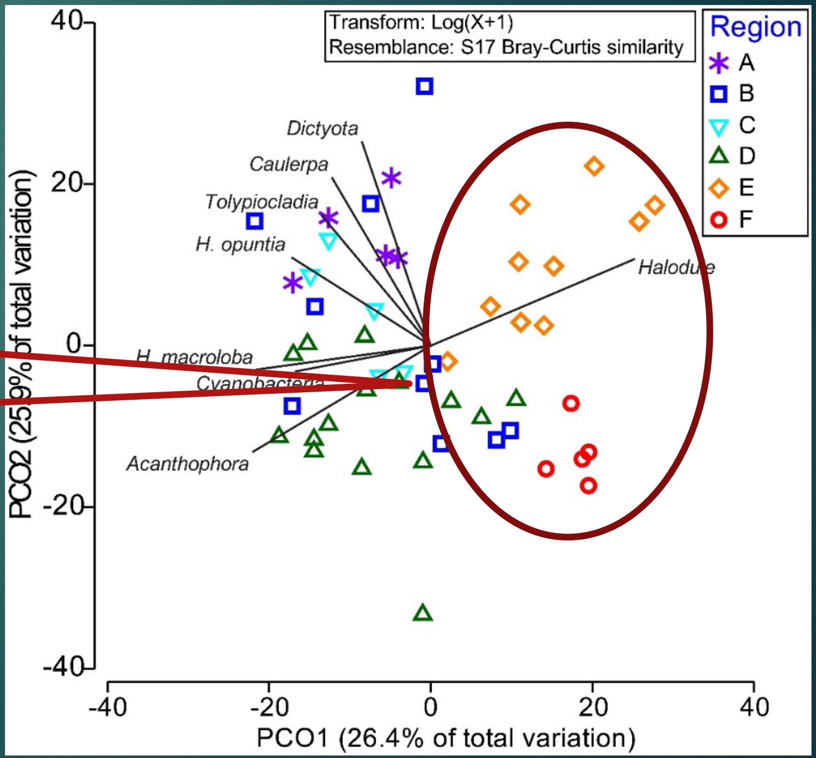
Seasonal Changes



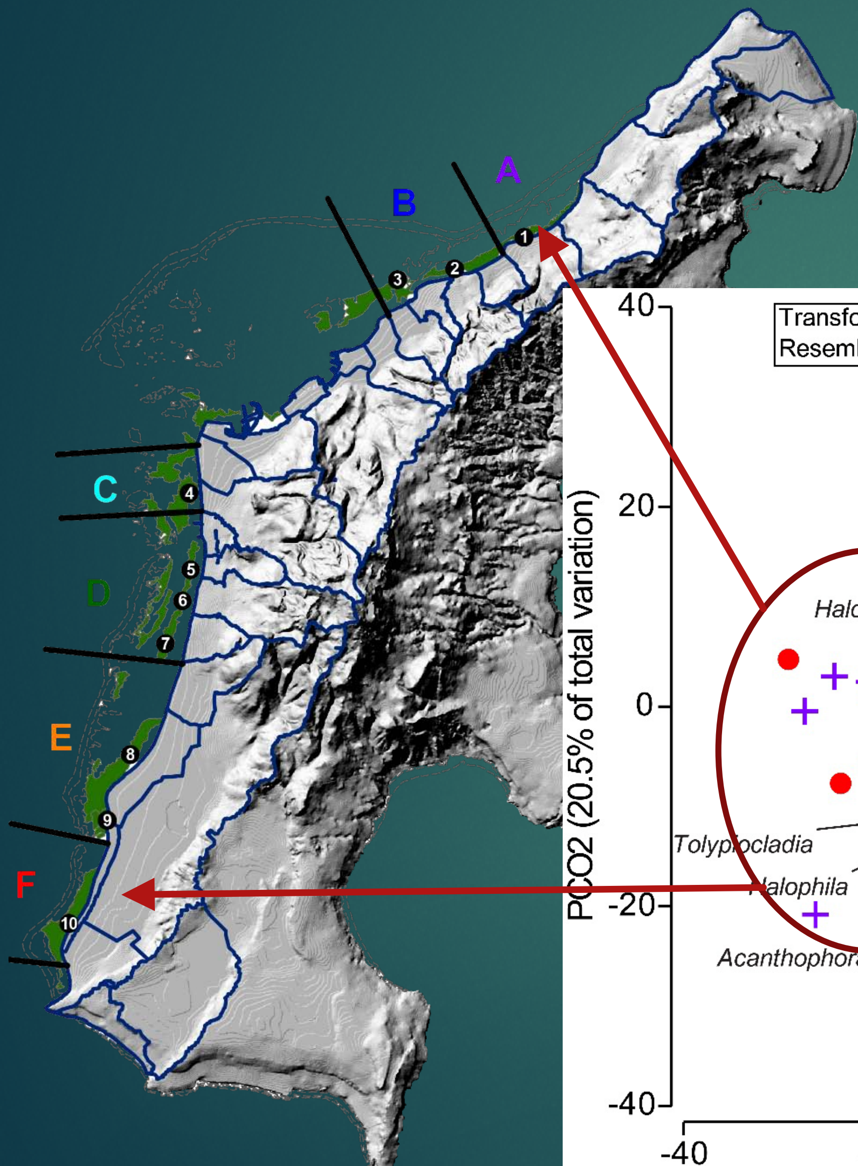
Spatial differences within each season

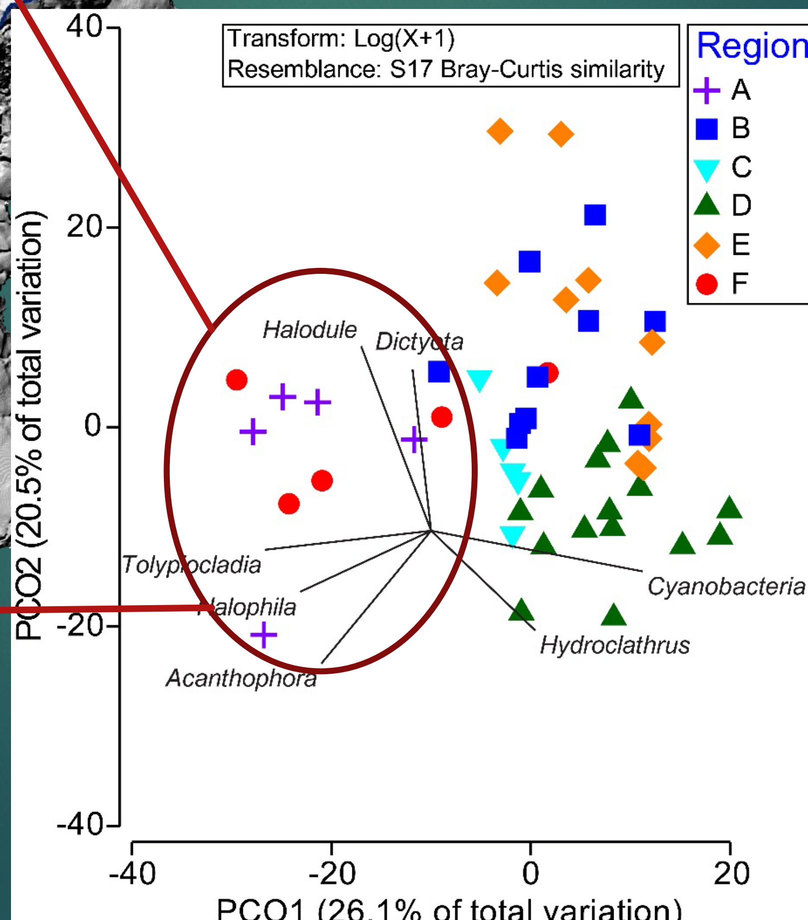
Wet Season





Spatial differences within each season



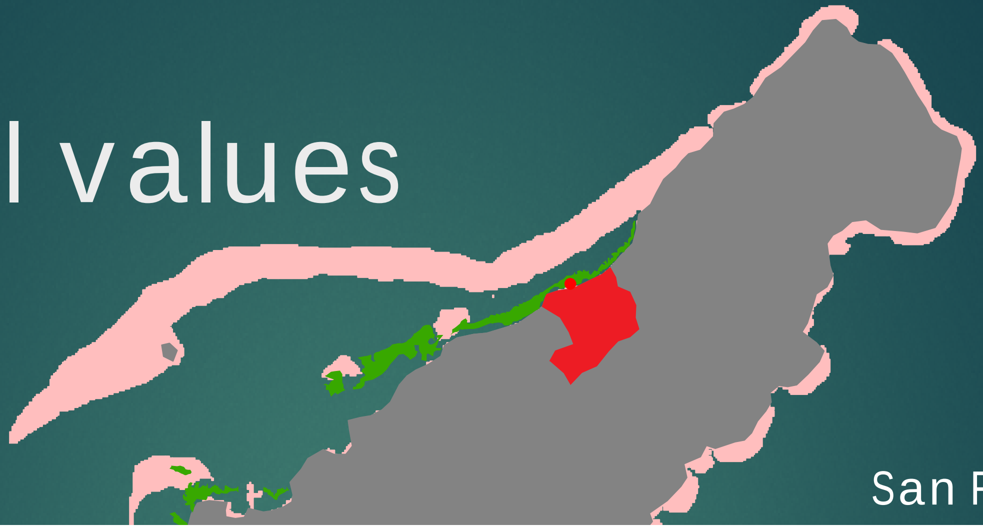


Dry Season

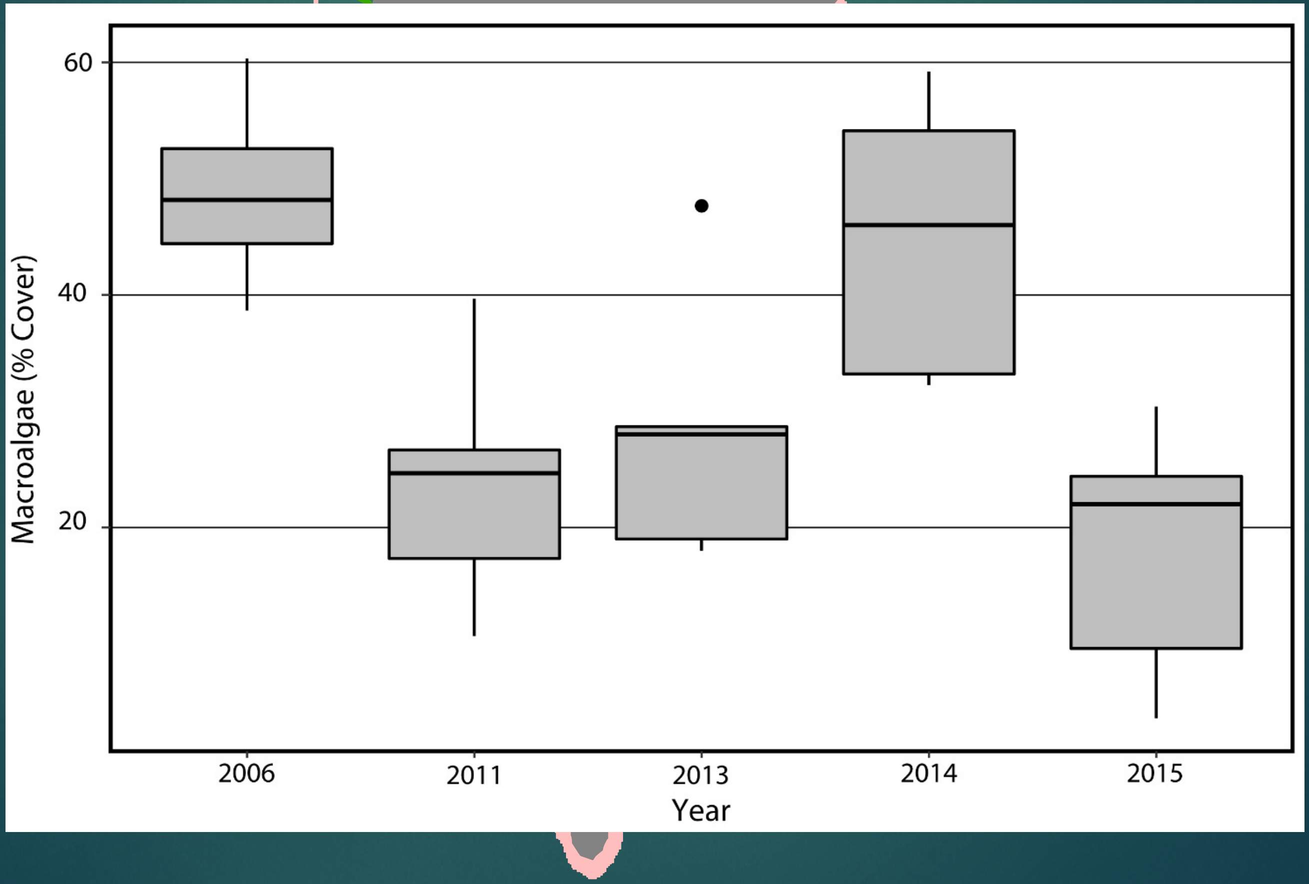
Removal of seasonal variance

Region	Site	Model	Slope (SE)	P- value
A	1	lm(red~rainfall)	0.02 (0.008)	0.005
B	2 and 3	lme(log(bg+1)~sst, random= ~1 | site)	-0.69 (0.14)	0
		lme(log(red+1)~rainfall, random= ~1 | site)	2.0 E^{-3} (1.0 E^{-3})	0.01
C	4 and 5	lme(log(bg+1)~sst, random= ~1 | site)	-0.69 (0.14)	<0.0001
		lme(log(red+1)~rainfall, random= ~1 | site)	3.0 E^{-3} (1.0 E^{-4})	0.001
D	6 and 7	lme(log(brown+1)~sst, random= ~1 | site)	0.88 (0.13)	0
		lm(bg~sst)	-11.33 (1.96)	<0.0001
		lm(log(red+1)~rainfall	3.0 E^{-3} (5.0 E^{-4})	<0.0001
E	8 and 9	lme(log(green+1)~gw, random= ~1 | site)	-0.06 (0.11)	<0.0001
		lme(log(brown+1)~gw, random= ~1 | site)	-0.23 (0.11)	0.05
		lm(log(bg+1)~sst)	-0.63 (0.18)	<0.001
F	10	lm(green~rainxgw)	4.19 (0.75)	<0.0001
		lm(log(brown+1)~rainxgw)	0.27 (0.06)	<0.0001

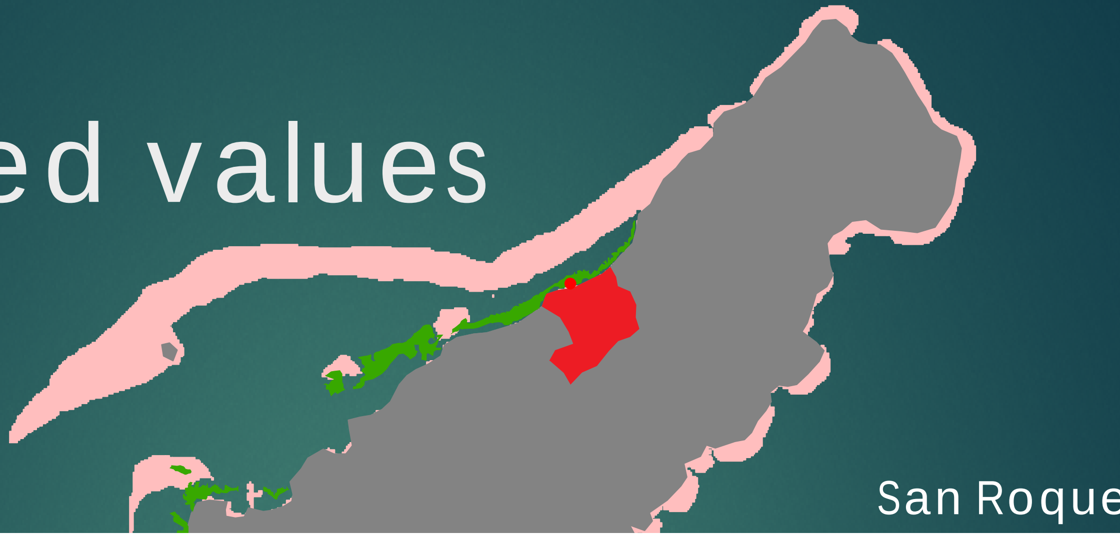
Normal values

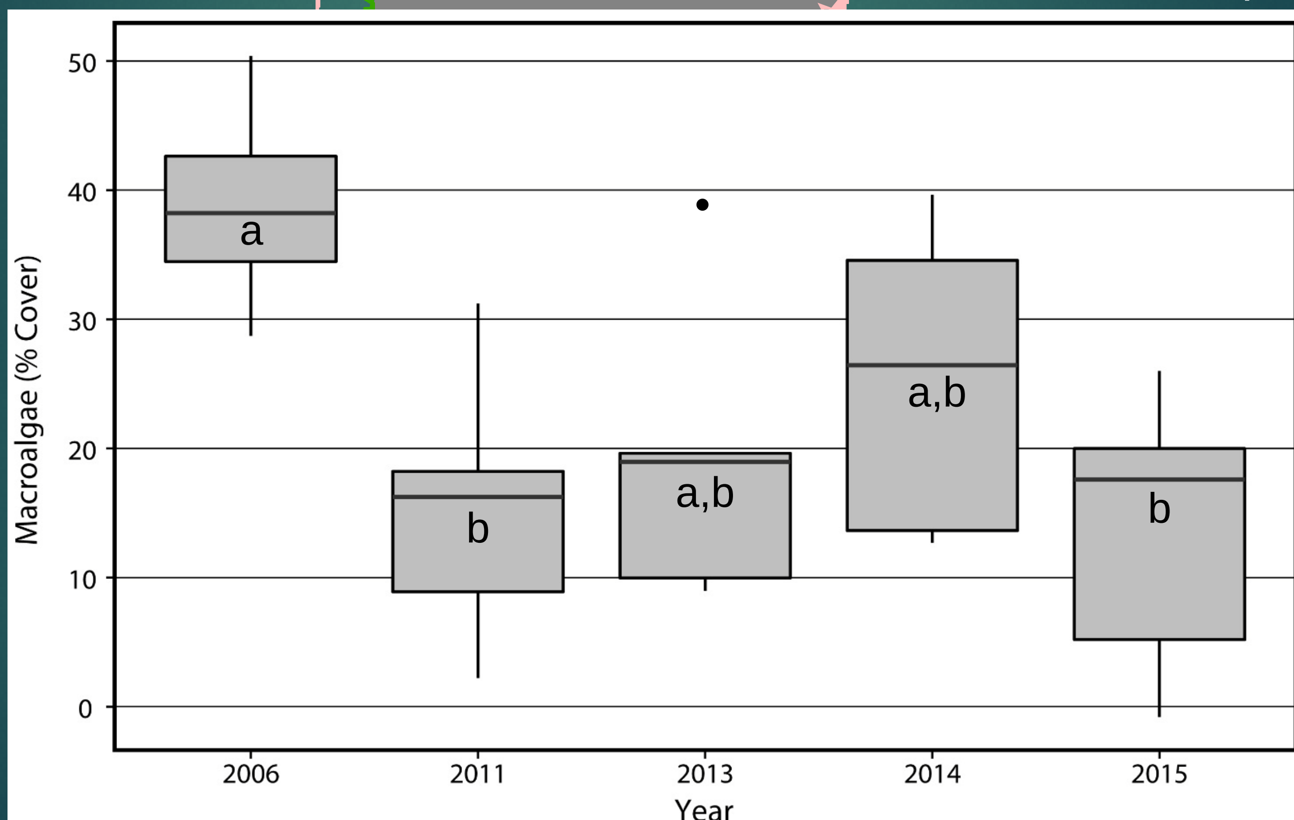


San Roque

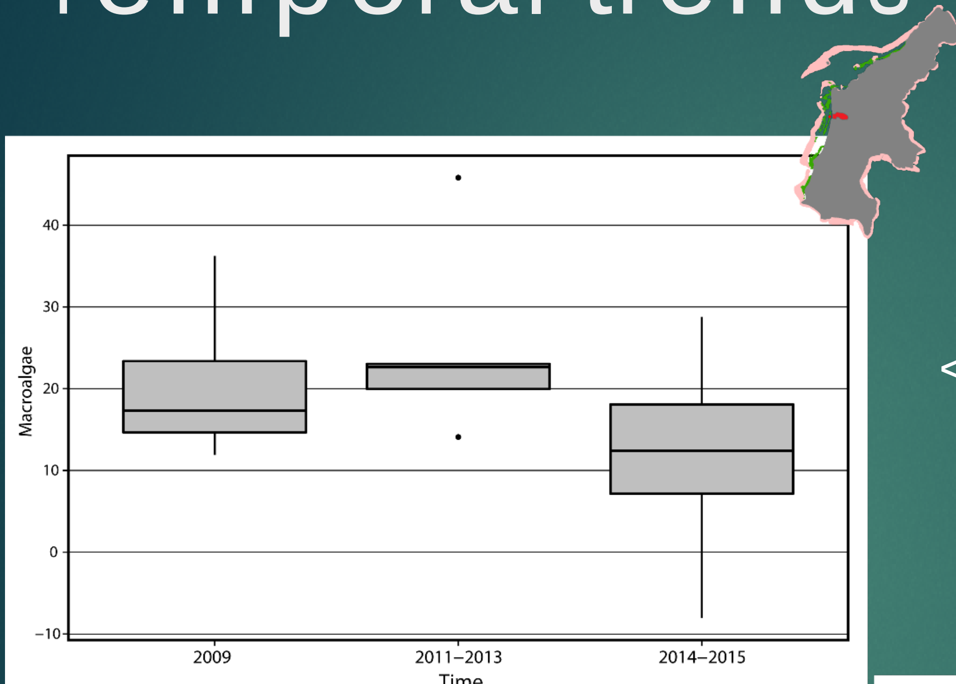


Adjusted values



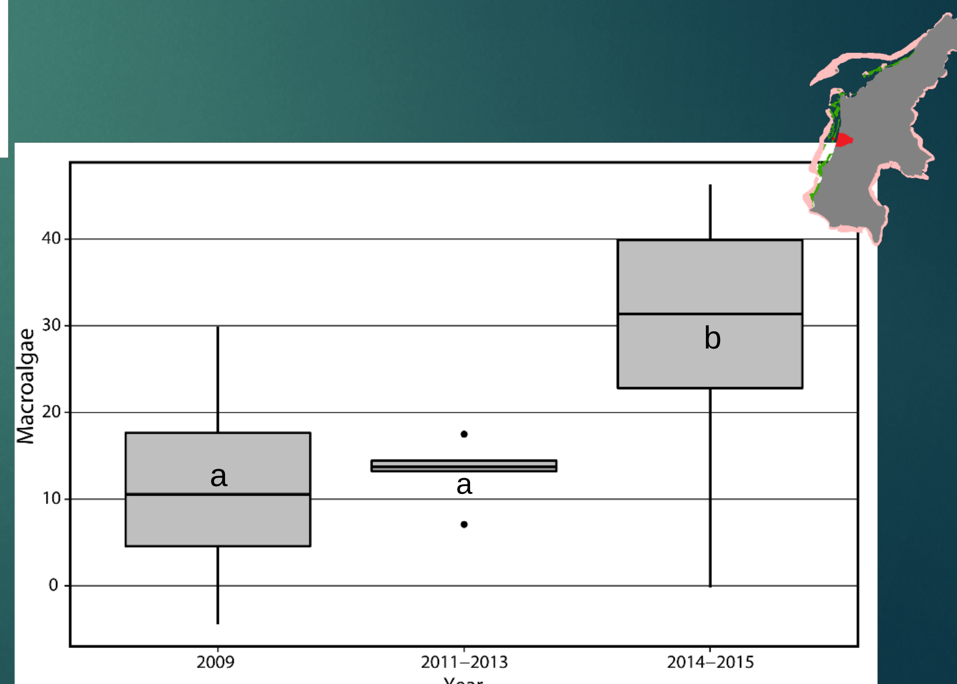


Temporal trends

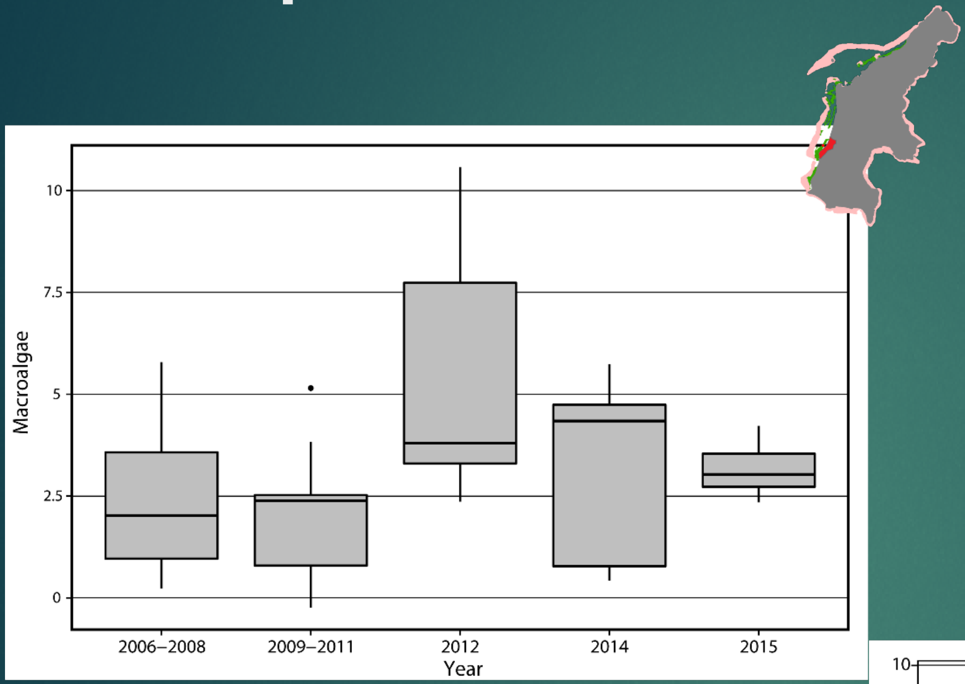


< 13 Fisherman (persistently high cover)

Quartermaster (significant increase) >

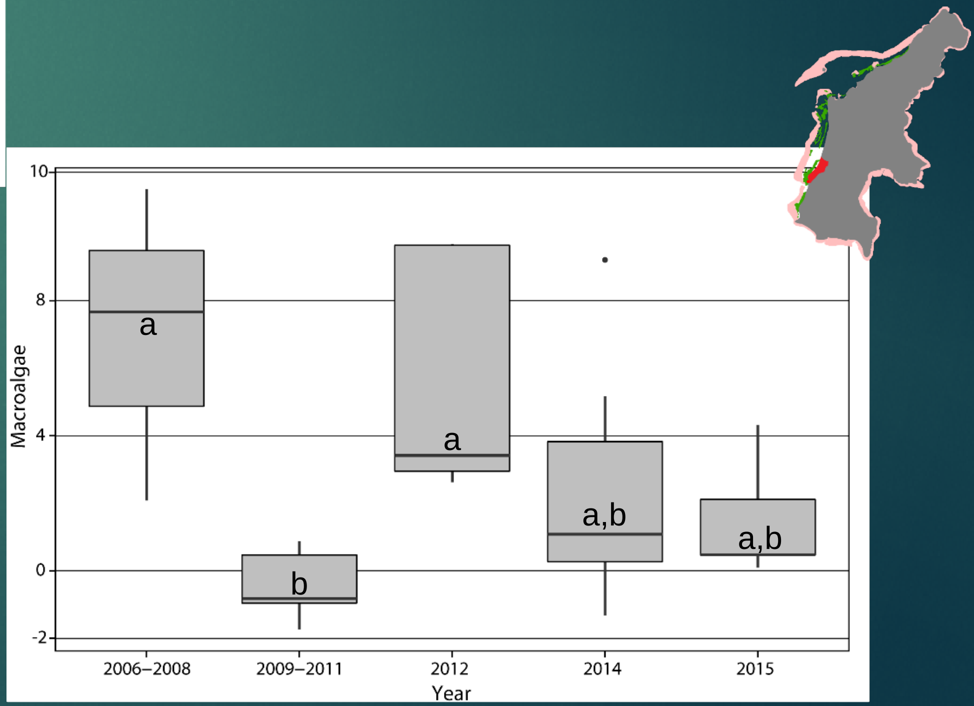


Temporal Trends



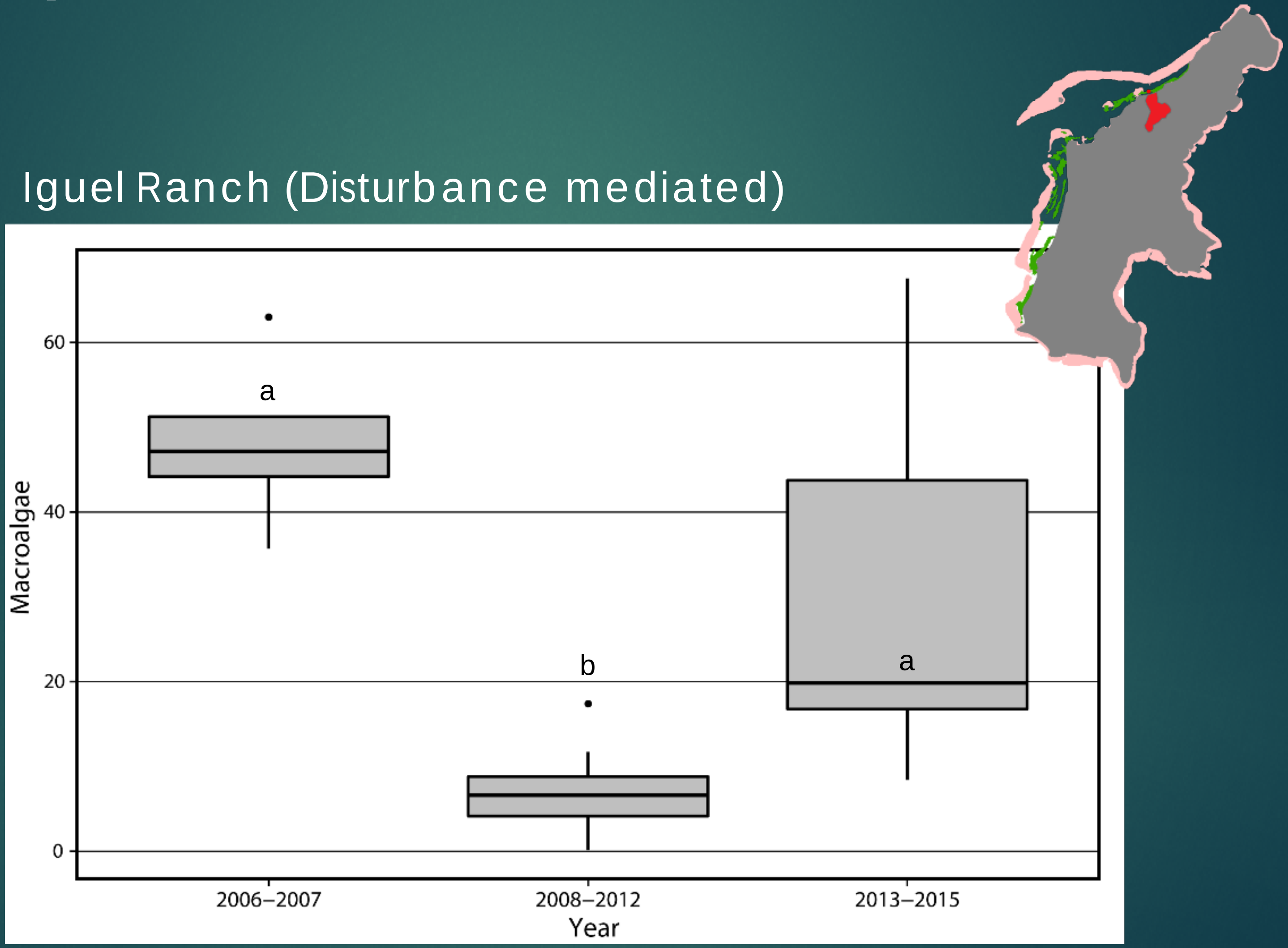
< Kilili (Persistently low canopies)

Sugar Dock (Persistently low canopies) >



Temporal trends

Iguel Ranch (Disturbance mediated)



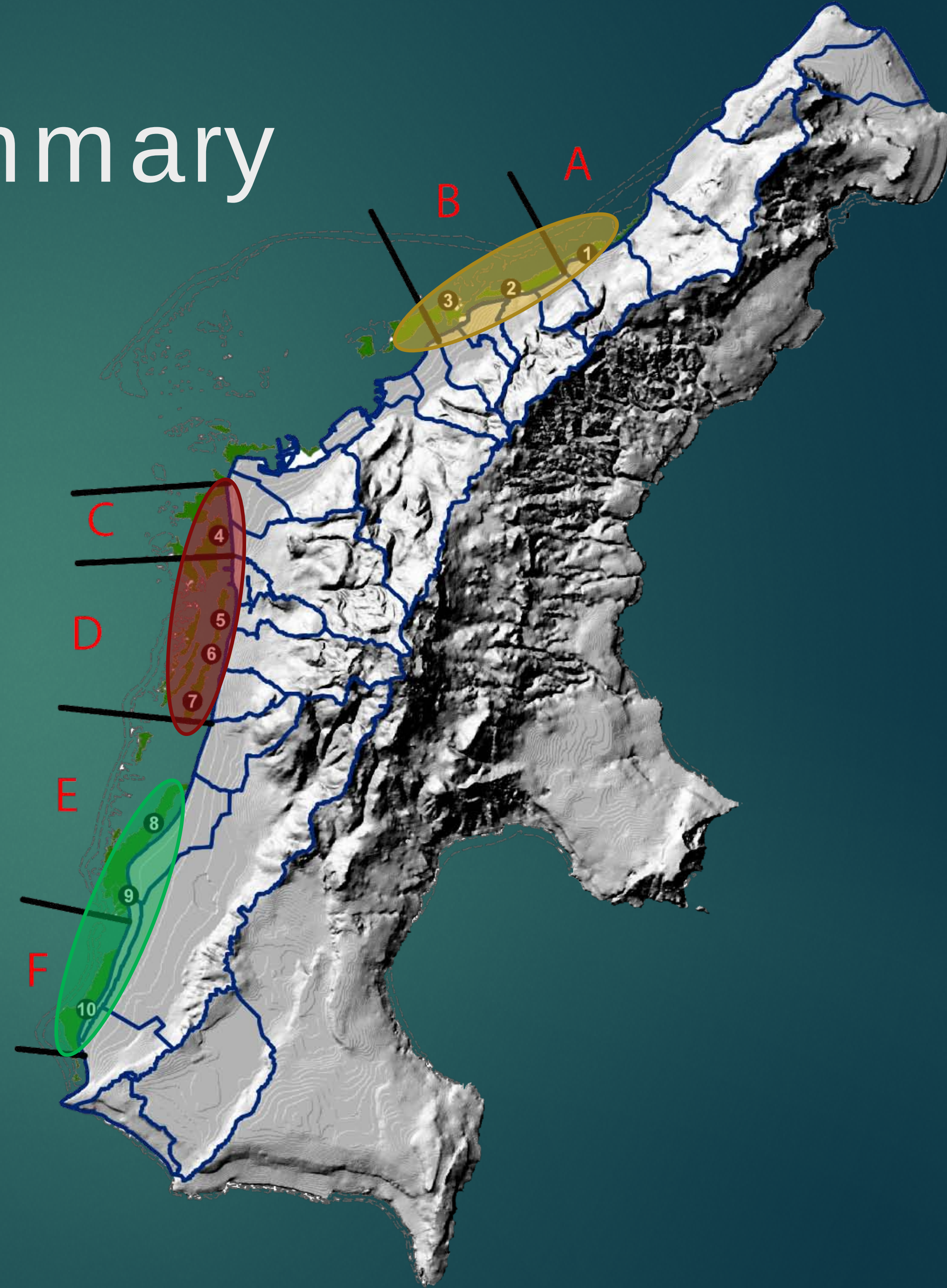
Furthering Houk and Camacho 2010, Bot Mar

Temporal Summary

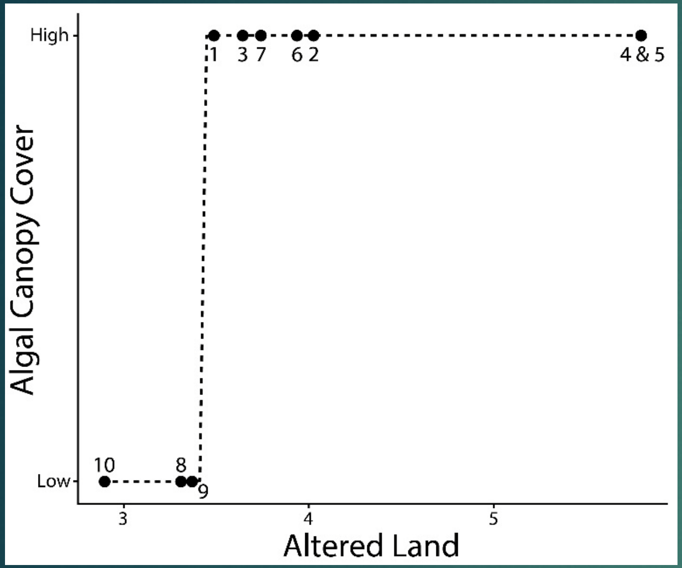
Red – Consistent High algal cover or significant increases in cover (2015 >20%)

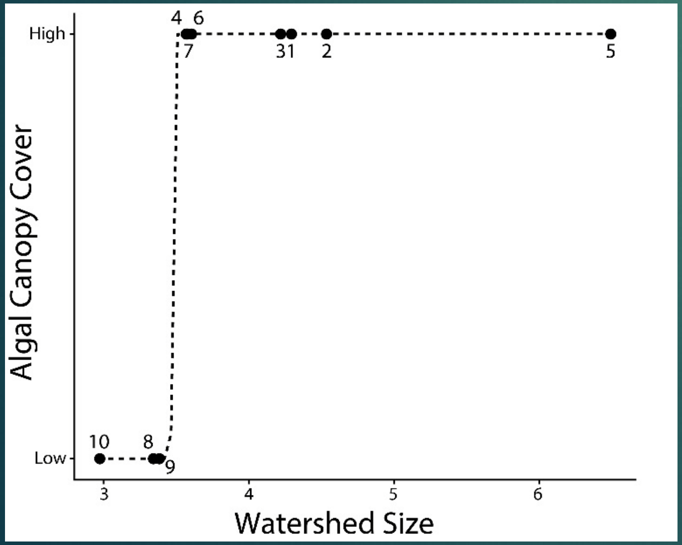
Yellow – Disturbance mediated (2015 >20%)

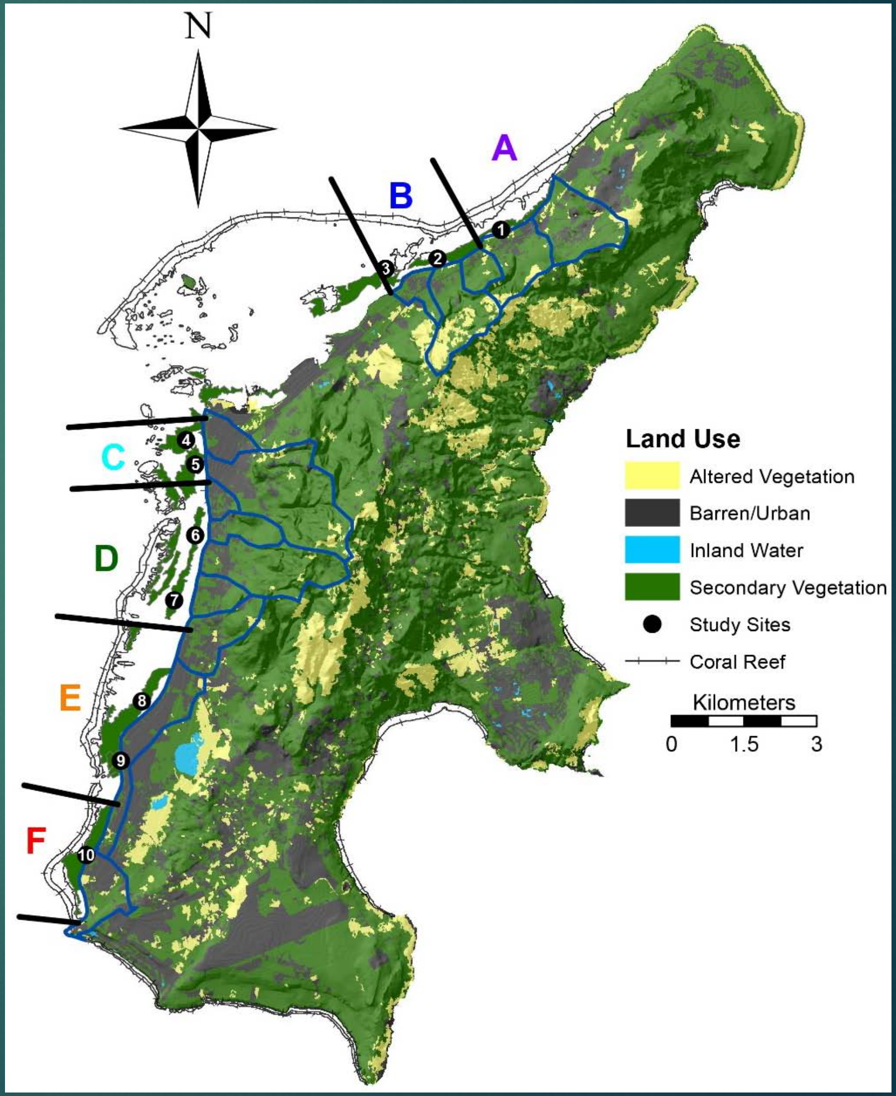
Green – Consistently low algal cover (2015 ≤10%)



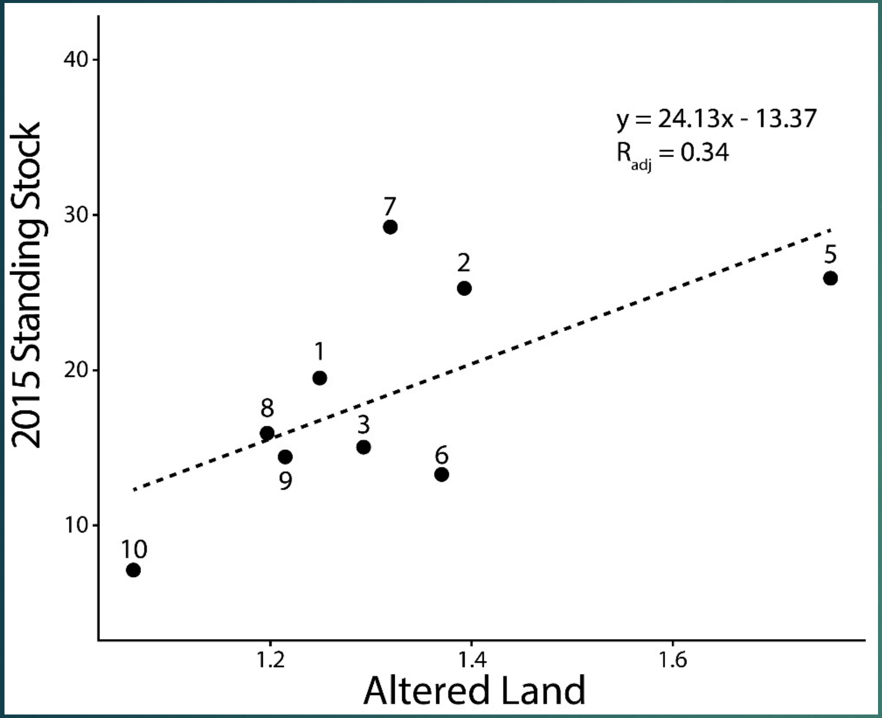
Binomial Models



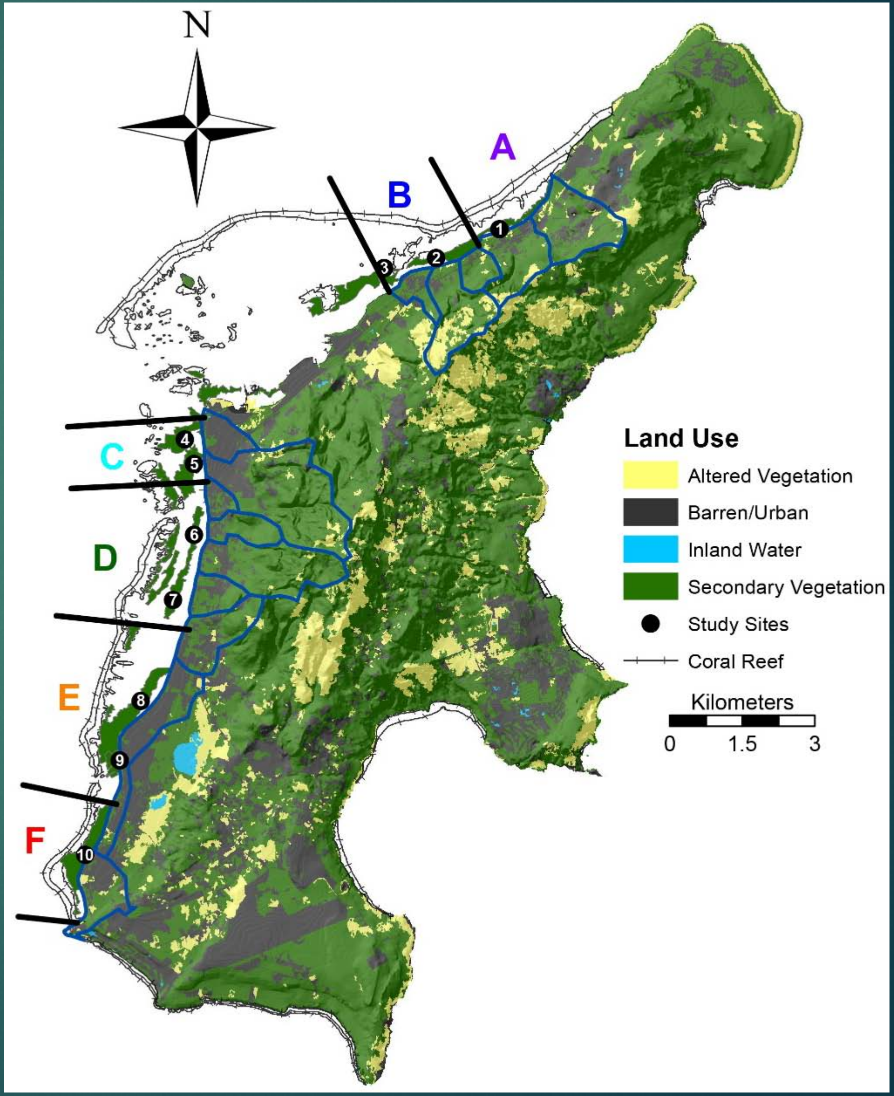




2015 Cover



y = 24.13x - 13.37
R_{adj} = 0.34
2015 Standing Stock
Altered Land
40
30
20
10
1.2
1.4
1.6
1
2
3
4
5
6
7
8
9
10



N
A
B
C
D
E
F
Land Use
Altered Vegetation
Barren/Urban
Inland Water
Secondary Vegetation
Study Sites
Coral Reef
Kilometers
0
1.5
3

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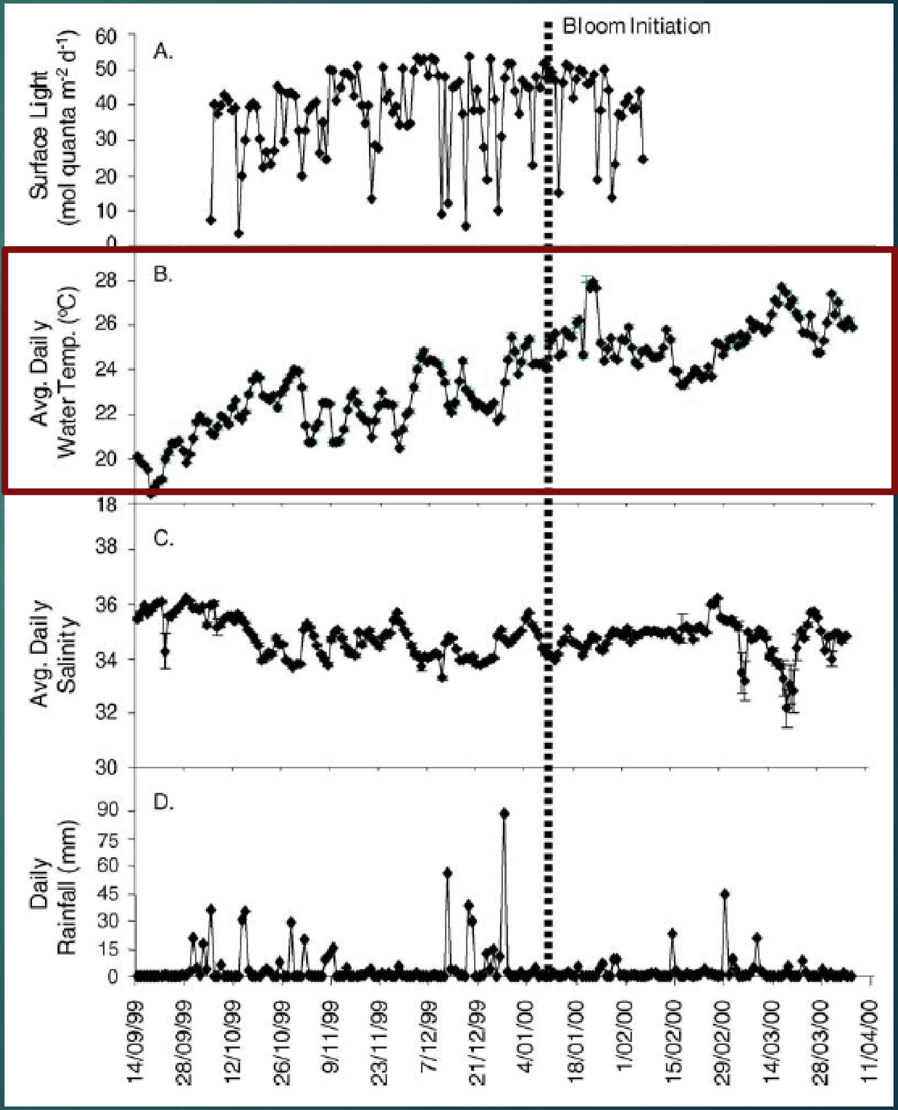
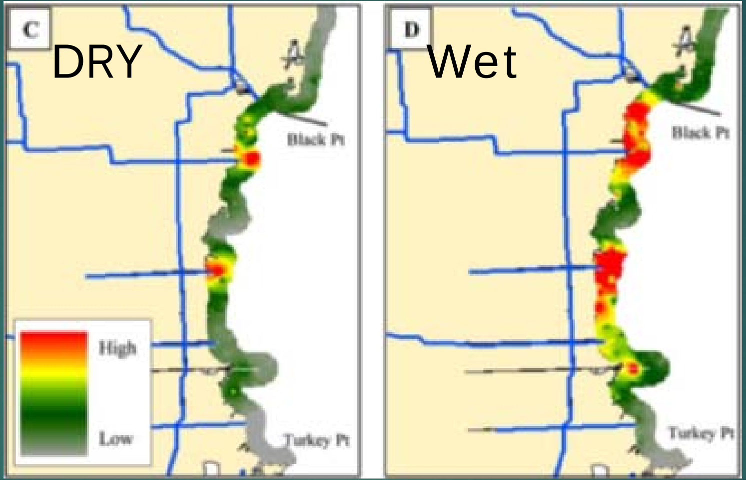
BG and SST

- Watkinson et al 2005
  - Water temperature is one key factor in promoting the growth of blue-green algae
- Eldredge & Center 1983
  - Cooler waters in Saipan contain higher concentrations of dissolved N and P
- Water temperature and nutrient concentrations individually or in combination promote BG growth



Seasonal effects – Rainfall



Biscayne Bay, Florida

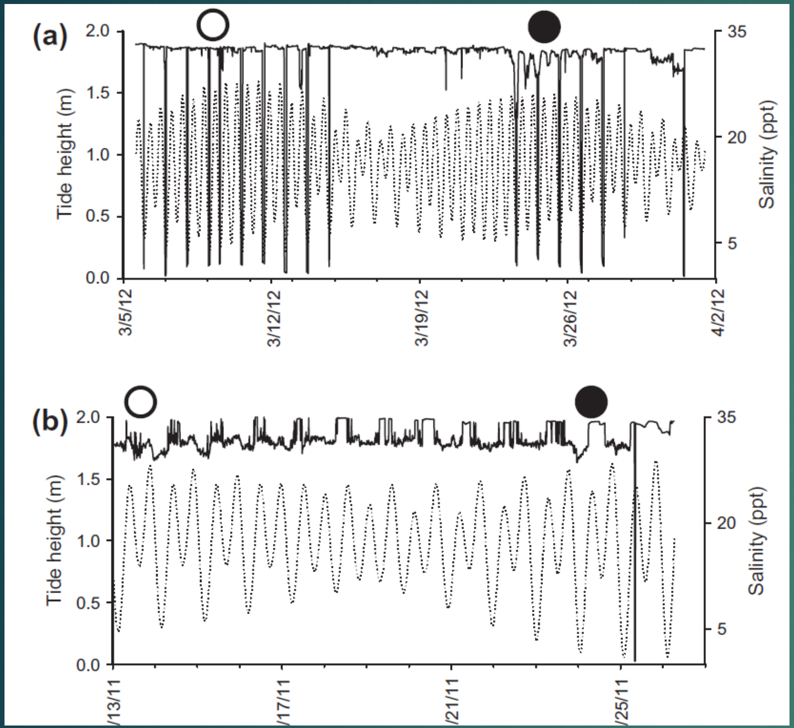
Table 3 Percent cover (S.D.) and percentage of sites where SAV was found in Western Biscayne Bay in the 2005 Dry (March–April) and Wet (July–August) seasons

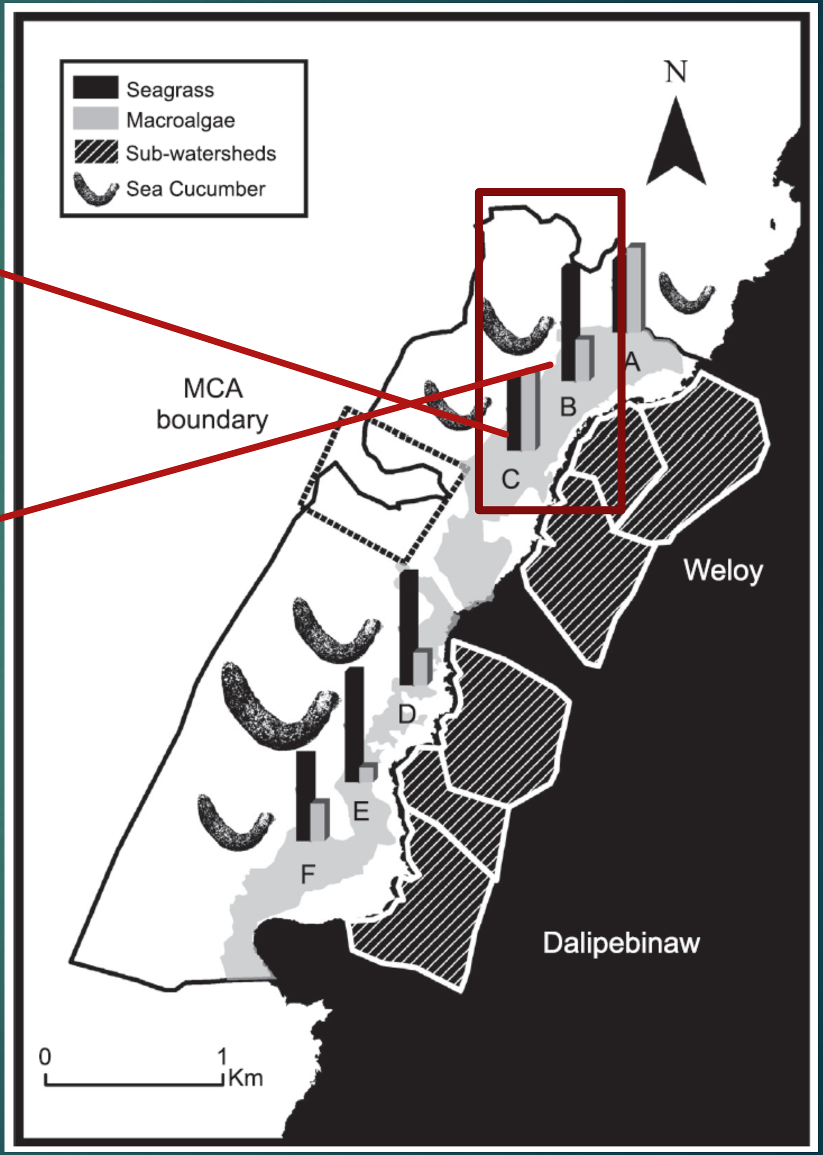
	% Sites dry season	% Sites wet season	% Cover dry season	% Cover wet season	*P* values
T. testudinum	68	63	19.9 (28.0)	19.2 (28.3)	ns
H. wrightii	38	50	1.4 (8.3)	4.0 (13.2)	<0.01
S. filiforme	15	21	4.2 (9.8)	5.2 (12.2)	<0.05
R. maritime	4	5	0.03 (0.2)	0.01 (0.1)	ns
Attached algae	64	66	4.0 (10.4)	29.0 (33.4)	<0.01
Drift algae	69	43	12.5 (18.7)	4.4 (10.4)	<0.01
Seagrass	78	80	25.5 (30.1)	28.4 (30.8)	ns
Macroalgae	77	74	16.5 (20.8)	33.4 (35.5)	<0.01

The mean cover of each taxon was compared between the dry and wet seasons using a *t*-test. ns = no significant differences between seasons. $n = 240$ sites each season

Lirman et al., 2008 HYDROBIOLOGIA

Groundwater





- Groundwater appears to influence macroalgal and seagrass dynamics within *Thalassia* habitats

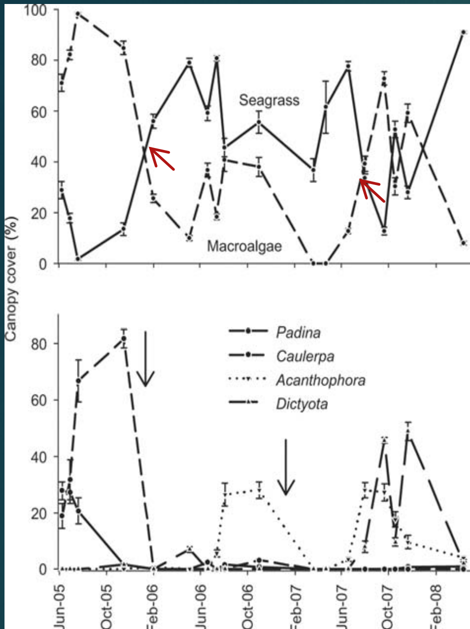
Saipan lagoon studies

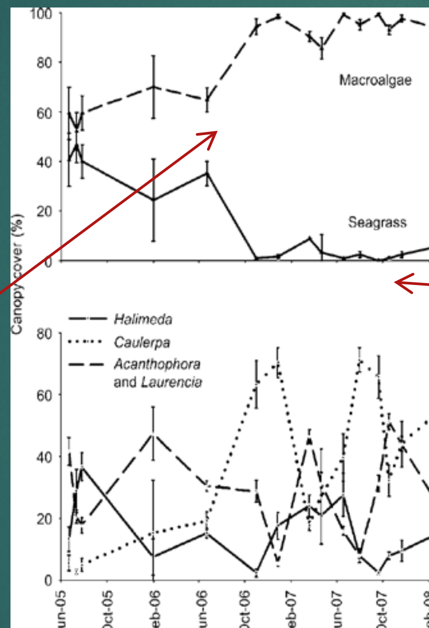
- Altered land and watershed size predicted a ratio of seagrass-to-macroalgae (Houk and Van Woesik, 2008 MEPS)

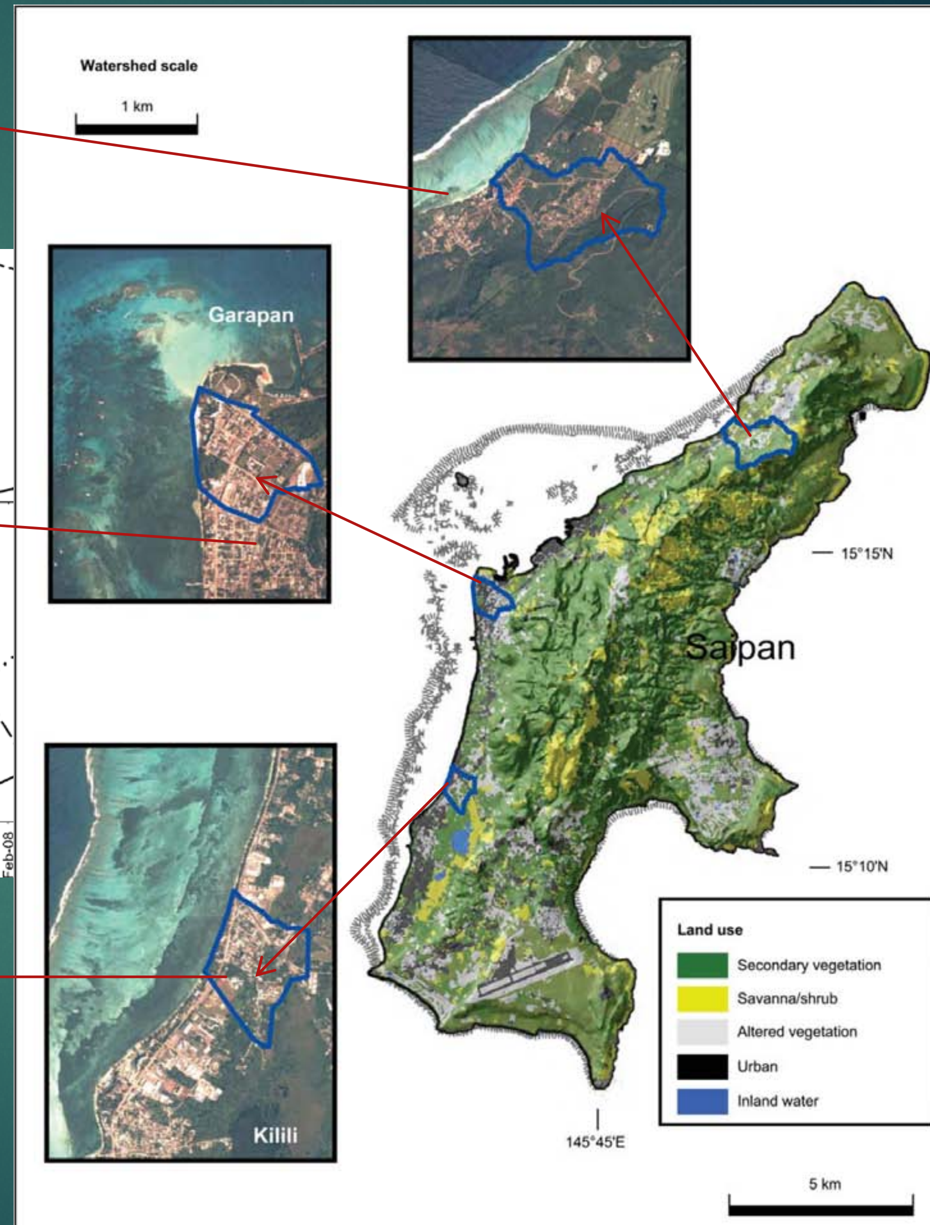
	Watershed Size			Watershed Development			Surface Current Velocity			Lagoon Width		
	Step #	Beta (SE)	R^2 (P-Value)	Step #	Beta (SE)	R^2 (P-Value)	Step #	Beta (SE)	R^2 (P-Value)	Step #	Beta (SE)	R^2 (P-Value)
Enhalus (n=7)	1	.16 (.03)	.91 (<.001***)		----			----		2	.05 (.03)	.96 (.001**)
Halodule (n=14)		----		2	.06 (.03)	.74 (<.001***)	1	-.15 (.03)	.63 (<.001***)		----	
Seagrass Total (n=14)		----		2	.15 (.03)	.82 (<.001***)	1	-.19 (.05)	.51 (.004**)		----	
Halodule / Macroalgae Ratio (n=10)	3	.35 (.23)	.8 (.016*)	1	-.36 (.16)	.43 (.039*)	2	-.38 (.19)	.69 (.017*)		----	

Houk and Camacho, 2010 Bot Mar

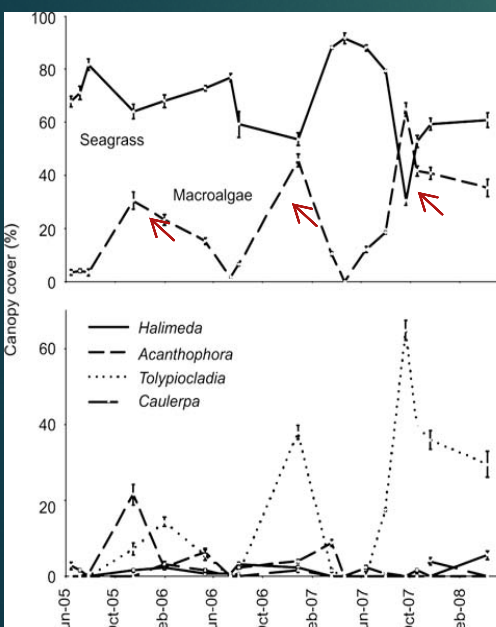
Disturbance-mediated dynamics







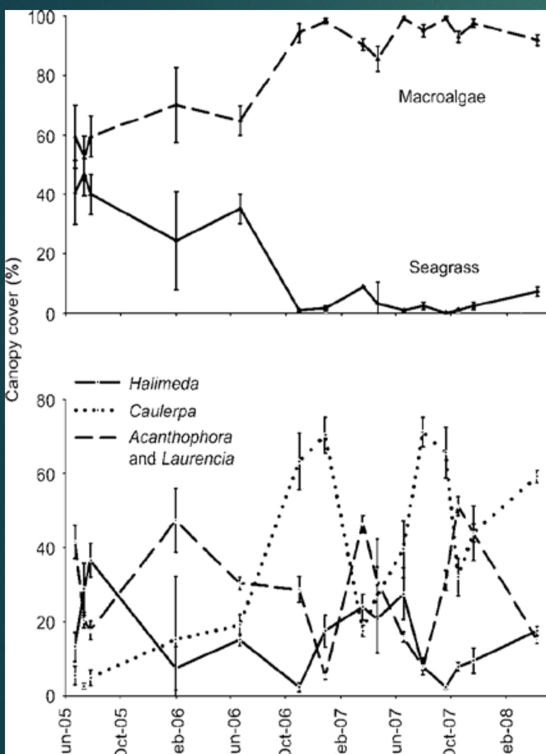
Eutrophication

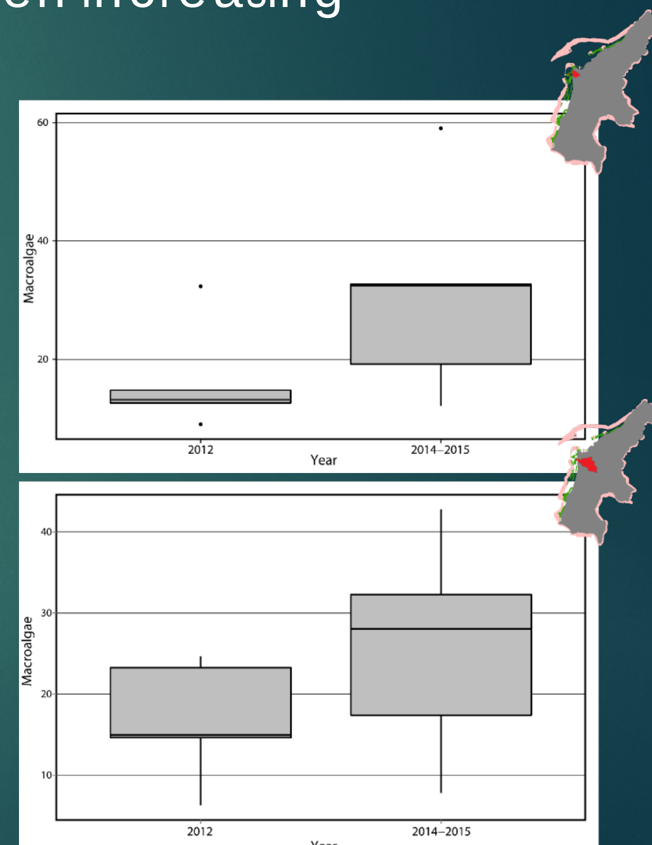


Seasonal dynamics

Synthesis

- Spatial patterns consistent for a decade, meanwhile algal canopies have been increasing





Lingering seasonal cycles with watershed pollution

Science-to-management

- Science to watershed working groups

- Identify and prioritize regions
  - Where to focus limited $ and capacity?

Thank you funders, monitoring partners, and committee

Thesis Committee:
Dr. Peter Houk (chair/member)
Dr. Jason Biggs (member)
Dr. Tom Schils (member)
Dr. Ryan Okano (outside member)

Thank You

QUESTIONS OR COMMENTS

Variables

Watershed Characteristics

- Watershed size
- Altered land area
- Watershed load
- Population

Environmental Factors

- Bacteria violation counts
- Surface current velocities
- Site to drainage distance
- Site to shore distance
- Site to reef distance
- Lagoon width

Key Questions

- What are the major effects of seasonal cycles?
- How has the Saipan lagoon been changing through time?
- Are current watershed land-use patterns contributing to temporal change?
- Can temporal trends and seasonal cycles be reconciled?

Answers help align management with science

Questions

- Seasonal cycle?
  - Same throughout the lagoon?
- Change through time
  - Seasonal and spatial trends present
  - Cover of algal the same through time
- Causes
  - Watershed characteristics
  - Environmental factors

Hypotheses (Seasonal dynamics)

- $H0_1$: Macroalgal canopy cover within *Halodule* beds across wet and dry seasons does not differ

- Falsified if multivariate test of comparison for canopy cover show differences.
  - *If significant differences are found, species-based correlations with PCO axes will be utilized*

Hypotheses (Seasonal dynamics)

- $H0_2$: Macroalgal canopy cover within each season does not differ spatially across the lagoon

- Falsified if multivariate test of comparison for canopy cover show differences.
  - *If significant differences are found, species-based correlations with PCO axes will be utilized*

Hypotheses (Temporal)

- $H0_3$: Seasonal and spatial trends were not persistent through time

- Falsified if linear models support that relationships between seasonal and environmental factors and macroalgal canopies exist
  - *Given significant linear models, the variance of seasonality will be removed by taking the residuals from the forward stepwise regression.*

Hypotheses (Temporal)

- $H0_4$: The persistence of the macroalgal canopies have been consistent through time across the study regions

- Falsified if ANOVA tests find significant differences macroalgal canopies through time
  - *If significant, post-hoc tests to determine which time frames are different within each region*

Hypotheses (Causative)

- $H0_5$: Locations with persistently high or significantly increasing macroalgal canopy cover are not related to watershed characteristics or environmental factors associated with each site

- This will be proven false if binomial models predict high macroalgal states are related to watershed characteristics or environmental factors
  - *If significant, current macroalgal canopies will be examined using linear models with the same watershed characteristics or environmental factors*